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Manual

Best Management Practices for Pollution Prevention in the Textile Industry

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Center for Environmental Research Information
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Notice

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

This manual, *Best Management Practices for Pollution Prevention in the Textile Industry,* funded through the Center for Environmental Research Information, is a pollution prevention guidance manual for processes and waste reduction in the textile industry.

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ABSTRACT

Textiles is one the nation's oldest industries, dating back to be beginning of the American industrial revolution in the 1790s. Despite perceptions of the decline of U.S. textile manufacturing in the face of offshore competition, the industry remains one of the largest, most diverse, and dynamic segments of the U.S. manufacturing sector.

This manual represents a comprehensive history of the U.S. textiles industry, describes wastestreams from diverse industrial processes and products, and provides excellent pollution prevention solutions to guide the environmental responsibility of the industry. The audience for this manual can range from small and medium-size companies in textile-related manufacturing to those involved in regulation, permitting and assistance in environmental management and pollution prevention planning.

This document is divided into eight sections, briefly described below. It has a comprehensive index to assist in selected topic searching.

1. An overview of the textiles industry in the United States, describing production processes and the technological base of the industry, with major waste and pollution issues that exist.
2. A general categorization for wastes generated in the textiles industry.
3. General P2 approaches applicable throughout the textiles industry.
4. Pollution prevention opportunities are identified for specific textile processes or operations, covering raw material handling and usage, yarn formation, slashing and sizing, fabric formation, textile preparation, dyeing, printing, finishing, and cutting and sewing operations.
5. A composite list of the key P2 features offer a comprehensive and effective plan for development and implementation of a successful program.
6. Business considerations of pollution prevention are discussed with incentives and barriers to implementation of a program.
7. A selection of published case studies exemplifying successful implementation *of pollut*ion prevention in textile processing
8. A comprehensive listing of references.

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Conversion Factors

To convert . . .	to . . .	multiply by . . .
cubic feet	cubic meters	2.831685×10^{-2}
degrees Fahrenheit	degrees Celsius	$t_{°C} = (t_{°F} - 32)/1.8$
feet	meters	0.3048
inches	centimeters	2.54
pounds	kilograms	0.45354237
pounds per cubic foot	kilograms per cubic meter	16.0184634
pounds per cubic foot	kiloPascals	6.895
square inches	square inches	6.4516
tons	metric tons	0.90718474
U.S. gallons	liters	3.785

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Chapter 1
Introduction

This chapter provides a brief overview of the textile industry in the United States, focusing on the production processes and technological base of the industry (Section 1.1) and identifying major waste and pollution issues (Section 1.2). The discussion of equipment and processes serves as background to later sections that describe process alternatives or equipment modifications to achieve pollution prevention, while the discussion of pollution and wastes provides an understanding of the nature, types, sources, and amounts of wastes associated with textile operations.

1.1 Industry Overview

The textile industry is one of the nation's oldest, dating back to the beginning of the American industrial revolution in the 1790s. Despite popular perceptions about the decline of U.S. textile manufacturing in the face of foreign competition, the industry remains one of the largest, most diverse, and most dynamic segments of the U.S. manufacturing sector. Shipments from the approximately 6,000 establishments in the textile industry reached a record $70 billion in 1992, and industry employment was around 630,000. The industry has maintained a competitive position in the face of strong import competition from lower wage textile-producing countries by specializing in high-value items, launching successful "Buy American" promotional campaigns, modernizing mills to equip them with the latest technology, and adopting "quick response" and "just-in-time" manufacturing strategies that permit the industry to respond rapidly to changing demands in the important apparel and home furnishings markets.

Textile manufacturing begins with the production or harvest of raw fiber. Fiber used in textiles can be harvested from natural sources (e.g., wool, cotton) or manufactured from regenerative cellulosic materials (e.g., rayon, acetate), or it can be entirely synthetic (e.g., polyester, nylon). After the raw natural or manufactured fibers are shipped from the farm or the chemical plant, they pass through four main stages of processing:

- Yarn production
- Fabric production
- Finishing
- Fabrication

In yarn production, natural fibers, predominantly cotton and wool, are cleaned, carded and/or combed, and then spun into yarn. Just over half of the total shipments of synthetic and cellulosic fibers are shipped as staple—short fibers similar to cotton or wool—which are spun in a process similar to that used for cotton and wool. Some of this volume is tow fibers, which are composed of bundles of staple fibers. The balance comes from the manmade fiber producer as filament yarn, strands of filament twisted together slightly that may be used directly or, after having been further twisted to the desired consistency, in throwing mills.

Fabric production, the second step, involves either weaving or knitting. Broadwoven mills consume the largest portion of textile fiber and produce the raw textile material from which most textile products are made. Manufacturers of knit fabrics also consume a sizable amount of yarns. Knit fabrics are generally classified as either weft knit (circular-knit goods) or warp knit (flat-knit goods). About 10 percent of fiber is knitted into fabrics such as jersey or into final products such as hosiery, underwear, outerwear, and gloves, while a small portion is woven into narrow fabrics such as ribbon and belting. Knits are used to a lesser extent for home furnishings. In addition to weaving and knitting, yarns are also used directly in the production of floor coverings in a process called tufting. Narrow wovens, waddings, nonwovens, and rope and cordage are used primarily in industrial applications.

Finishing represents the third step. Most broadwoven fabrics retain the natural color of the fibers from which they are made. Cotton fabrics at this stage are known as "gray goods," and the synthetics are said to be woven in the "greige." For most uses, these fabrics must undergo further processing, which can include bleaching, printing, dyeing, mechanical finishing, preshrinking, and shaping. Many different textures can also be obtained through the application of resins and sizings and the use of high temperature and pressure. Finishing is important mainly in cotton and synthetic production. For most wool products and some manmade and cotton products (e.g., gingham), the yarn is dyed before weaving; thus, the pattern is woven into the fabric.

Finally, the finished cloth is fabricated into a variety of apparel and household and industrial products. The simpler of these products, such as bags, sheets, towels, blankets, and draperies, often are produced by the textile mills themselves, but apparel or more complex housewares are usually fabricated by the cutting trades.

1.1.1 Textile Facilities

Textile facilities range from small, family-owned operations using older, traditional manufacturing processes to huge integrated mills operating the latest in textile machinery and equipment. The industry includes a diverse, fragmented group of establishments that produce and/or process textile-related products (thread, yarn, fabric) for further processing into apparel, home furnishings, and industrial goods.

Textile establishments receive and prepare fibers; transform fibers into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and finish these materials at various stages of production. Many textile facilities also produce final consumer products (e.g., thread, yarn, bolt fabric, hosiery, towels, sheets, carpet), while the rest produce transitional products for use by other establishments in the textile industry and by establishments classified in the apparel or other industries.

Table 1-1 shows the structure of the textile industry by identifying the number of establishments in each three-digit standard industrial classification (SIC) code category. This breakdown illustrates the diversity of the industry. The approximately 6,000 facilities fall into the following major categories:

- Yarn and thread mills
- Broadloom mills
- Narrow fabric mills
- Knitting mills
- Textile finishing
- Carpet and rug mills
- Miscellaneous textile products

The process of converting raw fibers into finished apparel and nonapparel textile products is complex; thus, most textile mills specialize. Little overlap occurs between knitting, narrow weaving, and broad weaving, or between manmade, cotton, and wool fabric production. A notable exception is the more than 300 integrated companies that combine spinning and weaving in their operations. Many of these companies buy or sell yarn in the merchant market, but their own weaving operations consume most of the yarn they spin. Even these large integrated companies, however, do not normally conduct their own finishing operations. This necessitates an extensive textile finishing industry, comprising approximately 700 finishing and dyeing mills.

Table 1-1. Number of Establishments in the Textile Industry by Three-Digit SIC Code (1)

SIC	Industry	Number	Total (%)
221	Broadloom mills—cotton	302	5.2
222	Broadloom mills—manmade fibers, including silk	418	7.2
223	Broadloom mills—wool	118	2.0
224	Narrow fabric mills	265	4.5
225	Knitting mills	2,028	34.8
226	Textile finishing, except wool	716	12.3
227	Carpets and rugs	428	7.3
228	Yarn and thread mills	621	10.6
229	Miscellaneous textile goods	940	16.1
	Total	5,836	100.0

In some cases, fabric producers are vertically integrated into the manufacture of textile products such as knit hosiery and knit apparel, carpets and rugs, tire cord, and rope and cordage. Most woven fabrics destined for apparel and home furnishings are further dyed and finished before the cut-and-sew operations, in which the finished products are manufactured. As noted, however, specialized dye and finish houses perform most of this work. Carpet producers are almost all integrated backward into yarn manufacturing, adhesive formulation, and finishing. Du Pont and Monsanto, for example, manufacture fibers, carpeting, and some of the chemicals used in carpet finishing.

1.1.1.1 Geographic Distribution

The textile industry is geographically concentrated in the South- and Mid-Atlantic regions, based partly on historical considerations. The industry developed first in the Northeast and grew southward because of the region's prominence in cotton production. Although synthetics have replaced cotton as the primary raw material in recent years, the Southeast continues to dominate the U.S. textile industry. Major concentrations of facilities are found in North Carolina, South Carolina, Georgia, Alabama, Tennessee, and Virginia, although certain segments of the industry are concentrated in other regions. For example, denim manufacture is centered in the Southeast, while a considerable amount of fabric dyeing and finishing takes place in New York, New Jersey, and the New England states.

1.1.1.2 Industry Concentration

Natural fibers tend to be shipped directly to textile mills with little preparation or processing of the fibers. For the most part, independent manufacturers perform the fiber preparation and yarn spinning, although numerous large integrated mills exist, and many separate yarn mills are affiliated with larger textile conglomerates. Chemical companies produce manmade fibers, and production in this segment tends to be highly concentrated among a small number of firms. According to a recent market report on textiles, the U.S. manmade fiber industry consists of over 100 companies operating approximately 150 plants, although only about a dozen are major producers (2). The top six companies—Du Pont, Hoechst Celanese, BASF, Allied-Signal, Monsanto, and Amoco—account for approximately 80 percent of production of manmade fibers. The dominant firms tend to fall into one of the following categories: 1) large, multiproduct chemical companies, 2) highly integrated petrochemical companies, or 3) widely diversified industrial firms with large chemicals- or materials-related segments (2). Approximately 60 percent of U.S. producers specialize in olefin fiber production, while the remaining market segments are controlled by a small number of firms. In acrylic, modacrylic, and rayon, for example, three firms account for all U.S. production. In acetate fiber and spandex, two firms account for 100 percent of U.S. output.

1.1.1.3 Research and Development

In the textiles industry, product development and innovation are vital. Success in the industry has always hinged on the ability of producers to innovate. Firms constantly introduce new fibers and are always trying to enhance and improve existing fibers (performance, aesthetics, blendability). The technical complexity of current fiber formulations and the role of proprietary knowledge account for the high degree of specialization in a relatively narrow range of product segments. Research and development (R&D) expenditures for large manmade fiber producers range from 4 to 10 percent, which is high compared with chemical industry standards (2).

1.1.1.4 Economies of Scale

Economies of scale in textile manufacturing are significant and limit entry into the market. The cost of a new fiber plant, for example, is approximately $100 million. Costs of raw materials are frequently volatile and typically account for 50 to 60 percent of the cost of the finished product. To hedge against supply shocks and to secure supply, many producers are vertically integrated backward into chemical intermediates (and in the case of companies such as Phillips, Amoco, DuPont, and Conoco, all the way to crude oil). Forward integration into apparel and product manufacture (e.g., carpeting) also is not uncommon.

1.1.1.5 Capital Investment

The textile industry spends 4 to 6 percent of sales on capital expansion and modernization, down from the 8 to 10 percent it averaged during the expansionary phase of the 1960s and 1970s. Most recent capital expenditure has paid for mill modernization and factory automation. Industry also reports spending more than $25 million each year on pollution and safety controls (2).

1.1.1.6 Merger Activity

In recent years, overcapacity and slower growth in some market segments have made facility rationalization a top priority. In the late 1980s and early 1990s, the market experienced a significant reduction in capacity. Present capacity appears to be in balance as demonstrated by the high utilization rates recorded even during the 1990-1991 recession.

1.1.2 Machinery

Textile manufacturing encompasses four different stages of production, and specialized machinery and equipment is used at each stage. The following sections discuss each of these stages of production:

- Preparation of fiber (natural) or fiber manufacturing (manmade).
- Conversion of fiber into yarn (spinning).
- Manufacturing of textiles from yarn (weaving and knitting).
- Coloring and finishing of textiles.

1.1.2.1 Fiber Preparation: Natural Fibers

As described in Section 1.1.3, two general categories of fiber are used in textile manufacturing: natural (e.g., wool, cotton) and manmade, which includes cellulosic (e.g., rayon, acetate) and synthetic (e.g., polyester, nylon). Natural fibers must be opened, blended, carded and/or combed, and drafted before spinning. Manmade fibers are often shipped as staple (similar in length to natural fibers), which is ready for spinning, or as filament yarn, which may be used directly or following further shaping or texturizing.

The following describes the main steps used for processing wool and cotton. Although equipment used for cotton is designed somewhat differently from that used for wool, the machinery operates in essentially the same fashion:

- *Opening/Blending:* Suppliers deliver natural fibers to the spinning mill in compressed bales. The fibers must be sorted based on grade, cleaned to remove particles of dirt, twigs, and leaves, and blended with fibers from different bales to improve the consistency of the fiber mix. Sorting and cleaning is performed in machines known as openers. The opener consists of a rotating cylinder, equipped with spiked teeth or a set of toothed bars. These teeth pull the unbaled fibers apart, fluffing them while loosening impurities. Because the feed for the opener comes from multiple bales, the opener blends the fibers as it cleans and opens them.

- *Carding:* Tufts of fiber from the blending and opening operation are conveyed by air stream and fed to a carding machine, which transports the fiber over a belt equipped with wire needles. A series of rotating brushes rests on top of the belt. The different rotation speeds of the belt and the brushes cause the fibers to tease out and align into thin, parallel sheets. Many shorter fibers, which would weaken the yarn, are separated out and removed. A further objective of carding is to better align the fibers to prepare them for spinning. The sheet of carded fibers is removed through a funnel into a loose ropelike strand called a sliver. Opening, blending, and carding are sometimes performed in integrated carders that accept raw fiber and output carded sliver.
- *Combing:* Combing is similar to carding except the brushes and needles are finer and more closely spaced. Several card slivers are fed to the combing machine and removed as a finer, cleaner, and more aligned comb sliver. In the wool system, combed sliver is used to make worsted yarn, while carded sliver is used for woolen yarn. In the cotton system, the term combed cotton applies to the yarn made from combed sliver. Worsted wool and combed cotton are finer than yarn that has not been combed because of the higher degree of fiber alignment and further removal of short fibers.
- *Drawing:* Several slivers are combined and fed to a machine known as a drawing frame. The drawing frame contains several sets of rollers that rotate at successively faster speeds. As the slivers pass through, they are further drawn out and lengthened, to the point where they may be five to six times as long as they were originally. During drawing, slivers from different types of fibers (e.g., cotton and polyester) may be combined to form blends.
- *Drafting:* Drafting, which takes place on the roving frame, stretches the yarn further. This process imparts a slight twist as it removes the yarn and winds it onto a rotating spindle. The roving, as it is now called, is about eight times the length and one-eighth the diameter of the sliver, or approximately as wide as a pencil. Following drafting, the rovings may be blended with other fibers before being processed into woven, knitted, or nonwoven textiles.
- *Spinning:* The rovings produced in the drafting step are mounted onto the spinning frame, where they are set up for spinning. The yarn is first fed through another set of drawing rolls, which lengthen and stretch it still further. It is then fed onto a high-speed spindle by a guide that travels up and down the spindle. The difference in speed of travel between the guide and the spindle determines the amount of twist imparted to the yarn.

1.1.2.2 Fiber Manufacture: Manmade Fibers

Manmade fibers (both synthetic and cellulosic) are manufactured by processes that simulate or resemble the manufacture of silk (i.e., forcing a liquid through a small opening where the liquid solidifies to form a continuous filament). Various shapes of solid and hollow fiber can be produced by using different shaped spinnerettes. The three main methods of fiber manufacture are described below:

- *Wet spinning:* In wet spinning, the polymer used to form the fiber is dissolved in solution. The solution is forced under pressure through an opening into a liquid bath in which the polymer is insoluble. As the solvent is dissipated in the bath, the fiber forms. Wet spinning produces rayon, acrylic, and modacrylic.
- *Dry spinning:* Dry spinning uses a solvent that evaporates in air. The dissolved polymer is extruded through the spinnerette into a chamber of heated air or gas, the solvent evaporates, and the fiber forms. The solvent is generally recovered for reuse. Acrylic is produced by dissolving the polymer in dimethyl formamide before dry spinning. Other fibers formed by dry spinning include acetate, triacetate, spandex, and aramid.
- *Melt spinning:* Some polymeric fibers are spun by melting the polymer to a liquid state. The liquid is forced through the spinner opening under pressure and cooled by a jet of air to form the filament. Nylon can be spun by melting nylon polymer chips in a melt-extruder, a long heated cylinder that contains a rotating screw. The chips are melted as they travel the length of the heated zone of the tube, pumped to the spinerettes, and extruded into a cold air stream. Melt spinning requires no chemical reactions and no solvent recovery system. In addition to nylon, polyester, olefin, and glass can also be produced by melt spinning.

Following spinning, the manmade fibers are drawn to align and orient the polymer molecules and strengthen the filament. Manmade filaments may then be texturized to give them spunlike properties. Texturizing uses curling, crimping, and tangling apparatuses to give straight rodlike filament fibers the appearance, structure, and feel of natural fibers.

1.1.2.3 Yarn Spinning

Yarns are classified as either spun yarns or filament yarns:

- *Spun yarns:* Spun yarns are formed from staple-length fibers. Natural fibers are harvested as staples, while manmade fibers may be cut to staple length for the purpose of spinning. Manmade staple may be produced in lengths suitable for processing on wool- or cotton-system machinery. Yarn spinning is basically an extension of the preparation steps described above for natural fibers. Additional twisting or texturizing of the yarn may occur, or multiple yarns may be twisted together to form plied yarns. Plying takes place on a machine similar to a spinning frame. Two or more yarns pass through a pair of rollers and onto a rotating spindle. The yarn guide positions the yarn onto the spindle and assists in applying twist. Plied yarns may be plied again to form thicker cords, ropes, and cables.
- *Filament yarns:* Yarns are produced from filament fibers in a process known as throwing. In the throwing mill, the filament fibers are wound onto bobbins and placed on a twisting machine. Manmade filaments require additional drawing and are processed in an integrated drawing/twisting machine.

1.1.2.4 Manufacturing of Textiles From Yarn

The major methods for fabric manufacture are weaving, knitting, and tufting. These are described in turn below.

Weaving

Weaving is performed on looms. The major components of the loom are the warp beam, heddles, harnesses, shuttle, reed, and takeup roll. The warp beam is a metal cylinder that holds the warp yarns and feeds them into the cloth. Heddles separate and guide the warp yarns, allowing some to be raised and others lowered, while the harnesses raise and lower the heddles. The shuttle carries the fill yarns and inserts them into the weave. The reed packs the fill yarns, and the takeup roll holds the woven cloth.

Warp yarns are wound onto the beam from packages mounted on creels, in a process known as beaming. The warp yarns normally pass through a sizing solution on route from the creel to the beam. Sizing protects the yarn against snagging or abrasion that could occur during weaving. The process of applying size to the warp yarn is known as slashing.

The wound beam is mounted in the loom. The yarns are passed through eye holes in the heddles, which hang vertically from the harnesses. The weave pattern determines which harness controls which warp yarns, and the number of harnesses used depends on the complexity of the weave.

In a shuttle loom, the filling yarn is wound onto a quill, which in turn is mounted in the shuttle. The shuttle is normally pointed at each end to allow passage through the shed (i.e. the vertical space between the raised and unraised warp yarns). As the shuttle moves across the loom laying down the fill yarn, the reed (which resembles a comb) presses or beets the fill yarn into the weave.

Conventional shuttle looms can operate at speeds of about 150 to 160 picks per minute. Several types of shuttleless looms have been developed that operate at higher speeds and reduced noise levels. Shuttleless looms use different techniques to transport the fill yarns faster across the shed, but regardless of the technique used, they all carry a cut piece of fill yarn, rather than a continuous piece:

- *Water-jet looms:* Water-jet looms transport the fill yarn in a high-speed jet of water and can achieve speeds of 400 to 600 picks per minute. Water jets can handle a wide variety of fiber and yarn types and are widely used for apparel fabrics.
- *Air-jet looms:* Air-jet looms use a blast of air to move the fill yarn and can operate at up to 320 picks per minute. These looms are limited in the types of filling yarns they can handle.
- *Rapier looms:* Rapier looms use two thin wire rods to carry the fill yarn and can operate at a speed of 510 picks per minute. Rapiers are used mostly for spun yarns and are widely used for cotton and woolen/worsted fabric. In a double rapier loom, two rods move from each side and meet in the middle. The fill yarn is carried from the rod on the fill side and handed off to the rod on the finish side of the loom.
- *Projectile looms:* Projectile looms use a projectile to carry the fill yarn across the weave.

These shuttleless looms have been replacing the traditional fly-shuttle loom in recent years. By the end of 1989, shuttleless looms represented 54 percent of all looms installed, up from 15 percent in 1980.

Knitting

In knitting, the fabric is formed through the interlocking of one or more sets of yarns through a set of loops. Knitting is performed using either weft or warp processes. In weft (or filling) knitting, one yarn is carried back and forth and under needles to form a fabric. Yarns run horizontally in the fabric, and connections between loops are horizontal. In warp knitting, a warp beam is set into the knitting machine. Yarns are interloped to form the fabric, and the yarns run vertically while the connections are on the diagonal. Several different types of machinery are used in both weft and warp knitting.

- *Weft knitting:* Weft knitting machines can produce both flat and circular fabric. Circular machines produce mainly yardage but may also produce sweater bodies, pantyhose, and socks. Flatbed machines knit full garments and operate at much slower speeds. The simplest, most common filling knit fabric is single jersey. Double knits are made on machines with two sets of needles. All hosiery is produced as a filling knit process.
- *Warp Knitting:* Warp knitting represents the fastest method of producing fabric from yarns. Fabric is produced in sheet or flat form using one or more sets of warp yarns. The yarns are fed from warp beams to a row of needles extending across the width of the machine. Tricot machines use a single set of spring-beard or compound knitting needles, while Raschel machines use one or two sets of vertically mounted latch needles.

Tufting

Tufting is the process of inserting additional yarns into fabric to create a pile fabric. The substrate fabric can range from a thin backing to heavy burlap-type material and may be woven, knitted, or web. In modern tufting machines, a set of hollow needles carries the yarn from a series of spools held in a creel and inserts the yarn through the substrate cloth. As each needle penetrates the cloth, a hook on the underside forms a loop by catching and holding the yarn. The needle is withdrawn and moves forward, much like a sewing machine needle. Patterns may be formed by varying the height of the tuft loops. To make cut-loop pile, a knife is attached to the hook and the loops are cut as the needles are retracted. Tufting is used for apparel fabrics, upholstery, and blankets, although most tufting machines are used for carpeting. Well over 90 percent of broadloom carpeting is made by tufting, and modern machines can stitch at rates of over 800 stitches per minute, producing some 650 square yards of broadloom per hour.

1.1.2.5 Coloring and Finishing

Most manufactured textiles are shipped from textile mills to commission dyeing and finishing shops (for further processing in integrated mills) for final coloring or finishing. Alternatively, dyers and finishers may purchase gray goods from mills for conversion to finished textiles. The finisher then sells the piece goods to apparel, furnishing, and industrial textile product manufacturers. A wide range of equipment is used for textile dyeing and finishing.

Dyeing

As described elsewhere in this manual, textiles are dyed using both continuous and batch processes, and dyeing may take place at any of several stages of the manufacturing process (i.e., stock, tow, yarn, fabric, garment). Table 1-2 describes the main types of dyeing machines in use in the U.S. industry, indicating the stage of processing at which each may be used, whether they are designed for batch or continuous operation, the machine capacities (width of fabric, weight of goods), as well as descriptions, advantages, and disadvantages. Figure 1-1 diagrams each of these machine types. In terms of overall volume, the largest amount of dyeing is performed using beck and jig equipment.

Printing

Fabrics are printed with color and patterns, using a variety of techniques and machine types. The major types of printing are described below:

- *Direct printing:* In direct printing, a large cylindrical roller picks up the fabric, and smaller rollers containing the color are brought into contact with the cloth. The smaller rollers are etched with the design, and the number of rollers reflects the number of colors. Each smaller roller is supplied with color by a furnisher roller, which rotates in the color trough, picks up color, and deposits it on the applicator roller. Doctor blades scrape excess color off the applicator roller so that only the engraved portions carry the color to the cloth. The cloth is backed with a rubberized blanket during printing, which provides a solid surface to print against, and a layer of gray cloth is used between the cloth and the rubber blanket to absorb excess ink.
- *Warp printing:* Warp printing places a pattern on the warp yarns prior to weaving. Fill yarns are white or yellow and carry no pattern.
- *Discharge printing:* Discharge printing is performed on piece-dyed fabrics. The patterns are created through removal, rather than addition, of color, hence most discharge printing is done on dark backgrounds. The dyed fabric is printed using discharge pastes, which remove background color from the substrate when exposed to steam. Colors may be added to the discharge paste to create colored discharge areas against the background.
- *Resist printing:* Resist printing encompasses several hand and low-volume methods in which the pattern is applied by preventing color from penetrating certain areas during piece-dyeing. Examples of resist printing methods include batik, tie-dyeing, screen printing, and stencil printing.
- *Jet printing:* Jet printing, used mainly for carpet, applies dye to the substrate fabric in continuous streams, using applicator jets.
- *Heat-transfer printing:* In heat-transfer printing, the pattern is first printed onto a special paper substrate. The paper is then positioned against the fabric and subjected to heat and pressure. The dyes are transferred to the fabric via sublimation.

Table 1-2. Comparison of Dyeing Equipment (3)

Machine Type	Material Processed	Capacity Width	Capacity Weight	Description, Advantages, Disadvantages
Stock	Fiber	—	500 kg	Fiber is dyed inside perforated tubes. Same machine can be used for package and beam dyeing. Large quantities of dyed fiber can be blended for color consistency.
Package	Yarn	—	550 kg	Yarn is stationary, bath is pumped through. Same machine can be used for beam or stock dyeing.
Skein	Yarn	—	100 kg	Yarn is dyed in hanks. Used for bulky acrylic and wool yarns.
Dope	Polymer melt-dyed prior to filament formation	—	Continuous	Pigments are added to polymer before extrusion into fiber.
Beck	Fabric	Rope	900 kg	Very versatile—can be used almost universally. Good for repair work. Causes substantial mechanical working of goods. Can cause cracks in delicate, lightweight goods (e.g., nylon and acetate).
Jet	Fabric	Rope	500 kg	Capable of high pressure and temperature. Fabric is handled gently. Fabric and bath are both in motion during dyeing.
Beam	Fabric	Up to 5 m	1,000 kg	Fabric is handled flat, thus reducing creases and cracks in delicate goods. Optimum for lightweight, wide, and delicate goods. Fabric is stationary, bath is pumped through. Same machine can be used for stock or package dyeing.
Jig	Fabric	2 m	250 kg	Fabric is handled flat, thus reducing creases and cracks. Does not run disperse dyes very well. Too much tension for weft knits.
Paddle	Fabric or product	—	100 kg	For products such as hosiery, rugs, etc.
Garment (rotary)	Garments	—	500 kg	Garments are dyed before cutting and sewing.
Chain (tow)	Yarn		Continuous	Used to dye yarns continuously.
Continuous	Fabric	Up to 3 m	Continuous	Best economics for long runs. Several types of fixing methods include steam, chemical reactions, thermofix, and cold batch methods. Not effective for general repair work. The only type of dye machine that can run pigments. Too much tension for knits.

Finishing

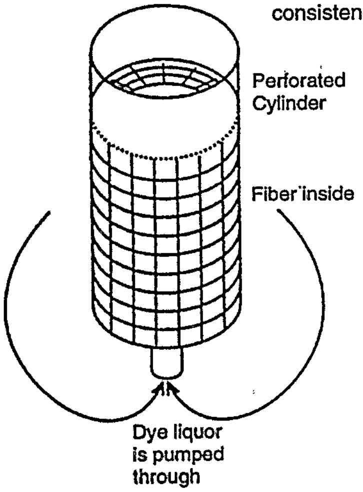
Finishing encompasses any of several processes performed on fiber, yarn, or fabric to improve its appearance, texture, or performance. Physical finishing methods include:

- *Bulking and texturizing:* Thermoplastic manmade fibers are often permanently heat-set after drawing and orientation. Thermoplastic yarns also can be texturized to give loft and bulkiness.
- *Optical finishing:* Luster can be added to yarns by flattening or smoothing the surfaces under pressure. This can be achieved by beating the fabric surface or passing the fabric between calendering rolls. The luster effect can be increased if the rolls are scribed with closely spaced lines to reinforce light scattering.
- *Brushing and napping:* Brushing and napping decrease the luster of fabrics by roughening or raising the fiber surface. These processes involve the use of wires or brushes that pull individual fibers.
- *Softening:* Calendering can be used to reduce surface friction between individual fibers, thereby softening the fabric structure and improving its feel.
- *Shearing:* Shearing is a process that removes surface fibers by passing the fabric over a cutting blade or a flame (singeing).
- *Compacting:* Compacting, which includes the Sanforizing process, compresses the fabric structure to reduce stresses in the fabric. The fabric and backing blanket are fed between a roller and a curved braking shoe, with the blanket under tension. The tension on the blanket is released after the fabric and blanket pass the braking shoe. The compacting reduces the potential for excessive shrinkage on laundering.

Chemical agents are also applied in textile finishing to impart a variety of characteristics, including:

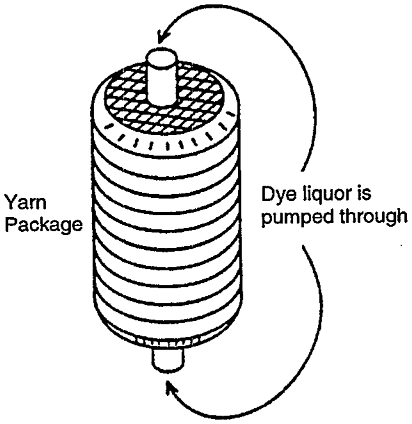
- *Optical finishes:* Finishes added to either brighten or deluster the textile.
- *Absorbent and soil release finishes:* Finishes that alter surface tension and properties to increase water absorbency or improve soil release,
- *Softeners and abrasion-resistant finishes:* Finishes added to improve feel or increase the ability of the textile to resist abrasion and tearing.

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Stock	Fiber		500 kg	Fiber is dyed inside of perforated tubes. Same machine can be used for package and beam dyeing. Large quantities of dyed fiber can be blended for color consistency.



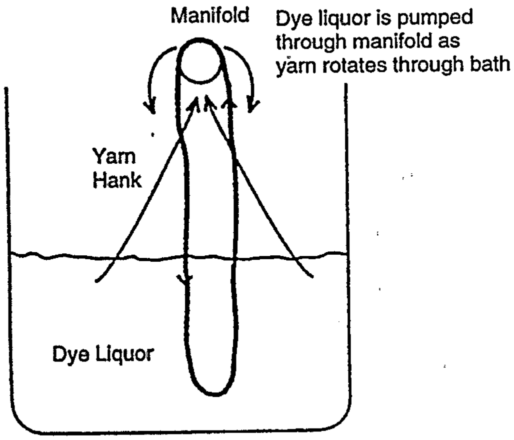
Stock Dyeing

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Package	Yarn		550 kg	Yarn is stationary, bath is pumped through. Same machine can be used for beam or stock dyeing.



Package Dyeing

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Skein	Yarn		100 kg	Yarn is dyed in hanks. Used for bulky acrylic and wool yarns.

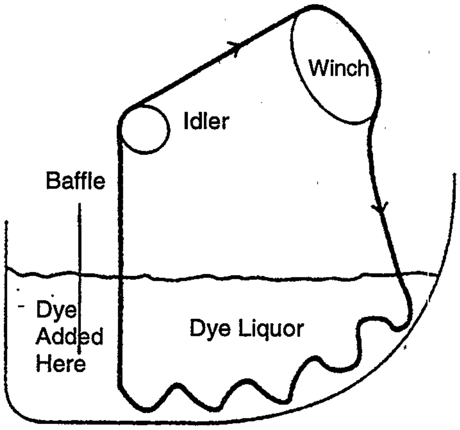


Skein Dyeing (end view)

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Dope	Polymer melt prior to yarn formation.		Continuous	Pigments are added polymer before extrusion into fiber.

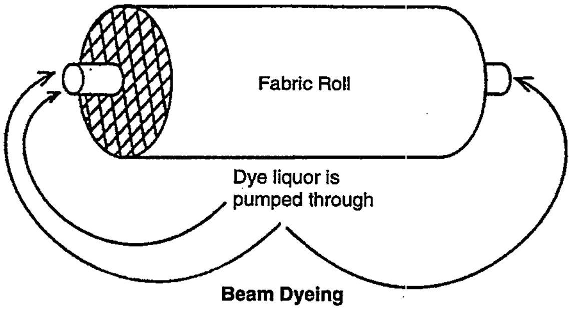
Figure 1-1. Dyeing machinery.

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Beck	Fabric	Rope	900 kg	Very versatile—can be used almost universally. Good for repair work. Causes substantial mechanical working of goods. Can cause creases and cracks in delicate, lightweight goods (e.g., nylon, acetate).



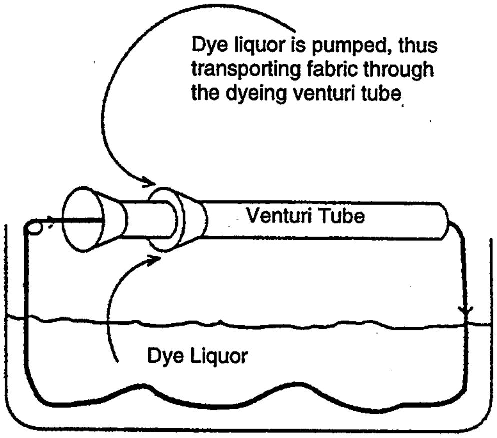
Beck Dyeing (end view)

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Beam	Fabric	Up to 5 meters	1,000 kg	Fabric is handled flat, thus reducing creases and cracks in delicate goods. Optimum for lightweight, wide, and delicate goods. Fabric is stationary, bath is pumped through. Same machine can be used for stock or package dyeing.



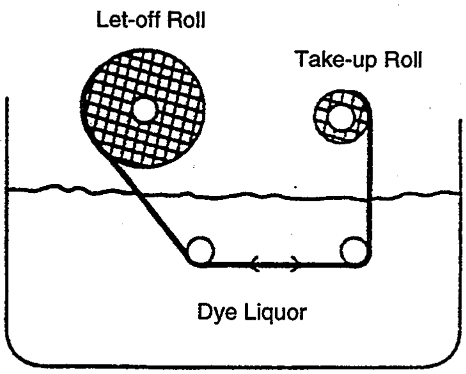
Beam Dyeing

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Jet	Fabric	Rope	500 kg	Capable of high pressure and temperatures. Fabric is handled gently. Fabric and bath both are in motion.



Jet Dyeing

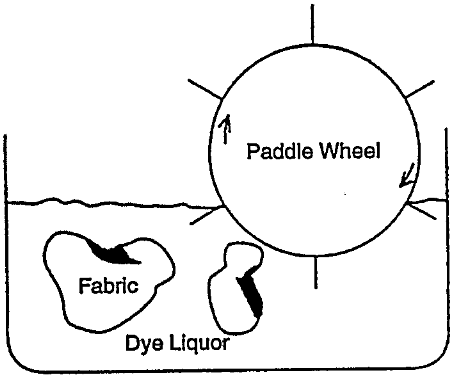
Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Jig	Fabric	2 meters	250 kg	Fabric is handled flat reducing creases and cracks. Does not run disperse dyes very well. Too much tension for weft knits.



Jig Dyeing (end view)

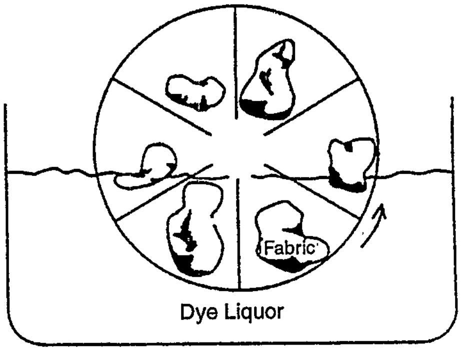
Figure 1-1. Dyeing machinery (continued).

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Paddle	Fabric or Products		100 kg	For products such as hosiery, rugs, etc.



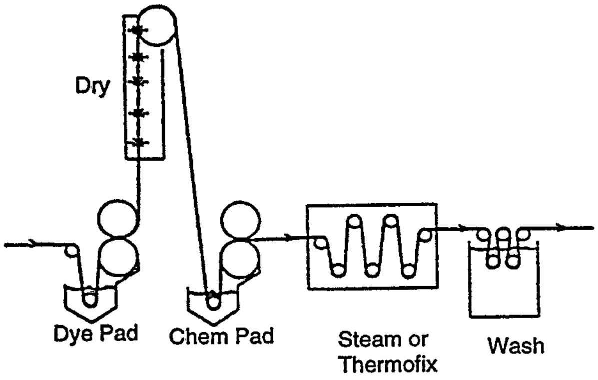
Paddle Dyeing

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Garment (Rotary)	Products (garments)		500 kg	Garments are dyed cutting and sewing.



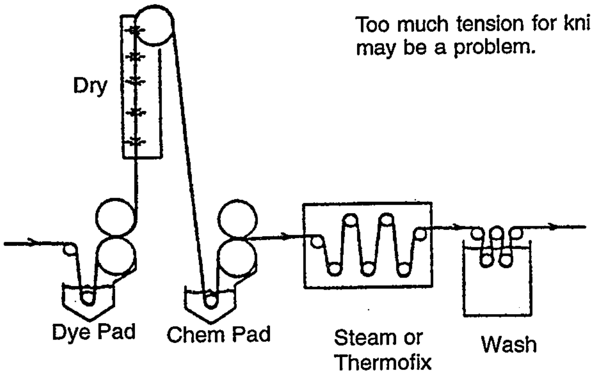
Rotary Garment Dyeing

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Chain (Tow)	Yarn		Continuous	Used to dye yarns continuously.



Continuous Yarn Dye

Machine	Type of Substrate	Width	Typical Configuration Capacity/Limitations/Advantages	
Continuous	Fabric	Up to 3 meters	Contin- uous	Best economics for long runs. Poor economics for short runs. Several types of fixing methods include steam, chemical reactions, thermofix, and cold batch methods. Not effective for general purpose repair work. The only type of dyeing machine which can run pigments. Too much tension for knits may be a problem.



Continuous Dyeing

Figure 1-1. Dyeing machinery (continued).

- *Stiffening and weighting agents:* Include temporary finishes added to improve processability of textiles as well as permanent sizes that stiffen the fabric.
- *Crease-resistant and stabilizing finishes:* Melanine or urea-formaldehyde resins applied to cellulosic fabrics to improve crease resistance and wrinkle recovery.
- *Other finishes:* Include photoprotective agents, antioxidants, oil and water repellents, antistatic treatments, biological protectants, and flame retardants.

Many chemical finishes are applied using padding machines, which pass the fabric through the finishing solution, under a guide roller, and between two padding rolls. The rolls remove excess liquid before the fabric is transported to a steaming or washing and drying machine. The backfilling machine is a variant of the padding machine that applies the finishing solution to only one side of the fabric.

1.1.3 Fiber

Textile fibers are categorized into two principal groups, natural and manmade. Natural fibers (cotton, wool, hemp, linen, jute, silk) are the products of agriculture. Of these, only cotton and wool are of commercial importance in the United States; silk, hemp, and jute are used but in insignificant amounts. During the past several decades, the proportion of cotton and wool textiles has decreased and the proportion of manmade fibers has increased. Manmade fibers now represent the major raw material source for the industry. In 1989, manmade fiber accounted for 68 percent (8.8 billion pounds) of total textile mill fiber consumption of 12.9 billion pounds.

Manmade fibers encompass both purely synthetic materials (e.g., nylon, polyester), derived from petrochemicals, and regenerative cellulosic materials (e.g., rayon, acetate), manufactured from wood fibers. Both types of manmade fibers are typically extruded into continuous filaments, which may then undergo treatment to impart texture to the fibers. The continuous filaments may be spun into yarn directly, or they may be cut into staple length and then spun in a process resembling that used for wool or cotton.

1.1.4 Products

The U.S. textile industry produces a diverse mix of products including woven and coated fabrics, knit goods, finished fabrics, carpets and rugs, yarn and thread, and miscellaneous textile products. It is convenient to consider the industry in terms of the categorization scheme followed in the U.S. government's *Standard Industrial Classification (SIC) Manual.* The textile industry as a whole is assigned the 2-digit SIC code 22, under which are nine three-digit industry groups and 23 four-digit industries. A total of 90 different product classes are produced. These industry categorizations are described further in Table 1-3.

Value of shipments data for the textile industry is shown in Table 1-4.

1.2 Overview of Pollutants and Waste Streams

Textile processing generates many waste streams, including water-based effluent as well as air emissions, solid wastes, and hazardous wastes. The nature of the waste generated depends on the type of textile facility, the processes and technologies being operated, and the types of fibers and chemicals used. This section presents information on the sources and amounts of air and water emissions and solid and hazardous wastes generated, as well as pollution prevention strategies for each.

1.2.1 Air Pollutants

Most processes performed in textile mills produce atmospheric emissions. Gaseous emissions have been identified as the second greatest pollution problem (after effluent quality) for the textile industry (6). Speculation concerning the amounts and types of air pollutants emitted from textile operations has been widespread (7-9), but, generally, air emissions data for textile manufacturing operations are not readily available. Most published data are based on mass-balance calculations, not direct measurements (10, 11).

Air pollution is the most difficult type of pollution to sample, test, and quantify in an audit. Measurement techniques such as direct reading tubes and gas chromatography (GC)/mass spectrometry have been used recently to collect more reliable data (12, 13). Continued collection of air emissions data from textile operations will result in better definitions of industry norms. Efforts are now underway to establish a reliable set of emissions factors for textiles (13, 14); however, no set is currently available that can be recommended for audit purposes.

1.2.1.1 Sources

Air emissions can be classified according to the nature of their sources:

- *Point sources:* Specific discharge points, such as stacks or vents, that are intended to be the point of atmospheric release for emissions.
- *Fugitive sources:* Sources for more general atmospheric emissions such as those that occur through evaporation, leaks, and spills.

Point sources of air pollutants include:

- *Boilers:* Boilers are one of the major point sources of air emissions in the textile industry. Primarily because of emissions of nitrogen and sulfur oxides from boilers, most textile plants are likely to be classified as major sources of air toxics under the NESHAPs of

Table 1-3. Textile Industry Categorization (4, 5)

SIC	Industry Name	Description
221	**Broadwoven fabric mills, cotton**	
2211	Broadwoven fabric mills, cotton 1990 establishments count: 302	Establishments primarily engaged in weaving fabrics more than 12 inches in width, wholly or chiefly by weight of cotton. Establishments primarily engaged in weaving or tufting carpet and rugs are classified in Industry 2273; those making tire cord and fabrics are classified in Industry 2296; and those engaged in finishing broadwoven fabrics are classified in Industry 2261.
222	**Broadwoven fabric mills, manmade fiber and silk**	
2221	Broadwoven fabric mills, manmade fiber and silk 1990 establishments count: 418	Establishments primarily engaged in weaving fabrics more than 12 inches in width, wholly or chiefly by weight of silk and manmade fibers excluding glass. Establishments primarily engaged in weaving or tufting carpet and rugs from these fibers are classified in Industry 2273; those making tire cord and fabrics are classified in Industry 2296; and those engaged in finishing manmade fibers and silk broadwoven goods are classified in Industry 2262.
223	**Broadwoven fabric mills, wool (including dyeing and finishing)**	
2231	Broadwoven fabric mills, wool (including dyeing and finishing) 1990 establishments count: 118	Establishments primarily engaged in weaving fabrics more than 12 inches in width, wholly or chiefly by weight of wool, mohair, or similar animal fibers; dyeing and finishing all woven wool fabrics or dyeing wool, tops, or yarn; and those shrinking and sponging wool for the trade. Establishments primarily engaged in weaving or tufting wool carpet and rugs are classified in Industry 2273.
224	**Narrow fabric and other smallwares mills: cotton, wool, silk, and manmade fiber**	
2241	Narrow fabric and other smallwares mills: cotton, wool, silk, and manmade fiber 1990 establishments count: 265	Establishments primarily engaged in weaving or braiding narrow fabrics of cotton, wool, silk, and manmade fibers, excluding glass fibers. These fabrics are generally 12 inches or less in width in their final form but may be made initially in wider widths that are specially constructed for cutting to narrower widths. Also included in this industry are establishments primarily engaged in producing fabric-covered elastic yarn or thread.
225	**Knitting mills**	
2251	Women's full-length and knee-length hosiery, except socks 1990 establishments count: 144	Establishments primarily engaged in knitting, dyeing, or finishing women's and misses' full-length and knee-length hosiery (except socks), both seamless and full-fashion, and panty hose. Establishments primarily engaged in knitting, dyeing, or finishing women's and misses' knee-length socks and anklets are classified in Industry 2252. Establishments primarily engaged in manufacturing elastic (orthopedic) hosiery are classified in Industry 3842.
2252	Hosiery, not elsewhere classified 1990 establishments count: 414	Establishments primarily engaged in knitting, dyeing, or finishing hosiery, not elsewhere classified. Establishments primarily engaged in manufacturing women's full-length and knee-length hosiery (except socks) and panty hose are classified in Industry 2251. Establishments primarily engaged in manufacturing elastic (orthopedic) hosiery are classified in Industry 3842.
2253	Knit outerwear mills 1990 establishments count: 693	Establishments primarily engaged in knitting outerwear from yarn or in manufacturing outerwear from knit fabrics produced in the same establishment. Establishments primarily engaged in hand knitting outerwear for the trade are included in this industry. Establishments primarily engaged in knitting gloves and mittens are classified in Industry 2259, and those manufacturing outerwear from purchased knit fabrics are classified in Major Group 23.
2254	Knit underwear and nightwear mills 1990 establishments count: 61	Establishments primarily engaged in knitting underwear and nightwear from yarn or in manufacturing underwear and nightwear from knit fabrics produced in the same establishment. Establishments primarily engaged in manufacturing underwear and nightwear from purchased knit fabrics are classified in Major Group 23. Establishments primarily engaged in knitting robes are classified in Industry 2253.
2257	Weft knit fabric mills 1990 establishments count: 309	Establishments primarily engaged in knitting weft (circular) fabrics or in dyeing or finishing weft knit fabrics.
2258	Lace and warp knit fabric mills 1990 establishments count: 220	Establishments primarily engaged in knitting, dyeing, or finishing warp (flat) knit fabrics or in manufacturing, dyeing, or finishing lace goods.
2259	Knitting mills, not elsewhere classified 1990 establishments count: 73	Establishments primarily engaged in knitting gloves and other articles, not elsewhere classified. Establishments primarily engaged in manufacturing woven or knit fabric gloves and mittens from purchased fabrics are classified in Industry 2381.

Table 1-3. Textile Industry Categorization (4, 5) (Continued)

SIC	Industry Name	Description
226	**Dyeing and finishing textiles (except wool fabrics and knit goods)**	
2261	Finishers of broadwoven fabrics of cotton 1990 establishments count: 268	Establishments primarily engaged in finishing purchased cotton broadwoven fabrics, or finishing such fabrics, on a commission basis. These finishing operations include bleaching, dyeing, printing (roller, screen, flock, plisse), and other mechanical finishing, such as preshrinking, calendering, and napping. Also included in this industry are establishments primarily engaged in shrinking and sponging of cotton broadwoven fabrics for the trade and chemical finishing for water repellency, fire resistance, and mildew proofing. Establishments primarily engaged in finishing wool broadwoven fabrics are classified in Industry 2231; those finishing knit goods are classified in Industry Group 225; and those coating or impregnating fabrics are classified in Industry 2295.
2262	Finishers of broadwoven fabrics of manmade fiber and silk 1990 establishments count: 262	Establishments primarily engaged in finishing purchased manmade fiber and silk broadwoven fabrics, or finishing such fabrics, on a commission basis. These finishing operations include bleaching, dyeing, printing (roller, screen, flock, plisse), and other mechanical finishing, such as preshrinking, calendering, and napping. Establishments primarily engaged in finishing wool broadwoven fabrics are classified in Industry 2231; those finishing knit goods are classified in Industry Group 225l; and those coating or impregnating fabrics are classified in Industry 2295.
2269	Finishers of textiles, not elsewhere classified 1990 establishments count: 172	Establishments primarily engaged in dyeing and finishing textiles, not elsewhere classified, such as bleaching, dyeing, printing, and finishing of raw stock, yarn, braided goods, and narrow fabrics, except wool and knit fabrics. These establishments perform finishing operations on purchased textiles or on a commission basis.
227	**Carpets and rugs**	
2273	Carpets and rugs 1990 establishments count: 621	Establishments primarily engaged in manufacturing woven, tufted, and other carpets and rugs, such as art squares, floor mattings, needle punch carpeting, and door mats and mattings, from textile materials or from twisted paper, grasses, reeds, coir, sisal, jute, or rags.
228	**Yarn and thread mills**	
2281	Yarn spinning mills 1990 establishments count: 416	Establishments primarily engaged in spinning yarn wholly or chiefly by weight of cotton, manmade fiber, silk, mohair, or similar animal fibers. Establishments primarily engaged in dyeing or finishing purchased yarns or finishing yarns on a commission basis are classified in Industry 2231 if the yarns are wool and Industry 2269 if they are of other fibers. Establishments primarily engaged in producing specialty yarns or producing spun yarns of other fibers are classified in Industry 2299.
2282	Yarn texturizing, throwing, twisting, and winding mills 1990 establishments count: 138	Establishments primarily engaged in texturizing, throwing, twisting, winding, or spooling purchased yarns of manmade fiber filaments wholly or chiefly by weight of cotton, manmade fiber, silk, mohair, or similar animal fibers, or in performing such activities on a commission basis. Establishments primarily engaged in dyeing or finishing purchased yarns or finishing yarns on a commission basis are classified in Industry 2231 if the yarns are wool and Industry 2269 if they are of other fibers. Establishments primarily engaged in producing and texturizing manmade fiber filaments and yarns in the same plant are classified in Industries 2823 or 2824.
2284	Thread mills 1990 establishments count: 59	Establishments primarily engaged in manufacturing thread of cotton, silk, manmade fibers, wool, or similar animal fibers. Important products of this industry include sewing, crochet, darning, embroidery, tatting, hand-knitting, and other handicraft threads. Establishments primarily engaged in manufacturing thread of flax, hemp, and ramie are classified in Industry 2299.
229	**Miscellaneous textile goods**	
2295	Coated fabrics, not rubberized 1990 establishments count: 176	Establishments primarily engaged in manufacturing coated, impregnated, or laminated textiles, and in the special finishing of textiles, such as varnishing and waxing. Establishments primarily engaged in rubberizing purchased fabrics are classified in Industry 3069, and those engaged in dyeing and finishing textiles are classified in Industry Group 226 or Industry 2231.
2296	Tire cord and fabrics 1990 establishments count: 14	Establishments primarily engaged in manufacturing tire cord and fabric of manmade fibers, cotton, glass, steel, or other materials for use in reinforcing rubber tires, industrial belting, fuel cells, and similar uses.
2297	Nonwoven fabrics 1990 establishments count: 121	Establishments primarily engaged in manufacturing nonwoven fabrics (by bonding and/or interlocking of fibers) by mechanical, chemical, thermal, or solvent means, or by combinations thereof. Establishments primarily engaged in producing woven felts are classified in Industry 2231, and those producing other felts are classified in Industry 2299.

Table 1-3. Textile Industry Categorization (4, 5) (Continued)

SIC	Industry Name	Description
2298	Cordage and twine 1990 establishments count: 187	Establishments primarily engaged in manufacturing rope, cable, cordage, twine, and related products from abaca (Manila), sisal, henequen, hemp, cotton, paper, jute, flax, manmade fibers including glass, and other fibers.
2299	Textile goods, not elsewhere classified 1990 establishments count: 434	Establishments primarily engaged in manufacturing textile goods, not elsewhere classified, including linen goods, jute goods, felt goods, padding and upholstery filling, and processed waste and recovered fibers and flock. Establishments primarily engaged in processing textile fibers to prepare them for spinning, such as wool scouring and carbonizing and combing and converting tow to top, are also classified here. Establishments primarily engaged in manufacturing woven wool felts and wool haircloth are classified in Industry 2231, and those manufacturing needle punch carpeting are classified in Industry 2273. Establishments primarily engaged in manufacturing embroideries are classified in Industry Group 229. Establishments primarily engaged in sorting wiping rags or waste are classified in Wholesale Trade, Industry 593.

Table 1-4. Value of Shipments Data, 1987

Industry Group	Value (billions of 1987 dollars)
Yarn and thread mills	10.1
Broadloom mills	14.7
Cotton	5.5
Manmade and silk	8.1
Wool	1.0
Narrow fabric mills	1.1
Knitting mills	13.7
Textile finishing, except wool	7.2
Carpets and rugs	10.0
Miscellaneous textile products	6.5
Total	63.5

the 1990 Clean Air Act Amendments. Air toxics, an emerging issue for the textile industry, are discussed in more detail in Section 2.2.3, "Toxic Air Emissions."

- *Ovens:* Probably the most prevalent source of air emissions in textile operations is high-temperature drying and curing ovens. The highest levels of emissions by far come from ovens used for coating operations. In some cases, the solvent content of the air in coating ovens can reach levels of several percent. Also, lower levels of emissions come from heatsetting and thermofixation, as well as drying and curing ovens. Typical operating temperatures range from 250°F to 400°F (see Table 1-5).
- *Storage tanks:* Typically, bulk storage tanks for textile chemicals have open vents to allow equalization of internal and external pressures. When the chemical is drawn out of the tank, when air cools (e.g., at night), or when the ambient atmospheric pressure rises, air is forced into the tank. When the tank is filled, when temperatures rise, or when the barometric pressure falls, air is forced out of the tank. When the chemical in the tank contains volatile components, these components can contaminate the air inside of the tank. The expelled air, therefore, constitutes an emission source.

Table 1-5. Typical Operating Temperatures of Textile Operations Contributing to Air Emissions

Operation	Operating Temperature
Drying	250°F–300°F
Curing of ordinary finishes	300°F–375°F
Thermofixation of dyes	350°F–400°F
Heatsetting	300°F–375°F

Fugitive or area sources of air pollutants in textile operations include:

- *Solvent-based cleaning activities:* Solvents are used widely for cleaning and maintenance in textile operations. Examples of solvent cleaning applications include general facility cleanup and maintenance, implement and parts cleaning, and print screen cleaning.
- *Wastewater treatment systems:* Aeration of secondary activated sludge biological treatment lagoons strips most volatile components of the mixed liquor, and these are emitted from the waste treatment system as a general area source. Volatile components of spent processing baths (e.g., dye carriers, solvent scours) as well as degradation products of these components can reasonably be expected to strip and emit during the treatment process; however, no public data are available to confirm this assumption.
- *Warehouses:* Fabric stored in warehouses can emit volatile emissions from process residues, especially printing or dyeing residues, or finishing chemicals that remain in the fabric. Formaldehyde residues have caused the most problems for the industry, but other residues, notably hydrocarbons from softeners and wax water-repellent finishes, also can be present in fabric and result in volatile emissions.
- *Spills:* Spills can emit volatile pollutants for years and, therefore, should be cleaned up promptly. Spill residues should be disposed of according to proper protocol, which in some cases requires handling residues as hazardous waste.

Common air pollutant emissions from ovens include mineral oil and other vapors (12). Others include knitting oils, fiber finishes, softeners, hydrocarbons, urea (from continuous printing and thermofix dyeing of fiber-reactive dyes), and volatile disperse dye carrier components that are sorbed into the fabric during subsequent heat-setting, drying, and curing (15, 16).

1.2.1.2 Indoor Air Pollution

In recent years, textile materials have been linked to indoor air quality (IAQ) problems. Textile materials that emit pollutants (primary emitters) as well as those that sorb and reemit air pollutants indoors (secondary emitters) are a concern for the textile industry (14).

At this time, researchers are studying primary emissions from the types of textile process residues listed below (14, 17):

- Chemical finishes
- Dyeing process residues
- Assembly and fabrication residues

Primary emissions from textile materials can include formaldehyde and amine odors. Formaldehyde is an eye, mucous membrane, and skin irritant, and has been shown to be carcinogenic. Emissions of formaldehyde from textile resin-treated materials decrease approximately 50 percent during the first year of use and approximately 90 percent during the following 4 years.

Test procedures exist for determining primary emissions, but other emissions are not well characterized or commonly analyzed. Some chemical components from the finishing process might survive through to exhaust as primary emissions in the final product. In addition, volatile chemical components of manmade polymers, fiber finishes, and residues from dyeing and printing might also exist in latent forms and degrade IAQ.

Various factors can affect a textile's ability to contribute to IAQ problems: fiber cross-sectional shape, specific surface area, yarn structure and tightness of weave for pure textiles, and textile-containing product (TCP) assemblies (e.g., upholstered furniture with fiberfill).

In addition, some textiles are believed to sorb chemicals from the surrounding atmosphere and later reemit these chemicals, which degrades IAQ. Therefore, the sorption/reemission characteristics of textile materials also are being studied. Knowledge of these characteristics will facilitate (14, 17):

- Using textile group products in an appropriate manner (i.e., compatible with other materials and end-use requirements).
- Developing better purchasing specifications.
- Understanding synergisms in pollutant release.
- Understanding *sorption/desorption from textile surfaces.*
- Modeling of workplace exposure.

Compounds commonly used for textile assembly include adhesives, sealants, and cleaning solvents. All these compounds can be sorbed and reemitted. Cross-media contamination also causes air pollutants. For example, storing textile products near sources of volatile organic compounds can result in sorption and reemission.

Several tests have been conducted on air emissions from drapery materials. Tables 1-6 and 1-7 list chemicals identified during monitoring of emissions from drapery materials and linings, respectively (18). Chemicals can derive either from process residues or from materials sorbed into the material during fabrication, storage, installation, or consumer use. A survey of finish chemical components listed on material safety data sheets (MSDSs) for typical commercial finishes includes a variety of somewhat volatile materials that might be emitted by the material (14). These chemicals are listed in Table 1-8.

The U.S. Occupational Safety and Health Administration (OSHA) has proposed an IAQ rule that will affect 21 million workers and will require the development and implementation of IAQ compliance programs (17). This rule can be expected to enhance awareness of IAQ issues in the workplace and focus further attention on textile sorption and emission characteristics.

1.2.1.3 Pollution Prevention Strategies

Textile mills often have difficulty identifying critical air pollutant issues and pollution prevention goals. In many cases, pollution prevention strategies are not based on the actual presence of air pollutants, but on linking potential air emissions problems to the types of inputs used. The kinds of audit data used to identify water

Table 1-6. Air Emissions From Drapery Materials (18)

Acetone
2,5-Dimethylfuran
Benzaldehyde
1,4-Dioxane
Benzene
Ethanol
Butanol
Methylene chloride
p-Xylene
Dimethyldisulfide
Decane
Toluene
Decenal
I,I,I-Trichloroethane
Dichlorobenzene
Trimethylbenzenes
1,2-Dichloroethane
m-Xylene
Chloroform
Tetrachloroethene

. . . plus 100 more volatile organic compounds (VOCs)

Table 1-7. Air Emissions From Drapery Linings (18)

Acetone
Chloroform
Decenal
Ethanol
Ethylmethylbenzenes
3-Hexanone
2-Methylfuran
Pyrollidine
Trichloroethene
Benzene
Decane
1,4-Dioxane
Ethyl acetate
Hexanes
Methylene chloride
Pyridinone
Toluene
m-Xylene

. . . plus 80 additional VOCs

Table 1-8. Listed Chemicals From MSDSs for Textile Finishing Agents (19)

Chemical Name	CAS[a] Number
Acetone	67-64-1
Ethyl acetate	141-78-6
Ethylene glycol	107-21-1
Fatty glyceride-based softener	NA[b]
Formaldehyde	50-00-0
Hydrocarbon wax emulsion (four reported)	NA
Methanol	67-56-1
Methylhydrogen polysiloxane	63148572
Nonylphenolpolyethylene glycol ether	9016-45-9
2-Pentanone, 4-methyl-	108-10-1
Polyoxyethylated tridecyl alcohol	24938918
Proprietary materials	NA
Residual monomers (acrylic)	NA
Tetrachloroethylene	127184
Toluene	108883
Triethanolamine	102716

[a] CAS = Chemical Abstract Service.
[b] NA = not applicable.

(Section 1.2.2), solid (Section 1.2.3), and hazardous wastes (Section 1.2.4) are not readily available for textile air emissions.

Strategies for preventing air pollutants are site specific, but some of the main strategies are noted below. These strategies also are discussed in more detail in sections covering individual processes (e.g., finishing, dyeing):

- Design products that do not require volatile chemicals. In particular, avoid specifying solvent-based (e.g., water-repellent) finishes unless absolutely necessary.
- Identify and quantify sources, if possible, by direct measurement. If that is not possible, use MSDS information for input chemicals along with knowledge of the process to estimate emissions. Prescreen and test all chemicals to ensure quality using the protocol described in Section 4.4, "Chemical Specialties."
- Optimize boiler operations. Although detailed discussion of boiler operations and maintenance is beyond the scope of this manual, boiler emissions are a main source of pollution and must be addressed through optimization as part of any pollution prevention program.
- Improve solvent processing operations. Carefully select solvents. Use nonvolatile alternatives.
- Keep detailed (redundant tracking) records of all solvents purchased, issued, reclaimed, reused, recovered, and disposed of to facilitate emissions mass balances. Use special monitoring procedures (direct reading tubes) in work areas and ventilation stacks. Install direct solvent dispensing machines wherever possible, and use the best equipment design and maintenance procedures. Optimize capture efficiencies for all air handling, exhaust, and ventilation operations.
- Prescreen fibers for volatile spin finishes, and develop raw material specifications for finish content of fibrous raw materials. A simple prescreening test involves heating a large fabric sample in a laboratory oven at the processing temperature (or higher). Volatile spin finishes generally will be visible as gray smoke coming from the oven vent.
- Trap bulk storage tanks with carbon canisters, and maintain these canisters on a regular basis.
- Minimize or eliminate the use of volatile chemical auxiliaries in aqueous processes.

1.2.1.4 Indoor Air Pollution Prevention Strategies

The following strategies can be used to reduce indoor air pollution:

- Review all MSDS information to identify potential latent emissions in manufactured textile products (14).
- Ensure that all reactive finishes are used under appropriate curing conditions (e.g., time, temperature, moisture) so that reactive volatile components (e.g., formaldehyde) are properly bound.
- Do not store volatile organic chemicals with textile products near a warehouse because the textiles can sorb and release the chemicals, causing indoor air pollution (14).
- Control sorption of perchloroethylene (dry-cleaning process solvent) by textiles stored near recently cleaned clothing (20).
- Minimize or eliminate the use of chemical finishes. Instead, substitute better fabric design and mechanical finishing wherever possible.

1.2.2 Water Pollution

Textile manufacturing is one of the largest industrial producers of wastewater (3). On average, approximately 160 pounds of water (20 gallons) are required to produce 1 pound of textile product. Textiles also is a chemically intensive industry, and therefore, the wastewater from textile processing contains processing bath residues from preparation, dyeing, finishing, slashing, and other operations. These residues can cause damage if not properly treated before discharge to the environment (10).

1.2.2.1 Pollution Prevention Targets

Because textile operations produce so much wastewater, mills may be tempted to assume that they cannot avoid large volumes of wastewater, and therefore, they may become lax in pollution prevention. In practice, mills vary considerably in the amount of water and wastewater pollutants they discharge. One essential and often difficult step in water pollution prevention is to accurately and realistically assess the mill's current status and its potential for improvement. This assessment is necessary to target specific waste streams that will maximize pollution prevention.

The first step in a pollution prevention strategy for water is a thorough audit and characterization of wastewater from textile operations. Comparing the information from this audit with benchmark data allows for realistic goal-setting and economic projections for water pollution reduction activities. Several options exist for benchmarking an operation and, hence, for identifying pollution prevention targets.

Any wastewater stream deserves attention if (21-24):

- It exceeds industry norms.
- It exceeds publicly owned treatment works (POTW) pretreatment or National Pollutant Discharge Elimination Standards (NPDES) permit limits.
- It is economically advantageous to eliminate.
- It is one of the four types most amenable to pollution prevention (high volume, offensive, persistent or resistant to treatment, dispersable).

This manual reviews many aspects of pollution prevention that relate to wastewater, but sets aside some issues for further discussion in other sections, including water conservation, which is covered in Section 2.2.7.

1.2.2.2 Definition of Norms

Many studies have been published on water pollution from textile operations. The most definitive, comprehensive source of information is the *Development Document for Effluent Limitations Guidelines and Standards for the Textile Mills* published by the U.S. Environmental Protection Agency (EPA) (25). This document assesses the quantities and characteristics of wastewater pollutants on a process-by-process and pollutant-by-pollutant basis, using data based on current practices in the U.S. textile industry. Tables 1-9 through 1-11 provide information on:

- Water consumption and wastewater discharge (Table 1-9).
- Pollutants generated as a function of water consumed (Table 1-10).
- Pollutants generated as a function of production output (Table 1-11).

Using these tables, mills can estimate pollutant amounts and concentrations in effluent for different types of textile operations and for varying levels of water consumption or production. With these benchmarking tables and an accurate wastewater audit, mills can compare their performance with industry norms, identify targets for pollution prevention, and establish realistic pollution prevention goals.

1.2.2.3 Comparison With Typical Permits

Certain pollutants in textile wastewater are more important to target for pollution prevention than others. For example, most dyeing machines have lint filters and other primary control measures to keep lint out of heat exchangers and off of the cloth; therefore, total suspended solids (TSS) levels are low in raw textile dyeing wastewater compared to many other industries (and compared to POTW pretreatment or NPDES discharge limits). On the other hand, biological oxygen demand (BOD) and chemical oxygen demand (COD) are relatively high in slashing, fabric formation, and wet processing and, therefore, are more important pollution prevention targets.

NPDES and POTW pretreatment permit limits can be compared with textile wastewater when audited to identify further targets for pollution prevention. When comparing typical raw textile wastewater with typical municipal sewer pretreatment requirements for indirect dischargers, opportunities for pollution prevention can be identified based on the limits shown in Table 1-12.

In addition to the pollutants shown in Table 1-12, the following pollutants are prohibited through permit language such as "no wastewater that imparts color," rather than through specific numerical limits:

- Color
- Radioactivity
- Paint
- Explosives
- Flammable effluent
- Mud
- Straw
- Grit
- Fibers and feathers
- Noxious and malodorous effluent
- Cinders
- Grain

Table 1-9. Water Consumption and Wastewater Discharge Volumes by Subcategory (25)

Subcategory	Water Usage (L/kg)			Water Usage (gal/lb production)			Discharge (median mill)		No. of Mills
	Min.	Med.	Max.	Min.	Med.	Max.	m^3/day	MGD	
1. Wool scouring	4.2	11.7	77.6	0.5	1.4	9.3	103	0.051	12
2. Wool finishing	110.9	283.6	657.2	13.3	34.1	78.9	1,892	0.500	15
3. Low water use processing	0.8	9.2	140.1	0.1	1.1	16.8	231	0.061	13
4. Woven fabric finishing									
a. Simple processing	12.5	78.4	275.2	1.5	9.4	33.1	636	0.168	48
b. Complex processing	10.8	86.7	276.9	1.3	10.4	33.2	1,533	0.405	39
c. Complex processing plus desizing	5.0	113.4	507.9	0.6	13.6	60.9	636	0.168	50
5. Knit fabric finishing									
a. Simple processing	8.3	135.9	392.8	0.9	16.3	47.2	1,514	0.400	71
b. Complex processing	20.0	83.4	377.8	2.4	10.0	45.2	1,998	0.528	35
c. Hosiery processing	5.8	69.2	289.4	0.7	8.3	34.8	178	0.047	57
6. Carpet finishing	8.3	46.7	162.6	1.0	5.6	19.5	1,590	0.420	37
7. Stock and yarn finishing	3.3	100.1	557.1	0.4	12.0	66.9	961	0.254	116
8. Nonwoven finishing	2.5	40.0	82.6	0.3	4.8	9.9	389	0.100	11
9. Felted fabric finishing	33.4	212.7	930.7	4.0	25.5	111.8	564	0.149	11

Table 1-10. Median Raw Waste Concentrations by Subcategory (Based on Effluent Volumes) (25)

Subcategory	BOD (mg/L)	COD (mg/L)	COD/ BOD	TSS (mg/L)	O&G[a] (mg/L)	Phenol (μg/L)	Chromium (μg/L)	Sulfide (μg/L)	Color APHA Units
1. Wool scouring	2,270	7,030	3.1	3,310	580	ID	ID	ID	ID
2. Wool finishing	170	590	3.5	60	ID[b]	ID	ID	ID	ID
3. Low water use processing	293	692	2.4	185	ID	ID	ID	ID	ID
4. Woven fabric finishing									
a. Simple processing	270	900	3.3	60	70	50	40	70	800
b. Complex processing	350	1,060	3.0	110	45	55	110	100	ID
c. Complex processing plus desizing	420	1,240	3.0	155	70	145	1,100	ID	ID
5. Knit fabric finishing									
a. Simple processing	210	870	4.1	55	85	110	80	55	400
b. Complex processing	270	790	2.9	60	50	100	80	150	750
c. Hosiery processing	320	1,370	4.5	80	100	60	80	560	450
6. Carpet finishing	440	1,190	2.7	65	20	130	30	180	490
7. Stock and yarn finishing	180	680	3.77	40	20	170	100	200	570
8. Nonwoven finishing	180	2,360	13.1	80	ID	ID	ID	ID	ID
9. Felted fabric finishing	200	550	2.75	120	30	580	ID	ID	ID

[a] O&G = oil and gas.
[b] ID = insufficient data to report values.

Table 1-11. Median Raw Waste Loads by Subcategory (Based on Production Volume) (11)

Subcategory	BOD (kg/kkg)	COD (kg/kkg)	TSS (kg/kkg)	O&G[a] (kg/kkg)	Phenol (g/kkg)	Chromium (g/kkg)	Sulfide (g/kkg)
1. Wool scouring	41.8	1,289	43.1	10.3	ID[b]	ID	ID
2. Wool finishing	59.8	204.8	17.2	ID	ID	ID	ID
3. Low water use processing	2.3	14.5	1.6	ID	ID	ID	ID
4. Woven fabric finishing							
a. Simple processing	22.6	92.4	8.0	9.1	8.2	4.3	7.6
b. Complex processing	32.7	110.6	9.6	3.8	7.7	2.6	12.5
c. Complex processing plus desizing	45.1	122.6	14.8	4.1	13.1	20.9	ID
5. Knit fabric finishing							
a. Simple processing	27.7	81.1	6.3	4.0	8.7	7.8	13.0
b. Complex processing	22.1	115.4	6.9	3.5	12.0	4.7	14.0
c. Hosiery processing	26.4	89.4	6.7	6.6	4.2	6.4	23.8
6. Carpet finishing	25.6	82.3	4.7	1.1	11.3	3.4	9.4
7. Stock and yarn finishing	20.7	62.7	4.6	1.6	15.0	12.0	27.8
8. Nonwoven finishing	6.7	38.4	2.2	ID	ID	0.5	ID
9. Felted fabric finishing	70.2	186.0	64.1	11.2	247.4	ID	ID

[a] O&G = oil and gas.
[b] ID = insufficent data to report values.

Table 1-12. Permitted Discharges (Survey of Six Cities, 1991 to 1994)

Item	Limit (max. ppm)
Ammonia N	40
Arsenic	0.004-1.0
Barium	1-100
Boron	1.0
Cadmium	0.005-0.7
Chromium	0.03-1.0
Copper	0.07-1.0
Cyanide	0.03-2.0
Lead	0.03-0.6
Manganese	1.0
Mercury	0.0002-0.1
Nickel	0.02-0.08
Nitrous oxide	10
Oil and grease	50-200
pH limit (low)	5-6
pH limit (high)	9-10
Phenol	10
Selenium	0.03-0.05
Silver	0.02-0.7
Solids	0.25-0.50 (inch)
Sulfide	5-10
Sulfur dioxide	10
Temperature	104-140 (°F)
Tin	1
Zinc	0.1-1.0

POTW pretreatment regulations control other parameters through surcharges. Surcharge systems provide economic incentives for reducing pollution. Examples of surcharges for pollutant parameters are shown in Table 1-13.

1.2.2.4 Emerging Wastewater Issues

In general, wastewater treatment methodologies in the textile industry are mature and well developed. The industry and its regulators have focused on improving the efficiency of existing treatment processes for some time. The textile industry is concerned that some pollutants might not be amenable to treatment with existing treatment systems (19, 26). For these pollutants, prevention, not treatment, must assume the primary role. These pollutants include:

- Color residues in dyeing wastewater
- Electrolytes in dyeing wastewater
- Toxic air emissions from wastewater
- Low metals in dyeing wastewater
- Aquatic toxicity in dyeing wastewater

In addition to pollution prevention, water conservation and treatability of wastes also need to be addressed for these pollutants. These issues are covered in other sections of this document.

Table 1-13. Examples of Economic Surcharges Applied to Effluent Characteristics (1991 to 1994 Survey)

Item	Limit	Surcharge
Flow	All	\$0.123 - \$0.35 per CCF[a]
BOD	250-325	\$0.04 - \$0.186 per excess pound
COD	600	\$0.122 per excess pound
TSS	250-300	\$0.021 - \$0.223 per excess pound

[a] CCF = hundred cubic feet.

1.2.2.5 Pollution Prevention Strategies

Appropriate pollution prevention strategies for wastewater are discussed in various sections on pollution prevention techniques and on individual unit processes. Although making generalizations about pollution prevention is difficult, most textile operations can develop and implement a pollution prevention plan to reduce pollution from problem areas such as those shown in Table 1-14.

1.2.3 Solid Wastes

By volume, solid wastes are the second largest waste stream in textile manufacturing, after effluent waste streams. Textile processing produces many varieties of solid waste, ranging from selvage trimmings to fly ash, from aluminum cans to wooden pallets, and many others.

In the last few years, significant progress has been made in preventing the generation of solid waste in textile plants. The American Textile Manufacturers Institute (ATMI) has formed a Solid Waste Subcommittee that champions pollution prevention initiatives.

Table 1-14. Priority Areas for Pollution Prevention in Textile Operations

Production Area	Area To Address
Slashing and sizing	BOD COD
Preparation	Water volume (from water-jet looms)
Dyeing	BOD COD Temperature pH Metals Aquatic toxicity
Printing	BOD COD TSS Copper pH Temperature Water volume Air emissions
Finishing	BOD COD TSS Water volume Air emissions

The quantities of solid waste generated depend greatly on the size and type of textile operation, the nature of the waste, the efficiency of the machinery or process generating the waste, and the level of awareness about solid waste problems and management techniques among operators and managers in the mill. According to a 1994 ATMI survey, the largest quantities of waste generated (by tonnage) are paper/trash, followed by wastewater sludge, cardboard, and fly/bottom ash. Encouraging news from the survey indicates that disposal methods for solid waste are changing dramatically. Compared with a 1989 survey, the percentage of solid waste sent to landfills fell from 70 to 33 percent, and the percentage of waste being recycled rose from 23 to 65 percent.

Pollution prevention efforts tend to focus on reducing solid waste through more efficient work practices; optimization of waste-generating machinery and processes; and reuse, recycle, salvage, and sale of solid waste. Examples of effective strategies include reusing containers, purchasing chemicals in reusable containers rather than bags, salvaging cardboard for sale to recyclers, and training employees to sew seams straight, which results in less off-cut waste.

1.2.3.1 Types of Solid Waste

Comprehensive studies have been conducted on solid waste generation in textile operations (27). The main types of wastes identified in these studies are listed in Table 1-15. For the 290 facilities that participated in the ATMI survey, the total amount of solid waste generated was more than 51,000 tons per month. The disposition of this waste was as follows (27):

- 32,675 tons, or 64 percent, was sent to public landfills.
- 11,984 tons, or 23 percent, was recycled.
- 3,119 tons, or 6 percent, was sent to private landfills.
- 467 tons, or 1 percent, was incinerated.
- 2,878 tons, or 6 percent, was disposed of by other means (mainly wastewater treatment sludge disposed of via land application).

1.2.3.2 Sources

Common types of solid waste and pollution prevention strategies for the wastes are described below. Usually, the sources of each waste type are obvious upon inspection. A solid waste audit can identify waste sources that might be overlooked in everyday operations. ATMI and other organizations have developed survey forms to identify sources of solid waste (27, 28). After identifying the sources, mills can reduce or eliminate the associated wastes if they remain committed to achieving their pollution prevention goals.

Table 1-15. Common Solid Waste Materials in Textile Processing

- Aluminum cans
- Ash
- Bale wrapping
- Cardboard
- Card waste
- Carpet backing
- Carpet remnants
- Carpet trim
- Carpet waste
- Compacted trash
- Computer paper
- Fabric waste
- Fiber waste
- Garbage
- Glass
- Hard plastic
- Hard thread (sized)
- Latex foam solids
- Metal drums
- Office paper
- Paper bags
- Paperboard drums
- Plastic bale wrap
- Plastic containers
- Plastic drum liners
- Plastic drums
- Plastic film
- Rags
- Scrap metal
- Scrap wood
- Selvage trimmings
- Slasher waste
- Soft thread
- Surface finishing waste
- Sweeps
- Wastewater treatment sludges
- Wooden pallets
- Yarn waste

Table 1-16. ***Packaging Wastes Used in Five Textile Plants (7)***

Material	Amount
Bale wrap	100 tons
Cardboard boxes	230 tons
Metal drums	3,250 count
Paper bags	41,500 count, or 10 tons
Paper drums	6,850 count
Plastic drums	1,150 count
Wooden pallets	1,550 count
Paper tubes and cones	NA[a]

[a] NA = not available.

Ash and Sludge

Two major sources of pollution, boilers and wastewater treatment, are directly related and are difficult to eliminate. These sources generated approximately one-fourth of the total, or more than 6,000 tons per month, in the 290 facilities surveyed by ATMI (27). Energy conservation programs can reduce boiler ash by decreasing the amount of incineration required. Reductions in the chemical content of wastewater and optimization of wastewater treatment systems can decrease the level of sludge generated.

Packaging Materials

Another major source of solid waste is packaging materials. These materials include cardboard boxes, bale-wrapping film or fabric, baling wire, wooden crates, paper sacks, and drums made of paperboard, plastic, or metal. In one operating division comprising five plants, approximately 500 tons of packaging material waste were generated in 1 year (7). Table 1-16 indicates the types and amounts of packaging wastes that were generated. Reducing these wastes is largely a matter of establishing and enforcing improved purchasing specifications. All raw materials should be received in bulk or returnable intermediate bulk containers (IBCs) if possible. Returnable IBCs or bulk purchases of raw materials eliminate waste and provide other benefits, such as:

- Reduced spillage
- Reduced handling costs
- Reduced packaging waste
- Reduced worker exposure to chemicals
- Simplified inventory
- Reduced cost of chemicals that are bought in bulk
- Savings in storage space (IBCs are stackable)

Drums

When purchasing chemicals in drums, returnable containers should be specified, and the vendor should be required to accept unwashed drums for return. Eliminating the need to wash each drum before pickup can prevent a significant amount of wastewater at the textile facility.

Bags

Many chemicals are purchased in bags (e.g., salt, trisodium phosphate [TSP], tetrasodium polyphosphate [TSPP], soda ash, warp size). Bags often break, resulting in spillage, and disposing of them is a nuisance. They cannot be stored near high traffic areas or wet locations. They also must be moved on skids, which frequently break, and handling bags requires a considerable amount of labor. Wherever possible, mills should specify a preference for IBC packaging rather than bags (all chemicals listed above are available in IBCs as well as bags).

Paper Cones and Tubes

Yarns can be supplied on reusable plastic cones, and cardboard yarn cases can be replaced with plastic yarn pallets, which can be reused for many cycles. Polyvinyl chloride (PVC) pipe is used as a durable replacement for paper tubes in many operations. In addition to waste savings, rigid PVC tubes reduce fabric distortion in knits.

Processing Wastes

Waste fabric, yarn, and fiber from processing accounts for one-third of the total solid waste generated. In one multifacility company (spinning, weaving, dyeing, and finishing), annual processing waste accounted for the following:

- Fiber/Fabric/Yarn = 1,000 tons
- Sweeps = 150 tons

In many operations, selvage trimming and seam cutout waste account for more than 2 percent of fabric produced. Proper training, even for such apparently simple tasks as sewing seams straight, can significantly reduce seam waste as well as prevent creases and dye streaks at seams. In a million-yard-per-week production facility, this training could easily recover several thousand yards per week of fabric waste.

Miscellaneous

Other solid wastes that textile facilities might generate include scrap metal, trash, paper, and semisolid waste oils, solvents, and sludges.

1.2.3.3 Pollution Prevention

Many industries have adopted the waste management hierarchy established by the Pollution Prevention Act of 1990 as the basis for their waste management plans. The Act emphasizes prevention of pollution at the source and identifies recycling as well as treatment and disposal as less desirable options. Using this approach, companies seek to reduce the generation of wastes wherever possible. Where source reduction of a waste is not feasible, opportunities for recycling should be explored. For wastes that cannot be reduced or recycled, treatment and disposal should take place in an environmentally sound manner.

Source Reduction

Generally, reducing the generation of solid waste is the most efficient method of pollution prevention. Waste reduction best proceeds from an auditing or waste mapping procedure that can identify inefficiencies in the operation. Options for dealing with these inefficiencies are investigated to identify the most promising options. Source reduction schemes should be examined carefully for their impact on costs and their potential to reduce salvage value or generate more pollution (or work) than a recycling or reuse effort.

Reuse

If reducing solid waste is not possible, reuse of materials is usually the next preferable waste management option. Uniformity of materials aids reuse options, as does waste separation. For example, drums are easier to handle, stack, and return if they are of only one type and size. Fiber wastes from one machine are easier to reuse if they are kept separate from other types of wastes.

Recycling

Recycling material can be considered the third-most efficient waste treatment option. Recycling differs from reuse in that energy may be required to convert the waste into a usable form. The energy use occurs at the recycling facility, rather than the textile mill (unless the mill does its own recycling). Recyclable materials should be specified in the production process wherever possible to replace nonrecyclable materials. For example, a mill might specify burlap bale wraps or Tyvek bale covers, rather than polypropylene, which is not easily recyclable.

Disposal

Efficient disposal options are those that make good use of the waste during disposal and that minimize environmental impacts. Examples include incineration of old and broken pallets to recover their fuel value. Note that to be efficient, incineration should be performed using environmentally safe techniques. The least efficient form of solid waste treatment involves dumping or landfilling, serving no purpose other than waste disposal. This, of course, has traditionally been the only solid waste disposal method used by most industries.

1.2.3.4 Types of Waste Management Practices

Auditing Solid Waste

The generation, location, and physical nature of the solid waste must be investigated, documented, and analyzed before developing a waste management plan. Auditing or waste mapping procedures are well documented in various reports, especially in *A Guide To Pollution Prevention in Woolen Mills* (29). Waste auditing can proceed by one of two general methods. Process flow mapping is a methodology that generates its information from direct observation and brainstorming of operational procedures. The second method of waste auditing involves touring the facility with worksheets or checklists of waste possibilities to aid the auditor in finding waste streams. The ATMI solid waste surveys presented fairly comprehensive forms on which to list solid waste streams (27). One limitation of this type of checklist is that it prespecifies the waste streams, which increases the possibility that important streams in a particular operation might be left out. The audit procedure should encourage the textile facility to think of other possible solid waste sources without constraint.

Cost Factors

Assigning cost factors to each kind of waste can be useful in evaluating the impact that changes in these waste streams could have on plants or departments. Cost factors can also be used to foster appropriate pollution prevention incentives at the facility. For example, fiber sweeps have almost no value and are to some extent preventable by orderly work practices. In the waste analysis, these should count heavily against a mill or operational group. Clean, reprocessable fiber waste, on the other hand, has a high reuse value and should not be weighted so high. Another example is pallets, which, if handled carefully, are reusable for a long time. Broken pallets should count fairly heavily against the mill on its "waste score." The following are important basis points in determining incentive or worker reward programs:

- Cost of disposal.
- Value of salvage.
- Loss of value from next best salvageable form (e.g., value difference between a broken pallet and an intact pallet).
- Influence a worker has on the waste (e.g., ash is not preventable and should not count much, whereas broken pallets are preventable and should count more).

Example of cost factors to consider are shown in Table 1-17.

A system such as this is appropriate for comparing similar operations, such as greige mills. This makes workers more aware of the amount of waste and their performance, and keeps waste in its in highest value form.

Salvage Value

Some companies "advertise" or otherwise offer potentially reusable materials to others to improve the efficiency of waste reuse and recycle. Advertising is conducted in waste exchange newsletters, through telephone hotlines, or on computer bulletin board systems (BBSs).

1.2.3.5 Pollution Prevention for Specific Categories of Solid Wastes

Paper and Cardboard

Common wastes such as paper, cardboard, and empty paper drums must be baled, crushed, or shredded before disposal or recycling. One central waste processing center may be able to handle this waste better and more economically than individual mills because of the cost of the equipment, such as shredders and balers. The disadvantage of this arrangement is the cost and logistics of transportation to the central location. The feasibility, however, of establishing a central waste processing center for outside recyclers should be considered.

Table 1-17. Cost Factors in Textile Wastes

Type of Waste	Disposal/Salvage Value per Unit (e.g., ton, count)	Next Best Form of Waste	Worker Influence
Pallets	$2 gain	None	None
Broken pallets	$6 loss	Pallet	Much
Empty size bags	$6 loss	None	None
Waste fiber	$2 gain	Reworkable waste	Moderate
Sweeps	$6 loss	Fiber waste	Great

Suppliers buy back used paper tubes and cones. Intact tubes can be reused directly, and damaged tubes can also be reused by salvaging shorter pieces from longer damaged tubes (e.g., a 60-inch tube with a damaged end can be cut off and used at standard 48-inch length).

Fibers and Fabric

Fibers, sweeps, rags, yarn, and cloth scraps have salvage value and should generally be collected and sold wherever possible. This is standard practice in most mills, and many buyers are available for these high-value wastes.

Reworkable fiber waste of 5 percent is typical in spinning operations and can be completely reclaimed by introducing it back into the opening line through a waste hopper. Fabric trimming can be difficult to compact and thus produces a very low-density waste that takes up a substantial amount of space in landfills.

Pallets

Pallet use should be minimized by buying as many large-volume chemicals as possible in IBCs or bulk or returnable containers, especially bagged chemicals such as warp size. Scrap pallets can be recycled or used in two ways, either as pallets or as fuel. Many pallet recycling operations recover materials and energy from broken pallets in an environmentally safe manner.

Not all pallets are recyclable, but using recyclable pallets despite higher initial cost is economical in the long term. Important factors in pallet recycling are listed below:

- Weight.
- Exact stringer length and size.
- Number of deck boards (top and bottom).
- Dimensions and length of deck boards.
- Whether they are two-way or four-way (accessible from two or four sides).

Pallets that cannot be sold can be chipped and burned in boilers, but this process generally requires removal of nails, staples, and other metal before chipping. Pallet chippers are readily available. A drum shredder, if available, can be used for shredding pallets, but the cost of such equipment is high compared with a pallet chipper. Drum shredders cost up to $80,000 and have a capacity of up to 500 units (e.g., pallets, drums) per day.

Drums

Metal drums, like pallets, can be recycled or shredded and sold as scrap metal. Several drum recyclers will pick up part loads as small as 50 drums. Other options for drums include returning them to the supplier and internal reuse. Purchasing contracts for chemicals should specify returnable drums or other containers, such as gas cylinders. Procedures for establishing such specifications are part of a facilitywide prescreening protocol described in Chapter 3.

One problem that can aggravate attempts to recycle drums is the sheer variety of drum sizes. This creates problems in handling, storage, and reuse. The main plastic and metal drum sizes are listed in Table 1-18.

Bags

Bags (empty chemical sacks), paper, and cardboard can be baled and resold for about $12 per ton. Most recyclers require that paper be bailed, an investment of about $6,000. Cardboard yarn cases can be reused several times, and many companies have policies requiring such material to be recovered and reused. An alternative to yarn cases is plastic yarn pallets, which are shrink-wrapped to pack the yarn for shipment.

By purchasing chemicals in bulk or in IBCs, the textile facility can not only reduce chemical costs but also reduce or eliminate problems such as waste paper sacks and pallets. Other advantages include reduced costs for storage, handling, labor/lifting, employee exposure, spillage (broken bags), inventory, and warehouse space. Chemicals often purchased in bags include:

- Common salt
- Glaubers salt
- Warp sizes
- Soda ash
- TSP
- TSPP

Table 1-18. Drum Sizes for Textile Chemicals

Chemical	Height (inches)	Diameter (inches)
Sodium bromate (oxidizer)	18	17
Processing assistants	38	22
Dyes	31	22
Dyes	27	22
Dyes	35	22
Miscellaneous (e.g., shop solvents)	27 or 37	22

Other Wastes

Burlap bale wrap can be sold with rags and other fiber waste through a waste exchange or to a recycler. Most bale covers, however, are either polypropylene or Tyvek. Although Tyvek covers can be sold or reused, the polypropylene is not reusable and should be avoided. Bale straps and bailing wire can be sold to scrap metal dealers only if they are cut into short pieces.

Summary

To avoid generating these wastes, mills should emphasize the following actions:

- Buy chemicals (e.g., size, salt) in bulk or IBCs to reduce the number of bags and pallets acquired.
- Recycle bags.
- Sell used pallets to a recycler.
- Donate damaged pallets to employees or institutions (high school shop) for the wood.
- Chip, then burn pallets in boilers.

1.2.4 Hazardous Waste

Most textile operations produce little or no hazardous waste as part of their routine operations, but a small percentage of textile mills (perhaps 10 percent to 20 percent) are hazardous waste generators. Any facility that uses chemicals can produce hazardous waste if a chemical exhibiting the hazardous characteristics of ignitability, toxicity, corrosivity, reactivity, or flammability is spilled on the ground. The contaminated soil from such a spill is often hazardous waste by the legal definition and must be handled accordingly.

Generators must prepare both for routine handling of hazardous waste and for emergencies through proper training, equipment, and policies. For facilities that generate and handle hazardous waste, hazardous waste policies are essential. Policies must be realistic and must actually encourage proper practices. Policies designed mainly to protect the employer from liability and that do not actually promote safety and pollution prevention should be avoided.

1.2.4.1 Waste Generation and Storage

Treatment and disposal of hazardous waste is expensive and difficult, and the associated liability is great. The key to minimizing cost and risk exposure is to minimize these wastes to the maximum extent possible. Thus, the economic incentive to eliminate these wastes through pollution prevention practices is great. Many textile mills have completely screened out materials that produce hazardous waste, and continue to do so, to avoid producing expensive hazardous wastes.

Facilities that produce or treat, store, and dispose (TSD) of hazardous waste must obey very specific regulations. Any hazardous waste generator must be fully aware of these regulations and must comply with them (e.g., by obtaining proper permits, keeping proper records). Any facility that stores hazardous waste more than 30 days is by legal definition a storage facility.

Generators are classified according to the amount of hazardous waste they produce. Large generators produce more than 1,000 kilograms per month of such waste, and small generators produce 100 to 1,000 kilograms per month. Each mill must determine its hazardous waste status and must understand and abide by the appropriate regulations.

1.2.4.2 Waste Disposal

Under national hazardous waste laws, generators of hazardous waste have the ultimate responsibility for safe removal and disposal of all hazardous waste they produce. A textile mill's liability cannot be assigned or transferred to a contractor who removes or disposes of the waste. Therefore, one of the most important issues for the hazardous waste generator is to monitor TSD contractor activities. The generator should contact local, state, and federal authorities to check the credentials of TSDs contractors.

If a TSD contractor fails to handle hazardous waste properly, both the transporter and the generator(s) who produced the waste are jointly liable for damages. Thus, the generator must make every effort to ensure that the transporter is perfectly reliable, properly trained, and highly prepared. A common practice is for a generator to accompany the transporter to verify the proper ultimate destruction or disposal of wastes.

1.2.4.3 Hazardous Waste Sources in Textile Operations

Several textile processes can potentially generate hazardous waste as a normal, routine by-product. In addition, occurrences such as spills, process excursions, and upsets can produce hazardous waste unexpectedly. Although many textile mills screen out chemicals that might potentially generate hazardous waste, abnormal events that result in hazardous waste spills can still occur and must be planned for.

Common sources of spills and upsets in textile operations include:

- Dry cleaning
- Solvent scouring
- Solvent-based coating operations
- Shop activities

Spills

Bulk off-loading and storage areas are susceptible to spills. Discharge of a reportable spill quantity of hazardous material beyond a preplanned containment constitutes a hazardous spill and the associated problem of hazardous waste disposal. The key concept is "preplanned." To avoid producing hazardous waste from spills, facilities must develop advance planning programs, including:

- Employee training on spill response.
- Policies regarding off-loading practices and activities.
- Preplanned containments.
- Facility design to ensure ease of spill cleanup.
- Absorbent materials on hand.
- Prescreening to avoid having hazardous materials on site.
- Auditing and preventive maintenance on a regular schedule.

Dry Cleaning

Some mills use chlorinated solvents for batch dry cleaning as well as spot removal in the final inspection department. These materials are efficient in removing oil-based stains from cloth and sewn products, but they have the potential to become a hazardous waste, even if recycled on site through distillation processes. In that case, the still bottoms must be disposed of as hazardous waste.

Facilities can avoid hazardous wastes from these processes in several site-specific ways. The most effective way is to address the source of the oil contamination. Often, the source is lubricating oils that drip or sling from moving or rotating machine parts (e.g., oven stacks and dampers, tenter frame drive chains, sewing machines, knitting oils). Because the main function of the dry-cleaning or spot-removal operation is repair work, improvements in preventive maintenance, better employee training in the use of lubricants, or selection of better lubricants can reduce or eliminate the need for extensive repair work.

Solvent-Coating Operations

Coating operations based on latex materials and solvents such as methyl ethyl ketone (MEK), methyl isobutyl ketone (MIK), acetone, toluene, and xylene are some of the largest sources of hazardous waste in the textile industry. These fabrics are used in waterproof products, offset printing blankets, landfill liners, and other engineered textile products. They often are produced by swelling or dissolving natural or synthetic rubber or latex materials in a mixture of solvents, as noted above. These solutions or plasticized materials are then spread or sprayed onto the fabrics, which are then dried or cured.

The residual portions of these solutions must be handled as hazardous wastes. As in printing or finishing, a key preventive measure is to ensure that only the exact amount of coating material necessary for the run is prepared. Mills that produce such products often do not follow this practice, however, because such products are high value-added items. These mills may view waste control as a secondary issue because economic incentives associated with waste prevention are weaker than those associated with commodity-type operations.

Mills should also explore the possibility of using water-based emulsions for fabric coatings. In many applications (though not all), this is a technically feasible substitution. Also, newer forms of materials (e.g., fiber-reinforced composites) may be a reasonable replacement for coated fabrics in certain applications. Where aqueous substitutes are not suitable, alternative product design should be considered for the specific end-use.

Shop Chemicals

Many shop chemicals are hazardous and become hazardous waste once they are used or become obsolete. These chemicals include insecticides, cooling tower treatment chemicals, weed killers, biocides, machine cleaners, paint strippers, and floor finishes. These classes of chemicals often are not evaluated with the same care as production chemicals. Every chemical in the mill, including shop chemicals, warrants the same level of hazardous waste screening.

1.2.4.4 Hazardous Waste Recordkeeping and Handling

Once hazardous waste is produced, maintaining proper documentation and proper waste handling procedures is essential. All hazardous wastes should be segregated from other wastes and raw materials to avoid increasing the amount of hazardous waste by mixing hazardous and nonhazardous wastes. Proper storage facilities are necessary to avoid leaks, seepage, or other release of the waste prior to pickup and disposal by a permitted TSD contractor. Records and manifests are required and should be available for review at any time.

Any chemical that potentially could become or contribute to a hazardous waste should be subjected to special audits and recordkeeping. Some of the important information to record about the hazardous waste includes:

- Amount
- Characteristics
- Disposal practices
- Annual reports submitted
- Permits (generator and TSD)

Generators must obtain permits not only to produce the waste but also to store it if the waste is held on site for more than 30 days. A storer who is not a generator (e.g., a trucking company depot) must obtain a permit no matter how briefly waste is held on site.

Shipping records must be carefully kept, and the shipper must maintain careful security of the waste, as well as a paper trail that leads clearly back to the generator. Appropriate training is required for truck drivers and other personnel involved in transport, storage, and disposal. Drivers must deliver wastes only to a permitted facility. All transportation vehicles must carry emergency equipment on board, and any losses or spills of hazardous waste must be reported immediately.

1.2.4.5 Prevention Strategies

The most powerful pollution prevention strategy for hazardous waste, and the most widely used in textiles, is total avoidance of pollution by prescreening chemicals. Dividing textile chemicals into two groups, commodities and specialties, facilities can establish methods to prescreen and check raw materials as they arrive to avoid many hazardous waste problems. These procedures are explained in detail in Sections 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities," but they are mentioned here specifically in relation to pollution prevention for hazardous waste.

One main reason for prescreening chemicals is to avoid introducing into the plant materials that will become or contribute to hazardous waste. Prescreening information must by law be specifically noted on the MSDS, along with appropriate spill control information.

Commodities are usually bought by the truck (or railway car), stored in bulk tank farms, and used in massive quantities. Many of these materials are corrosive or highly reactive. They are often handled with automated bulk chemical handling to reduce cost and potential for routine wastes. Bulk handling, however, increases the potential for large-scale spills from tank trucks and bulk handling systems, as well as associated production of hazardous waste.

Important pollution prevention considerations with these commodity chemicals are:

- Proper receiving, storage, and handling procedures.
- Routine, incoming raw material testing for impurities (e.g., metals) that might produce hazardous process wastes or treatment sludges.
- A strong program of preventive maintenance for bulk handling facilities.
- Thorough training of employees who use automated bulk chemical handling systems.
- Proper training on large-scale spill response.

Specialties, on the other hand, are generally complex mixtures of unknown composition to the user (and often to the vendor as well) and cannot be handled the same way as commodities. Testing and prescreening of specialties must follow a less specific and more generic protocol, as presented in Section 4.4, "Chemical Specialties." Careful review of all MSDS information is even more important with specialties because many seemingly harmless specialty chemicals can contain relatively insidious and hazardous ingredients.

To avoid the production of hazardous waste, textile mills should look for any component that:

- Is a listed hazardous air pollutant (HAP) or toxic air pollutant (TAP).
- Is a listed priority pollutant.
- Exhibits high aquatic toxicity.
- Contains hazardous or toxic metals.
- Tends to accumulate in facility or in treatment sludges.
- Will react with other chemicals on site to produce hazardous waste.
- Will be a hazardous waste if spilled on the ground.
- Is not suitable because the plant is not equipped to handle it in terms of:
  - Worker expertise, training
  - Engineering controls and storage facilities
  - Personal protective equipment

The plant should request all necessary information from the vendor before even starting to evaluate the chemical in production. If the vendor cannot or will not help in such an evaluation, the plant should identify and contact alternate vendors.

Once adopted, raw material testing of all incoming shipments should be conducted according to the protocols described in Sections 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities."

1.2.4.6 Process Review

In reviewing processes, mills should ask the following types of questions:

- What is mixed together?
- What reaction might occur under normal conditions?
- What reaction might occur under exceptional conditions?
- Is the level of expertise of the operator sufficient?
- Is the process machinery adequate?
- Is the process control system adequate?

If a hazardous waste is produced, the mills should then ask:

- Where does waste originate from in the process?
- Can the hazardous waste be reused or recycled on site?
- What are the alternative processes?

1.3 Summary

This chapter presented a brief overview of textile processes, the wastes that these processes generate, and the major pollution prevention approaches that are applicable to each process or waste stream. The chapter highlighted the enormous diversity of operations found within textile facilities. Although each process has its own unique wastes and environmental concerns, the chapter also identified numerous issues that are common to a variety of textile processes and corresponding pollution prevention approaches that can be applied to these problems.

The remaining chapters in this manual explore textile operations in greater detail. They identify both general and specific pollution prevention approaches to problems encountered in textile facilities:

- Chapter 2 first provides a method for categorizing wastes and identifies pollution prevention approaches applicable to each waste type. The chapter then takes a detailed look at some of the most important pollution problems in textile operations, such as color, salt, air emissions, wastewater treatability, metals, aquatic toxicity, and water conservation. In addition to providing data on the sources and extent of these problems in the industry today, the chapter identifies the main pollution prevention strategies available for addressing each problem.
- Chapter 3 describes general pollution prevention approaches that are not specific to individual processes but may apply throughout the textiles operation. It covers issues such as designing processes and products to incorporate pollution prevention, developing expertise for evaluating chemical use, operating and maintaining equipment to minimize pollution, operating equipment to reduce water consumption, and reusing and marketing process wastes.
- Chapter 4 is a process-by-process examination of textile operations that takes the reader through the life cycle of textile products, from raw fiber production and handling through yarn manufacturing, fabric formation, fabric preparation and finishing, and cutting, sewing, and fabrication. Each chapter describes the process, equipment, and chemicals that are used, identifies the pollutants that the process generates and their sources, and discusses pollution prevention opportunities available for reducing or eliminating wastes. The chapter highlights the need for a

global approach to pollution prevention because many pollution problems faced by textile facilities are the result of processes used at upstream production facilities or design, product, or finishing decisions made elsewhere.

- Chapter 5 provides an overview of the major steps involved in setting up and implementing a pollution prevention program. It describes the building blocks for an effective pollution prevention effort, such as management commitment, employee involvement, project evaluation skills, and communication about program results. It also details some of the major pollution prevention tools, such as waste audits, and how they can be applied in textile operations.
- Chapter 6 discusses the need to provide appropriate incentives to encourage and facilitate adoption of the pollution prevention approach. It identifies barriers that sometimes limit facilities' ability to implement pollution prevention and offers suggestions for breaking down these barriers.
- Chapter 7 provides abstracts of selected case studies of pollution prevention initiatives taken at textile facilities in the United States and elsewhere. Wherever possible, these case studies identify the costs of each initiative and the benefits obtained. Hopefully, these case studies will provide inspiration to companies as they undertake their own pollution prevention initiatives.

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Chapter 2
Waste Categorization/Prioritization for the Textile Industry

This chapter describes a general categorization scheme for wastes generated in the textile industry (Section 2.1) and numerous specific wastes or pollution issues that are considered priorities for the industry (Section 2.2). Section 2.1, "General Waste Categorization," provides a framework for thinking about different types of waste generated in textile operations and the general approaches applicable to each type. Section 2.2, "Specific Wastes or Waste Problems," addresses many specific waste types or waste problems for textile operations. These wastes may be produced in one or more textile process areas and thus may be cross-referenced to one or more sections in Chapter 4, "Pollution Prevention in Specific Textile Processes."

2.1 General Waste Categorization

This section describes four general categories of textile waste that are particularly suitable for reduction through pollution prevention measures such as material substitution, process modification, inventory control, better management techniques, recovery, reuse, and recycling. Each type of waste has specific characteristics that require different pollution prevention approaches. The four categories of wastes are:

- Dispersible wastes
- Hard-to-treat wastes
- High-volume wastes
- Hazardous and toxic wastes

2.1.1 Dispersible Wastes

Many wastes that are well contained when generated become highly dispersed once they are released or mixed with other wastes. It is important to segregate and capture such highly dispersible wastes at the source because removing them from a mixed waste stream requires substantially more treatment at greater cost and effort. Examples of these wastes in the textile industry include:

- Waste streams from continuous operations (e.g., finishing, dyeing, printing, preparation).
- Print paste (especially from screen, squeegee, and drum cleaning).
- Lint.
- Waste from coating operations (especially foam).
- Waste solvents from machine cleaning.
- Still bottoms from solvent recovery (especially drycleaning operations).
- Batch dumps of unused processing (especially finishing) mixes.

In each of these cases, facilities are generally able to capture the waste in its concentrated form for more efficient, cost-effective treatment. These wastes are often allowed to mix with other wastes, however, complicating collection, disposal, salvage, or recycle/reuse. Even if the waste does not have reuse or recycle potential, it can usually be collected and prepared for disposal much more easily if it is not diluted or contaminated.

Sources of dispersible wastes are widespread in textile wet processing:

- *Pastes:* Pastes generally come from printing and include oil/water pastes and acrylic polymers. Both types tend to gel and form lumps in drains. These wastes can be difficult to sample with automated equipment because of their tendency to stop up sampler lines, pumps, and filters.
- *Lint:* Lint can originate from many textile operations, particularly preparation, dyeing, and washing operations. Usually, removing lint is fairly easy using primary control measures such as filters, which can be placed in the circulation lines of dyeing machines and other equipment. The filters must be maintained and cleaned out on a regular basis to ensure proper operation. The collected lint usually can be dried and then landfilled or incinerated. Higher quality lint can be marketed.
- *Solvent:* Proper handling of solvents can make disposal much easier; once mixed with water, however, solvents become difficult to manage. Also, solvent reclamation and reuse is much easier before solvents are mixed with other wastes. Some tips and tech-

niques for proper handling are described in Sections 2.2.3, "Toxic Air Emissions," and 3.8, "Maintenance, Cleaning, and Nonprocess Chemical Control." In general, the key is to avoid dumping solvents down the drain with other wastes.

- *Wastes from continuous processes:* Dumps of dye and chemical mixes sometimes occur in continuous textile operations such as slashing, preparation, continuous dyeing, printing, coating, and finishing. Pollution prevention techniques that can be used include equipment modification, maintenance procedures, housekeeping, waste capture, and segregation of concentrated wastes from the general waste streams.

2.1.2 Hard-To-Treat Wastes

Hard-to-treat wastes include those that are persistent, resist treatment, or interfere with the operation of waste treatment facilities. They often contain nonbiodegradable or inorganic materials. Biological processes that occur in waste treatment systems generally cannot remove or break down these wastes.

Hard-to-treat textile wastes include color, metals, phenols, certain surfactants, toxic organic compounds, pesticides, and phosphates. Color and metals originate primarily from dyeing or printing operations, although metals are sometimes found in other processes (see Section 2.2.5, "Metals"). Phosphates are used primarily in preparation and dyeing (see Section 3.5, "Chemical Alternatives"). Nonbiodegradable organic materials include certain surfactants (see Section 4.4, "Chemical Specialties") and solvents (see Section 2.2.3, "Toxic Air Emissions"). These materials can resist treatment, pass through standard activated sludge systems, and contribute to aquatic or air toxicity.

Another example of a hard-to-treat waste is pesticide residue that is present in wool-processing wastewater. Mickelson et al. (1) report that several different chemical pesticides are used to process wool. The degradability of each is given in Table 2-1. Information such as this, in combination with other relevant data (e.g., aquatic toxicity of the materials, their degradation products, the amount of material released during production), should be used as a guide in selecting the appropriate pesticide (1). For more information, see Section 4.12, "Finishing."

Table 2-1. Degradability of Alternative Pesticides in Wastewater Treatment Systems (1)

Pesticide	Percent Degraded
Dieldrin	81
Dichlorofenthion	79
Diazinon	87
Cyperethrin-1	84
Cyperethrin-2	90
Deltamethrin	92

Achwal (2) reported that preservatives such as biocide additives in warp size materials can interfere with waste treatment system operation and can, in some cases, inhibit aerobic stabilization of wastewater. Some countries have banned the use of chlorinated phenols as a size additive. Undegraded size materials can cause biomass to aggregate (flock) and inhibit oxygen transfer. Starch can cause the growth of hard-to-settle filamentous bacteria, interfering with the operation of clarifiers. Synthetic sizes, mainly polyvinyl alcohol (PVA), do not cause these problems, nor are they toxic. Residues from other synthetic sizes, however (such as polyacrylic acid [PAA]), are also hard to treat and require tertiary treatment. For more information, see Section 4.7, "Slashing and Sizing."

Because of the difficulties involved in treating some of these wastes, efforts should be made to identify and eliminate their sources wherever possible. Several methods of prevention are particularly effective, including chemical or process substitution; improved process control and optimization; waste segregation, capture, and reuse/recycle; and improved employee work practices. Each method is discussed briefly below.

2.1.2.1 Chemical or Process Substitution

Several strategies are appropriate for eliminating offending and hard-to-treat chemicals from a process, including:

- *Substituting other, easier-to-treat chemicals:* Example: Substituting linear alkylbenzene sulfonates for hard-to-treat alkylphenol (AP) in scouring eliminates waste system pass-through and aquatic toxicity (see Section 4.4, "Chemical Specialties").

- *Making physical process changes to avoid the need for chemicals:* Example: Pressure dyeing polyester eliminates the need for nonbiodegradable dye carriers such as 1,2,4 trichlorobenzene (see Section 4.10, "Dyeing").

- *Altering a product or raw material specification to avoid the need for chemicals:* Example: Finishing cotton knits mechanically at natural width and yield avoids the need for resins that contain formaldehyde, which can contribute to hazardous emissions (see Section 4.12, "Finishing").

- *Substituting another process:* Example: Pad-batch dyeing of fiber reactive dyes on cotton eliminates the need for hard-to-remove salt and reduces hard-to-treat color (see Section 4.10, "Dyeing").

2.1.2.2 Improved Process Control and Optimization

With an enhanced understanding of the complex chemistry of a particular process and the response of the process to variables that can be controlled, facilities often can reduce or eliminate hard-to-treat wastes from that process. A good example is the reduction of hard-to-treat color in wastewater. Sections 4.3, "Dyes," and 4.10, "Dyeing," describe how to reduce color by selecting dyes of high affinity and controlling bath ratio.

2.1.2.3 Waste Segregation, Capture, and Reuse/Recycle

In most cases, when a waste is mixed with other wastes, it loses much of its reuse potential and value. Rather than allowing them to become mixed with other wastes, hard-to-treat wastes should be captured in their concentrated forms, thereby facilitating their reuse. This practice is called "dry capture" regardless of the physical state of the waste material (i.e., solid, liquid, gas, or semisolid sludge). A good example is the use of centrifugal extraction to remove excess mothproofing treatment solution from wool substrate. The concentrated residue removed from the centrifuge is returned to the process, reducing the amount that ultimately reaches the environment (see Section 4.12, "Finishing"). Another example is the recovery of caustic from mercerizing operations (see Section 4.9, "Preparation").

2.1.2.4 Improved Employee Work Practices

Often, workers can reduce the amount of hard-to-treat chemicals (e.g., dye spillage that produces colored wastewater) that are wasted if they are made more aware of prevention measures. The three steps necessary to prevent wastes resulting from employee work practices are identification, training, and control:

1. *Identification:* Each chemical that is hard to treat should be identified to workers.
2. *Training:* Workers should receive training on handling these chemicals with minimal losses.
3. *Control:* Worker performance should be audited to ensure proper control of materials.

2.1.3 High-Volume Wastes

High-volume wastes in textiles include water (especially washwater from preparation and dyeing stages), alkaline wastes from preparation, salt, cutting room waste, knitting oils, and warp sizes. These wastes sometimes can be reduced by recycle or reuse as well as by process and equipment modifications. Several methods of reducing specific high-volume wastes are described in other sections:

- *Water:* Section 2.2.7, "Water Conservation"
- *Salt:* Section 2.2.2, "Discharge of Electrolytes"
- *Acids and alkali:* Various sections (e.g., Section 4.10, "Dyeing")
- *Warp sizes:* Section 4.7, "Slashing and Sizing"

In addition, cutting room waste is another major waste stream that can be reduced. Palmer (3) estimated that carpet waste amounts to 2 percent of an annual 900 million square yards of production, or 18 million square yards of waste per year (a value of $100 million). Denim is another example. Approximately 800 million yards of denim are produced in the United States each year, at an average weight of 12 ounces per linear yard. Total denim production thus amounts to more than one-half billion pounds per year (4). Fabric utilization efficiency in cutting and sewing ranges from approximately 72 to 94 percent, and the efficiency for cutting denim is typically 84 percent or less. Cutting waste, therefore, represents approximately 16 percent of denim production, or approximately 100 million pounds annually. Proper design, planning, information, and communication are essential to managing this waste stream (4).

2.1.4 Hazardous or Toxic Wastes

Hazardous or toxic wastes are a subgroup of hard-to-treat wastes. Because hazardous wastes have such a substantial impact on the environment, they are discussed as a separate waste class. In textiles, hazardous or toxic wastes include materials such as metals, chlorinated solvents, nondegradable surfactants, and a few other nondegradable or volatile organic materials. These materials often are used for nonprocess applications, such as machine cleaning. Appropriate reduction strategies include conservation, substitution, process modification, and maintenance/housekeeping. Where source reduction is not possible, such wastes can often be recovered through recycling. When neither is feasible, however, proper management and disposal practices must be followed. Specific examples of hazardous wastes and the sections of this manual that address them include:

- *Air toxics:* See Section 2.2.3, "Toxic Air Emissions."
- *Metals:* See Section 2.2.5, "Metals."
- *Toxic organic materials:* See Sections 4.4, "Chemical Specialties," and 2.2.6, "Aquatic Toxicity."

See also Section 1.2.4, "Hazardous Waste."

2.2 Specific Wastes or Waste Problems

The preceding section discusses generic categories of wastes to identify the general characteristics of wastes that make them most amenable to pollution prevention. This section presents specific examples for these wastes that are often found in textile processes and typical pollution prevention strategies applicable for each.

The following sections discuss several specific waste problems facing the textile industry. The basis for targeting these difficulties for discussion is their importance as unsolved problems of the present or the near future. Each of the following represents a significant challenge to the textile industry because the industry now has (or soon will have) needs that traditional waste treatment approaches cannot meet. The specific pollution issues include:

- *Color:* Section 2.2.1
- *Salt:* Section 2.2.2
- *Air toxics:* Section 2.2.3
- *Improved treatability of wastes:* Section 2.2.4
- *Metals:* Section 2.2.5
- *Aquatic toxicity:* Section 2.2.6
- *Water conservation:* Section 2.2.7

These sections explain why traditional waste treatment techniques are (or will be) insufficient to address these waste issues and why pollution prevention is important and in many cases represents the only long-term alternative.

2.2.1 Color Residues in Dyeing Wastewater

Color in effluent from textile dyeing and printing operations is being increasingly regulated and is widely recognized as a compliance problem that must be addressed through pollution prevention (4-8). Effluent from most textile dyeing operations generally has a dark reddish-brown hue that is aesthetically unpleasing when discharged to receiving waters. Although only an aesthetic pollutant,[1] color might be easy to detect (depending on the flow of the receiving stream), and even trace quantities of commercial textile colorants in wastewater are readily evident to the naked eye. Although many methods of color removal exist, none works in every case (9). Because of the difficulties and expense in treating color, the best approach for minimizing color discharges is pollution prevention (6).

2.2.1.1 Measuring Color

Measuring color in textile wastewater is inherently difficult (9). If the wastewater sample is not filtered, suspended solids can interfere with transmission measurement, rendering the measurement meaningless. If the sample is filtered, then the resulting measurement probably will not reflect the appearance of the wastewater because the turbidity will have been removed. Despite these acknowledged difficulties, the industry uses several color measurements, including:

- *Color:* Two methods are available for measuring color, based on American Dye Manufacturers Institute (ADMI) and American Public Health Association (APHA) protocols. Each method measures the color of light transmitted through a filtered wastewater sample, resulting in the computed value of a single number characterizing overall color.
- *Turbidity:* Turbidity is a measure of the light-scattering properties of the wastewater. Turbidity is calculated by comparing the intensity of light scattered by a sample compared with a reference suspension under the same conditions.
- *Apparent Color:* Apparent color is a measurement that attempts to combine the two measurements above (color and turbidity).

Because of the extremely high variability of tinctorial characteristics of dye solutions, generalizations cannot be made about the amount of dye (in percent or parts per million [ppm]) that will produce a specific color perception, or color value on the ADMI, APHA, or turbidity scale. In addition, many color regulations are written in qualitative language such as "no appreciable change in the color of the receiving waters" that provides mills with little guidance on permissible levels in the waste stream. Thus, color measurement is at best difficult, sometimes meaningless, and often bears little relation to regulatory and permit compliance language.

2.2.1.2 Sources of Color in Wastewater

Dyes and pigments from printing and dyeing operations are the principal sources of color in textile effluent. Dyes and pigments are highly colored materials used in relatively small quantities (a few percent or less of the weight of the substrate) to impart color to textile materials for aesthetic or functional purposes (10). In typical dyeing and printing processes, 50 to 100 percent of the color is fixed on the fiber (see Table 4-14), and the remainder is discarded in the form of spent dyebaths or in wastewater from subsequent textile-washing operations (8).

Reactive dyes are widely used and fall in the lower range of the fixation scale. As such, they require special attention to maximize fixation and therefore minimize waste color discharge. Important factors are bath ratio, optimized salt use, and adequate time for exhaustion. These issues are discussed in detail in Sections 4.3, "Dyes," and 4.10, "Dyeing."

Since the mid-1800s, dye chemists have attempted to meet consumer demand for color with outstanding permanence (i.e., color that is unaffected by crocking [rubbing], exposure to light, oxidizing or reducing agents, attack by chlorine or ozone, hydrolysis, or essentially any other environmental factor) (4). Their success has resulted in dyestuffs that have outstanding permanence

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[1] Extremely high doses of color can interrupt photosynthesis in the receiving waters, producing impacts beyond the purely aesthetic. Most textile effluent, however, is not so severely colored.

and end-use qualities but are largely resistant to treatment or removal in wastewater treatment systems.

Three important ways of preventing and minimizing color discharges are:

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

Maximizing Exhaustion From Dyebaths

To maximize dye exhaust, the dyer must understand the relationships between exhaust, affinity, and bath ratio, the three major dyeing process control parameters.[2] Although these methods are discussed in much greater detail in Section 4.10, "Dyeing," the essential points are reviewed here as well.

Typical values for affinity, bath ratio, and exhaust are:

K (affinity) = 50 to 1,000 for various dye/fiber combinations
L (bath ratio) = 5 to 50 for various machines (11)
E (exhaustion) = 0.50 to 1.00 (50- to 100-percent exhaustion) (8)

K (affinity) is a partition coefficient, or the ratio of the concentration of the dye in solution to the concentration of the dye in the substrate, at equilibrium, i.e.:

$$K = c^f / c^s \qquad \text{(Eq. 2-1)}$$

where:

cf = concentration of dye in fiber at equilibrium
c^s = concentration of dye in solution at equilibrium

An important relationship is:

$$E = K/(K+L) \qquad \text{(Eq. 2-2)}$$

This equation says that when L increases, E decreases and more color is discharged. The effect is more pronounced on low-affinity dyes (i.e., when K is low). When K decreases, the dye remains in the solution and the color in the wastewater increases, especially if L is high.

Affinity is an important factor in determining dye exhaust but one that resists generalizations. Each dye class is generally applicable to (or has affinity for) specific types of fibers. Individual dyes within dye classes, however, can show large variations in affinity. Therefore, "typical" exhaustion data provide only general guidelines. With these caveats in mind, typical exhaustion/fixation levels for various dye types are given in Table 2-2 (8).

Table 2-2. Typical Exhaustion/Fixation Rates for Dyes of Various Classes (8)

Dye Class	Typical K[a]	Typical Fixation (%)	Fibers Typically Applied to
Acid	130	80 to 93	Wool, nylon
Azoic	200	90 to 95	Cellulose
Basic	700	97 to 98	Acrylic
Direct	100	70 to 95	Cellulose
Disperse	120	80 to 92	Synthetic
Premets	470	95 to 98	Wool
Reactive	50	50 to 80	Cellulose
Sulfur	50	60 to 70	Cellulose
Vat	130	80 to 95	Cellulose

[a] The typical K is computed by assuming a bath ratio of 17:1 (typical for becks) and solving for K = EL / (1 – E), where E is on a 0-to-1 scale. For acid dyes, the dye exhausted is typically 87 percent, or E = 0.87. Solving E = K/(K + L) for K results in K = L/(1 – E) = (17)/(0.13), or 130. Therefore, at equilibrium, the concentration of dye in the fiber is 130 times greater than the concentration of dye in the bath for a dye that exhausts 87 percent at 17:1 bath ratio.

As seen in the table, cellulose dyes typically have poor exhaustion and fixation characteristics. The popular fiber reactive dye classes exhibit the poorest fixation. The same conclusions are reflected in Table 2-3, which shows wastewater color values from processes using different types of dyes (5). More recent data would no doubt show improvements in exhaust ratios for some dyes.

Maximizing Fixation and Washoff

Fixation and afterwashing are important steps in dyeing and have substantial bearing on the levels of residual color in textile wastewater. Many methods are used for fixing dyes, including chemical insolublization of the dye by oxidation or coupling (vat, sulfur, and naphthol dyes), chemical reaction of the dye with the fiber to form a covalent bond (fiber reactive dyes), reaction of the dye with the fiber to form an ionic bond (acid and basic dyes), formation of solid solution (disperse dyes), and the use of fixative agents (direct and fiber reactive dyes). These methods generally provide good fixation for most dye classes (acid, basic, disperse, direct, vat, sulfur, and naphthol). For fiber reactive dyes, however, fixation is often less than 75 percent. The problem of fiber reactive dyes is discussed in detail in Section 2.2.1.3.

Washing is an important step in determining final product quality and is discussed in greater detail in Section 2.2.7, "Water Conservation." Especially important for minimizing color carryover is the role of bath ratio in drop/fill wash procedures and the control of flow and mixing in overflow washing. Special methods such as countercurrent washing can also reduce color in addition to providing other benefits.

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[2] This analysis applies only to dyes that do not react (including disperse, acid, and basic) or to reactive types during the exhaustion phase that precedes the beginning of the reaction.

Table 2-3. Wastewater Color Values Derived From Different Combinations of Dyes, Substrates, and Dyeing Equipment (5)

Dye Number and Class		Substrate	Method	ADMI Color	ADMI Apparent Color
1	Vat	Cotton	Exhaust/Package	1,910	—
2	2:1 Premetallized	Polyamide	Exhaust/Beck	370	—
3	Disperse	Polyester	Atmospheric exhaust	315	—
4	After coppered direct	Cotton	Exhaust/Beck	525	1,280
5	Reactive	Cotton	Exhaust/Beck	3,890	—
6	Disperse	Polyamide carpet	Exhaust/Beck	100	—
7	Chrome	Wool	Exhaust/Beck	3,200	—
8	Basic	Polyacrylic	Exhaust/Beck	5,600	12,000
9	Disperse	Polyester carpet	Exhaust/Beck	215	315
10	Acid	Polyamide	Exhaust/Beck	4,000	—
11	Direct	Rayon	Exhaust/Beck	12,500	—
12	Developed	Rayon	Exhaust/Beck	2,730	—
13	Disperse/Acid/Basic	Polyamide carpet	Exhaust/Beck	210	720
14	Disperse	Polyester	High-temperature exhaust	1,245	—
15	Sulfur	Cotton	Continuous	450	—
16	Reactive	Cotton	Continuous	1,390	—
17	Vat/Disperse	Cotton/Polyester	Continuous	365	1,100
18	Basic	Polyester	Atmospheric exhaust	1,300	2,040
19	Disperse/Acid/Basic	Polyamide carpet	Continuous/Kuster	<50	190
20	Azoic	Cotton	Exhaust/Package	2,415	—

Optimizing Dye Handling, Equipment Cleaning, and Housekeeping Techniques

In addition to selecting dyes and dyeing methods that promote maximum dyebath exhaustion, proper work practices in the mix kitchen, cleaning operations, scheduling, and other factors are important for reducing effluent color. Best management practices for these aspects of textile operations are described fully in Sections 3.8, "Maintenance, Cleaning, Nonprocess Chemical Control," 3.14, "Scheduling Dyeing Operations To Minimize Machine Cleaning," and 4.18, "Support Work Areas."

2.2.1.3 Fiber Reactive Dyeing

Poor fixation has been a longstanding problem with fiber reactive dyes (12), and batch dyeing with fiber reactive dyes represents perhaps the greatest challenge to the textile industry in terms of minimizing color discharge. Considerable research and development on this issue are now underway. Mill dyers must understand the fundamental principles behind fiber reactive dye fixation efficiency and their relationship to color discharges.

Typical fiber reactive batch dyeing processes include "two-step" and "all-in" processes. General procedures are shown in Table 2-4. In the two-step procedure, the dyeing process runs in a reversible exhaustion mode until alkali is added, at which time the dye starts reacting. Because the dye is more exhausted at the onset of the reaction, it is more likely to react with fiber. In the all-in process, no initial exhaustion occurs, and the entire dyeing process is a nonreversible, simultaneous diffusion and first-order reaction. The all-in process results in lower percentage fixation and, therefore, more color in the wastewater.

Bireactive "double-anchor" dyes, which are now being promoted to reduce wastewater color even when applied by the two-step process, do not achieve the full expected fixation from the second reaction because

Table 2-4. Comparison of Steps in Alternative Dyeing Procedures for Fiber Reactive Dyes

Two-Step	All-In
Fill machine	Fill machine
Set bath	Set bath
Load fabric	Load fabric
Add dye	Add dye
Start heating	Add salt
Add salt	Add alkali
Attain dyeing temperature	Start heating
Run 10 minutes	Attain dyeing temperature
Add alkali	
Run 30 to 45 minutes	Run 30 to 45 minutes
Hot patch decision	Hot patch decision
If okay, wash	If okay, wash
Cold patch decision	Cold patch decision
Drop bath and unload	Drop bath and unload

almost all the first-dye hydrolysis occurs in the solution. Therefore, the second reaction is always similar to the all-in process.

The key to high fixation (and less color in wastewater) in batch dyeing of fiber reactives is to get high exhaustion by:

- Using high-affinity dyes.
- Using low-bath-ratio dyeing machines.
- Achieving maximum exhaustion before adding alkali.
- Allowing sufficient time for full fixation.
- Using optimized temperature, salt, and alkali concentrations.

For some dyes, particularly "vinyl sulfone" types that react by the Michael addition mechanism, the activation energy for hydrolysis is not as great as the activation energy for the reaction with cellulose. Therefore (based on the Arrhenius equation), raising the temperature on these dyes causes hydrolysis to increase in rate faster than the reaction with cellulose, leading to more hydrolysis. The triazines, on the other hand, react by a nucleophilic substitution reaction (not addition) and thus have the same activation energy for water and for cellulose. As a result, temperature is not as significant in terms of color discharges.

Factors Affecting Fixation of Fiber Reactive Dyes

The fixation of fiber reactive dyes is influenced by many factors, including fiber shape, bath ratio, dye partition coefficient (affinity), and reaction rate constant. Although these factors interact in complex ways, evaluating the role of each parameter listed above is possible. The standard theoretical analysis is in terms of fixation efficiency (E), which should be maximized to reduce color in wastewater.

Fixation efficiency is an extremely complex, widely misunderstood subject. Theoretical models can be set up, but these models are based on primitive assumptions (e.g., infinite plane slab of substrate) to simplify the differential equations and boundary conditions. Even in simplified cases, the resulting differential equations sometimes cannot be easily solved. The problem of estimating fixation relates to simultaneous diffusion and first-order kinetics reactions (13). Despite these difficulties, equations and data verified by experiments show that three main factors are important. (A fourth factor, fiber shape, is also important, but is not controllable.)

The three main factors that influence fixation efficiency of fiber reactive dyes are:

- Process design (two-step versus all-in)
- Dye affinity/low-bath-ratio/maximum exhaustion
- Dye reactivity

Although many different kinds of fiber reactive dyes exist, they all involve two competing reactions:

Dye + water = hydrolyzed dye (washes away as color in wastewater)
Dye + fiber = desired colored textile material

Fixation efficiency is the ratio of the dye fixed (desired reaction) to the dye hydrolyzed (undesired reaction) (13). A fairly straightforward kinetic analysis leads to the following equation:

$$E = \frac{S}{L} \times \frac{[D_f]}{[D_s]} \times \sqrt{\frac{D}{K_H} \frac{R_f [CellO^-]}{[OH^-]}} \qquad \text{(Eq. 2-3)}$$

where:

E = fixation efficiency
S = fiber shape factor (fixed)
L = bath ratio
$[D_f]/[D_s]$ = instantaneous partition, a factor similar to K above
D = diffusion coefficient, related to K
k'_H = dye reaction rate constant
R_f = ratio of reaction rate constant with cellulose to reaction rate constant with water, usually a constant approximately equal to 1
$[CellO^-]/[OH^-]$ = ratio of ionization constants of cellulose to water, usually approximately 30:1 (cellulose ionizes approximately 30 times more completely than water)

In a typical dyeing, S, L, R_f are constant. K and k′ are known or can be determined for each dye, and D can be estimated from a graph of log K versus log D (13) to be a constant multiplied by $K^{1/2}$. Based on this, and lumping all the constant (fixed) terms into one, the following relationship can be obtained:

$$\text{Efficiency of fixation} \cong (\text{A constant}) * (K^{1/3})/(k^{1/2}) \qquad \text{(Eq. 2-4)}$$

This relationship is shown in Figure 2-1.

Using Conventional Fixatives

Standard practice in direct dyeing is to use dye fixatives to improve the resistance of direct dyes to washoff in the afterwashing steps, as well as in fastness tests. The use of fixatives, however, is not as prevalent on fiber reactive shades, except in yarn dyeing. Fixatives are effective on fiber reactive dyes, however, and can cause the fixation of hydrolyzed color, which otherwise would wash off. Thus, fixatives can reduce the amount of color in wastewater.

2.2.1.4 Pollution Prevention Strategies

A mill can take many actions to reduce color in wastewater. Each of these actions uses process optimization

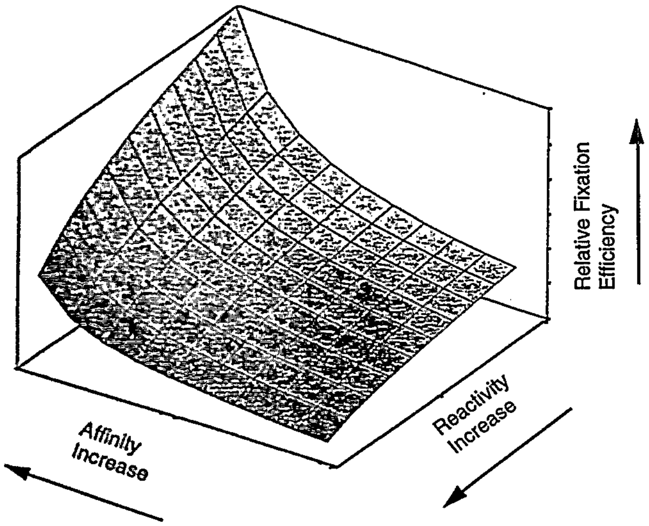

Figure 2-1. Relationship between affinity, reactivity, and fixation efficiency.

to achieve the highest possible fixation (8). The strategies for achieving high fixation vary depending on whether batch or continuous dyeing is performed because better fixation in batch dyeing is related to a combination of exhaustion and fixation, while in continuous dyeing it is usually related only to fixation.

Batch Dyeing

Because of the high k values for dyeing of synthetic fibers and wool, the main problems with color in effluent result from cotton dyeing. In the general design of cellulosic batch dyeing processes, the most important factors are to:

- Ensure a good cloth preparation.
- Use a low bath ratio.
- Select high-affinity dyes.
- Optimize pH and salt, if used, for each recipe.
- Use proper time-temperature profile relationships.
- Avoid auxiliaries that retard or reduce exhaustion.
- Minimize the use of auxiliaries and surfactants.
- Avoid adding more chemicals (e.g., defoamers) to offset the undesired side effects of other chemicals in favor of nonchemical alternatives (e.g., procedural or mechanical remedies, or changing the dye selection or the product itself).

For fiber reactive dyes (the worst offender of poor fixation):

- Use two-step dyeing for fiber reactive, not all-in.
- Use fixatives for fiber reactive (as well as direct).
- Ensure maximum fixation by proper sequencing of events: (1) use high-affinity dyes and low-liquor ratio, (2) optimize factors such as salt and temperature for each recipe, (3) maximize dyebath exhaustion before adding alkali, and (4) use bireactive dyes.

Continuous Dyeing/Printing

As in batch dyeing, the key to minimizing color discharges in continuous dyeing or printing operations is to maximize fixation, which occurs mainly through steam, thermofixation, or chemical agents. The proper dwell time and temperature in the steamer or thermofixation oven is essential. Also, the presence of air (oxygen) in steamers can oxidize vat dyes prematurely and lead to excessive washoff.

Also, making up only the amount of dye solution or print paste actually needed is equally important so that no extra solution or paste remains to be discarded at the end of the run. Discards and pad dumps are the main source of color in wastewater from continuous dyeing and printing.

Printing is an inherently messy operation, so housekeeping practices can have substantial bearing on overall color discharges. Paste handling 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 only into the next drum to be opened. If paste is left over (which it should not be), it should be reused or added to when making up a future (usually brown or black) color recipe. If using leftover paste in a future recipe is impossible, the paste should be scooped up, dried, and then landfilled as a solid material.

Work Practices/Scheduling

The following work practices in the drug room or color kitchen are part of an effective pollution prevention strategy (11):

- Use of intermediate bulk containers, or IBCs.
- Dry capture (vacuum).
- Avoiding powder spills.
- Minimizing implement washup by using different dippers for each chemical or using automatic chemical dispensing.

2.2.2 Discharge of Electrolytes

Many types of salt are either used as raw materials or produced as by-products of neutralization or other reactions in textile wet processes (see Table 2-5). Several authors have identified salt in textile-dyeing wastewater as a significant future problem area (8). Typical cotton batch dyeing operations use quantities of salt that range from 20 percent to 80 percent of the weight of goods dyed, and the usual salt concentration in such wastewater is 2,000 ppm to 3,000 ppm (14). Regulatory limits imposed on textile facilities and on publicly owned treat-

Table 2-5. Types of Salt Used in Textile Operations and Toxicity Characteristics

Salt Type	Typical Use	Aquatic TLm_{96} (ppm)	Typical Mammalian Oral Toxicity LD_{50} (mg/kg)[a]
Calcium chloride	Formed	>1,000[a]	3,500
Common salt	Dyeing	2,000[b]	3,000
Epsom salt	Fixing	NA	3,000
Glaubers salt	Dyeing	NA	6,000
Magnesium chloride	Catalyst	NA	8,100
Potassium chloride	Formed	1,000 - 100[a]	7,000

[a] From Sax (15)
[b] From Herlant (16).

ment facilities (POTWs) that receive textile wastewater start at 250 ppm (see Section 2.2.2.3).

The removal of salt from mixed textile wastewater to reduce chloride concentration from 3,000 ppm to 250 ppm is extremely difficult and expensive by any known treatment method. Therefore, reducing salt concentrations through pollution prevention measures is the only practical alternative to solve the dilemma presented by this hard-to-treat, toxic, high-volume waste.

This section considers mainly the chloride and sulfate salts of sodium, potassium, and magnesium. Certain specific organic anions and miscellaneous inorganic anions, as well as salts of the "heavy" metals, are discussed in more detail in other chapters. Common salt (sodium chloride) and Glaubers salt (sodium sulfate) constitute the overwhelming majority of total salt use. Other salts used as raw materials or formed in textile processes include Epsom salt (magnesium chloride), potassium chloride (from potassium hydroxide), and others in low concentrations. Although the mammalian and aquatic toxicities of these salts are very low, their massive use in certain textile-dyeing processes can produce wastewater that is well above the toxic limit.

2.2.2.1 Sources of Salt in Wastewater

The type and amount of salt used in dyeing processes is dictated by cost, corrosion considerations, the type of dyeing machine used, bath ratio, type of dye, and fiber being dyed. Common salt is the cheapest at about $0.04 per pound compared with $0.10 for Glaubers salt, but it is more corrosive to equipment and, therefore, some dyers prefer Glaubers salt. Also, Glaubers salt gives brighter shades with certain dyes.

In addition to the use of salt as a raw material, many reactions in textile wet processing produce salt as a by-product. In one case study (17), a moderate-sized mill, dyeing about 400,000 pounds per week of cotton knit fabrics, used substantial amounts of the major production acids and alkalis over a 6-week period. Quantities are shown in *Table 2-6. These acids and alkalis* ultimately reacted in the waste stream either with each other or with pH neutralization chemicals added in waste treatment to produce well over 50,000 pounds of salts plus a pH value of over 10 in about 200 million liters of water. Thus, the wastewater contained neutralization salts from just these top six acids and alkalis of about 60 ppm (17). In addition, many other chemical reactions that occur in textile processes produce salts. Table 2-7 lists some examples.

Many textile dyes and specialty chemicals also contain salt. Most notably, salt acts as a diluent in commercial dyes, and a typical direct or fiber reactive dye may actually be 20 to 70 percent salt.

2.2.2.2 Use of Salt in Dyeing Processes

Salt serves many functions in the dyeing process, and the literature has described its action in many ways. Generally, salt is used to assist the exhaustion of ionic

Table 2-6. Typical Amounts of Salt Used or Generated in Textile Operations (17)

Acid or Alkali	Amount (pounds)
Acetic acid	16,200
Caustic 35%	27,520
Caustic 50%	10,815
Soda ash	4,500
Sulfuric acid	2,854
TSP[a]	5,800

[a] TSP = trisodium phosphate.

Table 2-7. Types of Salt Discharged From Various Process Sources

Process Source	Type of Salt Introduced Into Wastewater
Diazotization of dyes	Sodium nitrate
Dyeing pH control	Ammonium sulfate, common salt, glaubers salt, acetate and formate salts
Incoming fiber	Common salt, other chlorides
Hypochlorite bleaching	Calcium chloride
Ion exchange filters	Glaubers salt, common salt
Process water from source	Common salt, calcium chloride, and magnesium chloride
Reduction clearing (hydro)	Sodium sulfate
Sodium chlorite stripping	Common salt
Triazine reactive dyeing	Common salt
Vat dye oxidation	Sodium iodide
Vinyl sulfone reactive dyeing	Glaubers salt
Water conditioning	TSPP[a]

[a] TSPP = tetrasodium phosphate.

dyes, particularly anionic dyes such as direct and fiber reactive dyes on cotton. Salt has many effects in the direct dyeing of cotton (13):

- Increases ionic strength of the dyebath
- Increases dye affinity for cellulose fiber
- Alters the dye diffusion coefficient
- Disrupts hydration of anionic dyes
- Disrupts hydration of cellulosic dye sites
- Increases potential for dye interactions (e.g., aggregation)
- Offsets fiber's negative zeta potential
- Provides electrical neutrality through counter/co-ions
- Salts out anionic dye by common ion effects

Figure 2-2 illustrates how salt addition can increase dyebath exhaustion. For Colour Index (CI) Direct Yellow 12, raising salt concentrations from 0.5 grams per liter to 4 grams per liter causes dyebath equilibrium exhaustion to increase by an order of magnitude (18).

2.2.2.3 Regulatory Status

The U.S. EPA has published national water quality criteria for chlorides, recommending that the 4-day average concentration of dissolved chloride (when associated with sodium) should not exceed 230 milligrams per liter more than once every 3 years and the 1-hour concentration should not exceed 860 milligrams per liter more than once every 3 years on average (19). States (or EPA) use this guidance to establish limits on a permit-by-permit basis through the National Pollutant Discharge Elimination System (NPDES). The federal criterion is for an instream concentration, so the limits on final effluent established in NPDES permits depend on factors such as the discharge flow, stream classification, the size of the receiving water (instream waste concentration or dilution factor), and the number of dischargers. Depending on the factors listed above, textile mills typically must meet POTW pretreatment limits or NPDES chloride permit limits of 250 ppm and upward (20).

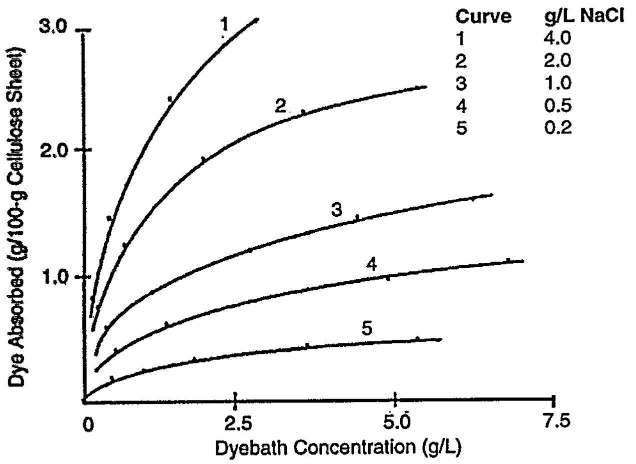

Figure 2-2. Adsorption isotherms of Chrysophenine G on cellulose sheet at 40°C and varying salt concentrations (see legend) (18).

2.2.2.4 Pollution Prevention Practices for Salt Reduction

To reach new instream limits for chloride of 250 ppm, mills need to initiate significant pollution prevention efforts on several fronts (21). Salt is cheap and effective and has low toxicity. As a consequence, mills often misuse or overuse salt (21). Salt is also very versatile; thus, a major research breakthrough would likely be required to find another chemical that could perform all the functions of salt at comparable cost and with lower toxicity.

Despite the difficulties apparent in eliminating salt, several approaches to reducing salt, specifically from cotton dyeing, are available. These should be examined closely in light of tightening limits for chloride in textile effluent. The general principles to follow to minimize salt use are listed below, and several are discussed in more detail in the paragraphs that follow. Each principle entails tradeoffs that should be understood before implementing them as possible solutions:

- Use the lowest practical bath ratio in batch dyeing.
- Optimize salt use individually for each dyeing (as opposed to standard procedures used for all batches or runs).
- Consider continuous dyeing pad-batch dyeing process alternatives.
- Minimize discards and production color changes in continuous dyeing and printing.
- Design and make products from fibers other than cotton.
- Reuse batch dye baths.
- Ensure proper handling of dyes and fabrics.
- Select dyes that exhaust with minimum salt.
- Optimize dyeing temperature individually for each recipe.
- Inform fashion designers which colors and fabrics have high associated environmental loads (due to salt use) and work to find alternatives that avoid these impacts.

Low Bath Ratio

In recent years, machine manufacturers have tended toward lower bath ratio dyeing systems for energy conservation as well as chemical savings. Ultra low liquor ratio (ULLR) dyeing systems are discussed in detail in Sections 3.19, "Pollution Prevention Through New Equipment," and 4.10, "Dyeing."

Batch dyeing at low bath ratios in these machines conserves salt because salt use is based on the amount of dyebath present (owb), rather than the weight of the fiber or the goods (owf or owg).[3] The rule is: owb times the bath ratio equals owg. For example, in a 5:1 bath ratio ULLR dyeing machine, 50 grams per liter of salt is 25 percent owg, but at 40:1 bath ratio in a hosiery dyeing machine, the same 50 grams per liter salt is 200 percent owg. In each case, the salt is the same (i.e., 50 grams per liter owb). Types of dyeing machines vary greatly in their bath ratios, as shown in Table 2-8, which translates into different salt requirements.

Table 2-8. Salt Requirements of Various Dyeing Machines (11)

Machine	Bath Ratio	Salt Required (pounds)[a]
Garment	50	2,500
Paddle	40	2,000
Skein, beck	17	850
Jet, stock	12	600
Beam, package	10	500
Low bath jet	8	400
ULLR, jig	5	250

[a] Pounds of salt required per typical 1,000-pound production lot to produce 50 gal/L bath concentration.

Each of the above batch dyeing systems has its own limitations and range of applicability to particular substrates and styles. Continuous and pad-batch dyeing of fiber reactives on cotton can completely eliminate the need for salt, but certain other restrictions and limitations apply in terms of economics as well as the types of substrates that can be handled (22). The topic of pad-batch dyeing is fully reviewed in Section 4.10, "Dyeing." Continuous methods are discussed in Section 3.10, "Process Alternatives."

Individual manufacturers' batch dyeing machines vary slightly within the generalization above. All batch machines should be filled consistently to a fixed volume of dyebath, and the weight of goods loaded should be the same for each dyeing. Otherwise, the bath ratio will vary, leading to poor shade repeats and other problems. This may seem elementary, but dyehouses often do not specify the fill level for the machine and, therefore, do not fill machines consistently. Variable lot sizes are also encountered because of variation in customers order sizes. The net effect is an undesirable variation in bath ratio.

The same types of consideration noted above apply not only to salt but also to all additives that act primarily on the bath (e.g., buffers, surfactants).

Optimized Salt

Each dye class requires characteristic amounts of salt, and dyes within a class exhibit wide variances. In general, the salt requirements for batch dyeing of cotton with various dye classes are as shown in Figure 2-3 (7).

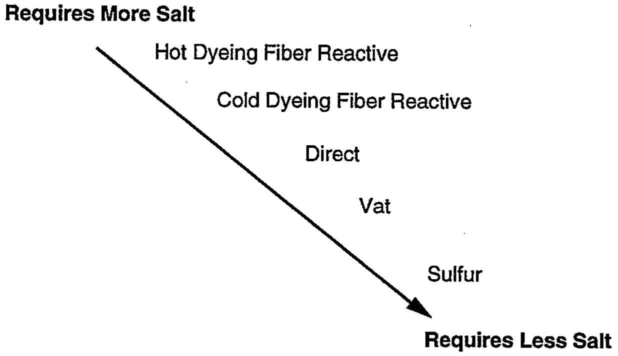

Figure 2-3. **Salt requirements for various dye classes—batch dyeing of cotton (7).**

Table 2-9 shows the amount of salt required to achieve 50-percent exhaust with a selection of direct dyes (18). Because of the variety in dye classes, no optimal amount of salt applies for all dyes and situations. Therefore, generalizations such as those shown in Table 2-10 may actu-

Table 2-9. Salt Required to Produce 50-Percent Exhaustion of Direct Dyes (18)

Dye	Salt Addition for 50% Exhaustion (% owf)
Chlorazol Brown MS	0
Benzopurpurine 10B	0
Benzopurpurine 4B	0.2
Chlorazol Dark Green PLS	0.4
Diazo Black OT	1.0
Melantherine BH	1.0
Chlorazol Green GS	1.2
Chlorazol Fast Yellow 5GKS	2.0
Oxyphenine GG	2.0
Primuline AS	2.0
Trisulphon Brown B	2.0
Chlorazol Fast Pink BKS	2.0
Diphenyl Brilliant Orange GR	4.0
Durazol Red 2BS	5.0
Benzo Fast Helio 4BL	4.5
Chlorazol Fast Eosine B	7.0
Benzo Fast Yellow RL	8.5
Benzo Fast Yellow 4GL	8.5
Chrysophenine G	13.0
Rosanthrene Pink	16.0
Rosanthrene Violet 5R	30.0

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[3] Because salt has essentially no affinity for cellulose cotton fibers and therefore does not exhaust onto the fiber, the amount of salt should be computed based on the owb. Other dyebath components (e.g., dyes, softeners, lubricants) that do have definite affinity for the fiber, and therefore do exhaust, are always based owf or owg in batch dyeing processes.

Table 2-10. Typical Salt Application for Direct and Reactive Dyes on Cotton (16)

Shade	Dye owf	Direct	Reactive
Pastel/Light	<1.5%	2.5-7.5 g/L	30-60 g/L
Medium	1.0-2.5%	7.5-12.5 g/L	70-80 g/L
Dark	>2.5	12.5-20.0 g/L	80-100 g/L

ally waste salt because recipes of some specific dyes may require significantly less salt. Each individual recipe should be optimized based upon controlled experimentation or analysis of production data. Typical salt-use practices for batch dyeing of cotton with direct and fiber reactive dyes are similar to those shown in Table 2-10 (16).

Another complication is that cost systems and computerized batch recipe programs often attempt to base all of the chemicals in the process owg. This is convenient from a cost accounting point of view but can lead to problems, for example, when the bath ratio varies due to fluctuations in lot size. If the salt is specified owg and the bath ratio varies, then the salt concentration owb will fluctuate, leading to poor shade repeats and environmental problems. A fixed amount of salt owg uses too much salt owb when bath ratio is low, or insufficient salt owb when bath ratio is high, leading to excessive color in the wastewater.

In response to the need to minimize salt, most major cotton dye manufacturers have active research and development programs to develop no- or low-salt exhaust dyeing systems. Hoechst Celanese has set a technical goal of reducing salt requirements to 25 grams per liter in the dyebath, while achieving dye fixation of 90 percent in exhaust dyeing of fiber reactive dyes (12). This is up to a 75-percent reduction compared with current commercial practice, which is to use up to 100 grams per liter of salt with fixation levels of 50 to 90 percent. The use of less salt generally provides lower exhaustion and, thus, more color pollution in wastewater.

Process Design

A major control point for salt is product, process, and machine selection. Selecting alternatives that allow for reduced salt use can, however, involve tradeoffs. If batch dyeing of cotton is selected, then simply reducing salt concentration in the dyebath generally results in the negative environmental consequence of increased color in wastewater and also results in poor shade repeats. The classes that require the least salt (i.e., vat, sulfur, and naphthol) are more often used for continuous dyeing and are somewhat more difficult for batch dyeing than fiber reactive and direct types. In addition, the range of colors that can be produced with either vat, sulphur, or naphthol is more limited.

Finally, each dye class that allows for reduced salt use has its own particular problems, for example:

- *Fiber reactive dyes:* Massive salt requirements; color in wastewater.
- *Direct dyes:* Less salt and color residue but limited color shade range and fastness properties.
- *Vat dyes:* Offensive oxidizing/reducing agents required; limited shade range.
- *Sulfur dyes:* Sulfide in wastewater; limited shade range.
- *Naphthols:* Offensive organic compounds; limited shade range.

Each individual direct dye has a temperature of maximum affinity. Therefore, maximum exhaust with minimum salt occurs at a specific temperature (23). Few if any dyers actually set the final exhaustion temperature based on the optimum for a particular recipe, even though that is not difficult with modern microprocessor controllers. Table 2-11 gives optimum exhaust temperatures for over 100 direct dyes (23). Using these temperatures not only produces maximum exhaust with minimum salt use but also ensures consistent shade repeats and better quality.

Product Design

Of course, fabric can be designed and produced from synthetic or woolen fibers, in which case salt use is very low or insignificant compared with batch dyeing of cotton. The tradeoff is the sacrifice of the comfort and aesthetics of cotton, plus the likely introduction of organic chemicals, dye carriers, levelers, and retarders required for other fibers. This may not be a viable option in all cases, but the important point is that fabric designers and fashion colorists should be made aware of the environmental loads associated with the selection of all types of fabrics and color ranges.

Handling

Because of the low cost of salt, substantial amounts tend to be spilled, wasted, and washed down floor drains without much thought to the consequences. Although proper salt handling practices do not completely solve the problem, they should be addressed as part of a pollution prevention strategy. Storage of salt near high traffic areas or where water can spill on the bags fosters waste and should be avoided where possible. One of the best solutions to this problem is to use bulk salt systems or intermediate bulk containers (IBCs). Salt is readily available in IBCs, which are less susceptible to breakage during handling and which produce less packaging waste. Whenever salt or any other powder or granular chemical is spilled, it should be vacuumed up, not washed down the drain.

Table 2-11. Maximum Affinity Temperature of Commercial Dyes (23)

Dye Name	Chemical Type[a]	Commer-cially Available?	Molecular Weight	Maximum Affinity (°C)
Yellows				
Yellow 4	1, 5	Yes	624	—
Yellow 6	5	Yes	470	—
Yellow 7	4	—	591	—
Yellow 8	1, 4	Yes	530	—
Yellow 11	5	Yes	474	70
Yellow 12	1, 5	Yes	680	40
Yellow 19	1, 5	—	680	—
Yellow 20	1	—	554	—
Yellow 26	1	—	584	50
Yellow 27	1, 4	Yes	662	35
Yellow 28	1, 4	Yes	680	80
Yellow 29	1, 4	Yes	946	100
Yellow 44	1	Yes	634	50
Yellow 50	1	Yes	1,004	60
Yellow 106	5	Yes	—	95
Oranges				
Orange 1	1	—	642	50
Orange 8	1	Yes	635	70
Orange 15		Yes	416	80
Orange 26	1	Yes	804	80
Orange 29	1	Yes	870	80
Orange 34	1, 5	Yes	753	80
Orange 37	1, 5	Yes	783	100
Orange 39	1, 5	Yes	739	80
Orange 102	1	Yes	870	—
Reds				
Red 1	1	Yes	651	90
Red 2	1	Yes	772	80
Red 7	1	—	804	80
Red 10	1	—	745	80
Red 16	1	Yes	685	60
Red 17	1	—	745	50
Red 20	1, 4	—	657	60
Red 23	1	Yes	861	90
Red 24	1	Yes	950	100
Red 26	1	Yes	1,010	100
Red 28	1	Yes	744	80
Red 31	1	Yes	761	50
Red 32	1	—	—	—
Red 37	1	Yes	700	80
Red 39		Yes	728	80
Red 72	1	Yes	1,009	100
Red 75	1	Yes	1,038	80
Red 76	1,5	Yes	813	100
Red 79	1	Yes	1,096	90
Red 80	1	Yes	1,420	100
Red 81	1	Yes	699	60
Red 83	1	Yes	1,068	100
Red 153	1	Yes	714	60
Violets				
Violet 1	1	Yes	776	100
Violet 9	1	Yes	715	40
Violet 22	1	—	848	—
Violet 47	1	Yes	1,048	90
Violet 48	1	Yes	979	100
Violet 51	1	Yes	743	40
Violet 66	1	Yes	951	—
Blues				
Blue 1	1	Yes	1,040	70
Blue 6	1	Yes	980	60
Blue 8	1	—	806	90
Blue 14	1	Yes	1,008	70
Blue 21	1	—	891	90
Blue 25	1	Yes	1,010	70
Blue 26	1	—	1,102	100
Blue 27	1	—	876	—
Blue 55	1	—	921	80
Blue 67	1	Yes	907	80
Blue 71	1	Yes	1,125	90
Blue 75	1	Yes	1,127	100
Blue 76	1	Yes	1,040	70
Blue 78	1	Yes	1,127	95
Blue 80	1	Yes	—	100
Blue 86	2	Yes	779.5	—
Blue 98	1	Yes	971	100
Blue 106	3	Yes	741	—
Blue 108	3	Yes	898	—
Blue 120	1	Yes	949	—
Blue 218	1	Yes	1,040	95
Greens				
Green 1	1	Yes	791	80
Green 6	1	Yes	836	80
Green 8	1	—	902	80
Green 11	1	—	788	60
Green 26	1	Yes	1,344	100
Green 28	1, 6	Yes	992	80
Browns				
Brown 1	1	Yes	680	100
Brown 2	1	Yes	651	70
Brown 6	1	—	682	100
Brown 25	1	—	991	90
Brown 29	1, 5	—	946	—
Brown 31	1	Yes	1,165	100
Brown 58	1	—	679	80
Brown 74	1	—	1,886	—
Brown 95	1	Yes	698	100
Blacks				
Black 3	1	—	567	100
Black 4	1	Yes	819	90
Black 9	1	Yes	816	100
Black 22	1	Yes	1,131	100
Black 38	1	—	805	—
Black 51	1	Yes	665	40
Black 56	1	—	947	80
Black 74	1	—	1,227	100
Black 80	1	Yes	978	90
Black 91	1	Yes	926	—
Black 166	1	Yes	—	—

[a] 1 = azo; 2 = phthalocyanine; 3 = dioxazine; 4 = thiazole; 5 = stilbene; 6 = anthraquinone.

Batch Dye Bath Reuse

In some cases, batch dye baths can be reused, thus eliminating the need for additional salt except the small amount (about 10 percent) that is carried out with the wet dyed fabric. The subject of dyebath reuse is reviewed in Section 4.10, "Dyeing."

2.2.3 Toxic Air Emissions

Textile operations involve numerous sources of air emissions, and these sources give rise to a variety of air quality issues. Unit operations that present the greatest concern are coating, finishing, and dyeing (24). The textile industry is a relatively minor source of air pollutants compared with other industries, but the industry emits a great variety of materials, making sampling, analysis, treatment, and prevention more complex (25).

2.2.3.1 Regulation

Air pollution from textile operations is not a new problem, but it has recently received increased attention. Title III of the 1990 Clean Air Act Amendments (CAAA) deals with air toxics, and will have a major impact on the textile industry. Title III identifies 189 hazardous air pollutants (HAPs) for which EPA is required to develop regulations (see Table 2-12). Specific HAPs emitted from textile processes, and their sources, are identified in Table 2-13. In addition to EPA, states also are developing regulations for air emissions. For example, the state of North Carolina has developed a list of 158 air pollutants to be regulated (26).

Because of emissions of nitrogen and sulfur oxides (NOx and SOx) from boilers, many textile plants are likely to be classified as "major sources" under Title III (i.e., sources that emit more than 25 combined tons per year of all listed HAPs). Although boiler emissions of NOx and SOx are the main sources of high-volume emissions, being classified as a major source will force textile plants to adopt controls for all emissions, including production and maintenance chemicals. The amounts of these materials emitted are low in most cases, however, and the economical approach is to reduce them as much as possible using pollution prevention practices.

Title III covers area sources of emissions as well as point sources. The CAAA's Maximum Achievable Control Technology (MACT) standards will likely require control technologies for the textile industry but the specifics of these technologies are still unknown. MACT is expected to include not only treatment measures but also pollution prevention measures such as chemical substitution, process changes, and capture of pollutants from processes, storage tanks, and fugitive sources. For some facilities, the expense of capture and treatment equipment will be immense.

Table 2-12. Initial List of 189 Hazardous Air Pollutants Identified in the Clean Air Act Amendments of 1990 (28)

No.	CAS[a] No.	Pollutant
1	75070	Acetaldehyde
2	60355	Acetamide
3	75058	Acetonitrile
4	98862	Acetophenone
5	53963	2-acetylaminofluorene
6	107028	Acrolein
7	79061	Acrylamide
8	79107	Acrylic acid
9	107131	Acrylonitrile
10	107051	Allyl chloride
11	92671	4-aminodiphenyl
12	62533	Aniline
13	90040	o-Anisidine
14	1332214	Asbestos
15	71432	Benzene (including benzene from gasoline)
16	92875	Benzidine
17	98077	Benzotrichloride
18	100447	Benzyl chloride
19	92524	Biphenyl
20	117817	Bis(2-ethylhexyl)phthalate (DEHP)
21	542881	Bis(chloromethyl)ether
22	75252	Bromoform
23	106990	1,3-Butadiene
24	156627	Calcium cyanamide
25	105602	Caprolactam
26	133062	Captan
27	63252	Carbaryl
28	75150	Carbon disulfide
29	56235	Carbon tetrachloride
30	463581	Carbonyl sulfide
31	120809	Catechol
32	133904	Chloramben
33	57749	Chlordane
34	7782505	Chlorine
35	79118	Chloroacetic acid
36	532274	2-chloroacetophenone
37	108907	Chlorobenzene
38	510156	Chlorobenzilate
39	67663	Chloroform
40	107302	Chloromethyl methyl ether
41	126998	Chloroprene
42	1319773	Cresols/Cresylic acid (isomers and mixture)
43	95487	o-Cresol
44	108394	m-Cresol
45	106445	p-Cresol
46	98828	Cumene
47	94757	2,4-D, salts and esters
48	3547044	DDE
49	334883	Diazomethane
50	132649	Dibenzofurans
51	96128	1,2-Dibromo-3-chloropropane

Table 2-12. Initial List of 189 Hazardous Air Pollutants Identified in the Clean Air Act Amendments of 1990 (28) (Continued)

No.	CAS[a] No.	Pollutant
52	84742	Dibutylphthalate
53	106467	1,4-Dichlorobenze(p)
54	91941	3,3-Dichlorobenzidene
55	111444	Dichloroethyl ether (Bis(2-chloroethyl)ether)
56	542756	1,3-Dichloropropene
57	62737	Dichlorvos
58	111422	Diethanolamine
59	121697	N,N-Diethyl aniline (N,N-Dimethylaniline)
60	64675	Diethyl sulfate
61	119904	3,3-Dimethoxybenzidine
62	60117	Dimethyl aminoazobenzene
63	119937	3,3'-Dimethyl benzidine
64	79447	Dimethyl carbamoyl chloride
65	68122	Dimethyl formamide
66	57147	1,1-Dimethyl hydrazine
67	131113	Dimethyl phthalate
68	77781	Dimethyl sulfate
69	534521	4,6-Dinitro-o-cresol, and salts
70	51285	2,4-Dinitrophenol
71	121142	2,4-Dinitrotoluene
72	123911	1,4-Dioxane (1,4-Diethyleneoxide)
73	122667	1,2-Diphenylhydrazine
74	106898	Epichlorohydrin (1-Chloro-2,3-epoxypropane)
75	106887	1,2-Epoxybutane
76	140885	Ethyl acrylate
77	100414	Ethyl benzene
78	51796	Ethyl carbamate (urethane)
79	75003	Ethyl chloride (chloroethane)
80	106934	Ethylene dibromide (dibromoethane)
81	107062	Ethylene dichloride (1,2-Dichloroethane)
82	107211	Ethylene glycol
83	151564	Ethylene imine (aziridine)
84	75218	Ethylene oxide
85	96457	Ethylene thiourea
86	75343	Ethylidene chloride (1,1-Dichloroethane)
87	50000	Formaldehyde
88	76448	Heptachlor
89	118741	Hexachlorobenzene
90	87683	Hexachlorobutadiene
91	77474	Hexachlorocyclo-pentadiene
92	67721	Hexachloroethane
93	822060	Hexamethylene-1,6-diisocyanate
94	680319	Hexamethylphosphoramide
95	100543	Hexane
96	302012	Hydrazine
97	7647010	Hydrochloric acid
98	7664393	Hydrogen fluoride (hydrofluoric acid)
99	123319	Hydroquinone
100	78591	Isophorone
101	58899	Lindane (all isomers)

Table 2-12. ***Initial List of 189 Hazardous Air Pollutants*** **Identified in the Clean Air Act Amendments of 1990 (28) (Continued)**

No.	CAS[a] No.	Pollutant
102	108316	Maleic anhydride
103	67561	Methanol
104	72435	Methoxychlor
105	74839	Methyl bromide (bromomethane)
106	74873	Methyl chloride (chloromethane)
107	71556	Methyl chloroform (1,1,1-Trichloroethane)
108	78933	Methyl ethyl ketone (2-butanone)
109	60344	Methyl hydrazine
110	74884	Methyl iodide (iodomethane)
111	108101	Methyl isobutyl ketone (hexone)
112	624839	Methyl isocyanate
113	80626	Methyl methacrylate
114	1634044	Methyl tert butyl ether
115	101144	4,4-Methylene bis (2-chloroaniline)
116	75092	Methyl chloride (dichloromethane)
117	101688	Methylene diphenyl diisocyanate (MDI)
118	107779	4,4'-Methylenedianiline
119	91203	Naphthalene
120	98953	Nitrobenzene
121	92933	4-nitrobiphenyl
122	100027	4-nitrophenol
123	79469	2-nitropropane
124	684935	N-Nitroso-N-methylurea
125	62759	N-Nitrosodimethylamine
126	59892	N-Nitrosomorpholine
127	56382	Parathion
128	82688	Pentachloronitrobenzene (quintobenzene)
129	87865	Pentachlorophenol
130	108952	Phenol
131	106503	p-Phenylenediamine
132	75445	Phosgene
133	7803512	Phosphine
134	7723140	Phosphorus
135	85449	Phthalic anhydride
136	1336363	Polychlorinated biphenyls (aroclors)
137	1120714	1,3-Propane sultone
138	57578	beta-Propiolactone
139	123386	Propionaldehyde
140	114261	Propoxur (baygon)
141	78875	Propylene dichloride (1,2-Dichloropropane)
142	75569	Propylene oxide
143	75558	1,2-Propylenimine (2-methyl aziridine)
144	91225	Quinoline
145	106514	Quinone
146	100425	Styrene
147	96093	Styrene oxide
148	1746016	2,3,7,8-Tetrachloro-dibenzo-p-dioxin
149	79345	1,1,2,2-Tetrachloroethane
150	127184	Tetrachloroethylene (perchoroethylene)
151	7550450	Titanium tetrachloride
152	108883	Toluene

Table 2-12. Initial List of 189 Hazardous Air Pollutants Identified in the Clean Air Act Amendments of 1990 (28) (Continued)

No.	CAS[a] No.	Pollutant
153	95807	2,4-Toluene diamine
154	584849	2,4-Toluene diisocyanate
155	95534	o-Toluidine
156	8001352	Toxaphene (chlorinated camphene)
157	120821	1,2,4-Trichlorobenzene
158	79005	1,1,2-Trichloroethane
159	79016	Trichloroethylene
160	95954	2,4,5-Trichlorophenol
161	88062	2,4,6-Trichlorophenol
162	121448	Triethylamine
163	1582098	Trifluralin
164	540841	2,2,4-Trimethylpentane
165	108054	Vinyl acetate
166	593602	Vinyl bromide
167	75014	Vinyl chloride
168	75354	Vinylidene chloride (1,1-Dichloroethylene)
169	1330207	Xylenes (isomers and mixture)
170	95476	o-Xylenes
171	108383	m-Xylenes
172	106423	p-Xylenes
173		Antimony compounds
174		Arsenic compounds (inorganic including arsine)
175		Beryllium compounds
176		Cadmium compounds
177		Chromium compounds
178		Cobalt compounds
179		Coke oven emissions
180		Cyanide compounds[b]
181		Glycol ethers[c]182
183		Manganese compounds
184		Mercury compounds
185		Fine mineral fibers[d]
186		Nickel compounds
187		Polycyclic organic matter[e]
188		Radionuclides (including radon)[f]
189		Selenium compounds

[a] CAS = Chemical Abstract Service.

[b] X'CN where X = H' or any other group where a formal dissociation may occur. For example, KCN or $Ca(CN)_2$.

[c] Includes mono- and diethers or ethylene glycol, diethylene glycol, and triethylene glycol $R-(OCH_2CH_2)n-OR'$ where
n = 1, 2, or 3
R = alkyl or aryl groups
R' = R, H, or groups that, when removed, yield glycol ethers with the structure $R-(OCH_2CH)n-OR$. Polymers are excluded from the glycol category.

[d] Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral-derived fibers) of average diameter 1 micrometer or less.

[e] Includes organic compounds with more than one benzene ring that have a boiling point greater than or equal to 100°C.

[f] A type of atom that spontaneously undergoes radioactive decay.

Table 2-13. Hazardous Air Pollutants Found in Textile Plants (14)

Chemical	CAS No.	Potential Source(s)
Acetic acid	64-19-7	Storage tank, dyeing machines, dryers
Ammonia	7664-41-7	Shop, storage tank
Chlorine	7782-50-5	Shop, water treatment
Ethylene oxide	75-21-8	Dryer stacks (wetting agents)
Formaldehyde	50-00-0	Bulk resin storage tanks, dryers, curing ovens, finished fabric warehouses
Hydrochloric acid	7647-01-0	Dryer stacks (catalyst)
Methylene chloride	75-09-0	Shop, paint stripper, etc.
Perchloroethylene	127-18-4	Dry cleaner, scour, carrier
Tetrachloroethane	79-34-5	Shop, inspection (spot remover)
Trichloroethylene	79-01-4	Shop, inspection (spot remover)
Toluene	108-88-3	Becks, dryers (carrier/scour)
Xylene	1330-20-7	Becks, dryers (carrier/scour)

Pollution prevention can be a viable low-cost alternative for accomplishing air quality improvement. In addition to being covered under Standard Industry Classification (SIC) 22, Textiles, fabric coating operations (some of the major HAP emitters) and surface finishers are tentatively covered under Surface Coating Processes (27).

2.2.3.2 Air Pollutants

Only recently have reliable data been collected regarding air toxics emissions from textile operations. As late as 1990, most estimates of air emissions from manufacturing operations were calculated using mass balance techniques rather than direct measurements (19). The mass balance technique often is not reliable because of the large quantities of input raw materials and output products. Using the difference between large input and output values to estimate the quantity of waste streams can lead to uncertain results (29).

Early attempts during the 1980s to measure air pollutants from textile operations were made using infrared transmission analysis (25, 30). This method proved to be a useful starting point, but it was unsatisfactory as a primary means for quantifying air pollution. The original Superfund Amendments and Reauthorization Act (SARA) Title III inventories of the early to mid-1980s also were a particularly poor source of air pollutant data. In most cases, the data were inaccurate, and groups with little knowledge of textile operations publicized the lists, leading to publication of data that were seriously flawed (26).

Several investigators have noted air pollutants that are of concern in textiles, including volatile organic compounds (VOCs), photoreactives (PRs), toxic air pollutants (TAPs), and HAPs (11, 25, 31, 32). As shown below, most of these pollutants subsequently have been detected in air emission testing of textile operations. Since the 1980s, direct reading tubes (DRAGER tubes) and gas chromatographs/mass spectrographs (GCs/MSs) have provided more reliable data (31, 33-35).

2.2.3.3 Sources

The main sources of air emissions in textile operations are:

- Boilers
- Machine and equipment cleaning:
  - General cleaners
  - Specific implements and parts cleaners
  - Screen-printing cleaners
- Processing machines:
  - Ovens, for drying and curing
  - Solvent processing units (e.g., dry cleaning)
  - Dyeing machines
  - Mix kitchens, drug rooms
  - Warehousing for finished cloth and chemical drums
- Storage tanks (breathing losses)
- Wastewater treatment systems

In addition to boilers, high-temperature finishing, drying, and condensation machines also emit many air pollutants. Hydrocarbons are emitted from drying ovens and, in particular, from mineral oil from high-temperature (200°C) drying/curing (35). These processes can emit formaldehyde, acids, softeners, and other volatile compounds. Residues of fiber preparations and their oxidation products sometimes form "blue haze" in heatsetting processes. Carriers and solvents used in dyeing and coating machines cause exhaust air pollution (36).

Textile manufacturing can produce oil and acid fumes (especially from the tenter frame), plasticizers, and other materials that can volatilize. Carbonizing of wool produces acids. Acetic acid emissions derive mostly from storage tanks, especially from vents during filling, and breathing losses (14, 36). The carbonizing process emits sulfuric acid fumes and decating produces formic acid fumes (37).

Dyeing and finishing operations can emit solvent vapors containing toxic compounds. These vapors might include acetaldehyde, chlorofluorocarbons, p-dichlorobenzene, ethylacetate, chlorobenzene, hexane, styrene, and others. Acetic acid and formaldehyde are two major emissions of concern in textiles. Some process chemicals exhaust into the fibers and are later evolved from dryers as VOCs; these chemicals include methyl naphthalene, chlorotoluene, trichlorobenzene, orthodichlorobenzene, perchloroethylene, methyl ester or cresotinic acid, butyl benzoate, and biphenyl (36). Formaldehyde might be emitted from bulk resin storage tanks, finished fabric warehouses, driers, and curing ovens.

Many types of cleaning and scouring operations are used in textile operations, both batch and continuous. Perchloroethylene is used for solvent scouring operations, and CFC-113, 1,1,1-trichloroethane, and trichloroethylene are used to a lesser extent (38). These materials also are used as solvents during application of water-repellent finishes and for machine cleaning. In the aggregate, cleaning and scouring chemicals were estimated at 10,500 metric tons in 1988 (38).

Quality control (QC) inspectors in fabric and garment manufacturing operations use solvent/air guns to remove spots that originate from sewing machines that sling oil during high-speed seam sewing. The proper pollution prevention strategy in such cases is to eliminate the oil spots by modifying the sewing operation to prevent oil slinging, which reduces the need for spotting and cutting, as well as solvents, and also minimizes labor requirements while improving quality.

Odors often are associated with oil or solvent vapors and are usually removed by eliminating the source of the odor. A common odor problem in textiles is carrier odors from aqueous polyester dyeing and subsequent processing. Resin finishing also produces formaldehyde odor. In addition, odor problems are associated with sulfur dyeing on cotton and cotton blends, reducing or stripping dyes with hydrosulfite, bonding, laminating, back coating, and bleaching with chlorine dioxide (36).

Dust and fly are produced during processing of natural fibers and synthetic staple, before and during spinning, and by napping and carpet shearing. Most textile processes produce lint, which is not measured as a pollutant but causes other difficulties (36). Lint can clog filters and screens, causing them to malfunction. Lint can also foul sensors in the air handling equipment and interfere with incineration units. It collects in the ducts and stacks, eventually becoming an extreme fire hazard.

2.2.3.4 Printing

In the past, printing operations used solvent-based print pastes in which an oil-water emulsion provided the appropriate rheology. These pastes have been replaced almost completely by polymeric thickeners, which produce essentially no airborne pollutants. A few printers, however, still use the oil-water emulsion systems as thickeners. A small number of specialty print shops also still use solvent-based printing inks. A major source of solvent emissions in screen printing operations is cleaning of machines, screens, and squeegees. In one plant, GC mass spectrometric analysis showed the presence of the following VOCs (39):

- Trimethylcyclohexane

- Propylcyclohexane
- Hexylcyclohexane
- Ethylcyclohexane
- Methylethylcyclohexane
- Butylcyclohexane
- Decahydronaphthalene
- Butylethylcyclopentane
- Methyldecane (three isomers)
- Xylene (three isomers)
- Ethylbenzene
- Trimethylbenzene (three isomers)
- Methylethylbenzene
- Other hydrocarbons

Urea is emitted from the curing of fiber reactive prints and thermofix continuous dyeing of reactives. Much emphasis has been placed on eliminating urea from print paste formulations because of problems with nitrogen nutrients discharged in wastewater. (See Section 4.11.4.11 for a discussion of urea and printing.)

2.2.3.5 Pollution Prevention Procedures

Many practical pollution prevention methods are available to reduce toxic air emissions. These methods are far-ranging and extend from optimization of boiler operation to redesign of products that produce fewer air toxics. Traditional air pollution control methods relied on end-of-stack add-on technologies to scrub or capture pollutants in the air stream. These technologies often are capital-intensive and usually have high operating costs. Pollution prevention methods often can achieve significant reductions in pollution with little capital expense.

The main pollution prevention methods for reducing air emissions are to:

- Design and manufacture products that do not produce HAPs.
- Identify sources and quantify emissions.
- Optimize boiler operations.
- Prescreen chemicals using material safety data sheets (MSDSs).
- Prescreen fibers for volatile spin finish components.
- Trap bulk storage tanks.
- Minimize or eliminate chemical auxiliaries in aqueous processes.
- Improve solvent processing operations.
- Avoid spills in bulk chemical off-loading areas.
- Investigate emerging technologies.

Design Products That Do Not Produce HAPs

Often, decisions made at the design stage significantly affect the manufacturer's decision to use products that contain VOCs, PRs, TAPs, and HAPs. These pollutants result from the use of processing specialties required to meet designer specifications. Usually, the designer has no knowledge or expertise in the pollution consequences of design decisions. The need to communicate this information, as well as the specific nature of the air issues involved, are reviewed in detail in other sections. (See Sections 3.2.2.1 and 3.2.2.2 for product design and Sections 1.2.1.1 through 1.2.1.5 and 2.2.3.1 through 2.2.3.5 for air pollutant issues.)

To summarize, the first step is to identify and communicate problem areas, especially which colors, styles, and fiber blends will produce air problems. Boiler emissions are the main air pollutant from textile mills, so products requiring low energy for production (and thus less steam and electricity) are preferred because they produce less air pollution. In addition, products with a high percentage of right-first-time performance are generally better in all pollution categories including air. Marketing decisions can also strongly influence pollution. For example, short runs, frequent style or color changeovers, and scheduling are also important, as discussed in Chapter 6.

Some specific examples of design issues include:

- The tendency to use hydrocarbon softeners instead of designing inherently soft fabrics. Softeners contain hydrocarbons that are emitted from drying ovens. In particular, mineral oil is emitted from high-temperature drying/curing (35).
- Printing of fiber reactive dyes using urea, which is emitted during the curing of fiber reactive prints and thermofix continuous dyeing of reactives. Design alternatives include the use of alternative colors (which can be produced with colorants other than fiber reactive) or adjustment of product fastness requirements to allow for pigment printing.
- The use of soil-release finishes (which are often solvent-based finishes) as opposed to selecting inherently soil-releasing fibers such as cotton.
- The use of water repellent finishes (which are often solvent-based finishes) as opposed to selecting inherently water repellent soil-releasing fibers, such as polyester or wool, and inherently water repellent fabric constructions.
- The use of polyester and other fibers that contain volatile spin finishes that volatilize during heatsetting, as opposed to natural fibers that contain no spin finish and do not require heatsetting. This eliminates

not only the spin finish air pollution but also the burner emissions required for the heatsetting oven.

Identify Sources and Quantify Emissions

Identifying sources and quantifying emissions are the first steps in pollution prevention (40). Potential sources can be identified by reviewing MSDSs for each chemical in the facility (41). Once identified, potential sources can be quantified by continuous emissions monitors and by applying emission factors or preparing mass balance calculations (40).

Point sources are the easiest to identify and monitor. Fugitive or area sources are more difficult to identify and quantify because of problems often encountered when measuring flow rates and concentrations. Because of the wide variety of sources and processes, the textile industry has been described as one of the most difficult in which to establish a good pollution prevention program for air emissions (40).

Optimize Boiler Operations

Boilers are a main source of hazardous emissions, including NOx and SOx. Improperly operated boilers can contribute excess amounts of such pollutants. Careful optimization of boiler operations is necessary to minimize air emissions.

Prescreen Chemicals Using MSDSs

As described further in Sections 3.7, "Incoming Raw Material Quality Control," and 3.12, "Raw Material Prescreening Before Use," best management practices for pollution prevention include a comprehensive program to prescreen all chemicals. Prescreening can start by first consulting the MSDSs. For air emissions, shop chemicals should receive special attention. Chemical inventory managers should seek maintenance and process chemicals that will not contribute to air emissions (i.e., nonvolatile, nonhalogenated, and nonphotoreactive chemicals and those not on the list of TAPs or HAPs).

Prescreen Fibers for Volatile Finishes

Incoming QC also can be performed on synthetic fibers to identify spin finishes with components that could vaporize during heatsetting. One method of prescreening is to heat the fabric (or yarn) in a laboratory oven and observe or sample the air from the oven vent. Sampling can be performed using various methods described in the literature (25, 30, 32, 34, 40).

Trap Bulk Storage Tanks

Storage tanks can be equipped with carbon canisters on vents to remove fugitive vapors. The carbon canisters must be maintained on a regular basis to effectively trap such vapors. Filling systems also must be designed and maintained to prevent spills and vapor losses during operation.

Minimize or Eliminate Chemical Auxiliaries

Use of pressure dyeing at 250°F to 265°F for polyester can eliminate the need for dye carriers. Mills should seek to reduce the use of dyeing auxiliaries in general, paying particular attention to those used for synthetics. Alternative methods are shown in Table 2-14.

Table 2-14. Nonchemical Methods To Assist in Eliminating Dyeing Auxiliaries

Fiber Type	Dyeing Assistants To Target	Alternative Methods of Control
Acrylic	Retarder	Rate of temperature rise
Nylon	Retarder	pH, temperature
Nylon	Leveller	pH, temperature
Polyester	Carrier	Temperature, time
Polyester/Cotton	Lubricant	Fabric transport mechanism

A considerable amount of information on alternative methods is included in Section 4.10, "Dyeing."

Improve Solvent Processing Operations

Solvents that pose hazards (PRs, HAPs, or TAPs) ideally should be replaced with nonsolvent systems (i.e., aqueous or mechanical/physical). In cases where replacement is not possible, other procedures can be undertaken:

- Review solvent selection to ensure use of the least offensive, least volatile solvent. Nonhalogenated solvents are generally preferable. Chlorinated solvents can be substituted with deodorized kerosene, hexane, or Stoddard solvent (38).
- Implement special practices for monitoring solvent losses from textile operations (38, 40). Careful records should be maintained to accurately estimate losses to the air. Solvent losses should be monitored during special events in the process (e.g., startup, shutdown, changeover).
- Dispense solvents directly from bulk container to machine; do not carry solvents in secondary containers. Submerge fill pipes to avoid splashing, which increases air/solvent contact (38).
- Purchase, or design and use, application-specific solvent-use devices (e.g., for parts cleaning) (11).
- Plan and document routine maintenance for solvent-use operations.
- Pay special attention to scheduling on solvent-use processes to reduce start/stop/change losses.
- Reclaim and reuse solvents, either on site or off site. A QC program for solvents is important because it helps

detect decomposition of solvents during processing or buildup of contaminants that can render the process less effective or inhibit reclamation of the solvents (38).

- Maximize capture efficiencies for solvent vapors from processes (e.g., coated fabrics for offset printing blankets) by proper design of containers, mix areas, dryers, etc. In some cases, mills have spent more than $1 million on reclamation equipment (e.g., carbon sorption, distillation) only to find that air pollution is still a problem because of poor capture efficiencies.
- Focus on worker training to ensure proper handling of materials, limiting their release to the atmosphere (38). Train operators to look for leaks and potential spill points.
- Maintain solvent recovery equipment in top working order. Batch distillation units generally range from as low as 60 percent for inefficient units or difficult solvents to 95 percent for efficient units (38).

Avoid Spills in Off-Loading Areas

Chemical spills frequently occur in off-loading areas. Avoiding these fugitive sources of air pollutants is a matter of proper procedures, work practices, worker training, and facility design. Offloading areas should be well lit and easily accessible with ample work space so that the area remains orderly even when in full use. The base or floor should be non-absorbent and should have drainage and spill control features built in. One good system often seen in bulk tank areas is gravel with an underlying concrete drain system. Drains in off-loading areas should flow to appropriate treatment or collection areas, not to the storm sewer. If the area has a solid floor, it should be smooth, well sealed, and have good drainage (to avoid standing water or spilled liquids), which facilitates cleanup. A vacuum should be available for capturing powder spills, rather than washing them down the drain with water from a hose.

Drums and bags of chemicals should not be stored in standing water or over floor drains. Spill containment pallets are available that help prevent small-scale spills when off-loading drum chemicals. Bulk delivery hoses should have automatic shutoff valves and should receive careful attention so that, in case of failure, the delivery pump will shut down.

All receiving areas (bulk and warehouse) should be clearly labeled because outside personnel (truck drivers) may not be familiar with the area. Two people should be present at all times during off-loading of chemicals. Proper spill control equipment and training are required. Deliveries should take place during daytime hours so that proper procedures can be observed and so that help will be available in case of an incident. Used drums being returned should not be washed on site, and residues should not be disposed of down the drain. Direct returnable IBCs should be used instead. If drums are used instead of IBCs, used drums should be emptied or drained thoroughly into new drums.

Proper equipment and good preventative maintenance in off-loading areas are essential, especially in bulk storage areas. Use of automatic bulk chemical systems helps control pollution, but the potential for large-scale spills is significant, especially during off-loading.

Investigate Emerging Technologies

Technologies under examination for the future are supercritical fluid scouring and dyeing. These technologies use high-pressure carbon dioxide as a solvent. When the scouring or dyeing process is finished, no solvent residues remain to be vaporized and no energy is consumed in drying. Conventional disperse dyes on polyester can be used. Off-the-shelf laboratory-scale equipment already is available, and major equipment manufacturers show some interesting products at the International Textile Machinery exhibit each year.

2.2.4 Improving Treatability

Properly designed waste treatment systems can remove or destroy many of the harmful contaminants in raw textile wastewater and produce an effluent that can be discharged safely to receiving waters. Certain wastes or contaminants, however, can interfere with the ability of treatment systems to operate to design specifications, resulting in system upsets and exceedences of permit limitations. Other contaminants are removed from the treatment system and partition into sludges, disposal of which can be difficult. Where possible, steps should be taken to avoid these wastes or to improve their treatability so that wastewater treatment systems can manage them more easily.

Prominent among these wastes are the four types that are amenable to pollution prevention (11, 42). These wastes, and the treatment problems they may pose, include:

Waste Type	Problems
Hard-to-treat	Pass through Interfere with systems
Dispersible	Hard to collect or capture for treatment
Offensive	Inhibit treatment system operation Produce hazardous sludges
High volume	Increase loading Cause shock loads if intermittent

The sections below describe treatment problems posed by these wastes and recommend strategies for either improving their treatability or reducing the amounts of waste generated.

Several characteristic problems that arise from the presence of hard-to-treat waste in textile waste treatment systems include:

- Respiratory inhibition
- Bulking, poor settleability
- Sludge contamination
- Shock loading
- Pass-through of nondegradable materials

These effects can be quantified by several methods. Moore suggested a system for treatability evaluation (including inhibition), which includes results of Organization for Economic Cooperation and Development (OECD) tests for biodegradability (301D), biomass impact (209), and aquatic toxicity (202).[4] Cooper reported an alternate system in which chemicals are ranked on a scale of 1 to 5 according to treatability using chemical oxygen demand to biological oxygen demand (COD:BOD) ratios (6).

Pollution prevention is a useful way to reduce treatment problems arising from these wastes. Wood and Bishop reported a highly successful pollution prevention program at DuPont to reduce hydraulic load, organic load (BOD), total suspended solids (TSS), methylene chloride, chloroform, and toluene (43). By reducing priority pollutants at the source and eliminating shock loads, wastes that interfered with treatment system operation were reduced, with a corresponding reduction in the incidence of permit violations (43). For more information, see Section 2.1.2, "Hard to Treat Wastes," and other sections mentioned below.

2.2.4.1 Respiratory Inhibition

Many types of materials inhibit the action of biological waste treatment systems. The specific causes vary, but the symptoms are generally the same: low specific oxygen uptake and low BOD removal efficiency. The pollution prevention strategy is to seek out and control materials that are toxic to the biomass. These include:

- Metals
- Chlorinated organics
- Biocides

Biocides comprise not only those materials used around the wet processing plant but also preservatives (biocide additives) in warp size materials. These can interfere with the operation of the waste treatment system and can inhibit aerobic stabilization of wastewater (2). Some countries have banned use of chlorinated phenol biocides as a size additive (2). *For more information, see* Section 4.7, "Slashing and Sizing."

2.2.4.2 Bulking and Poor Settleability

Some textile chemicals tend to form suspended solids that neither settle nor float. These are usually neutral, buoyant solids or materials with a large, hydrodynamic radius and derive from specific sources, such as:

- Foam waste from coating, dyeing, and finishing.
- Acrylic sizes and handbuilders, which coagulate and trap air.
- Print pastes based on acrylic materials as above.
- Resins, N-methylol film formers that coagulate with lint.
- Size materials, such as gums and synthetic sizes.

Many of these wastes result from printing, finishing, and continuous dyeing. Methods of controlling them are based primarily on reducing or eliminating discards. This is described in Sections 4.11, "Printing," and 4.12, "Finishing."

Undegraded size materials can cause biomass to aggregate (flock) and inhibit oxygen transfer (2). Starch, in some cases, causes growth of hard-to-settle filamentous bacteria that interfere with the operation of clarifiers (2). Polyvinyl alcohol (PVA) does not cause these problems, nor is it toxic. Polyacrylic acid (PAA) is hard to treat and requires tertiary treatment (2).

2.2.4.3 Sludge Contamination

Occasionally, textile wastewater treatment sludges are rendered hazardous because of accumulation of offensive materials in the sludge. Some common causes are:

- Metals
- Surfactants
- Chlorinated organics

Modak lists several materials of concern that fall into the above categories, such as chromium, copper, nickel, zinc, isocyanates, heavy metals, chlorinated organics, dioxins, mercury, cadmium, lead, pesticides (notably pentachlorophenol from wool finishing), and adsorbable organic halogens (AOX) (44). Richardson adds metals, solvents, surfactants, and quaternary amines (quats) to the list (21). Quats are used for processes such as disinfecting, scouring and softening (21).

In some cases, these materials can be readily identified from MSDS information (21). Special handling and use procedures for such materials (e.g., special training) are beneficial. Chemical substitutions should be investigated and implemented where possible. For further information on pollution prevention strategies, see

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[4] Moore, S., and Smith, B. 1994. Personal communication between Samuel Moore, Burlington Research, and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

Sections 2.2.3, "Toxic Air Emissions," 2.2.5, "Metals," and 2.2.6, "Aquatic Toxicity."

2.2.4.4 Shock Loading

Shock loadings occur when waste characteristics change rapidly and upset waste system operations (21). In textile batch operations, discharged processing baths, cleaning chemicals, and excess chemical mix disposal can create extreme short-term variations in properties, as indicated in Table 2-15.

Table 2-15. **Typical Short-Term Variations in Processing Bath Parameters**

	Extremes	
Property	High	Low
Temperature	≥210°F	75°F
pH	11+	3
Salt concentration	120 g/L	0 g/L
BOD	100,000 ppm	0 ppm
Redox	Strongly oxidizing	Strongly reducing

Equalization is required to eliminate these variations. Even so, several pollution prevention approaches can help. As discussed in several other sections, the use of chemical equipment cleaners can be minimized by proper process and equipment design, chemical selection, and scheduling. The need to dispose of obsolete chemicals can be avoided by proper auditing, handling, and prescreening protocol. Obsolete chemicals should never be disposed of down the drain. Finally, process alternatives can make the properties of processing baths less extreme. If a bath or waste stream has extreme properties, it may well have some direct reuse value if segregated.

2.2.4.5 Pass-Through of Nondegradable Materials

Many materials discharged from textile operations are not degradable in typical secondary activated sludge waste treatment systems. These include:

- Salt (see Section 2.2.2, "Discharge of Electrolytes").
- Chloro-organics (see Sections 2.2.3, "Toxic Air Emissions," and 4.12, "Finishing").
- Solvents (see Sections 2.2.3, "Toxic Air Emissions," and 4.12, "Finishing").
- Phosphates (see Section 3.5, "Chemical Alternatives").
- Color (see Sections 2.2.1, "Color Residues in Dyeing Wastewater," 4.3, "Dyes," and 4.10, "Dyeing").
- Surfactants (see Sections 2.2.6, "Aquatic Toxicity," and 4.4, "Chemical Specialties").
- Nonsettling solids (see Section 2.2.4.3).

Pollution prevention approaches for these materials are reviewed in other sections, as indicated. They originate from a wide variety of sources in wet processing. Color originates from print paste dumps, color kitchens, screen and squeegee cleaning, dye bath, and continuous dyeing mix discharges. Metals generally have the same sources as color, plus print screen making, photograph laboratory processes, and contamination from high-volume raw materials (e.g., salt, size). Solvents derive from nonaqueous printing thickeners, machine cleaning, screen cleaning, and shop uses. Nonsettling solids come from coating, dyeing, finishing, print pastes based on acrylic materials, warp size materials (e.g., gums and synthetic sizes), and foam from coating or carpet printing (45).

2.2.5 Metals

The presence of metals in textile mill effluents is of concern primarily because of their toxicity to aquatic and mammalian species (8, 11, 21). Metals also inhibit waste treatment operations and are difficult to remove or treat using pollution control technologies (11, 21).

2.2.5.1 Sources

The sources of metals can be difficult to identify in textile operations; locating metals sources requires careful examination of all aspects of plant operations (21). Among the possible sources are: incoming fiber, water, dyes, plumbing, and chemical impurities. The presence of metals in effluent is a worldwide concern (44). All industries in Europe, including the textile industry, are required to reduce 36 specific substances, including heavy metals such as chromium, copper, nickel, and zinc by 50 percent or more. In addition, 70-percent reductions of mercury, cadmium, and lead are required (44). Many textile mills have little or no metals in their effluent but, whenever metals are present, they often include those shown in Table 2-16. The table indicates only harmful metals. Materials such as iron are not listed.

Dyes

Some dyes include metals that are known to be toxic such as copper (46). Metals can be present in dyes for two different reasons. First, mercury or other metals are used as catalysts during the manufacture of some dyes and can be present as a by-product (47). Second, some dyes include metals as an integral part of the dye molecule (47).

Dye manufacturers now are considering the environmental impact of the dyes that they produce, in addition to traditional concerns such as economy, higher wet fastness, and high tinctorial value. Many anthraquinone

Table 2-16. Typical Sources of Metals in Effluent

Metal	Typical Sources
Arsenic	Fibers, incoming water, fugitive, treated timber
Cadmium	Impurity in salt
Chrome	Dyes, laboratory
Cobalt	Dyes
Copper	Dyes, incoming water, fiber
Lead	Dyes, plumbing, shop
Manganese	Permanganate strip (repair mildew)
Mercury	Dye/commodity chemical impurity
Nickel	Dyes
Silver	Photo operations
Tin	Finishing chemicals, plumbing
Titanium	Fiber
Zinc	Dyes, impurity in commodity chemicals, incoming water, plumbing

dyes are derived by sulfonation in the presence of mercury catalysts. The mercury can cause pollution problems during the manufacture of the dye. Some dye manufacturers (in Japan, for example) use mercury-free manufacturing practices (48).

Dyes Based on Metals. For dyes that contain metals as an integral part of the dye molecule, the metallic content is essential to the dye's performance as a textile colorant. The metals most commonly found in dyes as part of the dye structure are shown in Table 2-17 (8).

In addition to the dyes listed in Table 2-17, other types of dyes can also contain metals, notably yellow pigments based on lead chromate and orange pigments based on molybdate (49). Also, some other pigments of various colors are based on cadmium (49). Other studies (14, 45) present lists of dyes and printing inks that contain metals. The metal content of dyes easily can be determined by consulting the MSDS for the dye or the CI (11).

Table 2-17. Typical Metals Found in Dyes by Dye Class (8)

Dye Class	Typical Metals in Structure[a]
Direct	Copper
Fiber Reactive	Copper and nickel
Vat	None
Disperse	None
Acid	Copper, chrome, cobalt
Premets	Copper, chrome, cobalt
Mordant	Chrome

[a] Does not imply that all dyes contain these metals.

The issue of "bound" versus "unbound" metal often is raised regarding the metal content of dyes. Bound metals are those in which the metal is chelated with the dye molecule, forming an integral structural element. More specifically, the empty d-orbitals of the metal ions are supplied with electrons donated from organic ligands such as ethylene diamine triacetic acid (EDTA), diethylene triamine penta acetic acid (DTPA), nitrilo triacetic acid (NTA), or various substituents in the dye molecule. An unbound metal is one that is not structurally bound to the dye molecule but that simply exists in some quantity in the dye formulation.

Dye companies often point out that bound metals exhibit lower toxicity than free metals and that bound metals tend to exhaust onto the substrate in dyeing so that they are not discharged with the wastewater. Not all dye in the dye bath, however, is exhausted (see Sections 2.2.1, "Color Residues in Dyeing Wastewater," and 4.3, "Dyes"). Furthermore, not all dye wastes come from the dyebath; dye wastes also result from handling, weighing, small-scale routine working losses, implement and drum cleaning, and spills. Important factors to consider are that EDTA, DTPA, NTA, and dye molecules are susceptible to biological degradation and that secondary activated-sludge aerobic treatment of the metal/ligand chelate produces free metals (50, 51). As the chelate degrades in the waste treatment system, metals are released as either precipitate in the sludges or in pass-through that is discharged in wastewater (50, 51). Also, at this time EPA regulations do not recognize any distinction between bound and unbound metals.

Dyes With Low-Level Metal Impurities. ADMI analyzed 1,298 dyes by x-ray fluorescence that do not contain bound metal as an integral part of the dye molecule for eight metals (arsenic, cadmium, chromium, cobalt, copper, lead, mercury and zinc), as shown in Table 2-18. Specific dyes within the various classes can contain significant amounts of metals. The data do not include dyes that are known to be metal-bearing as bound, integral parts of the dye structure. The metals numbers in Table 2-18 are based on casual metal in dyes (47). Table 2-19 lists specific dyes having relatively high copper content (45). Note that these data are somewhat dated but represent the only detailed analysis of the metal content of dyes.

Dyeing Processes

Other sources of metals include the dyeing process. Several sources in dyeing are not directly related to the dyestuffs themselves, including afterchrome processes for wool and clearing or discharge printing; copper aftertreatments for certain direct dyes, and impurities in fibers, salt, caustic, and soda ash; as well as chemical oxidizers and reducers.

Afterchrome processes for wool dyeing are discussed below and also are discussed in Section 4.3, "Dyes," and 4.10, "Dyeing." Some mills may still use afterclearing or

Table 2-18. Average Metal Concentration of Selected Dyes (47)

Metal	Acid	Basic	Direct	Disperse	Fiber Reactive	Vat
	Number of Dyes Tested and Average Metal Concentration by Dye Type[a]					
Arsenic	413	137	313	177	46	58
	<1	<1	<1	<1	1.4	<1
Cadmium	417	137	313	177	46	58
	<1	<1	<1	<1	<1	<1
Chromium	404	137	303	117	46	58
	9	2.5	3	3	24	83
Cobalt	300	135	271	154	46	58
	3.2	<1	<1	<1	<1	<1
Copper	399	136	285	153	46	59
	79	33	35	45	71	110
Lead	408	135	315	161	46	58
	37	6	23	37	52	6
Mercury	450	132	350	196	46	94
	<1	0.5	0.5	<1	0.5	1
Zinc	421	122	311	166	46	59
	<13	32	8	3	4	4

[a] Top figure in each cell indicates the number of dyes tested; bottom figure indicates average metal concentration.

Table 2-19. Dyes With High Copper Content (45)

Dye	Copper Content (%)
Belamine F Red 3BL	4.00
Belamine B Blue LT	3.68
Pyrazol F Violet MXD	3.00
Solantine Brown BRL	3.00
Atlantic Blue 8GLN-K	2.70
Atlantic Resinifast Blue 2R	2.50
Sirius Supra Turquoise LG	2.29
Superlitefast Blue 2GLL	1.00
Direct Navy OFS	0.70
Belamine Red 3BL	4.00
Solophenyl Brown BRL	3.00
Fastolite Blue L	2.70
Atlantic Black NR	1.50

discharge printing with zinc-stabilized reducing agents (for disperse dyes on polyester). The technical literature refers to these agents as "zinc sulfoxylate formaldehyde." These agents are discussed under oxidizing and reducing agents below. Chemical oxidizers containing manganese and chrome also are used in dyeing. In the 1960s, the use of dichromate was phased out (see discussion of oxidizers below). Impurities (e.g., zinc, mercury) in salt, caustic, and soda ash also can come from dyeing processes. Fibers contain many types of metals at low levels (52). Copper sulfate was discontinued as an aftertreatment for direct dyes such as CI Direct Blue 98 at least 30 years ago, although some authors still write about this topic.

Afterchrome Dyeing. A study group of the International Wool Secretariat (IWS) identified four high-priority areas, including the reduction of chromium in wool processing wastewater from chrome dyeing (53). Approximately 70 percent of wool dyeing currently uses heavy metals, primarily chrome. Development of low-chrome methods has been underway since 1976. Results of these methods show reductions from approximately 155 ppm for conventional dyeing to levels of about 33 ppm, 8 ppm, and near 0 ppm for pH control, fresh bath, and thiosulfate methods, respectively. The best solution would be to develop black and navy dyes that do not require chrome (53). These, however, are not currently available.

Another development is azo dyes based on iron instead of other more harmful metal ions such as cobalt, nickel, chromium, nickel, lead, and zinc. Research already has shown promise in substituting iron for cobalt in Acid Red 182 and Acid Blue 171 and substituting iron for chromium in Acid Black 172. These new dyes are nonmutagenic and do not introduce metals into dyeing wastewater (4). Commercialization of these dyes is still several years away, however.

Plumbing

Metals can derive from plumbing, pumps, valves, and other similar sources. Combining galvanized pipes with brass fittings, valves, pump impellers, or other parts is a common mistake, leading to galvanic reactions when the pipes are exposed to acids, alkalis, or very high salt concentrations found in textile processing solutions and wastewater. These reactions liberate zinc from the galvanized surface.

Metals in a mill's influent raw water supply (notably copper in city water) can exchange ions with solder joints in plumbing, producing lead or tin effluent wastewater.

Residues can collect in wood, asphalt, soil, or old, cracked or porous concrete sumps, pits, trenches, drains, and treatment systems. These sorbed metals can be released slowly over a period of months or even years. This fugitive source of metals often defies easy identification.

Chemicals

Sources of metals may also include chemicals used in textile processing, as described in the following paragraphs.

Oxidizing and Reducing Agents. During the 1940s and 1950s, the use of dichromate and permanganate as oxidizers was common in textile mills, contributing to high chromium levels in effluent. Zinc sulfoxylate formaldehyde reducing agents also were common. Zinc sulfoxylate formaldehyde is used for afterclearing and for discharge printing and stripping (i.e., repair work) (54). During the last 30 years, however, most mills have replaced these chemicals with the substitutions shown in Table 2-20.

Finishes Containing Metals. Certain textile finishes contain metals, including:

- *Antifungal and odor-preventive finishes:* Used for socks and based on organo-tin compounds.
- *Water repellents:* Based on chrome chloride stearic acid adducts (55).
- *Flame retardants:* Based on either decabromobiphenyl oxide plus antimony oxide or titanium chloride for wool (55).

Table 2-20. Replacements for Dichromate, Permanganate, and Zinc Oxidizing Agents

Previous	Replaced With
Dichromate	Peroxide Periodate Perborate Air
Permanganate	None, but the main necessity for permanganate was mildew removal repair procedure, and mildew control has improved with the advent of air-conditioned warehouses. In other words, the need has been eliminated.
Zinc-reducing agents	Sodium hydrosulfite ("hydro")

From a pollution prevention point of view, controlling releases of these metals in finishes is a matter of ensuring appropriate handling practices, worker training, control of pad dumps and mix discards, auditing, and other processes (14, 21).

Low-Level Metal Impurities in Commodities. Fibers received in wet processing operations can contain significant amounts of metals. Table 2-21 shows concentrations of calcium, magnesium, iron, copper, manganase, and zinc brought to the bleaching stage in raw cotton (52). These concentrations exceed the raw water supply concentrations because of the leaching of metals from the cloth being processed. Table 2-22 shows the results of testing two cotton samples for trace elements (including metals). Natural fibers can absorb metals from the environment. For example, raw cotton has been found to contain metals at levels between 75 and 100 ppm, which could translate to up to 10 ppm in wet processing effluent. Sources of metals include agricultural residues for natural fibers (e.g., arsenic), polymerization catalysts and delusterants in synthetic fibers (e.g., copper, titanium), and impurities added to fibers (e.g., in warp size) (21). Low-level metals are a significant problem. Salt, caustic, soda ash, and other chemicals also contain trace amounts of zinc, cadmium, and mercury.

Although the impurities in fibers and commodity chemicals are present in ppm or smaller quantities, a large operation can use, in the aggregate, several million pounds per week of commodity raw materials. The net

Table 2-21. Contaminants in Processing Solutions in Textile Mills: Peroxide Saturator Solutions From Three Mills Bleaching Cotton Fabric in J Boxes[a] (52)

	Dissolved Metal in Processing Solution (ppm)[b]		
		Range	
Metal	Average of 14 Samples[c]	Lowest	Highest
Calcium	68	28	130
Magnesium	24	7.7	49
Iron	1.5	0.5	3
Copper	0.25	0.065	0.68
Manganese	0.03	0.01	0.06
Zinc	0.49	0.14	0.8

[a] H_2O_2; 35% 15 to 30 g/L; sodium silicate, 42 Be., 15 to 39 g/L.

[b] As metal. Tests performed by Industrial Testing Laboratories, Inc., 2350 Seventh Boulevard, St. Louis, MO 63104.

[c] From four trials each in two mills and six trials in one mill.

Table 2-22. Trace Element Analysis of Cotton After Preparation (51)[a]

Element	Sample I (ppm)	Sample II (ppm)
Titanium	2.11 ± 5%	<0.5
Iodine	0.140 ± 7%	0.0104 ± 7%
Manganese	1.632 ± 0.5%	1.741 ± 0.5%
Magnesium	7.24 ± 15%	9.80 ± 15%
Copper	2.29 ± 8%	3.16 ± 8%
Vanadium	0.070 ± 10%	0.032 ± 10%
Chlorine	24.156 ± 5%	21.32 ± 5%
Aluminium	33.91 ± 1%	29.45 ± 1%
Mercury	<0.010	<0.010
Samarium	<0.005	<0.005
Uranium	<0.001	<0.001
Lanthanum	<0.4	<0.4
Cadmium	<0.8	<0.8
Gold	<0.0001	<0.0001
Arsenic	<0.2	<0.2
Antimony	<0.05	<0.06
Bromine	1.081 ± 1%	0.131 ± 5%
Sodium	<500.0	<500.0
Potassium	<500.0	<500.0
Cerium	<0.2	<0.2
Calcium	<100.0	<100.0
Selenium	<0.1	<0.1
Thorium	<0.004	<0.004
Chromium	0.095 ± 7%	0.142 ± 3%
Europium	<0.001	<0.001
Ytterbium	<0.03	<0.03
Barium	<5.0	<5.0
Cesium	0.0076 ± 10%	0.0083 ± 10%
Silver	<0.005	<0.005
Nickel	<5.0	<5.0
Scandium	0.0038 ± 2%	0.0038 ± 2%
Rubidium	<20.0	<30.0
Iron	68.29 ± 10%	60.04 ± 10%
Zinc	7.38	7.35
Cobalt	0.017	0.024
Molybdenum	<1.0	<1.0

[a] Neutron activation analysis of trace elements in cotton fabric.

effect is to generate significant amounts of metals in wastewater.

Raw Water. Metals often are found in incoming water, as city drinking water supplies can often contain more than 1 ppm of zinc, copper, and/or iron (21). Tests reported in Smith (4) in the southeastern United States, however, showed levels below 0.1 ppm for each of these (see Table 2-23). Copper is added to public water systems to control algae growth in tanks and ponds. Aluminum, in the form of alum, is another commonly added material. These metals can undergo ion exchange with plumbing (especially lead solder joints), valves, and pump parts to produce lead or other less electromagnetive metals in the mill's effluent.

2.2.5.2 Pollution Prevention Strategies

Procedures to reduce or eliminate metals must start with identification of metals and their sources and follow with an analysis of metals levels to determine the relative importance of that metal pollution. Identification can be made either by analysis of effluent or examination of input chemicals and process requirements, such as water. General pollution prevention methods of reducing or eliminating metals include:

- Careful prescreening of all chemicals (see Section 3.12, "Raw Material Prescreening Before Use").
- Substituting for metal-containing compounds (e.g., with nonmetal dyes).
- Improving efficiency of the process or operations by lowering chemical use while maintaining product quality objectives, perhaps by means of automation. Another method is to improve management of operations (e.g., better chemical handling skills).
- Elimination of galvanized plumbing.

Table 2-23. Raw Water Quality in Textile Mills in Southeastern United States (52)[a]

		Concentration of Constituents (ppm)		
			Range	
Constituent	Equivalency	Average of 10	Lowest	Highest
Calcium	$CaCO_3$	12.9	1	46.5
Magnesium	$CaCO_3$	3.8	1.5	7.8
Sodium	$CaCO_3$	36	5.7	76.1
Alkalinity				
Bicarbonate	$CaCO_3$	27.7	10	110
Carbonate	$CaCO_3$	1.4	0	10
pH	—	7.2	5.7	7.8
Iron	Fe^{2+}	0.1	0.01	0.31
Copper	Cu^{2+}	0.02	0.01	0.1
Manganese	Mn^{2+}	0.01	0	0.05
Zinc	Zn^{2+}	0.11	0	0.24

[a] Tests performed by Industrial Testing Laboratories, Inc., 2350 Seventh Boulevard, St. Louis, MO 63104.

As metals analysis has improved over the years and detection limits have decreased, regulatory limits on metals have also been lowered. Regulatory authorities may now set metals limits for some mills in the low ppb range. For example, a small textile operation discharging 50,000 gallons of wastewater per day with a 3-ppb limit on a particular metal discharges less than 200 milligrams of metal per day.

Dyes without metals should be used wherever possible. If a shade cannot be matched with a metal-free color (as is often the case with bright green and royal blue direct and fiber reactive colors), reducing the metal-bearing dye content is often possible by substituting part of the dye. In the case of green shades, brighter blues and greens contain metals. In the example shown below, a blue/yellow/red match of a green shade could be substituted with a lower metal version by replacing the red with a duller, but non-metal-bearing blue. This substitution could carry the necessary dullness in the shade and at the same time reduce the amount of metal-bearing brilliant blue in the recipe:

Best Match Recipe

1.4 percent	Metal-bearing blue
2.0 percent	Yellow
0.1 percent	Red for shading

Alternative Reduced-Metal Match

0.5 percent	Metal-bearing blue
0.8 percent	Non-metal-bearing blue
1.7 percent	Yellow

No red shading color because nonmetallic blue is duller

As a good pollution prevention practice, a mill should always insist on knowing the CI designation of all dyes used, in addition to their pollution status, including metal content. This issue is important because some of the major dye companies have withdrawn support for the CI system.

Pollution prevention strategies for dealing with metal-containing dyes are to:

- Seek substitutes (for all or part of the metal-containing dye) that do not contain metal (14, 45). Table 2-24 provides a good selection of fiber reactive dyes that do not contain metal as a component of the dye structure (8).
- Ensure maximum fixation by optimizing the process (45).
- Provide special auditing, handling, and worker training where these dyes are used. Special handling and use procedures for metal-bearing materials (e.g., segregating waste streams with separate plumbing systems) are necessary in some cases to keep metals out of the wastewater and to reduce aquatic toxicity (21).

Table 2-24. *Non-Copper-Containing Direct and Fiber Reactive Dyes*

Yellow 50	Red 153
Yellow 106	Blue 75
Orange 37	Blue 98
Red 76	Blue 106
Red 80	

Using disperse dyes that can be aftercleared with caustic (alkali) only eliminates the need for reducing agents (e.g., hydro), which can contribute BOD and, in some cases, metals to the effluent (48).

2.2.6 Aquatic Toxicity

Compounds that contribute to aquatic toxicity are a particular environmental concern for all industry. The national policy prohibiting discharge of toxic pollutants is embodied in Section 101(a)(3) of the federal Clean Water Act. EPA has identified toxic compounds under the general heading "Priority Pollutants," numbering approximately 126 compounds in 65 classes (see Table 2-25). Categorical discharge standards regulate these compounds. EPA identified priority pollutants on the basis of their known or suspected carcinogenicity, mutagenicity, teratogenicity, or high acute toxicity (56).

2.2.6.1 Aquatic Toxicity of Textile Wastewater

The aquatic toxicity of textile industry wastewater varies considerably among production facilities. Data are available that show that some facilities have fairly high aquatic toxicity, while others show little or no toxicity. Table 2-26 summarizes the results for about 75 mills in North Carolina.[5] Of the mills tested, effluent from about one-half showed no toxicity. The median value of all positive tests was 48.5 percent, indicating that a 48.5-percent solution of the mill's treated effluent caused 50-percent mortality among tested organisms.

2.2.6.2 Testing for and Determining Toxicity

Numerous compounds in textile effluent can contribute to aquatic toxicity, including dyes, dyeing auxiliaries, and surfactants. Identifying all the toxic compounds used in textile production is impossible because of the huge variety of chemicals used and the lack of data on their toxicities. Several methods may be used, however, to identify compounds of concern. Knowledge of the chemical compounds used by a mill and their associated toxicities (or classes of toxicity) can help

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[5] Tedder, S.W. 1986. Aquatic bioassay toxicological summary (memorandum). North Carolina Division of Environmental Management, Raleigh, NC (March 31).

Table 2-25. List of EPA Priority Pollutants[a]

Code	CAS[b] No.	Pollutant
P058	100027	4-nitrophenol
P038	100414	Ethylbenzene
P101	1024573	Heptachlor epoxide
P034	105679	2,4-Dimethylphenol
P027	106467	1,4-Dichlorobenzene
P002	107028	Acrolein
P010	107062	1,2-Dichloroethane
P003	107131	Acrylonitrile
P042	108602	Bis(2-chloroisopropyl) ether
P086	108883	Toluene
P007	108907	Chlorobenzene
P065	108952	Phenol
P019	110758	2-chloroethyl vinyl ether (mixed)
P111	11096825	PCB-1260 (aroclor 1260)
P107	11097691	PCB-1254 (aroclor 1254)
P108	11104282	PCB-1221 (aroclor 1221)
P109	11141165	PCB-1232 (aroclor 1232)
P018	111444	Bis(2-chloroethyl)ether
P066	117817	Bis(2-ethylhexyl)phthalate
P009	118741	Hexachlorobenzene
P078	120127	Anthracene
P008	120821	1,2,4-Trichlorobenzene
P031	120832	2,4-Dichlorophenol
P035	121142	2,4-Dinitrotoluene
P037	122667	1,2-Diphenylhydrazine
P051	124481	Chlorodibromomethane
P110	12672296	PCB-1248 (aroclor 1248)
P085	127184	Tetrachloroethylene
P084	129000	Pyrene
P071	131113	Dimethyl phthalate
P116	1332214	Asbestos (fibrous)
P129	1746016	2,3,7,8-Tetrachlorodibenzo-P-dioxin (TCDD)
P079	191242	1,1,2-Benzoperylene (benzo(ghi)perylene)
P083	193395	Indeno(1,2,3-cd)pyrene (2,3-o-phenylenepyrene)
P074	205992	3,4-Benzofluoranthene (benzo(b)fluoranthene)
P039	206440	Fluoranthene
P076	218019	Chrysene
P089	309002	Aldrin
P102	319846	Alpha-BHC
P103	319857	Beta-BHC
P105	319868	Delta-BHC
P093	3547044	4,4’-DDE (p-p’-DDX)
P092	50293	4,4’-DDT
P073	50328	Benzo(a)pyrene (3,4-Benzopyrene)
P059	51285	2,4-Dinitrophenol
P060	534521	4,6-Dinitro-o-cresol
P106	53469219	PCB-1242 (aroclor 1242)
P082	53703	1,2,5,6-Dibenzanthracene (dibenzo(a,h)anthracene)
P033	542756	1,3-Dichloropropylene (1,3-Dichloropropene)
P017	542881	Bis(chloromethyl)ether (deleted)
P006	56235	Carbon tetrachloride (tetrachloromethane)
P072	56553	1,2-Benzanthracene (benzo(o)anthracene)
P121	57125	Cyanide (total)
P091	57749	Chlordane (technical mixtures and metabolites)
P104	58899	Gamma-BHC (lindane)
P022	59507	Parachlorometacresol
P090	60571	Dieldrin
P036	606202	2,6-Dinitrotoluene
P063	621647	N-nitrosodi-n-propylamine
P061	62759	N-nitrosodimethylamine
P023	67663	Chloroform (trichloromethane)
P012	67721	Hexachloroethane
P004	71432	Benzene
P011	71556	1,1,1-Trichloroethane
P098	72208	Endrin
P094	72548	4,4’-DDD (p,p’-TDE)
P122	7439921	Lead (total)
P123	7439976	Mercury (total)
P124	7440020	Nickel total)
P126	7440224	Silver (total)
P127	7440280	Thallium (total)
P114	7440360	Antimony (total)
P115	7440382	Arsenic (total)
P117	7440417	Beryllium (total)
P118	7440439	Cadmium (total)
P119	7440473	Chromium (total)
P120	7440508	Copper (total)
P128	7440666	Zinc (total)
P046	74839	Methyl bromide (bromomethane)
P045	74873	Methyl chloride (chloromethane)
P016	75003	Chloroethane
P088	75014	Vinyl chloride (chloroethylene)
P044	75092	Methylene chloride (dichloromethane)
P047	75252	Bromoform (tribromomethane)
P048	75274	Dichlorobromomethane
P013	75343	1,1-Dichloroethane
P029	75354	1,1-Dichloroethylene
P050	75434	Dichlorofluoromethane (deleted)
P049	75694	Trichlorofluoromethane (deleted)
P100	76448	Heptachlor
P053	77474	Hexachlorocyclopentadiene
P125	7782492	Selenium (total)
P054	78591	Isophorone
P032	78875	1,2-Dichloropropane
P014	79005	1,1,2-Trichloroethane
P087	79016	Trichloroethylene
P015	79345	1,1,2,2-Tetrachloroethane
P113	8001352	Toxaphene
P070	84662	Diethyl phthalate
P068	84742	Di-n-butyl phthalate

Table 2-25. List of EPA Priority Pollutants[a] (Continued)

Code	CAS[b] No.	Pollutant
P081	85018	Phenanthrene
P067	85687	Butyl benzyl phthalate
P062	86306	N-nitrosodiphenylamine
P080	86737	Fluorene
P052	87683	Hexachlorobutadiene
P064	87865	Pentachlorophenol
P021	88062	2,4,6-Trichlorophenol
P057	88755	2-nitrophenol
P055	91203	Naphthalene
P020	91587	2-chloronaphthalene
P028	91941	3,3-Dichlorobenzidine
P005	92875	Benzidine
P025	95501	1,2-Dichlorobenzene
P024	95578	2-chlorophenol
P056	98953	Nitrobenzene
P030	NA[c]	1,2-Trans-dichloroethylene
P069	NA	Di-n-octyl phthalate
P096	NA	Beta-endosulfan
P097	NA	Endosulfan sulfate
P112	NA	PCB-1016 (aroclor 1016)
P026	NA	1,3-Dichlorobenzene
P095	NA	Alpha-endosulfan
P001	NA	Acenaphthene
P041	NA	4-bromophenyl phenyl ether
P075	NA	1,2-Benzofluoranthene (benzo(b)fluoranthene)
P040	NA	4-chlorophenyl phenyl ether
P043	NA	Bis(2-chloroethoxy) methane
P077	NA	Acenaphthylene
P099	NA	Endrin aldehyde

[a] 46 CFR 2264 (January 1981).
[b] CAS = Chemical Abstract Service.
[c] NA = not applicable.

predict whether an effluent toxicity problem exists. One source of information is MSDSs, which list chemical ingredients, their known toxic effects, and other characteristics. Other sources include manufacturer formulations if they are listed or can be provided by the manufacturer. Analysis of these compounds or of the effluent to determine their precise chemical nature (including toxicity) is, practically speaking, impossible.

Table 2-26. Results From Aquatic Toxicity Testing of Effluent From 75 Textile Mills[a,b]

Toxicity (%)	Number of Tests in That Range
<9	7
10-19	6
20-29	8
30-39	2
40-49	4
50-59	9
60-69	3
70-79	8
80-89	2
90-100	3
>100 (no toxicity)	38

[a] Toxicity in the table is LC$_{50}$ in percent; thus, higher numbers represent lower toxicity.
[b] See footnote 2.

Another approach for assessing toxicity is to measure whole effluent toxicity (chronic or acute), without regard to the specific chemical compound(s) that contributes to toxicity. The textile industry produces many thousands of compounds in effluent, and identifying and testing all of them is impractical. As a result, toxicity testing of the whole effluent stream on aquatic organisms is a cost-effective means of determining overall toxicity. Toxicity testing proceeds by exposing freshwater, estuarine, and marine life forms in tanks to either stationary, renewed, or flowing effluent. Species tested include algae, shrimp, silversides, and minnows. Toxicity is calculated in various ways: measuring death rates, observing birth defects, and noting other biological indications. One common measure of toxicity is LD$_{50}$, which stands for lethal dose 50 percent, meaning the amount of chemical dose required to cause mortality in 50 percent of the test population. LC$_{50}$ (lethal concentration 50 percent), another common measure, represents the concentration of effluent in the dilution water that causes mortality in 50 percent of the test population (56).

2.2.6.3 Types of Toxic Chemical Compounds

The sources of aquatic toxicity in textile wastewater can be hard to identify (21). Despite the lack of knowledge concerning the exact composition or toxicity of many textile dyes and auxiliary chemicals, many generally known groups of chemical agents contribute to aquatic toxicity of textile wastewater. These agents include (21):

- Salt
- Surfactants
- Metals
- Toxic organic chemicals
- Biocides
- Toxic anions

Examples of compounds in each of these classes and their sources are shown in Table 2-27. Information related to the toxicity of these compounds and pollution prevention strategies effective for each are discussed in the following paragraphs. In addition, each category is also discussed in other chapters of this document. These sections provide further details concerning

Table 2-27. Typical Causes of Aquatic Toxicity

Agent	Chemical Example	Typical Source
Salt	NaCl, Na_2SO_4	Dyeing
Surfactants	Ethoxylated phenols	Multiple sources
Metals	Copper, zinc, etc.	Dyes
Organics	Chlorinated solvents	Scour, machine cleaning
Biocides	Pentachlorophenol	Wool fiber contaminant
Toxic anions	Sulfide	Sulfur dyeing

amounts, sources, and appropriate pollution prevention practices.

Dyes

Most textile dyes have low aquatic toxicity. A study of 46 commercially important dyes, summarized in Table 2-28, showed that 29 (60 percent) had very low aquatic toxicity of (LC_{50} greater than 180 ppm) (57). The toxicity distribution of the dyes is shown in Table 2-29.[6] The numbers indicate that, for example, 7 of the 46 dyes exhibited toxicity at concentrations of between 1 and 10 ppm.

For the few dyes that exhibit higher toxicity characteristics, it is important to realize the degree of dilution that normally occurs.

- A typical batch (exhaust) dyebath using 1 percent dye owg at 10:1 bath ratio contains 1,000 ppm of dye.
- If the dye is 90 percent exhausted onto the fabric, the concentration would drop to 100 ppm in the spent dyebath.
- When combined with other process wastewater from processes such as preparation, or washing off, the concentration drops to about 5 ppm. (Note: assumes millwide water consumption of 20 gallons per pound of fabric at 8.34 pounds per gallon.)
- Assuming that the in-stream concentration/dilution factor for the textile wastewater is 10 percent in the receiving stream (a fairly severe assumption), the "in-stream concentration" would be less than 1 ppm. This assumes that none of the color is removed in treatment and that the toxicity of the degradation products is equal to that of the original dye.

If the spent dyebath is combined, however, with cleanup waste, spilled dye, and discarded mixes, the in-stream value could be higher.

As a class, certain types of dyes exhibit higher toxicity than others. Table 2-30 shows the toxicity of the 47 dyes

Table 2-28. Effect of 46 Selected Dyes on the Fathead Minnow, *Pimephales Promelas,* in Static Bioassay Tests (57)

C.I. Number	Dye	LC_{50}, 96 Hour (mg/L)	Temperature (°C)
10338	Disperse Yellow 42	>180	15
11855	Disperse Yellow 3	>180	15
14645	Mordant Black 11	6	15
15510	Acid Orange 7	165	17
15711	Acid Black 52	7	15
18965	Acid Yellow 17	>180	17
19555	Direct Yellow 28	>180	15
20170	Acid Orange 24	130	17
20470	Acid Black 1	>180	15
21010	Basic Brown 4	5.6	20
22610	Direct Blue 6	>180	17
24401	Direct Blue 218	>180	17
24890	Direct Yellow 4	>180	15
24895	Direct Yellow 12	125	15
25135	Acid Yellow 38	23	15
26360	Acid Blue 113	4	15
28160	Direct Red 81	>180	17
29025	Direct Yellow 50	>180	17
29160	Direct Red 23	>180	17
20145 (or 30145)	Direct Brown 95	>180	17
30235	Direct Black 38	>180	17
31600	Direct Black 80	>180	17
40000	Direct Yellow 11	>180	17
40622	Fluorescent Brightening Agent 28	>180	17
42000	Basic Green 4	0.12	18
42535	Basic Violet 1	0.047	15
47020	Disperse Yellow 54	>180	15
48055	Basic Yellow 11	3.2	18
51005	Basic Blue 3	4	15
53185	Sulfur Black 1	>180	15
53630	Vat Blue 43	>180	15
59105	Vat Orange 1	>180	15
59825	Vat Green 1	>180	15
61505	Disperse Blue 3	1	15
61570	Acid Green 25	6.2	18
62055	Acid Blue 25	12	15
62500	Disperse Blue 7	52	15
63010	Acid Blue 45	>180	15
67300	Vat Yellow 2	>180	15
69015	Vat Brown 3	>180	15
69500	Vat Green 3	>180	15
69825	Vat Blue 6	>180	15
74180	Direct Blue 86	>180	17
NA[a]	Acid Yellow 151	29	15
NA	Disperse Red 60	>180	15
NA	Direct Yellow 106	>180	17

[a] NA = not available.

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[6] Note that this study used purified dyes. Typical commercial dyes contain 20 to 80 percent other materials; thus, toxicities of in-use dyes should be 20 to 80 percent below those reported for the pure substances.

Table 2-29. Frequency Distribution of Toxicity Test Results for 46 Commercial Dyes (57)

Toxicity Range (LC_{50} ppm)	Number of Dyes in Range	Percent of Total
>180	29	63.0
100-180	3	6.5
10-100	4	8.7
1-10	7	15.2
0.1-1	2	4.3
<0.1	1	2.2
Totals	46	100.0

Table 2-30. *Toxicities of Various Dye Classes (57)*

Dye Class	Number Tested	Number Toxic	Percent Found To Be Toxic
Disperse	6	2	33.3
Acid	12	8	66.7
Mordant[a]	1	1	100.0
Direct	14	1	7.1
Basic	5	5	100.0
Brightener	1	0	0.0
Sulfur	1	0	0.0
Vat	7	0	0.0
Fiber reactive	0	0	—

[a] Mordant is an obsolete class similar to acid dyes.

by dye class. Cationic materials generally are very toxic. Fortunately, cationic dyes exhaust essentially 100 percent in batch dyeing operations (see also Section 4.3, "Dyes"). At the time of this study, the fiber reactive dyes that are now popular were not in widespread use. These would exhibit similar toxicity to acid and direct dyes except that they are typically accompanied in wastewater by large amounts of salt.

From the above, pollution prevention strategies can be directly deduced, including:

- Selecting nontoxic dyes if information is available.
- Using minimum amounts of dye.
- Using dyes of high tinctorial value.
- Ensuring maximum exhaustion of the dyebath by proper dyeing process, pH, salt, etc. (see Sections 2.2.1, "Color Residues in Dyeing Wastewater," and 4.3, "Dyes").
- Selecting treatable dyes that degrade to nontoxic products. Unfortunately, data on these dyes are not readily available to dyers.
- Maintaining proper processes such as special handling, worker training, recordkeeping for dyes of high toxicity (e.g., basic dyes).

Surfactants

Surfactants and related compounds (detergents, emulsifiers, dispersants) are used in almost every textile process and can be an important contributor to effluent toxicity (and BOD). The wide variety of available alternatives allows for selection of less-polluting chemicals.

Quaternary amines used for processes such as disinfecting, scouring, softening are particularly toxic and should be avoided wherever possible (21). These are reviewed in detail in Section 4.4, "Chemical Specialties."

Surfactants are important in a large number of textile processes, including:

- Lubricating
- Spin finishing
- Desizing
- Scouring
- Mercerizing
- Bleaching
- Wet finishing
- Foam finishing
- Dyeing
- Foam dyeing

Most textile surfactants are either nonionic or anionic. Nonionic surfactants dissolve in water without forming ions, while anionic surfactants form negative ions when dissolved in water. The major classes of each are:

- Nonionic surfactants:
  - Alcohol ethoxylates
  - Alkylphenol ethoxylates
- Anionic surfactants:
  - Alkylbenzene sulfonates
  - Alcohol ethoxysulfates

Surfactants are a major contributor to the aquatic toxicity of textile effluent and foaming. Nonionic surfactants of the type used in textile processing can be acutely toxic to aquatic life at levels as low as 1 ppm and can produce chronic effects in the 0.1 to 1.0 ppm range (58). Surfactants in raw textile waste have been found in concentrations ranging from 50 to 200 ppm (58). The concentration in treated effluent depends on the degree of biodegradation of the surfactant in the treatment plant. The choice of surfactant determines the degree of degradation and the ultimate concentration in discharged effluent. Linear alcohol ethoxylate (LAEs), linear alkylbenzene sulfonates, and alcohol ethoxysulfates are more biodegradable than APs (58-60) and thereby produce less foaming in receiving waters. These are discussed in detail in Section 4.4, "Chemical Specialties."

Salt. Salts of various types are used as raw materials or are produced as by-products of other textile wet processes (e.g., neutralization). Several authors have identified the large amounts of salt used in textile dyeing, particularly in conjunction with fiber reactive dyes, as a significant future problem area for the textile industry (8).

Typical cotton batch dyeing operations use quantities of salt that range from 20 percent to 80 percent owg, and the usual salt concentration in such wastewater is 2,000 to 3,000 ppm (11). Federal guidelines for in-stream salt concentrations have been established at 230 ppm (21). The treatment of mixed wastewater to reduce salt to levels that meet such limits is extremely difficult and expensive by any known method. Pollution prevention is the only reasonable alternative to solve the dilemma presented by this hard-to-treat, toxic, and high-volume waste. General methods of dealing with salt are discussed in Section 2.2.2, "Discharge of Electrolytes." In addition, two specific methods for reducing salt requirements (pad-batch dyeing and dyebath reuse) are reviewed in detail in Section 4.10, "Dyeing."

Toxic Organic Chemicals. Textile effluents may contain numerous types of toxic organic compounds, both volatile and nonvolatile. In the 1980s, the state of North Carolina studied toxic materials (excluding surfactants) in wastewater from five textile wet processing mills that had shown aquatic toxicity in the past (61).[7] Results from these tests, shown in Table 2-31, identified between 8 and 42 toxic organic compounds.

Table 2-31. Toxic Organics Detected in Wastewater From Five Textile Wet Processing Mills (61)

	Number of Toxic Organic Chemicals Identified		
Site	**Volatiles**	**Nonvolatiles**	**Total**
1	34	8	42
2	12	2	14
3	0	11	11
4	4	4	8
5	4	5	9

Most of the identified materials were hydrocarbons. Several chlorinated organic solvents were detected, including perchloroethylene, trichlorobenzene, methylene chloride, and chloroform. Many esters were also detected, primarily benzoates, phthalates, and esters of hexanedioic acid. Other compounds identified included acetone, cyclohexanone, cyclohexanol, and other alcohols, such as 2-ethyl hexanol, and acids, such as hexadecanoic acid.

Halogenated organics, particularly organochlorines, are produced as a by-product of wool shrinkproofing processes. These chemicals are of concern when they later appear in receiving water or drinking water supplies as AOX. The chlorine/Hercosett process of shrink proofing wool with chlorine generates 39 milligrams AOX per liter of liquid discharged (53). This is far higher than the proposed United Kingdom standard of 1 milligram per liter (53).

The aquatic toxicities of numerous organics found in textile wastewater in the five-mill study are shown in Table 2-32 (61). Of the approximately 50 compounds identified, aquatic toxicity data were readily available for only 11. This points to a basic problem in preventing aquatic toxicity: the lack of data on aquatic toxicity of chemical compounds. Also, in many cases, the chemical constitution of specialty chemical processing assistants is unknown to the user. Methods of addressing this problem are described in Section 4.4, "Chemical Specialties."

Biocides. Biocides are used for two major purposes in textiles: 1) to prevent biological growth during textile processing, and 2) as a finish to impart biocidal properties to textile products.

Biocides for in-process textile use include:

- Weed killers used around bulk storage tanks and buildings.
- Disinfectants for restrooms.
- Algae suppressants in air-cooling tower systems.
- Mildew inhibitors as a component of warp size.
- Biocides applied to sheep, a source of contaminants in wool.
- Defoliants and insecticides applied to cotton in farming.

Table 2-32. Aquatic Toxicities of Organic Chemicals Found in Effluent From Five Textile Mills (61)

Chemical	Aquatic Toxicity Range (ppm)
Acetone	>1,000
Chloroform	10-100 (animal carcinogen)
Cyclohexane	10-100
Cyclopentane	>1,000
Decahydronaphthalene	100-1,000
Ethyl benzene	10-100
Methylene chloride	100-1,000
Perchloroethylene	10-100 (animal carcinogen)
Trichlorobenzene	0-10
Xylene	10-100

---

[7] See footnote 2.

These may end up in effluent, sanitary wastewater, or stormwater discharges (runoff) from the industrial facility.

Several biocidal finishes are also applied to textile materials, including:

- Insecticides for carpets
- Mothproofing agents for wool
- Odor suppressants for socks/hosiery

The simplest, cheapest method of applying these compounds to wool products is through dyebath addition. Unfortunately, the biocides, such as permethrin, do not exhaust fully onto the fabric and consequently are discharged with the effluent.

Several European countries are now requiring textile operations to reduce discharges of specific pesticide materials, notably pentachlorophenol (PCP) for wool finishing and AOX (44). PCP and its salts and esters are used as industrial biocides to prevent deterioration of wood and cellulosic fibers. PCPs have been used in carpet manufacture, but their presence is not limited to wool carpets. Carpet backing materials, particularly jute, polypropylene, and latex, also contain PCP, often at levels greater than those found in wool fibers (62). PCP use on textile products has been criticized, and its use for indoor materials is banned in Germany, Sweden, Switzerland, Japan, and the United States (62).

In the United Kingdom, mothproofing of wool and wool blend carpets was previously performed using chlorphenylid-based agents; these have since been banned. Other mothproofing agents in use include permethrin and cyfluthrin. Permethrin is effective and has low toxicity to humans but high aquatic toxicity (63). Quantities of all three mothproofing agents are found in British rivers and current practices are not expected to comply with environmental quality standards (EQS) established in the United Kingdom (53). The discharge of leftover portions of processing baths is the main source of the problem (63). This is one of the four high-priority areas identified by the IWS study group (53).

Substitutes for permethrin and cyfluthrin are thus being sought. Diphenylurea and cyfluthrin can replace permethrin. Diphenylurea may exhibit less aquatic toxicity but, in some cases, is less biodegradable. A synthetic pyrethroid alternative to permethrin, cycloprothrin, exhibits good performance and has aquatic toxicity three orders of magnitude less than permethrin. Nippon Kayaku manufactures cycloprothrin and markets it as Cyclosal. The toxic properties are very low. The mammalian toxicity LD_{50} in rats and mice is greater than 5,000 milligrams per kilogram, and no irritant, carcinogenic, teratogenic, or mutagenic properties have been observed (64).

Pesticide Residues. Residues of pesticides used to prevent parasitic infestation on sheep may be present in effluent from wool scouring operations. At one time, many organochlorine pesticides were in widespread use, but many countries have banned these pesticides because of concerns over mammalian toxicity. Some countries still use organochlorine pesticides such as lindane (gamma-hexachlorocyclohexane), campheclor (or toxaphene), and dieldrin. Organophosphate and synthetic pyrethroids are more commonly used today. Both of these groups have lower mammalian toxicity and are less persistent in the environment than organochlorine pesticides, although they may still contribute to effluent toxicity.

The degradability of various chemical pesticides in wastewater treatment plants has been assessed in studies by Mickelson et al. (1). Dieldrin was degraded by 81 percent, dichlorofenthion by 79 percent, diazinon by 87 percent, cyperethrin-1 by 84 percent, cyperethrin-2 by 90 percent, and deltamethrin by 92 percent. These are discussed further in Section 4.12.4.

Toxic Anions. The main source of toxic anions in textile operations is sulfide from sulfur dyeing. Sulfides are very odiferous and toxic, and can be a significant problem in wastewater from sulfur dyeing.

When initially introduced in the late 1800s, sulfur dyes were reduced in the dyehouse by boiling the dye with soda ash and sodium sulfide to render them soluble (12). A by-product was foul-smelling sulfur dioxide. A later advance was the introduction in 1936 of prereduced/presolubilized sulfur dyes, which eliminated the need for onsite reduction processes. In the 1990s, new types of sulfur dyes have been introduced that feature lower sulfide content, thus producing less sulfide in the effluent and fewer hydrogen sulfide odors in the mill and in the waste treatment system. The chemical nature of the proprietary reducer is not revealed, but it appears to be an organosulfur reducing agent (12).

One strategy for reducing sulfide in wastewater is to substitute glucose for sulfide-containing reducing agents (44). Even cheaper reducing sugars from corn can reportedly perform the same function. In one case, the sulfide concentration was reduced from 30 ppm to 2 ppm in the effluent. A small increase in BOD resulted, which was easily handled in the treatment system, whereas the sulfide waste was not amenable to waste treatment. The zone settling velocities of the clarifiers improved as a result of the decrease in sulfide, thus increasing waste treatment efficiency. In addition, odors decreased substantially.

The change to glucose did not increase operating costs. Estimated cost savings were $20,000 per year from avoided costs for sulfide removal equipment, and a savings of $30,000 per year in waste treatment operation costs. The corn sugars were a waste stream from the corn starch industry, and the corn starch manufacturer saved $12,000 in waste treatment system expansion and $2,400 in operating expenses (44).

Other Toxic Compounds. Other potential sources of toxicity in wastewater may be present in textile operations:

- Evidence shows that some dyes and other compounds have the potential to degrade from relatively safe forms into toxic compounds. For example, the dye FD&C Food Red #5, although not a textile dye, degrades into products that are both carcinogenic and mutagenic (46).
- Sequestering agents such as EDTA and DTPA form stable complexes with heavy metals. These complexes can pass right through a treatment plant and into receiving waters, where the compounds eventually break down, releasing the metals into the environment (50, 51).
- Phosphonates and polyphosphates can be used as dispersing agents as well as complexing agents. Both compounds have a low bioeliminability and have been banned in several countries because of eutrophication problems (50, 51).
- Four high-priority areas in wool finishing identified by the IWS study group are: 1) pesticide residues in wastewater from wool contaminated with pesticides, 2) discharge of mothproofing agents from wool carpet manufacture, 3) halo-organic compounds from wool shrinkproofing, and 4) chromium from chrome dyeing (53).

Pollution Prevention Strategies

Pollution prevention strategies for toxic chemical compounds include:

- Special handling and use procedures for the compounds described above may be necessary to keep them out of the wastewater. Strategies include employee training to improve awareness of the toxicity potential of priority compounds and improve their handling, separate plumbing to segregate these wastes and facilitate special treatment and screening procedures to identify ingredients and evaluate their potential contribution to toxicity before being put in use.
- Chlorinated solvents should be replaced with nonchlorinated types (21).
- Rapid, large pH variation can also produce aquatic toxicity and should be avoided (21).
- MSDSs are a good, but often limited, source of information. MSDS data focus on human exposure and toxicity, which may correlate with environmental effects. Some specific chemical types, however, may have low human toxicity but high aquatic toxicity (e.g., quaternary amines). Other prescreening techniques are discussed in Section 3.12, "Raw Material Prescreening (Before Use)."
- Products, colors, and finishes that require the use of toxic production chemicals should be identified to the designer and to the consumer, and alternatives that can be produced more safely should be promoted. Many producers and consumers of textile products are aware of environmental concerns and factor information about environmental impacts into their purchasing decisions.
- Nonprocess chemicals, such as those used for cleaning, maintenance, and weed killing should receive special attention in terms of prescreening evaluation (see Section 3.12, "Raw Material Prescreening (Before Use)"), employee training (see Section 5.3, "Training Programs and Worker Attitudes"), as well as storage and handling in general (see Sections 3.8, "Maintenance, Cleaning, and Nonprocess Chemical Control," and 4.18, "Support Work Areas").
- Ultraviolet disinfection is a good replacement for biocides in cooling water towers.

2.2.7 Water Conservation

Water is used extensively throughout textile processing operations. Almost all dyes, specialty chemicals, and finishing chemicals are applied to textile substrates from water baths. In addition, most fabric preparation steps, including desizing, scouring, bleaching, and mercerizing, use aqueous systems.

The amount of water used varies widely in the industry, depending on the specific processes operated at the mill, the equipment used, and the prevailing management philosophy concerning water use. Reducing water consumption in textile processing is important for furthering pollution prevention efforts, in part because excess water use dilutes pollutants and adds to effluent load.

Mills that currently use excessive quantities of water can achieve large gains from pollution prevention. A reduction in water use of 10 to 30 percent can be accomplished by taking fairly simple measures. A walkthrough audit can uncover water waste in the form of:

- Hoses left running.
- Broken or missing valves.
- Excessive water use in washing operations.
- Leaks from pipes, joints, valves, and pumps.
- Cooling water or wash boxes left running when machinery is shut down.
- Defective toilets and water coolers.

In addition, many less obvious causes of water waste exist. These causes are presented below by subcategory, unit process, and machine type.

2.2.7.1 Water Consumption in Textiles

Subcategory

Textile operations vary greatly in water consumption. Table 2-33 summarizes the water consumption of various types of operations (14). Wool and felted fabrics processes are more water intensive than other processing subcategories such as wovens, knits, stock, and carpet.

Water use can vary widely between similar operations as well. For example, knit mills average 10 gallons of water per pound of production, yet water use ranges from a low of 2.5 gallons to a high of 45.2 gallons. These data serve as a good benchmark in determining whether water use in a particular mill is excessive.

By Unit Process

Water consumption varies greatly among unit processes, as indicated by Table 2-34. Certain dyeing processes and print afterwashing are among the more intensive unit processes. Within the dyeing category, certain unit processes are particularly low in water consumption (e.g., pad-batch). Low water-consuming dyeing alternatives are discussed in depth in Section 4.10, "Dyeing."

By Machine Type

Different types of processing machinery use different amounts of water, particularly in relation to the bath ratio in dyeing processes (the ratio of the mass of water in an exhaust dyebath to the mass of fabric). Washing fabric consumes greater quantities of water than dyeing. Water consumption of a batch processing machine depends on its bath ratio and also on mechanical factors, such as agitation, mixing, bath and fabric turnover rate (called contact), turbulence and other mechanical considerations, as well as physical flow characteristics involved in washing operations. These factors all affect washing efficiency.

Table 2-33. Water Use in Textile Processing (14)

Processing Subcategory	Water Use (gallons per pound of production) Minimum	Median	Maximum
Wool	13.3	34.1	78.9
Woven	0.6	13.6	60.9
Knit	2.4	10.0	45.2
Carpet	1.0	5.6	19.5
Stock/Yarn	0.4	12.0	66.9
Nonwoven	0.3	4.8	9.9
Felted fabric	4.0	25.5	111.8

Table 2-34. Water Consumption by Unit Process (8, 11, 46, 65, 66)

Process	Water Consumption	Reference
Yarn and fabric forming	Nil	
Slashing	0.06 to 0.94	66
Preparation:		
Singeing	Nil	
Desizing	0.3 to 2.4	8, 66
Scouring	2.3 to 5.1	66
Continuous bleaching	0.3 to 14.9	66
Mercerizing	0.12	8
Dyeing:		
Beam	20	11
Beck	28	46
Jet	24	46
Jig	12	46
Paddle	35	11
Skein	30	11
Stock	20	11
Pad-batch	2	65
Package	22	46
Continuous	20	46
Indigo range	1 to 6	66
Printing	3	8
Print afterwashing	13.2	8
Finishing:		
Chemical	0.6	8
Mechanical	Nil	

In general, heating of dyebaths constitutes the major portion of energy consumed in dyeing. Therefore, low-bath-ratio dyeing equipment not only conserves water but also saves energy, in addition to reducing steam use and air pollution from boilers. Low-bath-ratio dyeing machines conserve chemicals as well as water and also achieve higher fixation efficiency. But the washing efficiency of some types of low-bath-ratio dyeing machines, such as jigs, is inherently poor; therefore, a correlation between bath ratio and total water use is not always exact.

2.2.7.2 Types of Wastewater

Many sources of different types of wastewater can be found in textile operations. The most common categorization scheme for wastewater is:

Category	Example
Noncontact	Cooling
Storm	Parking lot and roof drains
Cleanup	Machines, facility, filter backwash
Process waste	Prepare, dye, finish, water-jet loom
Condensate	Boiler traps, blowdown

Each type of wastewater offers different possibilities for conservation, recycle, and reuse.

Noncontact Cooling Water

Noncontact cooling water typically is isolated from all processes and, therefore, remains essentially pure after use. Cooling water includes water from water-cooled bearings and heat exchangers in dyeing machines, cooling cans on continuous ranges, and cooling towers for power boilers. In general, cooling water can be recycled directly back into the clear well or other process water supply reservoir. Most mills use excessive amounts of cooling water; therefore, this area presents significant conservation possibilities. In particular, water-cooled bearings require only a small amount of water to operate properly. A relatively simple solution is to regulate the water with flow restrictors, although this is rarely done. Another excessive use of water is cooling water left running when machines are shut down. Finding cooling water, as well as washbox water, running on dye ranges that have been shut down for months or even years is not unusual.

Stormwater

Stormwater from parking lot and roof drains always should be handled in a separate discharge that is properly permitted and monitored. Stormwater sometimes is improperly connected to the process wastewater treatment system, resulting in additional load. An examination of the correlation between rainfall and treatment system influent can detect an improper connection. Stormwater should be audited on a regular basis to detect and address problems as they occur. Stormwater originating off site should not be allowed to run onto mill property and mix with onsite stormwater, resulting in external causes for stormwater permit violations.

Cleanup Water

Cleanup water derives from machine maintenance and cleaning, filter backwash, facility cleaning, and other activities. The dirty water generally collects in floor drains because mills often clean the shop floors by washing them down with water, which runs into floor drains. Because of this practice, floor drains should never be plumbed into the stormwater system. Instead, floor drains should lead directly to the process wastewater treatment system. The practice of using water to wash down the floors and letting water run into floor drains also should be eliminated from all mill procedures. Spills and other cleanup activities should be done with wet/dry shopvac vacuum cleaners wherever possible. To minimize spills, chemical handling procedures should be implemented. In particular, automated chemicals dispensing, weighing, and handling systems are useful (see Section 4.18, "Support Work Areas").

If water is used for machine and facility cleaning, it should be provided through low-volume, high-velocity nozzles, which clean more efficiently with less water. All hoses should be equipped with automatic shutoffs so that the flow automatically stops whenever the hose is not being used. A single running hose can waste 5,000 to 8,000 gallons per day. Plants often have 5 or 10 of these hoses running at different locations. Often, the shutoff valves on hoses are broken, inconveniently located, or nonexistent. Wherever possible, cleanup water should be obtained from washwater waste, not from the freshwater supply.

Process Water

Wastewater from processing is the most common source of environmental concerns for textile operations. The main unit processes that produce waste are washing operations. These operations are found in almost all areas of preparation and dyeing. The details of water conservation in washing operations are discussed below.

Washing and rinsing operations are two of the most common operations in textile manufacturing that have significant potential for pollution prevention. Many processes involve washing and rinsing stages, and optimization of washing processes can conserve significant amounts of water. In some cases, careful auditing and implementation of controls can achieve wastewater reductions of up to 70 percent (67). The washing and rinsing stages of preparation typically require more water than the preparation stages (e.g., bleaching, dyeing) (67). Several typical washing and rinsing processes include:

- Drop and fill batch washing.
- Overflow batch washing.

Table 2-35. Water Consumption for a Typical Bleach Range (68)

Stage	Water Consumption (gallons per hour)	Percent
Saturators	550	5.0
Steamer and J boxes	150	1.4
Washers		0.0
Desize	3,700	33.5
Scour	3,100	28.1
Bleach	3,100	28.1
Dry cans	450	4.1
Total	11,050	100.0

- Continuous washing (countercurrent, horizontal, or inclined washers).

A report on water consumption for a typical continuous bleach range found that consumption was more than 11,000 gallons per hour or 0.27 million gallons per day (see Table 2-35). Washing stages accounted for 9,900 gallons per hour, or 90 percent of the total. The application of the following simple, low-technology methods of water conservation reduced water use (68):

- *Properly regulate flows:* 300 gallons per hour savings.
- *Counterflow bleach to scour:* 3,000 gallons per hour savings.
- *Counterflow scour to desize:* 3,000 gallons per hour savings.

The total water savings without process modification was 0.15 million gallons per day, or 55 percent of water use. A process modification such as a combined one-stage bleach and scour also would save 6,200 gallons of water per hour, or an additional 0.15 million gallons per day, along with energy savings (68).

Drop-Fill Versus Overflow

In the drop/fill method of batch washing, spent washwater is drained and the machine is refilled with a fresh wash bath. The fabric or other substrate in the machine retains much of the previous bath, perhaps up to 350 percent owg. This percentage can be reduced by mechanical means (e.g., extraction, blowdown) (67). Comparison of several methods of washing after bleaching shows the benefits of countercurrent wash methods (see Table 2-36). Methods 5 and 6, which implement countercurrent washing, produce savings of 26 and 53 percent compared with the standard drop/fill method. These results are based on comparisons of washing processes that would produce the same degree of reduction of fabric impurities using computer models.

Countercurrent washing processes require the addition of holding tanks and pumps (67). The capital cost of setting up such a reuse system is low (69). Typically, the following installation costs can be expected for a system capable of recycling 75,000 gallons per day:

System	Cost
Pump	$3,000
Tank	$14,000
Piping	$5,000
Electrical	$1,000
Total	$23,000

Table 2-36. Water Use in Batch Washing (67)

Process Description	Wash/Rinse (Bath Ratio)	Water Use (gal/lb)	Percent Change From Standard
1 Standard—three-step drop/fill	1:8	1.62	—
2 Reduced bath—seven-step drop/fill	1:5	1.26	–22.2
3 Continuous overflow	1:8	2.38	+46.9
4 Continuous overflow—reduced bath	1:5	1.49	–8.0
5 Three-step drop/fill, reuse bath 2	1:8	1.19	–26.5
6 Three-step drop/fill, reuse bath 2 and 3	1:8	0.75	–53.7

Typical savings from such an installation are $95,000 per year. In many cases, reducing wastewater also reduces the need for expensive waste treatment systems.

Brenner et al. (67) present a computer analysis that assumes complete knowledge of the state of washing systems at any given time (i.e., the amount of contaminant remaining in the fabric). In the real world, time constraints and the ability to accurately control such processes are issues. For example, in the drop/fill method, counting the number of drops and fills is relatively simple. This method facilitates matching of actual mill production processes with the computer-predicted results above.

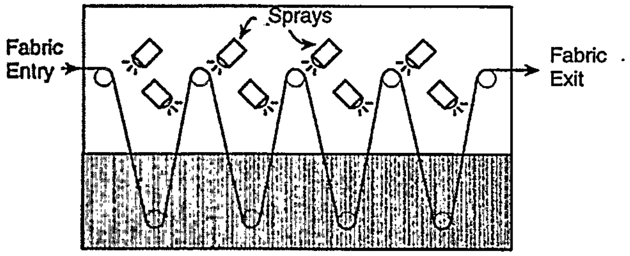
On the other hand, controlling overflow washing is more difficult. Optimum control of overflow washing would require a knowledge of the amount of contaminant left in the substrate. In practice, this level of monitoring and control is not possible, and as a result, flow and time control are inadequate. Therefore, the overflow washing method almost always uses more water than predicted above because of a lack of control. Further information about the water-saving features of drop/fill versus overflow can be found in Brenner et al. (67), Smith (14), and Wagner (8).

2.2.7.3 Washwater Reuse

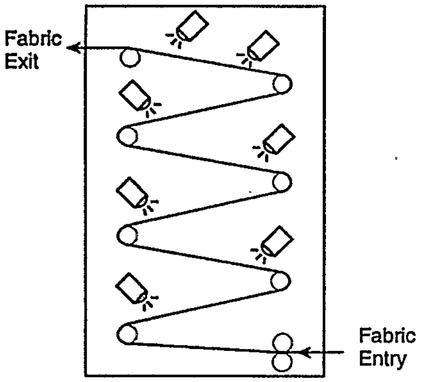
Many strategies can be applied for reusing washwater. Three of the most common strategies are countercurrent washing, reducing carryover, and reusing washwater for cleaning purposes.

Countercurrent Washing

The countercurrent washing method is relatively straightforward and inexpensive to implement in multistage washing processes. Basically, the least contami-



Vertical Configuration



Horizontal Configuration

Figure 2-4. Vertical and horizontal washer configurations (11).

nated water from the final wash is reused for the next-to-last wash and so on until the water reaches the first wash stage, after which it is discharged. This technique is useful for washing after continuous dyeing, printing, desizing, scouring, or bleaching.

An important variant of the countercurrent principle is "horizontal" or "inclined" washers, as shown in Figure 2-4 (11). Horizontal or inclined washing is more efficient because of the inherent countercurrent nature of water flow within the process. The mechanical construction of an inclined or horizontal countercurrent washer has to be much better than a traditional vertical washer, however. Sloppy roll settings, weak or undersized rolls, unevenness, bends, bows, biases, bearing play, or other misalignments within the machine are much more important in a horizontal or inclined washer because the weight of water pressing down on the fabric can cause it to sag, balloon, or stretch. If properly constructed and maintained, horizontal or inclined washers can produce high-quality fabrics with much better washing efficiency and reduced water use.

Low Carryover

Because the purpose of washing is to reduce the amount of impurities in the substrate, as much water as possible must be removed between sequential washing steps in multistage washing operations. Water (containing contaminants) that is not removed is "carried over" into the next step, contributing to washing inefficiency. Proper draining in batch drop/fill washing and proper extraction between steps in the continuous washing process are important. Often, 350 percent owg is carried over in typical drop/fill procedures (67). This amount can be reduced in some batch machines (e.g., yarn package dyeing, stock dyeing) by using compressed air or vacuum blowdown between washing steps.

In continuous washing operations, squeeze rolls or vacuum extractors typically extract water between steps. Equipment employing vacuum technology to reduce dragout and carryover of chemical solutions with cloth, stock, or yarn is used to increase washing efficiency in multistage washing operations. These devices are described in Section 3.19, "Pollution Prevention Through New Equipment."

In one case history, a processor installed vacuum slots after each wash box in an existing multistage continuous washing line and was able to reduce the number of boxes from eight to three (70). Wash boxes with built-in vacuum extractors are available for purchase, as well as washers for prints that combine successive spray and vacuum slots without any bath for the fabric to pass through. Because the fabric is never submerged, bleeding, marking off, and staining of grounds is minimized, and water use decreases (70). Another washer configuration with internal recycling capabilities is the vertical counterflow washer, which sprays recirculated water onto the fabric and uses rollers to squeeze waste through the fabric into a sump, where it is filtered and recirculated. The filter is unique, consisting of continuous loops of polyester fabric that rotate continuously and are cleaned of filtrate at one end with a spray of clean water. This construction allows for maximum removal of suspended solids from water before discharge or reuse in another process. High-efficiency washing with low water use results. Energy use decreases greatly because less water must be heated.

Reuse for Cleaning Purposes

In many types of operations, washwater can be reused for cleaning purposes. In printing, cleanup activities can be performed with used washwater, including (71):

- Backgray blanket washing
- Screen and squeegee cleaning
- Color shop cleanup
- Equipment and facility cleaning

A typical preparation department may also reuse washwater as follows (71):

- Reuse scour rinses for desizing
- Reuse mercerizer washwater for scouring

- Reuse bleach washwater for scouring
- Reuse water-jet loom washwater for desizing
- Recycle kier drains to saturator

2.2.7.4 Water Conservation

Work Practices

Workers can greatly influence water use. Sloppy chemical handling and poor housekeeping can result in excessive cleanup. Poor scheduling and mix planning also can require excessive cleanup and lead to unnecessary cleaning of equipment such as machines and mix tanks. Leaks and spills should be reported and repaired promptly. Equipment maintenance, especially maintenance of washing equipment, is essential.

Inappropriate work practices waste significant amounts of water; good procedures and training are important. When operations are controlled manually, an operations audit checklist is helpful for operator reference, training, and retraining.

In one case history, a knitting mill experienced excessive water use on beck dyeing machines (20). A study of operating practices revealed that each operator was filling the machines to a different level. Some operators filled the becks to a depth of 16 inches, others as much as 24 inches. Also, the amount of water used for washing varied. Some operators used an overflow procedure, and others used drop/fill or "half baths" (repeatedly draining half of the bath, then refilling it). Inspection of the written procedures showed that the fill step simply said "fill." The wash step simply said "wash." Without training and without a specific operating procedure, operators were left to determine water use on their own.

This case may seem extreme, but even the best mills, which have well-documented production procedures, often do not have documented cleaning procedures. Cleaning operations that contribute large amounts of pollution to the total waste stream include machine cleaning, screen and squeegee cleaning, and drum washing.

Engineering Controls

Several areas of engineering control have been discussed, but a few additional areas deserve mention.

Every mill should have moveable water meters that can be installed on individual machines to document water use and evaluate improvements. In practice, mills rarely measure water use but rely on manufacturers' claims concerning equipment and water use. The manufacturers' estimates are useful starting points for evaluating water consumption, but the actual performance of equipment depends on the chemical system used and the substrate. Therefore, water use is situation-specific and should be measured on site for accurate results. The water meters should be regularly maintained and calibrated.

Other important engineering controls, some of which have been discussed in other sections of this chapter, include:

- Flow control on washers.
- Flow control on cooling water (use minimum necessary).
- Countercurrent washing.
- High extraction to reduce dragout.
- Recycle and reuse.
- Detection and repair of leaks.
- Detection and repair of defective toilets and water coolers.

Machinery should be inspected and improved where possible to facilitate cleaning and to reduce susceptibility to fouling. Bath ratios sometimes can be reduced by using displacers that result in lower chemical requirements for pH control as well as lower water use. An example is shown in Figure 2-5.

Process Changes

Several process changes are worth mentioning in terms of water conservation. These changes are briefly noted here and covered in more detail in Sections 4.10, "Dyeing," and 4.9, "Preparation":

- Pad-batch dyeing

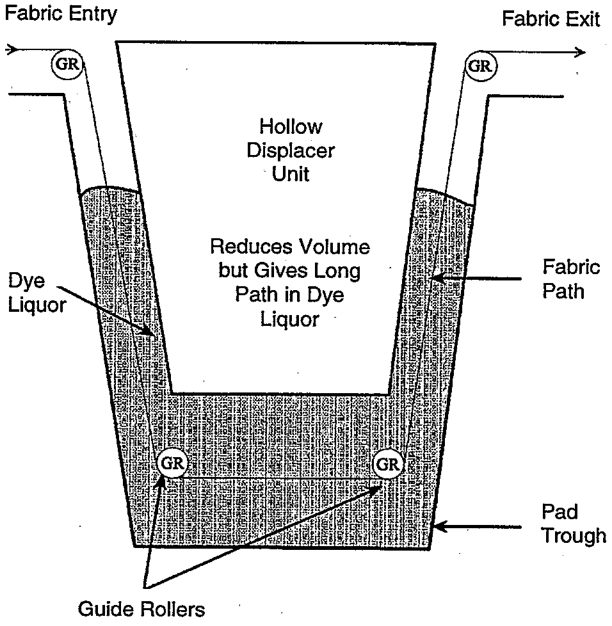


Figure 2-5. Pad with displacer.

- Processing bath reuse
- Water recycle in preparation

Pad-Batch Dyeing. Three major problems that face cotton dyers are water-use reduction and elimination of color and salt from dye wastewater. Fiber reactive dyes for cotton require large amounts of water for application and washoff (8).

One pollution prevention method for the application of reactive dyes is the pad-batch method. Pad-batch dyeing solves these problems without affecting the properties of fiber reactive dyes. In addition, it improves productivity and energy savings (65).

Pad-batch dyeing has been used successfully worldwide and now is being adopted in the United States (11). It is a reliable, easy-to-control method that is known for its reliable laboratory-to-production correlation on first-run dyeings.

In pad-batch dyeing, prepared fabric is padded with a solution of fiber reactive dyestuff and alkali, then stored (or batched) on rolls or in boxes and covered with plastic film to prevent evaporation of water or absorption of carbon dioxide from the air. The fabric then is batched for 2 to 12 hours. Washing can be done on whatever equipment is available in the mill.

Pad-batch dyeing offers several significant advantages, primarily cost and waste reduction, simplicity, and speed. Production of between 75 and 150 yards per minute, depending on the construction and weight of the goods involved, is common. Also, pad-batch dyeing is flexible compared with a continuous range. Either wovens or knits can be dyed in many constructions. Frequent changes of shade present no problems because reactives remain water soluble, making cleanup easy. This method of dyeing is useful when versatility is required. Water use typically decreases from 17 gallons per pound to 1.5 gallons per pound, a reduction of more than 90 percent (65). A full description of pad-batch dyeing can be found in Section 4.10, "Dyeing."

Processing Bath Reuse. Water from many processes can be renovated for reuse by a variety of methods. Several research efforts are underway. In a few operations, up to 30 percent of the treated wastewater is recycled directly back from the effluent to the raw-water intake system with no adverse effects on production. In some cases, specific types of wastewater can be recycled within a process or department. Examples are dyebath reuse, bleach bath reuse, final rinse reuse as loading bath for next lot, washwater, countercurrent washing, and reuse for other purposes.

Several treatment strategies also are available to clean up or renovate water for reuse. Often, no treatment is needed, or a simple conventional filter step is used. The most studied methods of renovation are:

- Chlorination (72)
- Ozonation (73)
- Ultrafiltration (74)

These techniques are depicted in Figures 2-6, 2-7, and 2-8, respectively. Laboratory studies have thoroughly validated the technical and economic feasibility of each technique, but surprisingly few commercial operations have adopted these practices in the United States.

Chlorination decolorizes water by saturating it with chlorine gas in a holding tank, making it useful for dyebaths (72). The dyes, if selected properly, are destroyed without affecting other components of the bath (e.g., buffers, carriers, leveling agents, salt, dispersing agents). Of course, the waste generated and the chemicals (with associated BOD) and energy used are reduced in this

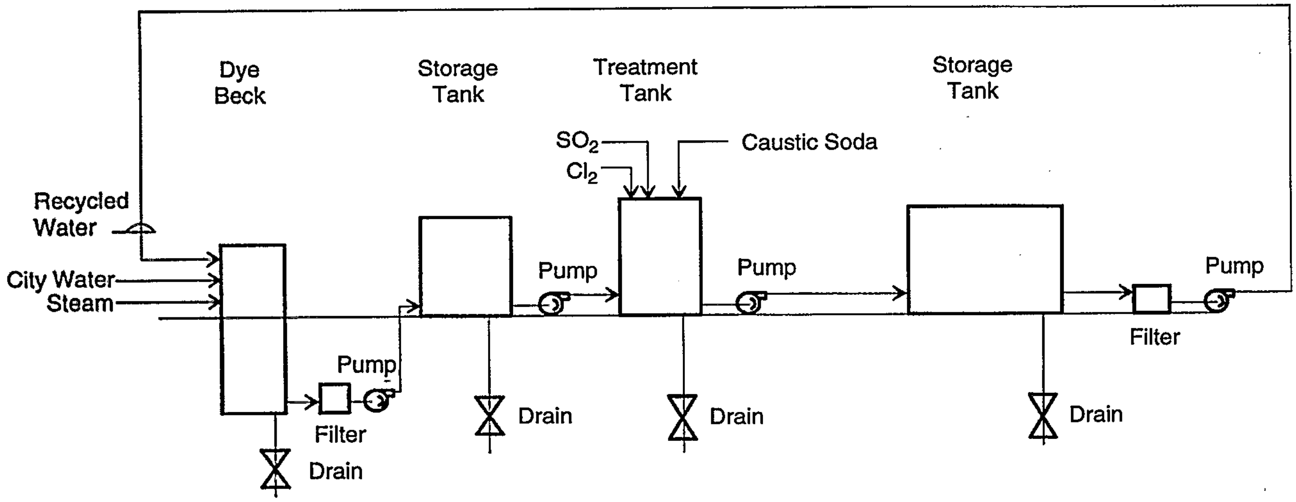


Figure 2-6. Flow diagram for chlorination water treatment system (69).

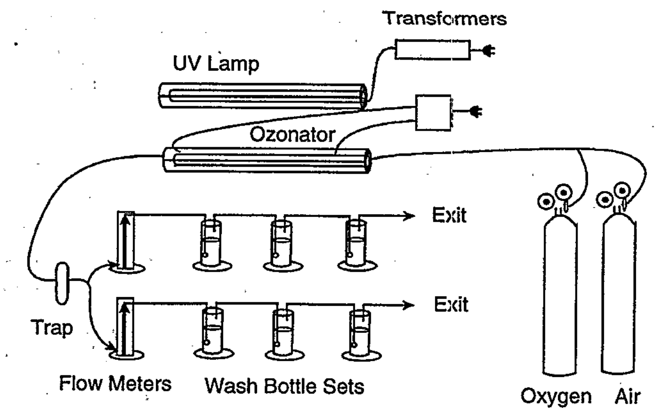


Figure 2-7. Ozone generation equipment (70).

system. One commercial operation recycles 75 percent of the dye wastewater (72). A drawback to chlorination is that it produces chloro-organics in the treated water.

Ozonation has been widely studied and, like chlorination, has been proven in repeated laboratory trials (73). The process, however, has not been widely adopted in commerce. In this method, a generator (shown in Figure 2-7) is used to produce ozone or pure singlet oxygen (73). Laboratory studies indicate that ozone is more effective than singlet oxygen, and recent studies have focused primarily on ozone (73).

Examples of the *decolorization ability of ozone for CI* Disperse Yellow 42, CI Basic Yellow 11, and CI Acid Red 151 are shown in Figures 2-9 and 2-10. Depletion of desirable dyebath auxiliaries is shown in Figure 2-11 (73). Ozonation has been used for multicycle repeat dyeings in laboratory settings with success and has been evaluated commercially.

Ultrafiltration has been more widely adopted than the above reactive chemical treatments. Some advantages of ultrafiltration are:

- No undesirable reaction products
- Simpler, safer operation
- Safety
- Effectiveness
- Separate recovery of chemicals and water

Ultrafiltration is essentially the same technology as that used for caustic and size recovery. Figures 2-8 and 2-12 show the basics of the ultrafiltration recovery scheme (74). Membranes are tailored to the required pore size for removal of the species of interest (see Figure 2-13) (74). Ultrafiltration can produce 95-percent water recovery in commercial practice (74). These systems have been widely adopted in commerce and have proven invaluable. Payback for dyebath recovery is estimated

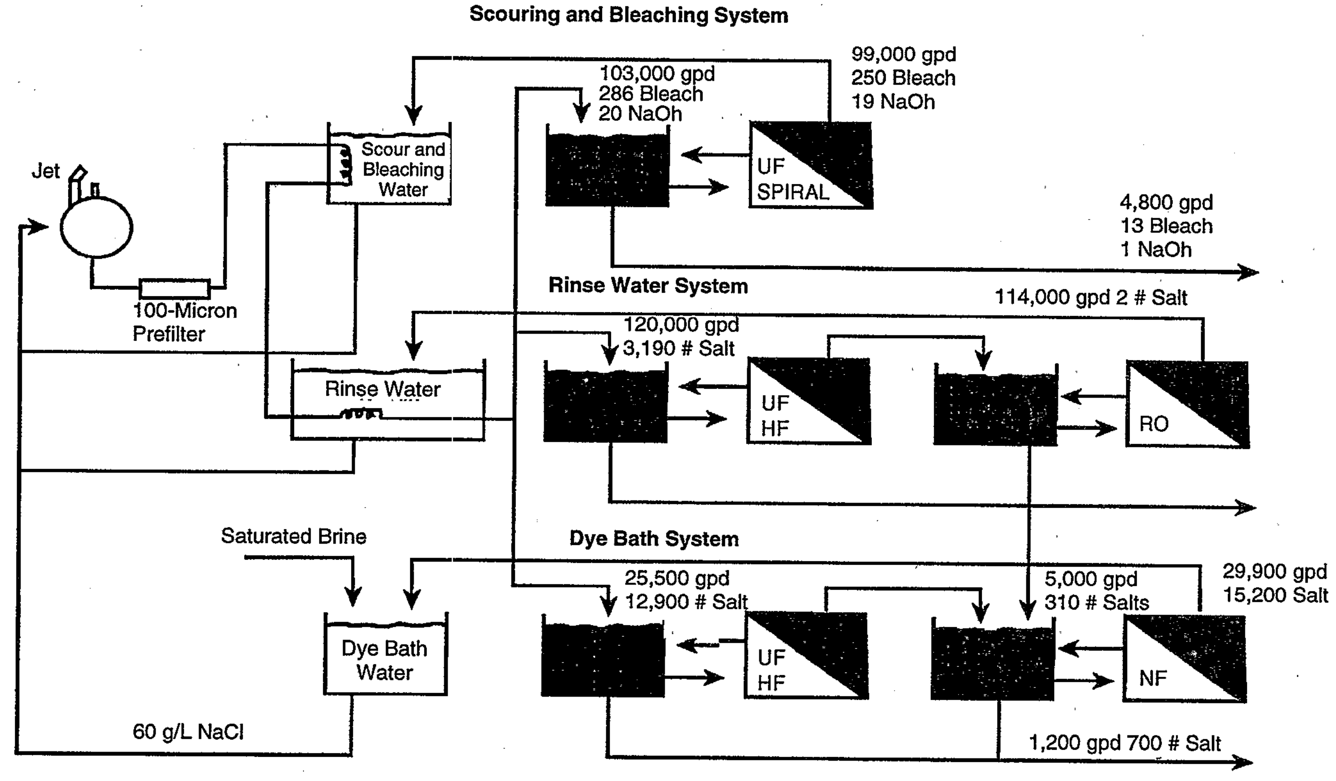


Figure 2-8. Recycle of jet dyeing machine flows using ultrafiltration (71).

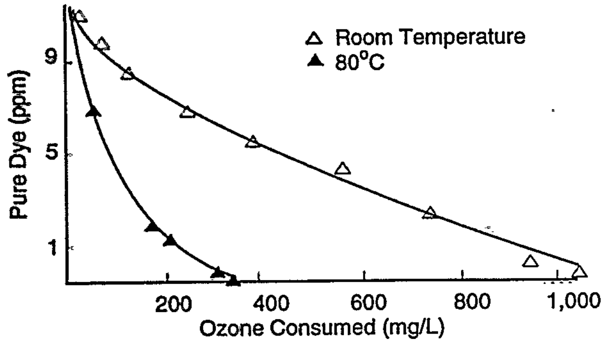


Figure 2-9. Ozone decolorization of Disperse Yellow 42 (70).

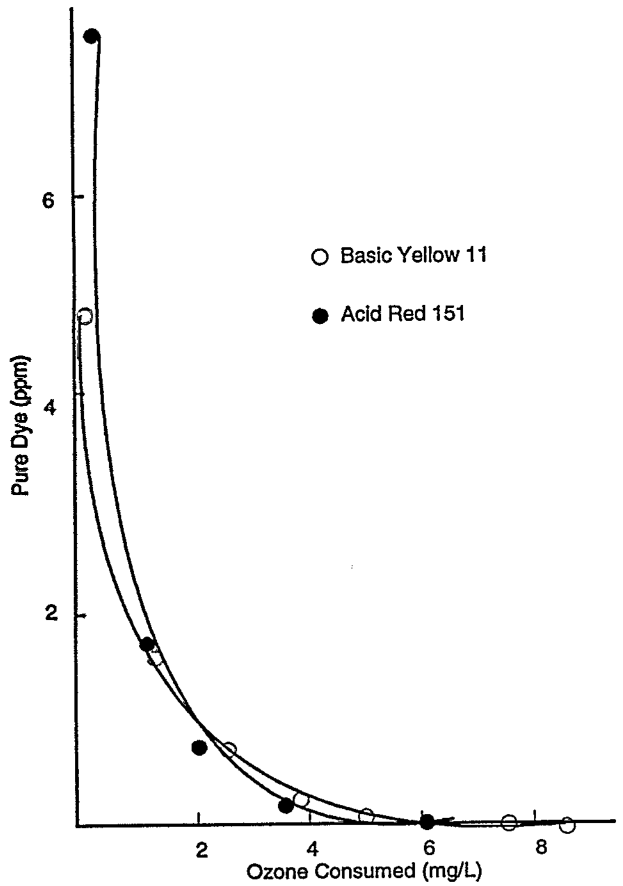


Figure 2-10. Dye decolorization by ozone (70).

to be 1.5 years, and shade reproducibility is better than the reactive methods listed above (74).

Dyebath Reuse

In the 1960s, about 10 to 16 percent of textile wastewater was reclaimed or recycled (14). Recent improvements, including dyebath reuse, have dramatically increased the potential for reuse, with corresponding

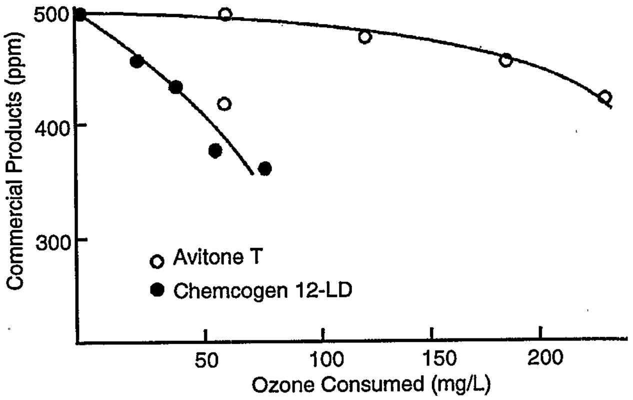


Figure 2-11. Ozone oxidation of auxiliaries (70).

cost savings and waste reduction. No current study of water reuse in textile mills has been published. Dyebath reuse, one pollution prevention method for water conservation, has been shown to reduce flow, BOD, and COD loadings by up to 33 percent (14). Dyebath reuse also shows a return on investment in the form of dye, chemical, and energy savings that pretreatment does not. Savings, installation costs, and operating expenses are site-specific, but a typical payback period is 13 to 20 months (14). This is discussed in detail in Section 4.10.6.5.

Bleach Bath Reuse

Cotton and cotton blend preparation (e.g., desizing, scouring, bleaching) are performed using continuous or batch processes and usually are the largest water consumers in a mill. Continuous processes are much easier to adapt to wastewater recycle/reuse because the waste stream is continuous, shows fairly constant characteristics, and usually is easy to segregate from other waste streams.

Waste-stream reuse in a typical bleach unit for polyester/cotton and 100-percent cotton fabrics would include:

- Recycling J-box and kier drain wastewater to saturators.
- Using countercurrent washing.
- Recycling continuous scour washwater to batch scouring.
- Recycling washerwater to backgray blanket washing.
- Recycling washerwater to screen and squeegee cleaning.
- Recycling washerwater to color shop cleanup.
- Recycling washerwater to equipment and facility cleaning.
- Reusing scour rinses for desizing.
- Reusing mercerizer washwater for scouring.

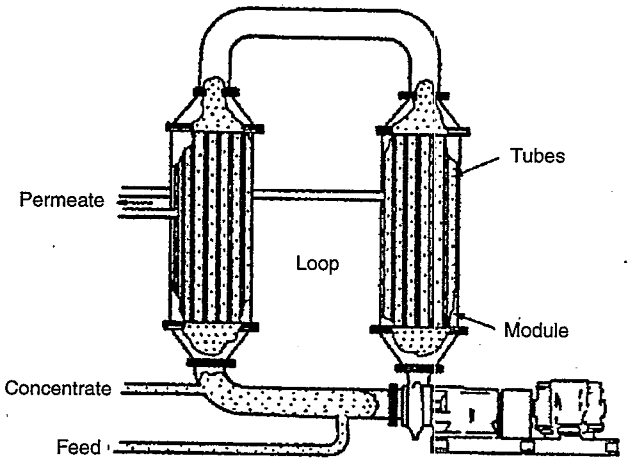


Figure 2-12. Typical membrane configuration for ultrafiltration (72).

- Reusing bleach washwater for scouring.
- Reusing water jet loom washwater for desizing.
- Recycling kier drains to saturators.

Preparation chemicals (including optical brighteners and tints), however, must be selected in such a way that reuse does not create quality problems such as spotting.

Batch scouring and bleaching are less easy to adapt to recycling of waste streams because streams occur intermittently, drains generally go into pits and are not easily segregated, and batch preparation steps frequently are combined. With appropriate holding tanks, however, bleach bath reuse can be practiced in a similar manner to dyebath reuse, and several pieces of equipment are now available that have the necessary holding tanks (67). The spent bleach bath contains all of the alkali and heat necessary for the next bleaching operation (67). Peroxide and chelates must be added to reconstitute the bath. Like dyebath reuse, the number of reuse cycles in bleach bath reuse is limited by impurity buildup. The main impurities are metals, such as iron, that can interfere with the bleaching reaction.

Continuous Knit Bleaching

New types of rope bleaching units for knits featuring 6- to 12-stage jet transport systems have made continuous bleaching of most knit styles possible (70). These units were introduced in the late 1970s and typically produce 40 pounds per minute of knit fabric or more than 1 million pounds per month based on a three-shift, 6-day operation. These machines have become very popular with large knit processors because of their flexibility and ability to conserve energy, water, and chemicals. They also have complete countercurrent capabilities built in. These units are being promoted for use in afterwashing fiber reactive and other types of dyes (e.g., after pad-batch dyeing) in addition to use as continuous knit preparation ranges. This is discussed further in Section 3.19, "Pollution Prevention Through New Equipment."

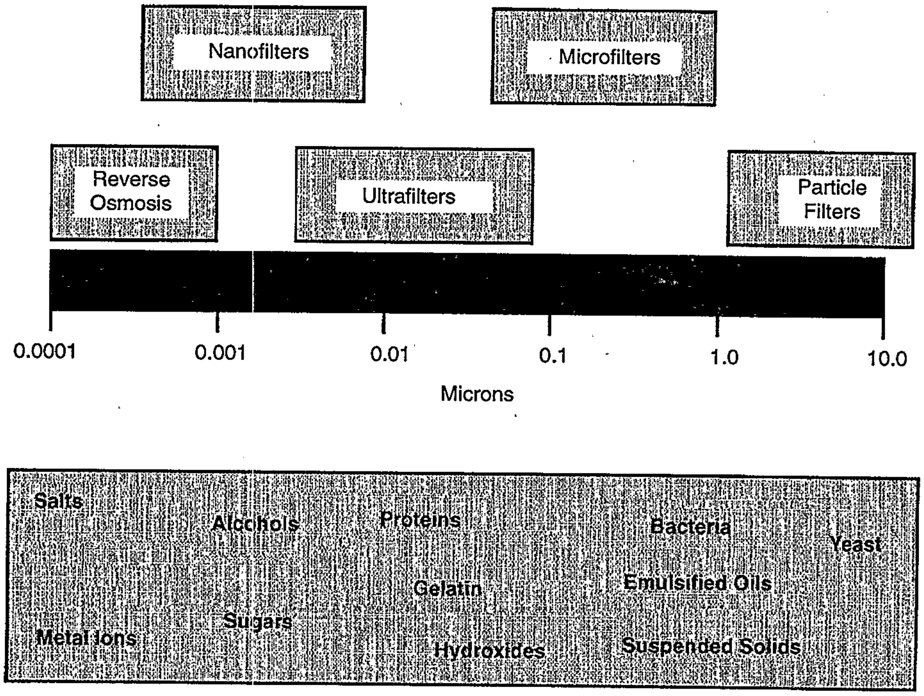


Figure 2-13. Tangential flofiltration (71).

Final Rinse Reuse as Loading Bath for Next Lot

One simple technique that saves water and, in some cases, BOD loading is to reuse the final bath from one dyeing cycle to load the next lot. This technique works well in situations where the same shade is being repeated or where the dyeing machine is fairly clean.

A good example of this technique is acid dyeing of nylon hosiery. The final bath usually contains an emulsified softener that exhausts onto the substrate, leaving the emulsifier in the bath. This technique can serve as the wetting agent for loading the next batch, thus saving the water, heat and wetting agent, and associated BOD.

2.2.7.5 Waterless Alternatives

Several waterless processing methods deserve comment. The most widely practiced method is mechanical finishing, which is described in Section 4.12, "Finishing."

In the area of preparation and dyeing, waterless processes are based on supercritical carbon dioxide fluid (SCF) technology. These processes use no water, and drying is simply a matter of letting the carbon dioxide flash off, which happens immediately upon releasing the supercritical pressure. One advantage of these systems is that commercially available disperse dyes for polyester can be used, so no special colorants have to be developed. Waterless processes are being used only in laboratories and pilot plants at this time, but they deserve attention.

Waterless mercerization can be accomplished by the use of liquid ammonia, which is recovered and reused. Liquid ammonia mercerization is effective and practiced on a wide scale commercially. One promising area of research at this time is the use of ammonium thiocyanate in the ammonia bath to elevate the boiling point of the liquid ammonia to room temperature, reducing the need for expensive cooling systems to run the liquid ammonia mercerization process.

Another laboratory development is the use of powder colorants and xerographic printing techniques for waterless textile coloration processes.

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Chapter 3
General Pollution Prevention Approaches Applicable Throughout the Textile Industry

In companies with superior environmental management programs, pollution prevention is a daily activity that applies to all business functions. This chapter describes general principles and approaches to pollution prevention that are applicable to all types of textile operations, regardless of the processes they use or the products they produce.

3.1 Building Blocks of an Effective Pollution Prevention Program

3.1.1 Management Commitment

A prerequisite to a successful pollution prevention program is firm commitment at the management level. Companies should develop and adopt a comprehensive policy that definitively states their commitment to pollution prevention principles. The policy should include 1) a general management statement emphasizing the importance of pollution prevention and the company's commitment to pollution prevention principles, 2) defined goals or targets for pollution prevention, 3) allocation of organizational and technical resources to pollution prevention, and 4) a method for tracking pollution prevention performance (1).

3.1.2 Employee Commitment

A well-planned pollution prevention program is built upon a framework of employee involvement and commitment. Experience has shown that employees are extremely knowledgeable about sources of waste and pollution in their facility and are an excellent source of ideas for reducing waste and preventing pollution. Thus, management must foster employee awareness in order for a pollution prevention program to be successful. Chapter 5 provides some concrete guidance on how to get employees involved in the pollution prevention initiative.

3.1.3 Low-Technology Approaches

A surprising number of successful pollution prevention ideas are based on simple, low-technology principles. Adopting these approaches can help facilities avoid expensive waste treatment, disposal, and liability costs. In the United States, approximately $75 billion is spent annually for waste treatment. This figure is expected to rise by 33 percent to $100 billion in the future because of new air pollution regulations (2). Pollution prevention can produce outstanding results for a fraction of this cost, often with a rapid return on investment.

Initial pollution prevention efforts in a textile operation should focus on low-technology approaches, which have the highest return on investment and encourage further progress. Figure 3-1 shows that the "worst" mills, which do not practice even common pollution prevention techniques, can have the greatest decrease in pollution with the least expenditure simply by applying known, proven technologies, such as those listed in Table 3-1 (3).

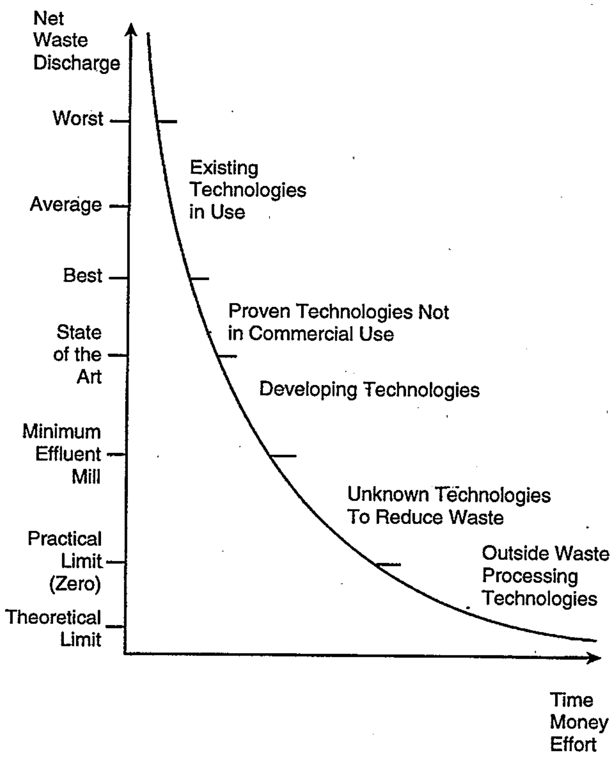

Figure 3-1. Waste reduction achievements as a function of pollution prevention efforts over time.

Table 3-1. Known Pollution Source Reduction Strategies That Are Widely Used in Textiles

- Design stage planning for processes
- Equipment maintenance and operations audit
- High extraction, low carryover process step separations
- Incoming raw material quality control
- Maintenance, cleaning, and nonprocess chemical control
- Material utilization in cutting and sewing
- Optimized chemical handling practices
- Raw material prescreening before use
- Segregation, capture, recycle, and reuse of wastes
- Training
- Development of a conservationist worker attitude

Figure 3-1 illustrates the concept of receiving the most return for the least time, effort, and money by using technology transfer to carry out known pollution prevention practices (3). Many large companies employ an environmental staff person to coordinate pollution prevention activities. This person serves as the expert facilitator for technology transfer of pollution prevention between operations and processes (2). The coordinator at each site can review information from other sites and identify pollution prevention opportunities, a critical part of general pollution prevention efforts (1).

Eventually, as a mill's pollution prevention program becomes more sophisticated, and the mill has adopted all appropriate, existing, and proven technologies, it must seek out new technologies. The easiest technologies to implement are those proven in other industries. For example, Section 3.18, "Improved Process Control," describes a research area that involves the adoption of known aerospace techniques (real-time, adaptive, multichannel control using fuzzy logic or neural networks). by the textile industry. Technologies that have been successful in other industries, however, may be more expensive to adopt than same-industry technologies and have a lower probability of success, resulting in a lower return on investment and a flatter slope on the cost/benefit curve (see Figure 3-1) (3).

Even more expensive and of less immediate benefit is investment in the development of new technologies and new science. Many companies inappropriately bypass the implementation of known technologies and immediately investigate new technologies and new science. This type of investigation is appropriate only after completing pollution prevention activities with known technologies, orderly work practices, optimization of processes, and training (3). Future improvements will use known but unused technologies (e.g., technology transfer from other industries), new technologies based on known science, and perhaps even the developments of new science (see Table 3-2 for examples of these technologies).

3.1.4 High-Technology Approaches

The discussion of low-technology approaches above does not imply that high-technology approaches are inappropriate. Once a mill has a good framework for pollution prevention, high-technology innovations are a far more effective long-term approach than "process tweaking." Orderly work practices pay big dividends in the short-term, but new technology is important for long-term success. Radical redesign of processes, including changes in raw material selection, is an essential component of a long-term pollution prevention program (1).

3.1.5 Long-Term Commitment

Persistence is important, and a sustained effort at pollution prevention must be made over a long period to see complete results. The pollution prevention plan should begin with commitment and training, and continue through the pollution prevention techniques described below, from low-technology to high-technology approaches, then to new technology development. Mills usually can achieve significant results without major capital expenditure, while simultaneously reducing costs and increasing profit (4).

3.1.6 Documenting Accomplishments

Textile facilities should set internal goals and document their progress. For example, the chemical industry (suppliers of textile chemicals) reports it has achieved a 50-percent reduction in hazardous waste and a 20-percent reduction in wastewater by applying the pollution prevention techniques listed in Table 3-3. These findings were based on a survey of 681 factories (1). By docu-

Table 3-2. Future Pollution Prevention Innovations for the Textile Industry

- Better risk assessment, methods, data, and procedures
- Better-informed customers, designers, managers, and suppliers
- Disposal facilities for captured waste
- Optimized chemical handling practices
- Higher purity raw materials
- Improved waste audit procedures
- Improved standard test methods and definitions
- Less disinformation and politics
- More global, integrated view of manufacturing
- More technology transfer
- More recycling opportunities
- More markets for waste
- More chemical expertise and general industry competence

Table 3-3. Pollution Prevention Techniques in the Chemical Industry

- Process change
- Modified operating procedures
- Advanced process control
- Substituted chemicals
- Higher quality materials
- Recycling of wastes
- Direct reuse in the process
- Direct reuse in another process
- Regenerations for reuse
- Sale of by-products
- Improved waste treatment
- Waste filtration
- Waste decantation and separation
- Administrative controls
- Minimization of washdown
- Reduced cleaning frequency
- Longer turnaround time
- Improved spill control
- Segregation of hazardous and nonhazardous waste
- Discontinuing manufacture

menting and publishing their success, they provide further stimulus to other facilities to investigate pollution prevention.

3.1.7 *Right-First-Time Production*

One very important principle in textiles is right-first-time production, which reduces waste by avoiding chemically intensive adds and reworks (4). Right-first-time production is not discussed as a pollution prevention technique, but a large body of literature and experience exists on improving right-first-time production (5). The amount of off-quality production runs and reworks in mills varies greatly, and the better mills have a greater cost and pollution prevention advantage over the others (5).

3.2 Design-Stage Planning for Facilities, Processes, and Products

The planning stage for new processes, products, and facilities is essential because it offers the opportunity to design in pollution prevention. Ultimately, pollution prevention must become integral to all parts of the textile operation (i.e., all products, processes, and aspects of facility operations, including suppliers and customers). The main points to understand regarding design-stage planning are:

- Product, process, and facility technical design criteria that can reduce pollution exist and are well known (see Chapter 4).
- For pollution prevention to be successful, the designer, manufacturer, and customer must be involved and work together.
- Pollution prevention through design is facilitated by technical knowledge; effective communication between the designer, manufacturer, and customer; establishment of priorities and pollution prevention goals; and a willingness to try new ideas.

3.2.1 *Design-Stage Planning for Processes*

Design-stage planning for processes focuses on arranging production activities in such a way as to avoid the generation of pollution and waste (4). Although pollution prevention can produce substantial gains through tweaking or optimizing existing processes, effective, long-term pollution prevention requires an examination of processes at the fundamental design level to improve quality and reduce costs and waste (6). Berglund presents an interesting way of thinking about design-stage planning in Table 3-4 and Figure 3-2 (7).

This section focuses on machinery selection and chemical selection as two ways of altering processes at the design stage to reduce pollution.

Table 3-4. Suitability of Waste Management Options Checklist (7)

Technical

- Is technology available and usable without modification?
- What major equipment modifications are needed?
- Are major waste modification or pretreatment needed?

Environmental

- How will waste be reduced in volume or hazard?
- Will secondary releases, now or in the future, result in new air, water, or solid waste pollution problems?
- Could the technology result in new worker safety problems?

Regulatory

- Will the technology result in wastes of less regulatory concern?
- Can permits realistically be obtained in a reasonable timeframe for the technology?
- Will additional regulations be imposed that could result in additional air, water, and solid waste controls?

Public Acceptance

- Will the use of technology to reduce the waste at the proposed location be acceptable to the citizens (or political groups) affected by the operation?

Economic

- What is the cost compared with other technologies?

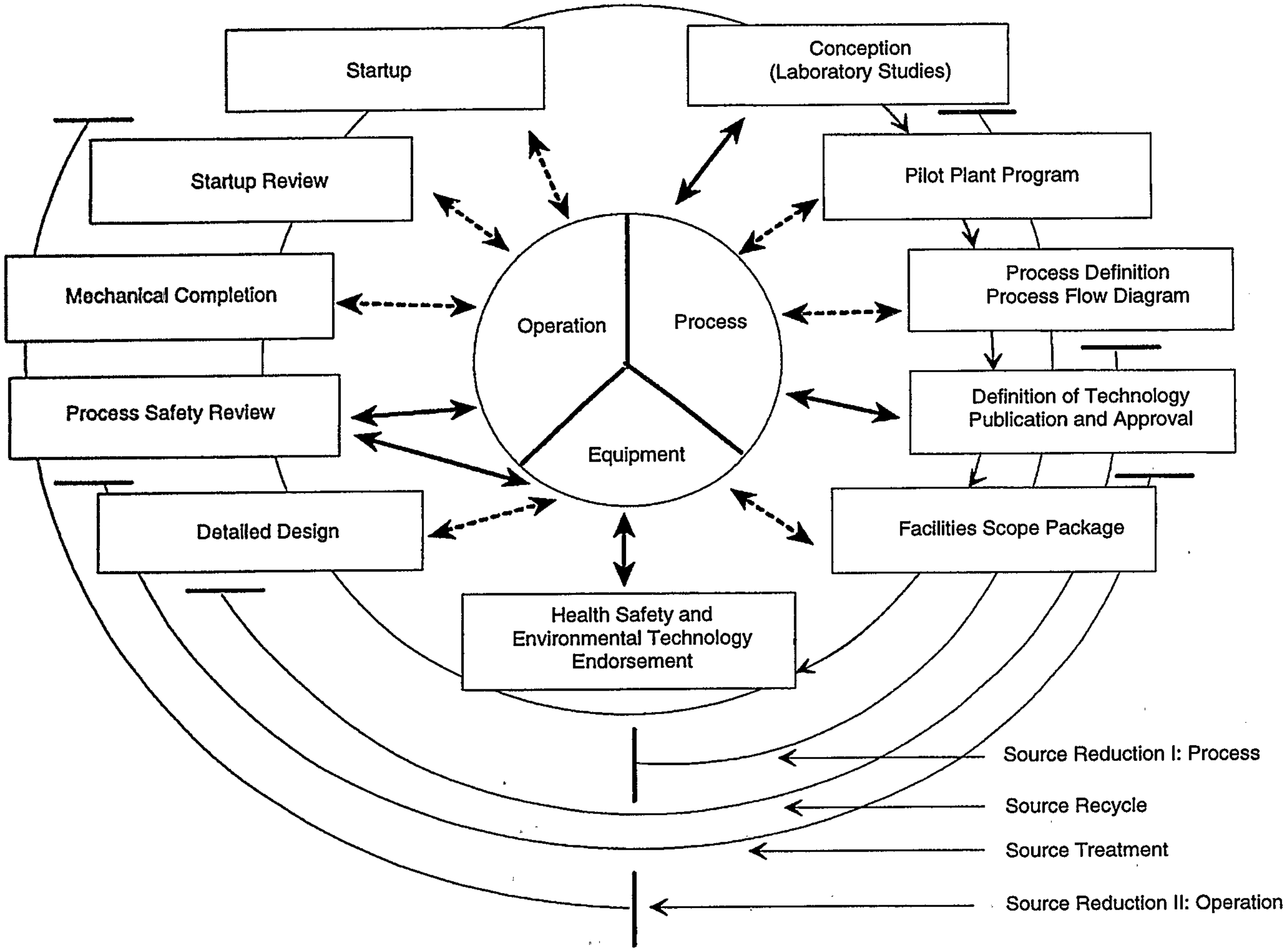

Figure 3-2. Waste reduction and new technology development (7).

3.2.1.1 Machinery Selection

A substantial part of the current design effort in textile machinery focuses on reducing water consumption and preventing pollution (8). To stay abreast of these developments, process managers must constantly stay informed about new types of machinery. Currently available machinery that has proven to be effective in reducing pollution and water consumption includes (8):

- Ultra-low-bath ratio dyeing machines.
- Continuous dyeing ranges for continuous knits.
- Automatic dispensing systems for dyes and chemicals.
- Continuous preparation ranges.
- Very high-extraction systems, including centrifugal, vacuum, and Mach nozzles.
- Improved control systems.

These types of systems will be adopted more and more as the costs of water, effluent treatment, and waste disposal rise. Within a few years, most current machinery will be outdated and subsequently replaced by new, emerging technology. State-of-the-art machinery is always changing, and textile processors must stay current.

3.2.1.2 Chemical Selection

Most textile processes use an array of chemicals to accomplish or facilitate specific tasks. Often, textile manufacturers rely on the advice of chemical vendors when choosing which chemicals to use. Although vendors can be an excellent source of information concerning the use of chemicals, all textile operations should have sufficient internal chemical expertise to enable them to assess the need for chemicals independently and to evaluate and select chemicals for use in the mill only after consideration has been given to nonchemical alternatives. Several related ideas are discussed in detail in Sections 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities."

Considerable progress can be made toward eliminating some chemicals (and the associated costs and pollution) if a processing manager understands how to control processes mechanically, rather than relying on chemicals to compensate for mechanical inadequacies. An example using knit design is discussed in detail in Section 3.2.2.2. Table 3-5 offers several additional examples of mechanical alternatives.

These examples illustrate the kind of substitution for chemical processing that should be considered in textile manufacturing operations. When problems arise in a process, the first response should be to go back to the basics of the process, not add a chemical to remedy the situation. Finishing is a particularly important area in which mechanical effects can often be substituted for chemical agents. Many examples of mechanical substitutions are discussed in the following sections and in Section 4.12, "Finishing."

Table 3-5. Examples of Mechanical Processes That Substitute for Chemical Processing Assistants

Chemical Processing Assistant	Mechanical Substitute
Dyebath lubricants	Adjust machine speed, plaiter action (jet), and reel speed (beck)
Specialty leveler	Control dye exhaustion by controlling dye, salt, chemical addition, and rate of heating
Defoamer	Remove high-foaming chemicals from process recipes
Soil release agent for cotton fabric	Cotton is naturally soil-releasing, so the best strategy is to find out which finishing chemical additive is causing soil retention, then eliminate it from the finish recipe
Solvent scour to remove knitting oil from cotton knits	Arrange knitting processes so the oil does not get on the cloth, and use self-emulsifying oil

3.2.2 Design-Stage Planning for Products

Many consumers now expect and seek out environmentally well-designed products. To be competitive in today's market, textile manufacturers need to adopt a new attitude in which they consider product properties required by the customer, including environmental aspects, at the design and raw material selection stage (9). For example, fiber, yarn, and fabric waste must be eliminated or preplanned to facilitate recycling (10). Shades and colors should be selected that use the most environmentally benign dyes. Textile manufacturers wishing to improve their environmental performance need to remember that textile products are not permanent, and ultimately, every textile product becomes waste.

One significant driving force toward improved pollution prevention in product design is the potential economic benefit. For example, Morris (2) cites a typical case in which solvent concentrations of 300 parts per million (ppm) to 350 ppm were found in wastewater from a fabric-coating operation. Implementation of a pollution prevention program focusing on product design changes reduced solvent concentrations to well below 100 ppm (2). This reduction in pollution can result in significant cost savings to the textile manufacturer.

An overview of integrated customer/manufacturer pollution prevention activity at the global design stage is presented in Figure 3-3 for a printing facility. In this model, the customer is involved at important points in the development of the manufacturing process (11). Although this example applies only for print pattern development, expanded schemes of this type could help the customer to understand, for example, when a particular color will require a metal-bearing dye. In this way, alternatives such as other shades or other substrates can be developed at the design stage (see also Section 4.17, "Globalization of Pollution Prevention").

3.2.2.1 Identifying and Communicating Problem Areas

Effectively communicating information about pollution problems is very beneficial in helping mills achieve gains in pollution prevention. One example of a problem that can be addressed partly through improved communication is the presence of metals in dyeing wastewater. While the dyers generally know that a dye contains metal, they usually cannot remedy the situation because customer requirements dictate the use of such dyes, and dyers are not in direct contact with customers. On the other hand, personnel responsible for sales, scheduling, and other customer-related activities generally are not aware of the environmental issues surrounding customer selections and do not know how to address such issues with the customer.

Mill personnel with responsibilities such as design, sales, and scheduling should receive training on problem dyes and be instructed on how to recommend less polluting alternatives. Simply asking customers if they are interested in using environmentally preferable techniques and materials for their products may be sufficient. Mills rarely do this, although it could potentially lead to substantial improvements (see Section 4.17, "Globalization of Pollution Prevention").

Personnel should also identify problem fabric structures and blends for the customer. In particular, mills should target products with poor right-first-time performance as

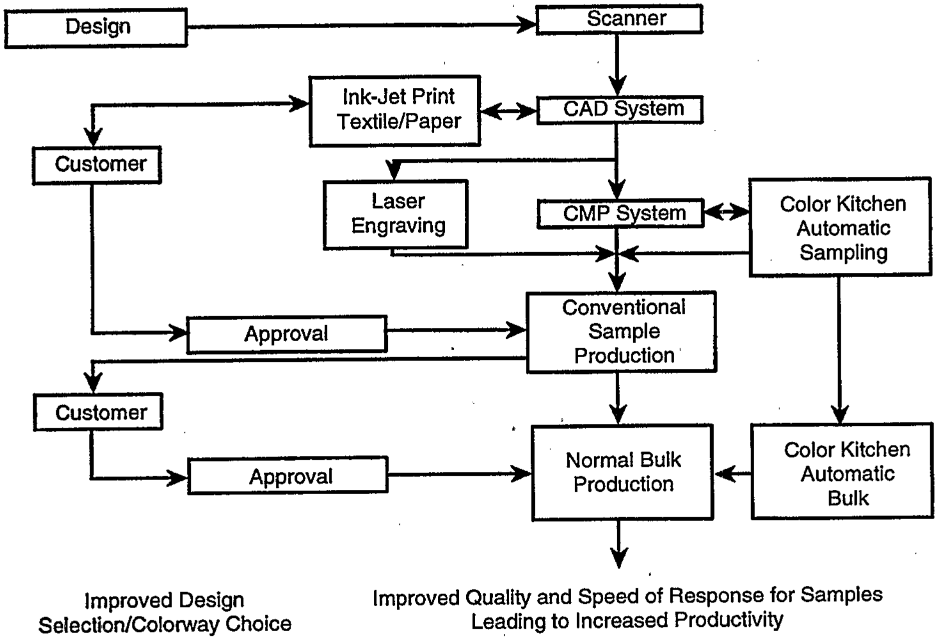

Figure 3-3. Computerization of the preprint process (11).

part of their pollution prevention efforts. A major factor contributing to pollution problems in the industry today is the tendency toward short runs, small lots, and just-in-time (JIT) production. These trends necessitate greater use of batch processing, which is generally more polluting than continuous processing. Also, JIT production requires more frequent changeovers of machines from one style or color to another to meet changing delivery schedules. Every changeover has the potential to create additional waste from startups, stopoffs, and changeovers. Scheduling becomes less flexible, lot sizes vary, and machines are often underloaded. Information about the additional pollution and cost impacts of short-run production must be made available to those people making product design and production decisions.

3.2.2.2 Knit Design

Mills must provide knit fabrics to the customer at a specified shrinkage, width, and yield. In addition, other properties such as torque, stretch, recovery, and strength must be within reasonable limits. Unlike woven fabrics, knits exhibit stretch properties that allow the fabric to be pulled into nonequilibrium conditions. One common practice among knit processors is to force a knit to desired (nonequilibrium) customer width and yield specifications and then stabilize the knit using resins, heatsetting, and/or other techniques. This practice occurs for several reasons (some more valid than others), including:

- Oversold capacity on some machine groups forces the knitter to knit fabric on the "wrong" machine.
- Scheduling expediency and delivery pressures cause fabric to be knit on the "wrong" machine.
- Designers, schedulers, knitters, and finishers misunderstand knit structures.
- Designers, knitters, finishers, and customers do not communicate effectively.
- Poor handling causes stretch and makes knitted fabric lose its equilibrium shape.
- The wrong count yarn is used. Correct yarn may not be available, or it may be too expensive to set up an inventory of many different yarn sizes to get just the right yarn for each style of knit fabric.
- The knitting machine setup is incorrect.

Formaldehyde-containing resins often are applied to cotton and cotton/blend knits for shrinkage control and sewability (12). Mills can, however, stabilize knits without using chemical additives if the customer specifications match equilibrium configuration of the knit fabric in terms of width, yield (weight), and shrinkage, and the manufacturing process allows for complete relaxation (9, 12). A key to relaxed fabric is to keep the processing as tensionless and consistent as possible after the knit has been properly constructed. Commercial knit finishing equipment (e.g., compacting, relaxed drying) is available that adequately controls width and length dimensions of the fabric during processing, allowing the knit to fully relax (see also Section 4.12, "Finishing") (12).

Computer-aided (technical) design (CAD) of knit fabrics can help to ensure the correct weight (yield) and shrinkage of knit goods, eliminating the need for chemical finishing (9). Furthermore, CAD systems allow the designer to make the correct yarn selection and determine proper tensions, stitch length, machine cut, diameter, and other knitting parameters for producing knit constructions to customer specifications (12). Selection of the proper yarn and knitting parameters, followed by tensionless handling of the fabric, ensures that the fabric ultimately achieves a relaxed equilibrium configuration. If the relaxed configuration meets customer specifications, then the need for chemical finishes is eliminated (9). In this respect, many mills use CAD knitting systems.

Implementation of improvements in knitting programs requires the cooperation of other departments because scheduling may sometimes limit the knitter's ability to match styles to the appropriate machine, thereby undermining pollution prevention efforts. This is especially true where production needs exceed the capacity of the available machine (or machine group). The alternatives usually are either to delay delivery or to knit on another machine, which means an associated need for chemical resins (with formaldehyde) to stabilize the fabric at the customer's specifications (9).

Design programs that can facilitate proper machine setup are explained in detail in the literature (9, 12).

3.2.3 Design-Stage Planning for Facilities

In many cases, facility design factors are based on well-known, sound engineering practices. Some of the more common design factors can be very helpful when designing new mills or expanding existing mills. In other cases, optimizing facilities for pollution prevention might require a departure from existing facility design practice.

Existing facilities most often exhibit design inadequacies that contribute to pollution in the following areas:

- Bulk chemical tank farms
- Parking lot and roof drains
- Warehouse, shipping, and receiving areas
- Production areas
- Chemical mix areas

3.2.3.1 Bulk Chemical Tank Farms

The design and configuration of bulk chemical tank farms requires special consideration. From a pollution prevention standpoint, the most important aspects of tanks are 1) the arrangement of tanks and their location, 2) control systems for spills, and 3) weed control. Tanks should be placed in gravel or concrete paved areas, away from natural drainage paths to waterways (such as parking lot drains). Incompatible chemical types should be located in separate tanks and areas. Contents must be clearly marked; many accidents and even tragedies have occurred as a result of incompatible ingredients being pumped into a poorly labeled tank. Safety showers and eyewashes should be installed nearby. Tanks should be diked, and drainage of stormwater from inside of the dike or berm should be sent to an appropriate waste treatment system. Ample space should be available for maneuvering tanker trucks. Locations for such equipment as check valves, pumps, and sight glasses should be planned carefully, and the equipment should be maintained regularly.

3.2.3.2 Parking Lot and Roof Drains

Parking lot and roof drains should be kept separate from sanitary sewer, process water, cooling water, and other wastewater handling systems. Flows from these drains should be discharged and monitored separately from all other wastewater. Furthermore, no drainage from any ditch should be permitted to flow onto the plant property. Ditches that originate elsewhere should be closed off or rerouted around the facility; otherwise, the plant might assume liability for a problem that began outside the facility (e.g., a roadside). All water drainage connections should be properly documented with up-to-date plumbing diagrams.

3.2.3.3 Warehouses, Shipping, and Receiving Areas

Warehouses and shipping and receiving areas should be designed with ample space to store materials out of the way of forklifts and other traffic. Incompatible chemicals should be stored in separated areas. Chemicals, yarn, and other raw materials should be stored in metal racks to avoid stacking containers directly on top of each other. In this way, broken bags, damaged drums, and the spillage associated with them can be avoided. Adequate vertical clearance (at least 18 inches) to any sprinkler head should be allowed. No floor drains should be present in any warehouse and storage areas because personnel may wash spills down the drain. Any spills that do occur should be contained and cleaned up with the proper absorbent and wet/dry vacuums.

3.2.3.4 Production Areas

Material flow in production areas should be well laid out. Process chemicals should have their own storage areas near, but not within, production areas. Floors should be designed for proper drainage and should be sealed. Smooth, unobstructed access to all areas and all parts of machines and floor space should be designed in order to facilitate cleaning.

3.2.3.5 Chemical Mix Areas

Chemical mix areas should be located as close as possible to the production areas that they serve yet still remain isolated. An important pollution prevention design consideration is to avoid long runs of plumbing and pipes. Generally, material in these pipes becomes a waste with each changeover (e.g., of color, size). Multiplied by the number of changes that occur, this waste can be significant.

Poor conditions, cramped space, and areas or surfaces that are hard to clean should be avoided. Valves and other water controls should be mounted in highly accessible locations. Hoses in mix areas commonly are left running continuously because the valves are installed on a wall in an inaccessible area (e.g., behind the mix tanks).

3.2.3.6 Novel Design Practices

Sometimes, a departure from current design practice is necessary. For example, the traditional approach to wastewater collection has been to collect all wastewater in a single drain system. Over the years, single drain systems have given way to multiple water handling systems. Many mills have multiple wastewater systems such as:

- Potable water supply.
- Process water supply.
- Noncontact cooling water return systems.
- Boiler condensate water recovery systems.
- Roof, parking lot, and other normal stormwater discharge systems.
- Systems for stormwater from tank farms and spill containments.
- Sanitary wastewater systems separate from process wastewater.
- Within-process recycle and countercurrent systems.
- Systems enabling hot wastewater streams to be sent to heat exchangers.
- Process wastewater collection for treatment.

Further improvements can still be made in wastewater collection designs, however. Suggestions include dual-drain systems for process water so that wastewater from processes can be diverted to its most appropriate destination (recycle, conditioning prior to recycle, treatment, discharge) (13). Because many new regulations address problems that are very expensive to treat, such as color and salt, segregation of highly concentrated waste streams might be desirable to limit the volume of such wastewater that must be treated. Segregation is especially important for batch processes in which batch processing bath dumps are the norm. The problem is less significant with continuous processes because the wastewater tends to come from a point source more uniformly over time and can be easily plumbed into treatment or reuse (e.g., neutralization of an alkaline stream).

3.3 Enhanced Chemical and Pollution Prevention Expertise

Current trends in textile management are toward flatter organizational structures. As a result, education and training of mill personnel are more important than ever because a greater need exists for technical understanding at the worker and first-line supervisor level (14). In fact, one purpose of this pollution prevention manual is to provide materials that can be used to educate and train workers and first-line supervisors. Worker training and education can constitute one of the highest return, low-technology, and low-risk approaches to pollution prevention and should form the foundation of any good pollution prevention program.

3.3.1 Training

Employee work practices and attitudes towards pollution are an important key to success in pollution prevention programs, especially for companies attempting rapid, high-impact startups. Employees should be educated from the beginning about how their jobs relate to waste and pollution. The dual goals of pollution prevention and improved quality through right-first-time processing go hand in hand. Barriers such as poor housekeeping, training, maintenance, and facilities should be removed to enhance workers' and supervisors' attitudes (15).

A different and improved working culture can be developed with an attitude that "wherever there is waste, there is money to be made" (4). Employees should be trained to recognize process waste and to realize that their actions bear directly on the environment and the success of their jobs (15). Training first-line supervisors and department managers as well as production employees is a productive pollution prevention activity with short-term payback (1).

Pollution prevention should be an integral part of corporate policy and worker training programs (16). Ideally, training should be process-specific and machinery-specific and thus is best done internally. Employees should be given specific instructions and appropriate equipment to do their jobs properly (15). Production line and maintenance employees should be involved in all stages of training program implementation, evaluation, and updating (16). In addition, orderly and clean work practices on a shift-by-shift basis are important (1). These practices should be audited, and the results should be used for designing periodic retraining (15).

Employee suggestions should be actively solicited and acted upon (15). Companies that are well managed from a pollution prevention standpoint encourage all employees to participate in identifying and solving pollution problems. Companies that value employee input and act on their suggestions can count on a steady flow of creative ideas and solutions. Conversely, nothing stops employee participation in a pollution prevention program faster than failure to act on comments and suggestions.

The topics of training should be oriented to real workplace issues, with emphasis on pollution prevention practices as described in the following subsections.

3.3.2 Education

A more long-term approach to pollution prevention can be taken through formalized employee education. Education programs are more general and less job-oriented than training programs. Several specific topics have been documented in the literature, including:

- The need for an in-depth understanding of chemistry, reaction kinetics, thermodynamics, fluid mechanics, and fine-particle technology among process designers. This knowledge is essential to pollution prevention and long-term improvements (1).
- The establishment of corporate-level work groups to develop and distribute information concerning pollution prevention engineering, pollution prevention auditing, waste exchanges, and innovative pollution prevention ideas (16). Internal training and education through process improvement groups are a hallmark of a few major corporations as they work to improve their work force. In-house newsletters devoted to pollution prevention topics are another effective way to communicate information and educate employees.
- The commitment to consider alternatives before adding a new chemical to a process (17). This commitment requires both chemical and process expertise on the part of the production process designer.

Other areas mentioned below are also important.

In general, most pollution prevention training is best conducted internally because job-related issues are very site-specific. On the other hand, general education can be conducted either internally or externally. Several useful external training and education mechanisms are:

- Conferences and meetings.
- Equipment and trade shows.
- Trade organizations.
- Televised education.
- Videotape training aids.
- In-plant courses by outside experts or plant technical personnel.
- Correspondence courses from textile colleges.
- Evening classes at community colleges.

3.3.2.1 Trade Organizations, Committees, and Conferences

A good forum for information exchange is to participate in trade organizations (18). As an example, over the last 20 years approximately 90 papers specifically addressing environmental issues have been presented at the American Association of Textile Chemists and Colorists (AATCC) National Technical Conference. Twice as many papers are probably presented in local and regional meetings of AATCC.

In addition to conferences, many trade association committees actively concern themselves with pollution prevention in the textile industry. These include:

- RA 100 of AATCC (Environmental and Safety).
- American Textile Manufacturer's Institute (ATMI) Environmental Committee.
- North Carolina Textile Manufacturer's Association Environmental Committee.
- Carolina's Air Pollution Control Association.
- Northern Textile Association.

Many of the textile trade associations focus strongly on environmental presentations. In fact, at a recent wool processing conference, 24 percent of the chemical processing papers focused on environmental aspects of wool processing, and 7 percent had environmental issues as secondary themes (19).

Major new processing equipment with pollution prevention potential is shown regularly at international shows like International Textile Manufacturers Association (ITMA) (8). Two notable domestic shows are the Bobbin Show and American Textile Machinery Exhibition (ATME) International.

3.3.2.2 Televised Education

At colleges and universities with textile programs, textile courses may be available on video. These videos form the basis of regular college courses that can be taken for credit or audited at the undergraduate or graduate level. Examples of offerings at North Carolina State University (NCSU), one of the largest textile programs, are:

- Polymer chemistry
- Yarn production systems
- Weaving systems
- Dyeing and finishing technology
- Rheological and mechanical properties of polymers
- Marketing management
- Apparel technology management

- Spun yarn manufacturing
- Fabric formation and structure
- Fiber science
- Fiber formation (extrusion)
- Preparation and finishing chemistry
- Chemistry of processing assistants
- Physical properties of polymers
- Instrumentation and control systems
- Quality control
- Warp knit engineering
- Composites
- Comfort properties of textiles

These courses offer a high level of education at a reasonable cost.

3.3.2.3 Videotape Training Aids

AATCC, as well as NCSU and other universities, offer videotape libraries. Facilities can rent or buy these videotapes and use them for training. The tapes range in length from 5 to 50 minutes and cover hundreds of topics.

3.3.2.4 Industrial Short Courses

AATCC, several universities (notably North Carolina Vocational School, NCSU, and Clemson), and numerous industry consultants offer short courses on specific textile topics. These courses can be conducted at the mill or off site using the facilities of a trade association, university, or other organization. The duration is typically 1 to 5 days, and many courses are tailored to the industrial setting. Textile-oriented short courses for 1994 from AATCC and NCSU covered:

- Textile fundamentals.
- Implementing process improvements.
- Weft knitting.
- Weaving fundamentals.
- Spun yarn manufacturing.
- Pollution prevention in textiles.
- Indoor air pollution.
- AATCC National Technical Conference.
- Reengineering textile and apparel operations.
- Information systems for textile manufacturing.
- Dyeing and finishing fundamentals.
- Quality conference.
- Color science.
- Troubleshooting in textile wet processing.
- Controls conference.
- Presentations at AATCC local and section meetings and committee meetings.

3.3.2.5 Correspondence Courses From Textile Colleges

Most major universities offer correspondence courses in which the student transacts all studies through the mail.

3.3.2.6 Evening Classes

Most universities and community colleges offer a wide variety of evening classes or classes conducted in regular time slots to accommodate working students. In many cases, these classes are taught on demand, so a textile operation or group of textile operations located in close proximity can coordinate and arrange for courses to be offered as needed.

3.4 Equipment Maintenance and Operations Audit

Poorly maintained equipment leads not only to bad work, off-quality production runs, high reworks, and poor employee attitudes, but also to increased pollution. Preventive maintenance is the solution to these problems and can be accomplished through proper audits (20) (see also Chapter 5). In the auditing process, the following problem areas should receive special attention:

- Major machinery
- Leaks
- Filters
- Automatic chemical systems
- Chemical measuring and dispensing devices

Employees are an important source of information regarding problem areas, and their reports of problems such as equipment malfunctions and leaks should receive prompt attention. Some common problems seen in textile operations are cited below. These examples are instructive because they point to potential problems. The main goal is to create a watchful attitude in employees and an effective preventive maintenance program for each machine.

3.4.1 Major Machinery

Every major machine should have a checklist for routine maintenance and an operations checklist. An example for dye becks is shown in Tables 3-6 and 3-7. A similar checklist should be available as a training and audit aid for each machine. In addition, certain types of equipment components should receive their own periodic checks. These include pumps, valves (especially check valves), filters,

Table 3-6. Routine Maintenance Checklist for Dye Becks (22)

- Reel type, shape, cover, speed: compatible with substrate and dye recipe.
- Idler reel: turns free and true.
- No snags or rough edges in the machine.
- Tangle detector: rake and reel overload.
- Tangle alarm: audible and visible.
- Controller accuracy: temperature and rate of rise.
- Leaking valves: drain, fill, steam types.
- Steam quality available (while other demands are "on").
- Circulating pump and heat exchanger (if any): performance at operating temperature.
- Location and integrity of temperature sensor.
- Location and evenness of steam injection when heating and also when holding at 140°F and 200°F and end-to-end temperature differences.
- Overhead steam (if any).
- Damper and door (front and rear) operations.
- Damper ability to exhaust, fumes.
- Fill water temperature.

Table 3-7. Operations Checklist for Dye Becks (22)

- Load out the entire cloth.
- Be sure load size is appropriate: 60 to 80 pounds per beck root is typical.
- Be sure all strands are the same length, because long strands dye light, and short strands dye dark.
- Load out fully and evenly.
- Sew seams straight, with no twist in the strands, and no holes in seams.
- Control the liquor level according to the fabric; too high gives tangles and "swimming" of cloth, and too low gives abrasion, streaks, blotchy dyeing.
- Schedule light shades first, and dark shades later.
- Base electrolyte and buffer on the bath, not the cloth.
- Ensure moderate ballooning by allowing some foam or air to collect inside tubular goods; inflate with airhose if needed.
- Be sure to take a slow rate of rise near the critical points, such as wet T_g and dye strike temperature.
- Do not boil a beck—tangles will result.
- Use overhead steam to prevent drips, especially in winter.
- Be sure doors and dampers are closed when running at high temperatures to avoid cracks and drips.
- Be sure goods have adequate turnover rate—once per minute is typical.

level switches, and flow or pressure regulators. Each machine should be inspected for integrity and proper performance at regular intervals. The most common defects are missing guards; frayed or loose electrical cords; water, steam, and compressed air leaks; and improper operation of controls. In addition to process machinery, maintenance checks should be made on utility services (e.g., boilers, hot water systems, thermal insulation ducts).

3.4.2 Leaks

Nagar (21) estimates that annually, 100 million gallons of lubricating oils from industrial manufacturing plants are lost to the environment through leaks and other preventable circumstances. In textiles, lubricants are widely used as crankcase oil, heat transfer fluids, transformer oils, process oils, machine lubricants, bearing greases, and other uses. A leak of only three drops per second from a faulty seal can discharge 1,300 gallons per year to the environment. Proper leak control and preventive maintenance can avert 75 percent of all leaks (21).

Steps to prevent leaks include: 1) designing systems with minimum numbers of joints and potential leakage points, 2) using proper materials in constructing systems, and 3) training maintenance workers to recognize leaks and properly repair them. Also, facilities should ensure that lubricants do not become contaminated in service, requiring replacement more often than necessary. For textiles, contamination originates with incompatible greases from other parts, lint, packing/gasket fragments, rust, paint flakes, pipe scale, and water. A checklist for reservoir maintenance includes fitting lids with proper gaskets and secure seals, proper oil filters, and air filters over breathers. Lubricants also can break down thermally, so oil that is compatible with machine operating temperatures must be used (21).

Housekeeping and maintenance are essential for leak control. Audits should be carefully conducted for broken and leaking pipes, leaking drums, leaking pumps and valves, and running hoses. Small leaks can contribute large amounts of pollution and high costs if undetected or left unchecked. For example, a water leak smaller than the radius of a pencil has been estimated to cost as much to the company in a year as a week's paid vacation for one worker (15). DuPont's division for organic chemicals, plastics and synthetic fibers determined that leaking pump seals produced 450 kilograms per day of total organic carbon (TOC) load. Correcting this problem reduced pollution loads to the treatment facility by 50 percent while producing $7 million in savings and a dramatic reduction in permit violations (23).

3.4.3 Filters

Maintenance of filters and filter media is another area in which to focus pollution prevention efforts. Filters are used in many processes as a primary control treatment for lint removal and water purification.

Screen filters are commonly used to keep suspended solids out of the effluent by capturing them at the source (a primary control method). To be effective, filters must be cleaned on a regular basis. Most importantly, the recovered lint and debris filtered from the bath must be removed and landfilled or recycled as waste fiber, not dumped back into the drain. Often, however, workers clean out lint filters in dyeing machines or bleach ranges and discard the lint into the floor drains.

Many mills use various types of filters for water purification, including sand and gravel, activated carbon, water softeners, and ion exchange. In general, these filters require careful maintenance, and the filter media must be periodically cleaned and replaced. Many bleaching and dyeing problems stem from impurities in incoming water and ineffective filter systems, or neglected filter media maintenance.

3.4.4 Automatic Chemical Systems

Routine maintenance is essential for automatic chemical feed systems and equipment such as bulk chemical storage tanks, pumps, and valves. These systems are an excellent aid to pollution prevention because they tend to reduce routine working losses and small-scale spills. Bulk automated systems increase the chance of a catastrophic release of chemicals. Therefore, routine preventive maintenance for bulk automated chemical dispensing systems is essential. Generally, a weekly or monthly inspection of all system components is recommended. Typical points of attention are:

- Tank integrity.
- Label viability and correctness.
- Spill-containment integrity around tank, pipes, pumps, valves, and lines.
- Availability of spill control equipment and sorbent.
- Condition of off-loading devices (e.g., couplings, blowers).
- Condition of eyewash and safety shower in off-loading area.
- Sight glass integrity and protection.
- Pumps.
- Valves.
- Lockouts and other pump controls.
- Other site-specific items.

3.4.5 Calibrations of Chemical Measuring and Dispensing Devices

Any device used to measure or dispense chemicals to a process should be regularly calibrated or verified for accuracy. This includes drug room scales and automatic dispensing systems, as well as other devices used to measure and dispense chemicals.

3.4.6 Employee Input

Employees are a vital source of information concerning equipment in need of repair. Employee reports should be addressed immediately, not only to correct equipment problems, but also to convey management's commitment to pollution prevention, which will hopefully translate into worker commitment (15).

3.5 Chemical Alternatives

This section provides information about preventing pollution in textile operations through chemical substitutions and presents a few widely applicable chemical substitutions as examples of what is possible and how to initiate and conduct a substitute evaluation. Chemical substitutions also are covered in sections of this manual that cover specific individual processes. For example, information on substituting non-metal-bearing dyes for metal bearing dyes may be found in Section 4.3, "Dyes."

Textile manufacturing is a chemically intensive process, so a primary focus for pollution prevention should be on textile process chemicals (20). Best management practices for preventing pollution involve substituting less-polluting chemicals where possible, as opposed to treating chemical-bearing waste streams (20). Substitution can eliminate the waste load and the need for treatment, whereas treatment can simply result in transfers of pollutants to solid waste (sludge) or air emissions (volatile organic compounds [VOCs]). A wide variety of chemical substitutions can be made in textile wet processing. Many authors have described these substitutions (15, 24-27), and the sections below review some of these substitutions (see also Sections 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities").

Textile mills often view pollution as a chemical supplier's problem (28). In part, this is because suppliers often withhold composition and pollution information about their products as "proprietary trade secrets." The supplier should take responsibility, however, for providing adequate information that enables mills to make reasonable environmental evaluations, even on proprietary products. At the same time, the mill has the ultimate responsibility for pollution because suppliers cannot control the specific conditions of use of their products in terms of:

- Amount used
- Manner of handling
- Other chemicals used in the processing bath
- Process conditions
- Equipment used
- Possible in-process reactions
- Quality of waste treatment available

- Technical qualifications of the user

In other words, the supplier and the mill share responsibility for assessing chemical requirements, use conditions, and environmental impact. The supplier assumes a certain degree of responsibility for proprietary chemicals, yet the mill also must understand that the chemical only performs as promised (in terms of both processing characteristics and environmental impact) if used properly. Ongoing consultation with chemical suppliers is key to a successful pollution prevention program (see also Section 4.17, "Globalization of Pollution Prevention").

3.5.1 Chemical Substitutions

Opportunities for chemical substitution vary substantially among mills because of differences in:

- *Environmental conditions:* Permit requirements, ambient air quality, receiving water classifications, etc.
- *Process conditions:* Availability of processing equipment, quality of control systems.
- *Product:* Fiber blends, market and customer requirements, marketing and management philosophy.
- *Raw materials:* Incoming fiber and water quality, other raw material interactions.

Nevertheless, examining general examples and typical success stories from other companies can be instructive because they demonstrate the use of chemical substitution for preventing pollution. Typical pollution prevention opportunities related to chemical alternatives are noted below:

- *Chemical expertise:* Every effort should be made to understand the chemistry of the process (see Section 3.3, "Enhanced Chemical and Pollution Prevention Expertise," for more information). Ensure that the chemical being considered is appropriate to the technical needs of the process. Do not use dyes or chemicals of unknown constitution.
- *Chemical information:* Mills should insist on all necessary information concerning environmental aspects of a chemical's use before accepting it for production or for maintenance use. If the vendor is not forthcoming with environmental information, seek other sources (see Section 4.4, "Chemical Specialties," for more information).
- *Adopt a conservative approach:* Experiments should be conducted to determine the minimum number and amount of chemicals necessary in mixes to ensure adequate performance (15). Many mills use large quantities of specialty chemical processing assistants while others use essentially none. This suggests that factors other than chemical use may account for differences in results.
- *Identify nonchemical solutions:* Sometimes mills add chemicals (such as defoamers) to counteract inadequacies or deficiencies caused by other chemicals or by process conditions (15). A better strategy is to identify the process conditions that necessitate the use of such chemicals and reduce or eliminate them.
- *Interdepartmental communication:* To reduce the number and amount of chemicals used, coordination among departments and plants in multifacility operations is helpful (and sometimes necessary). The same chemicals often can be used in more than one process or department, reducing inventory, cost, prescreening requirements, and incoming quality control duties (15).
- *Prescreen chemicals:* Procedures should be established to prescreen all chemicals before use. All alternatives, both chemical and mechanical, should be considered (27). Further information on prescreening procedures can be found in Section 4.4, "Chemical Specialties."
- *Manage chemical inventories:* Mills should avoid accumulating chemicals when changes are made in the chemicals used and leftover stock of the old chemicals remain (15). An important part of chemical optimization and conservation begins with proper disposal of out-of-date chemical inventory, or a purchasing policy which avoids accumulation of obsolete materials.
- *Implement quality control:* Incoming chemical shipments should undergo testing to ensure that they conform to standards and vendors should know that testing is being done (27). Further information on the procedures for quality control screening can be found in Section 4.4, "Chemical Specialties."
- *Specify the proper chemicals packaging:* Intermediate bulk containers (IBCs) are preferable to bagged chemicals because they reduce the amount of waste generated and minimize spills caused by breakage.
- *Pay particular attention to non-process chemicals:* Nonprocess maintenance chemicals are a major source of pollution problems and must be included in a pollution prevention plan. Particular attention should be given to the evaluation of maintenance and laboratory chemicals (15).

3.5.2 Obtaining Information on Substitutions

A significant barrier to evaluating chemical substitutions is the proprietary nature of many textile chemicals, as discussed in Section 4.4, "Chemical Specialties," and above. Several efforts are now underway to develop databases of environmental information for textile

Table 3-8. Pollution Capability of Some Chemicals/Products Used in the Textile Industry (20)

General Chemical Type	Difficulty of Treatment	Pollution Category
Alkali Mineral acids Natural salts Oxidizing agents	Relatively harmless inorganic pollutants	1
Starch sizes Vegetable oils, fats and waxes Biodegradable surfactants Organic acids Reducing agents	Readily biodegradable; moderate-to-high BOD	2
Dyes and fluorescent brighteners Fibers and polymeric impurities Polyacrylate sizes Synthetic polymer finishes Silicones	Dyes and polymers difficult to biodegrade	3
Wool grease PVA[a] sizes Starch ethers and esters Mineral oil Surfactants resistant to biodegradation Anionic and nonionic softeners	Difficult to biodegrade; moderate BOD	4
Formaldehyde and N-methylol reactants Chlorinated solvents and carriers Cationic retarders and softeners Biocides Sequestering agents Heavy metal salts	Unsuitable for conventional biological treatment; negligible BOD	5

[a] PVA = polyvinyl alcohol.

Table 3-9. Chemical Classification Scheme for the Textile Industry (31)

Biofate Class		
COD		COD/BOD Ratio
1	≤1,000,000 ppm	≤4
2	>1,000,000 ppm	≤4
3	≤1,000,000 ppm	>4
4	>1,000,000 ppm	>4
Disposal Class		
1	Not RCRA[a] regulated	
2	Regulated as hazardous waste by RCRA	
3	Regulated as extremely hazardous waste by RCRA	
Air Pollution Class		
1	≤25% VOC	
2	≤25-50% VOC	
3	≤50-75% VOC	
4	>75% VOC	
Toxicity Class		
1	No priority pollutants present	
3	Priority pollutants present below regulatory limit	
5	Priority pollutants present at or above regulatory limit	

[a] RCRA = Resource Conservation and Recovery Act.

chemicals to make information available to textile mills (20, 29-31).[1]

Cooper (20) classified textile chemicals into several general categories based on their degradability, as shown in Table 3-8 (20). This classification scheme is similar to the approach taken by Virkler (31) and shown in Table 3-9. These classification schemes rate biodegradability in terms of the ratio of COD to 5-day BOD. The literature indicates that a COD:BOD ratio between 2:1 and 5:1 represents normal degradability for textile chemicals, and that ratios higher than 5:1 represent hard-to-treat chemicals (27, 31, 32). After gaining experience with this method, however, mills have determined that certain components of mixtures degrade rapidly over the 5-day assay period, while others degrade more slowly but nonetheless sufficiently over a reasonable period. Such mixtures produce high COD:BOD ratios based on 5-day BOD tests, compared with the ultimate BOD.[2] Therefore, one component with a high 5-day BOD can give the appearance of biodegradability when actually other components are quite resistant to biodegradation, and the biodegradation slows markedly after the first few days. An alternative method of rating biodegradability is the ratio of COD to 28-day BOD. This method is now preferred for evaluating chemical biodegradability.[3]

As the usefulness of these methods is fully assessed, improved systems of user information might be developed that preserve the trade secrets of textile chemical auxiliaries. The characteristics being entered into these databases are shown in Table 3-10 (30). In addition to the chemical properties, important information concerning synergisms, chemical alteration during processing, reactions, and the effects of mixing are included in some databases (30).

Aside from these efforts and an excellent review of surfactant properties by Kravetz et al. (33) (see Section 4.4 "Chemical Specialties"), relatively little information has been published that helps a textile mill select alternatives. Most published BOD, COD, and other data are obsolete within a few months or years as products change. With that caveat, published BOD and COD information on several commercially available products is shown in Table 3-11. This serves as a point of reference in comparing future test data. Information on major concerns such as aquatic toxicity and ultimate environ-

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[1] Moore, S. and B. Smith 1994. Personal communication between Samuel Moore, Burlington Research, and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

[2] See footnote 1.

[3] See footnote 1.

Table 3-10. Environmental Database Parameters (37)

Common name
Synonym
Chemical name
CAS[a] Registry number
Molecular formula
Molecular weight
Melting point
Boiling point
Density
Vapor pressure
Vapor density
Saturation concentration
Water solubility
pH or pKa
Octanol/water partition coefficient (KoW, or LogP)
Sorption partition
Coefficient to organic carbon (KoC)
Henry's Law constant or air-water partition coefficient
Flammability
BOD
COD
Theoretical oxygen demand (TOD)
Total organic carbon (TOC)
Odor index (OI)
Color
Metals
Suspended solids
Total solids
Halogens
Bioconcentration factor (BCF)
Ecological magnification (EM)
Activated sludge respiration inhibition
Aquatic toxicity
Polytoxicity
Half-lives in the environment
  — Air
  — Surface water
  — Ground water
  — Soil
  — Sediment
  — Biota
Environmental fate rate constants or half-lives
  — Volatilization/evaporation
  — Photolysis
  — Oxidation or photo-oxidation
  — Hydrolysis
  — Biotransformation/biodegradation
  — Bioconcentration uptake and elimination constants
Fate factors
  — Air
  — Water
  — Solid
  — Product
Biodegradability index
Mixing characteristics/process
  — Chemical
  — Reaction
  — Residues
Oxidizing agent
Reducing agent
Acid
Base
Metals
Salts
OECD[b] procedures
  — Biodegradability test OECD 301D
  — Biomass toxicity test OECD 209
  — Acute test OECD 202 part I and II, OECD 203 and 204

[a] CAS = Chemical Abstract Service.
[b] OECD = Organization for Economic Cooperation and Development.

mental fate is not available in most cases (34). For further information, see Sections 4.3, "Dyes," 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities."

3.5.3 *Typical Substitutions*

Some typical substitutions in textile operations that have been reported in the literature are cited below. These examples illustrate not only the types of substitutions that can be made but also the processes used to evaluate substitutes, including identifying the tradeoffs involved. Many authors have addressed this topic (15, 20, 24-26, 35, 36).

Modak (24) has reported several useful chemical substitutions, most of which are discussed in other parts of this document:

- Synthetic thickeners for printing in place of kerosene.
- Synthetic warp sizes for starch.
- Surfactant substitutions to reduce BOD and aquatic toxicity.
- Permanent adhesives in printing instead of gums.
- Nonmetal dyes for metal-bearing types.
- Formic acid for acetic acid in dyeing to reduce BOD.

In addition, the U.S. Environmental Protection Agency (EPA) (36) made the following suggestions in the development document prepared in support of the original effluent limitations for the textile industry:

- Biodegradable surfactants for nonbiodegradable detergents.
- Peroxide or periodate for chrome oxidizers (reduces metal).
- Sulfuric acid for soap in wool fulling (reduces BOD).
- Mineral acids for acetic (reduces BOD).
- Nonionic emulsifiers plus mineral oil for olive oil in wool carding.
- Warp size substitutions.

Table 3-11. Published BOD and COD Data for Selected Chemical Products Used in Textile Operations

Name	Vendor	BOD	COD
Acetic acid (56%)	Commodity	350,000	446,000
Adhesive TG-17	Pioneer	9,000	NA
Ammonium sulfate	Commodity	18,000	NA
Chemabind S	Chematron	23,300	NA
Chemlube SL	Chematron	114,000	NA
Conco NI-100	NA	162,000	NA
Deltaclean 503	Delta	516,000	NA
Deltaset K 650	NA	18,000	NA
Fabritone PE	Patchem	76,500	NA
Finish mix A (1)	Internal mix	6,800	118,900
Finish 144	High Point	115,500	961,500
Finish mix B (2)	Internal mix	14,300	34,700
Foam stabilizer 314	Valchem	12,000	NA
Foaming agent FT	Patchem	258,000	NA
Gloterge 107	Glotex	102,000	NA
Hemitone PE	High Point	288,000	NA
Hipochem SR	High Point	270,000	530,000
Hipochem TFXI	High Point	680,000	1,030,800
Hipochem RPS	High Point	750	557,600
Hipochem TFX-I	High Point	680,000	2,010,000
Hipochem GEP	High Point	60,000	NA
Hipochem PEK	High Point	750	1,087,800
Hipochem MS	High Point	730,000	2,080,000
Hipochem DOC	High Point	290,000	420,000
Hipochem EFK	High Point	140,000	200,000
Hipochem GEP	High Point	<300	287,500
Hipochem WSS	High Point	350,000	700,000
Hydroquest 444	Hydrolabs	8,300	8,400
LubSoft NLS	Lyndall	33,000	622,000
Machine cleaner 417	NA	20,300	166,000
Madoil 909	Madison	600	16,030
Madoil 934	Madison	3,360	30,470
Madoil 966	Madison	2,700	17,690
Magrastop TA 637	Tanatex	100,500	NA
Nocurl WPC	Consolidated	<300	44,600
Nonstix 84	Nutex	220,000	NA
Patsoft 1261	Patchem	70,500	NA
Racalev GR	Raca	102,000	NA
Rapidase XC-T	NA	54,000	NA
Raycafix EDS	Rayca	6,800	141,200
Reactodye	IVAX	NA	44,600
Reg Foam JFK-66	Parachem	43,500	NA
Revatol SP	Sandoz	6,000	76,000
Rexwet N-35	NA	162,000	NA
Sandolube NV	Sandoz	245,000	750,000
Scour All	NA	321,000	671,500
Scour TER	Consolidated	15,800	131,300

These substitutions also are reviewed throughout other parts of this document in process-specific settings (see Chapter 4).

3.5.4 Tradeoffs

When one chemical is being considered as a substitute for another, the textile mill must be aware of the potential for substituting one pollutant, or one pollution problem, for another. A good example is in the use of surfactants. Lower BOD-type surfactants, while reducing dissolved oxygen demand, can pass through treatment and contribute to aquatic toxicity (see Section 4.4, "Chemical Specialties"). Mills should have personnel experienced in chemical evaluation because all aspects of a substitution must be considered. The goal of identifying the alternative that produces the greatest net environmental gain can become complex in some cases.

3.5.5 Phosphates

Phosphate substitution illustrates the tradeoff issues that can arise and highlights the need for experts to assist in evaluations. Phosphates are a common problem for mills that discharge into nutrient-sensitive receiving waters. One dyer in eastern North Carolina, for example, was treating wastewater and discharging it into a nutrient-sensitive stream. To reduce phosphate discharges, the dyer evaluated two options: 1) install expensive phosphate removal treatment equipment or 2) reduce phosphorus discharged into the wastewater through pollution prevention measures (38). Several nonphosphorus chemical substitutions, shown in Table 3-12, were made without adverse effects on production or quality. Phosphorus concentrations in treated effluent decreased from 7.7 ppm to less than 1 ppm (38).

In other cases, alternatives for phosphates can lead to different types of pollution problems, necessitating an evaluation of which alternative is the least damaging. For example, substituting acetic acid for monosodium phosphate (MSP) lowers the phosphate nutrient content of wastewater but simultaneously increases the BOD

Table 3-12. Available Substitutions for Phosphates (27, 38)

Phosphate	Use	Substitute(s)
MSP[a]	Acid salt, pH	Acetic acid
TSPP[b]	Water conditioner	Soda ash
Phosphoric acid	Strong acid	Hydrochloric acid
TSP[c]	Alkali builder	Caustic, soda ash
Hexaphos	Water conditioner	EDTA,[d] silicate
Phosphate surfactants	Scouring	Ethoxylates, amines
Phosphates	Flame retardants	Varies
Phosphonamides	Flame retardants	Varies

[a] MSP = monosodium phosphate.
[b] TSPP = tetrasodium polyphosphate.
[c] TSP = trisodium phosphate.
[d] EDTA = ethylene diamine triacetic acid.

and acidity. In considering such a substitution, the textile mill must examine the site-specific conditions (i.e., the ability of the local waste treatment system to degrade BOD compared with the nutrient sensitivity of the receiving waters). A mill (in consultation with regulatory authorities, as the case may be) must decide which problem takes the higher priority. In many cases, one must consider not only reducing the amount of chemical pollutant in the wastewater but also improving the waste stream in other ways (i.e., treatability, hazardous characteristics, eutrophication potential, dispersabilty, volatility, aquatic toxicity, inhibition of waste treatment processes). Of course, mechanical alternatives can often eliminate pollution altogether and should not be neglected.

In the example cited above, BOD and pH are generally easier to treat than phosphates, and the wastewater with acetic acid can be handled more easily by most treatment systems. In this case, the substitution produced a "better" waste stream compared with the original, phosphate-rich discharge. In other circumstances, however, substitution may produce a negative effect.

3.5.6 Biological Oxygen Demand and Chemical Oxygen Demand

The majority of the BOD and COD load from mills is often attributed to a small number (6 to 8) of chemical products used (39). The major sources can be identified by considering the amount of BOD and COD discharged and the COD or BOD of each individual chemical (39). The amount discharged is estimated from the amount used and the fixation percentage (i.e., what fraction actually becomes part of the fabric) (39). Dyeing chemicals, warp size, knitting oil, and fiber finishes contribute most of the BOD and COD (26).

Publicly owned treatment works (POTW) sewer surcharges for direct dischargers usually are computed using a formula involving BOD and COD concentrations. Although BOD and COD are readily treated by the POTW and are not a major environmental concern (in the way that metals might be), they do affect the mill from an economic standpoint and should be addressed as part of the pollution prevention program.

The formulas used to compute POTW charges give mills an incentive to reduce BOD and COD in their waste streams. Much BOD and COD comes from wasted chemicals (batch dumps), starch size, knitting oils, and biodegradable surfactants (as discussed in other sections of this manual); these problems should be addressed because they impose two types of costs (raw material loss and sewer charges). Other actions taken to reduce BOD and COD may be economically productive but environmentally inferior. Chemical substitutions that reduce BOD while increasing toxicity or metals concentration, for example, should be carefully examined (see Section 4.4, "Chemical Specialties"). All substitutes for high BOD/COD chemicals should be evaluated to determine what, if any, environmental problems they present.

3.5.7 Solvents

Several examples of substitutions involving solvents are discussed in Section 2.2.3, "Toxic Air Emissions." A few examples will be presented here to illustrate methods for applying pollution prevention and substitution to solvent emissions problems.

Organic solvents are widely used in textile processing, either as emulsions in water or in their natural form (27). Typical solvent emulsions include scouring agents and dye carriers for synthetic fibers, especially polyester. These materials typically exhaust into the fiber and later are evolved from dryers as airborne VOCs. Examples of such materials include methyl naphthalene, trichlorobenzene, chlorotoluene, ortho dichlorobenzene, perchloroethylene, methyl ester of cresotinic acid, butyl benzoate, and biphenyl (27).

In addition to being emitted to the atmosphere, volatile solvents can become part of the wastewater stream through spills, leaks, cleanup (drums, tanks), batch chemical dumps, and poor housekeeping. The wastewater treatment process often strips these volatiles from the wastewater and releases them to the atmosphere.

In scouring, nonchlorinated materials can replace more objectionable chlorinated materials. One example is substituting xylene for chlorotoluene (27). Substitutes are also available for nonaqueous solvents. These are frequently used as machine cleaners, parts degreasers, and in laboratory applications (e.g., for extraction procedures) (35). Wasted solvents such as machine cleaners and degreasers can be reduced by using a device such as the one shown in Figure 3-4 or by using substitutes. Laboratory or machine-cleaning solvents should never be disposed of in a sanitary sewer. Instead, solvent recovery bottles should be available for later pickup and proper disposal. Keeping different types of solvents separate is usually economically advantageous because disposal and recovery methods vary. At a minimum, separate waste containers should be available for chlorinated solvents, nonchlorinated solvents, and water-free oils. The use of chlorinated solvents in the laboratory should be minimized, particularly by substituting Freon, xylene, or toluene for chlorinated solvents (e.g., methylene chloride, perchloroethylene, chloroform) or by substituting less-toxic or less-hazardous solvents (e.g., xylene or toluene) for benzene (35).

In several case histories, solvent substitutions have produced outstanding pollution prevention results. Wood and Bishop reported that DuPont's division for organic chemicals, plastics and synthetic fibers substituted less offensive materials for priority pollutants such as methylene chloride, chloroform, and toluene in many

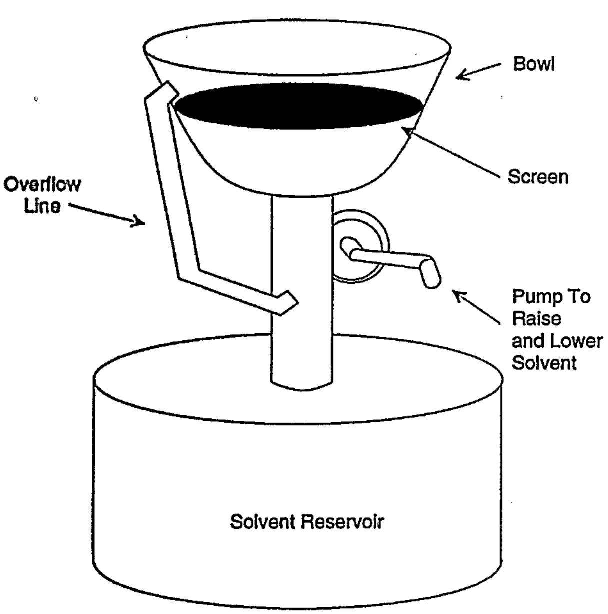

Figure 3-4. Schematic of a small parts cleaning system.

applications (23). Morris reported that one company applied 70 percent of coatings using solvent systems, and the substitution of aqueous systems reduced this to 30 percent (2).

3.6 High-Extraction, Low-Carryover Process Step Separations

Textile operations often expose substrates to a processing solution, all or part of which is subsequently removed. The amount of solution the substrate retains is called wet pickup (WPU). When several wet steps follow each other in succession, mills commonly dry the fabric between each step. This minimizes carryover and downstream contamination, and ensures even pickup of the subsequent processing solution.

Sometimes, drying the fabric between each step can be avoided, saving energy (gas or steam), associated air emissions, and boiler ash (a solid waste). Mechanical extraction of water is possible to achieve fairly low WPU (e.g., 25 percent to 50 percent). Minimizing WPU can often reduce downstream processing bath contamination, which helps avoid fouling of machines and reduces the need for cleanup activities. Typically, continuous processes work this way, and often batch processes do as well. Several reasons exist for minimizing WPU:

- To control the exact amount of processing bath on the substrate to produce a desired result (i.e., to limit WPU to a minimum level for energy efficiency).
- To minimize, control, or equalize the moisture content of substrate before it goes into another process, such as wet-on-wet dyeing or finishing, or a drying operation.
- To recover the processing mix material and prevent it from carrying over into downstream processing solutions (i.e., to prevent carryover).
- To recover the processing mix material and prevent it from escaping into the environment (i.e., to eliminate dragout).

Several applications of this technique are presented in other sections of this document (see Sections 2.2.7, "Water Conservation," and 4.12, "Finishing").

For finishing or continuous dyeing, a substrate is saturated (usually by immersion) with a processing bath. Excess amounts are removed to the bath to achieve a controlled add-on level. This is called saturation/expression. The other option for controlling add-on is to use sprays, foams, and kiss rolls (see Section 4.12, "Finishing"). The amount of material added on in the wet state is expressed in terms of WPU:

$$\text{WPU} = \frac{\text{mass of solution sorbed}}{\text{mass of dry substrate before treatment}} \qquad \text{(Eq. 3-1)}$$

Typical WPU values for saturation/expression processes on previously dry fabric are shown in Table 3-13. As the table shows, the use of high-extraction methods can reduce the amount of dragout or carryover by up to one-half.

Table 3-13. Typical WPU Values for Saturation Expression Processes on Previously Dry Fabric

	WPU Typically Achieved	
Type of Substrate	Conventional	High Extraction[a]
Cotton	90%-130%	45%
Synthetic	25%-85%	25%

[a] Minimum required to thoroughly wet substrate, depending on substrate structure.

The substrate generally responds to the amount of chemical add-on, not the WPU. To describe this, the term dry add-on is used. Dry add-on is:

$$\text{Dry add-on} = \frac{\text{mass of dry chemical solids added on}}{\text{mass of substrate before treatment}} \qquad \text{(Eq. 3-2)}$$

A third parameter is the mix concentration, which is:

$$\text{Concentration} = \frac{\text{mass of solids in the mix}}{\text{mass of chemical mix total}} \qquad \text{(Eq. 3-3)}$$

The relation between the WPU, dry add-on, and concentration is:

$$\text{Dry add-on} = \text{concentration} * \text{WPU} \qquad \text{(Eq. 3-4)}$$

When the WPU of a process changes, the mix concentration must be adjusted to achieve the same dry add-on, thus the same end result on the fabric. For example, a resin might be applied conventionally at 10 percent concentration and 110 percent WPU, giving 11 percent dry add-on. If a low add-on method were used, with 45 percent WPU, then the required mix concentration would be:

$$\text{Dry add-on} = \text{concentration} * \text{WPU} \quad \text{(Eq. 3-5)}$$
$$0.11 = \text{concentration} * 0.45$$
$$\text{Concentration} = (0.11/0.45) = 0.244$$
$$\text{or about 25 percent}$$

3.6.1 Wet Pickup Minimization

Minimizing the exact amount of processing bath picked up by the substrate to produce a desired result has several benefits. Less energy is used to dry the water, and chemicals are used more efficiently in the low add-on process because of less thermal migration in the drying stage. High-extraction (or low add-on) devices are used to achieve the minimum WPU and evenness required for dyeing and finishing. These devices are described in Sections 2.2.7, "Water Conservation," and 4.12, "Finishing."

3.6.2 Wet-on-Wet Processing

Normal practice, as indicated above, is to apply finishes (or dyes in continuous dyeing) to dry fabric. If the substrate comes directly from a previous wet state, however, a drying step can be eliminated by using a wet-on-wet process in which the substrate is treated to ensure a very low and even moisture content. Finish can then be applied at a higher WPU, thus giving add-on of finishing chemicals (see Figure 3-5).

During this process the water in the incoming substrate tends to dilute the finish mix. This often necessitates a control system to sense and adjust the chemical feed to the finish mix saturator. The process does not work without a high-extraction, low-carryover separation of the water saturator from the finish saturator. Also, the process tends to be uneven if the water saturator step is not performed properly because the water settles out in the storage boxes, resulting in very uneven finish, dry add-on and uneven fabric performance.

In addition to the wet-on-wet finishing example cited above, the same technique can be used for dyeing some styles, notably toweling. In these applications, the cost and energy savings are attractive because toweling by its nature retains high levels of moisture and is therefore expensive to dry. The toweling is desized, scoured, and bleached, then wet out and extracted with a high-extraction device, followed by wet-on-wet dye application in a continuous range.

3.6.3 Process Step Separations

Maintaining good isolation between incompatible mixes in sequential process steps is crucial to achieving long runs out of process solutions without having to stop off for cleanup and refurbishing processing baths (with associated discards). Often, continuous dye application involves a sequence of chemically incompatible steps. The sequence for vat dyes, for example, is shown below:

- Reduce vat dye in a holding tank (or use prereduced dye).
- Pad substrate with reduced vat (reducing bath).
- Apply steam to the substrate for penetration.
- Wash off unpenetrated surface dye and residual reducing agent.
- Perform high-extraction/low-carryover step separation.
- Oxidize vat dye within the fiber (oxidizing bath).
- Wash.
- Dry.

Any carryover of reducing agents into the oxidizing bath produces contamination that degrades the quality of the process and requires the addition of more oxidizer to the mix. Similar situations exist with naphthol and sulfur dyes, where separations are required for various reasons. In other processes, incompatible pH or other situ-

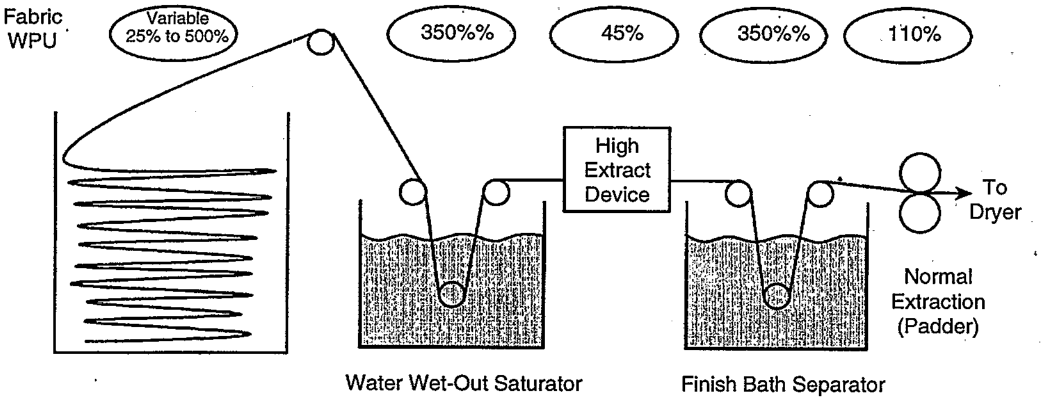

Figure 3-5. Wet-on-wet processing to eliminate drying stage.

ations may exist. For example, residual alkalinity from mercerizing can cause premature reaction of fiber-reactive dyes in continuous dyeing. The high-extraction device, when used as described above, prevents contamination of the oxidizing bath with reducing agents and prevents dilution of the bath with washwater.

3.6.4 Recovery of Offensive Materials

Several textile processes, notably mothproofing of wool, are based on offensive materials such as permethrin. In such processes, material recovery of as much dragout as possible is integral to environmental protection.

Recovery of dragout for batch process mothproofing of wool is done with a specially adapted centrifugal extractor, as explained in Section 4.12, "Finishing." This concept applies in general to applications of materials followed by washing processes. The higher the mechanical extraction of materials, the less washoff discharged to the environment.

3.6.5 High-Extraction/Low-Add-On Devices

Many different versions of low add-on or high-extraction devices exist, as listed below (40):

- Centrifugal extractors
- Curved blade applicator
- Engraved rollers
- Fabric transport loops
- Gas-phase finishing
- High-extraction pads
- Kiss rolls
- Mach nozzles
- Sprays
- Stable foams
- Unstable foams
- Vacuum extractors

At ITMA 1987 and 1991, many new high-extraction devices and low add-on systems were shown (8, 41). Some of the more noteworthy were vacuum systems and centrifugal extractors. Vacuum technology reduces dragout and carryover of process solutions from step to step, thus avoiding process efficiency losses because of downstream bath contamination. This reduces chemical use, cleaning frequency, bath discards, and machine cleaning, and is particularly effective at improving washing efficiencies. Several companies showed innovative centrifugal extractors with interchangeable baskets. These are very flexible and efficient in moisture removal from yarn packages, fabrics and garments. (8).

3.7 Incoming Raw Material Quality Control

In discussing pollution prevention programs, most experts raise the issue of incoming raw material quality control (QC) (15, 26-28, 42-45). QC of incoming raw materials seems obvious and simple, but textile mills rarely, if ever, practice proper raw material QC techniques.

One important fact to realize is that the most frequently touted techniques for pollution prevention (i.e., right-first-time production and process optimization) depend completely on raw material consistency as a foundation. Without a uniform, consistent raw material input, constant process adjustments and changes must be made in a never ending (and never successful) quest for optimization.

Figure 3-6 lists incoming raw materials that should undergo QC testing. They are ranked roughly according to typical testing frequency. Interestingly, some of the highest volume raw materials (e.g., commodity chemicals, synthetic fibers) are the least tested, along with often highly toxic maintenance and cleaning chemicals.

Most Often Tested

Yarns
Fabric
Natural Fibers
Water
Dyes
Specialty Chemicals
Commodity Chemicals
Synthetic Fibers
Utilities (e.g., Air, Steam, Electric, Fuels)
Maintenance and Cleaning Chemicals

Least Often Tested

Figure 3-6. Incoming raw materials that should undergo QC testing.

Raw material testing procedures vary greatly according to the type of raw material. For example, tests of commodities by titration are appropriate for process performance but not for detecting environmental problems. Trace impurities in raw materials (e.g., synthetic fiber finishes), which standard tests cannot detect, can cause substantial pollution problems. These should be separately tested using an appropriate test protocol. Detailed testing procedures for these raw materials are given in Sections 3.16, "Consumer, Installer, and End-User Information," 4.2, "Fibers," 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities."

The groundwork for successful implementation of an incoming raw material QC program must be laid in two areas: (1) prescreening raw materials before use (26) and (2) establishing specific and appropriate purchasing, packaging, and inventory control policies to prevent the ordering and use of untested materials (43).

Standardized testing and reporting procedures are important (46), as is a review of all test results by customer and supplier, even when no problem is apparent. This is necessary to establish a baseline and a protocol for dealing with future difficulties (see Section 4.17, "Globalization of Pollution Prevention").

A good example of the value of testing for impurities is cited in a study by Holme (44). The study covered 70 percent of woolen mills in the United Kingdom, both large and small. Pentachlorophenol (PCP), a harmful agricultural residue in wool, was detected in wastewater from finishing plants. Researchers determined that it originated in the incoming greige goods. The presence of PCP in wastewater decreased by 50 percent after companies specified, as a part of their purchasing policies, that they would not accept PCP-containing greige goods for finishing. No acceptable treatment technology is known for PCP, so this pollution prevention strategy was the only method of environmental protection (44).

3.8 Maintenance, Cleaning, and Nonprocess Chemical Control

Chemicals used for maintenance and cleaning are often among the most toxic, offensive materials found in textile mills (15, 26). Many mills that have otherwise good pollution prevention programs overlook these chemicals, however. Because the chemicals are not used directly in production processes, they often escape the rigorous evaluation and prescreening that production chemicals must undergo (27).

In addition, mills usually do not specify procedures for using maintenance and cleaning chemicals nearly to the extent that they do for production chemicals. For example, the frequency, amount, and manner of use for machine cleaners, facility cleaning agents, and other shop chemicals are rarely as well documented (if at all) as chemicals used in production processes. Further, shop employees often are not trained in chemical handling to the same extent as process operators. All of this leads to a substantial potential for environmental problems related to maintenance and cleaning chemicals.

Typical examples of chemicals used in maintenance and cleaning operations are:

- Acid-based parts cleaners.
- Adhesives.
- Biocides for air washers.
- Boiler chemicals.
- Lubricants.
- Paints.
- Solvent-based materials (e.g., paint strippers, floor cleaners).
- Weed killers used around bulk storage tanks.

Mills can minimize the potential environmental impacts from these materials in several ways, the first of which is to treat maintenance chemicals the same way as all other chemicals in a facility. The procedures used to monitor and control these chemicals should include:

- Prescreening
- Incoming chemical quality control
- Worker training
- Procedures for use
- Disposal of obsolete chemicals
- Inventory control
- Packaging
- Purchasing specifications

3.8.1 Solvents

Solvents are a frequently misused class of shop chemicals. Waste solvents originate from all types of machine cleaning and shop activities, as well as from print screen cleaning. Simple control methods can often be effective. A useful system for small parts cleaning consists of mounting a bowl on top of a delivery tube, which in turn is positioned above a reservoir as shown in Figure 3-4 (27). When needed, solvent is pumped into the bowl where small parts to be cleaned are placed. A screen prevents the parts from falling down the tube and into the reservoir. After use, the solvent flows back down into the reservoir by gravity. This device can also be used to wet rags with solvent for cleaning. Both uses of this system avoid the need to dispose of leftover solvent that has been poured into a separate container for use.

Contaminated solvent, whether from parts or machine cleaners, or from processing uses such as solvent scouring ranges or dry cleaning, can be recovered by distillation. Sludges, residues, and still bottoms not recovered should be kept separate from other wastes and disposed of separately. In some cases, these may have commercial value (e.g., lanolin from wool dry cleaning).

3.9 Developing Markets for Wastes

The textile industry has benefitted from the establishment of formal and informal networks for exchanging certain types of wastes. In these waste exchanges, two or more organizations develop a mutually beneficial relationship whereby materials that would otherwise be thrown away are made available to organizations that can use them. Waste exchanges redirect materials back into the manufacturing or reuse process by matching generators of specific wastes with companies that can use those wastes as manufacturing inputs. This not only helps to extend the lives of products and supplies but also reduces purchasing and waste disposal costs.

Benefits of waste exchanges include:

- Reduced waste disposal costs
- Savings in material and supply costs
- Savings from more efficient work practices
- Revenues from marketing reusable materials

Waste exchanges are one of the simplest, most inexpensive waste prevention strategies a company can implement. The first step toward implementing a waste exchange program is to conduct a companywide inventory of potentially reusable products and supplies. In addition, employees often have good suggestions about materials that can be reused, so their opinions should be solicited.

Most state offices of waste reduction can supply information and lists of recyclers who will buy waste products, provide information on existing active and passive waste exchanges, and supply details and guidance on how to establish a waste exchange. In some places, computer- and catalog-based networks have been established to help match up companies who wish to participate in exchanging their materials.

In the textile industry, scraps, fibers, rags, and other materials are routinely sold to other mills or to recyclers. Other materials may also have potential scrap or reuse value. Table 3-14 contains a partial list of waste materials that can be exchanged.

3.10 Process Alternatives

New, cleaner technologies and process alternatives can simultaneously reduce pollution and cut processing costs (2). Equipment manufacturers, responding to changing environmental priorities, are offering equipment (e.g., dyeing machines) that is more energy efficient, features reduced water consumption, accommodates recovery and recycle of waste streams, and allows for more precise control over operating parameters, an important factor in preventing pollution.

Various sections of this document describe specific process alternatives that are inherently less polluting. Table 3-15 lists some conventional processes along with cleaner technology alternatives. The table also points to sections in this document that discuss such equipment. The sections below describe cleaner alternatives for specific production processes.

Table 3-14. Examples of Textile Industry Waste Materials That Can Be Exchanged

Aluminum
Batteries
Brass
Cardboard
Chlorinated solvents
Cloth scraps
Cones (paper yarn cones)
Copper
Corrosive liquids
Cotton
Cutting oil
Fibers
Fuel oil
Glass
High-density polyethylene
Hydraulic oil
Inks
Iron
Lead
Metallic sludges
Motor oil
Office paper
Oil/water mixtures
Organic solvents
Paints
Pallets
Paper tubes
Plastic
Polymer scrap
Polypropylene
Polystyrene
PVC
Rags
Rubber
Seam cutouts
Selvage trimmings
Solvents
Steel
Steel drums
Tin
Tires
Urethane materials
Wood scraps
Wool
Yarn
Zinc

3.10.1 Improved Coatings Systems

Solvent-based coating systems are the largest producers of hazardous air pollutants like methyl ethyl ketone (MEK), toluene, and acetone from textile operations (47). Air testing, sampling, analysis, and treatment for these pollutants are very difficult and expensive, so pollution prevention is an attractive alternative to controlling these emissions (48). One alternative is to use water-based systems in place of solvent-based systems wherever possible (2). In addition, solventless coating systems have the potential to substantially reduce VOCs.

Wilkinson (49) describes an approach based on powder coating technology. Since synthetic polymers became available in the 1940s, coated products, including coated textiles, have been in high demand by consumers. Typical products include high-technology coated and laminated fabrics, waterproof laminates, fire-retardant backcoated upholstery and drapery, and tennis shoe uppers. Also, many industrial fabrics, such as conveyer belts, tarpaulins, and offset printing blankets, are made with this technology. Conventional systems use latex or other synthetic polymers in an organic solvent medium. This is sprayed on the cloth, and the solvent

Table 3-15. Process Alternatives That Can Reduce Pollution

"Normal" Process	Pollution Prevention Alternative	Section(s)
Chemical handling	Automatic chemical systems	4.12, 4.18
	IBCs vs. drum chemical handling	1.2, 2.2, 3.11, 4.4
	Bulk chemical storage	4.5
Control	Adaptive/improved control	2.1, 3.19
Dye handling	Automated color kitchen	3.18, 3.19, 4.10
Dyeing	Dye class alternatives	4.3, 4.10
	Dyebath reuse	3.19, 4.10
	Continuous vs. batch dyeing	4.10
	ULLR dyeing	3.19, 4.10
Finishing	Foam finishing	4.12
	Mechanical finishing	4.12
	Low add-on finishing	4.12
	Spray finishing	4.12
General	Bath reuse	2.2, 3.19, 4.9, 4.10
Knit dyeing	Knit dye ranges (continuous)	3.19
Padding	High-extraction systems	3.6
	Vacuum extractors	3.19
Print screen making	Laser screen making	3.19, 4.11
Printing	Ink-jet printing	4.11
	Transfer printing	4.11
Reactive dyeing	Pad batch dyeing	4.10
Washing	Countercurrent washing	3.19, 4.9
Waste discharge	Recovery systems	3.19

evaporates, leaving the latex or polymer coating. This process releases undesirable VOCs to the atmosphere. Powder coating can substitute for waterless systems, producing the same end results as solvent-based coatings but with less pollution. Wilkinson used three application methods: 1) powder scatter, 2) paste point (see Figure 3-7), and 3) engraved rollers.

This is an emerging technology, based on the desire for a waterless, solventless coating system. NCSU has conducted similar experiments, in which thermoreactive epoxide materials (i.e., powder paints) or thermoplastic xerographic materials have been used for solid dye shades as well as for fabric printing. Undesirable VOCs from coating operations, including MEK, xylene, toluene, and acetone, are completely eliminated.

3.10.2 "Cold" Processes

The textile industry provides many opportunities for further application of cold batch processes, similar to those used for pad-batch dyeing (see Section 4.10, "Dyeing"). In these processes, the processing solution is applied to the textiles with a pad. The textiles are then wound on

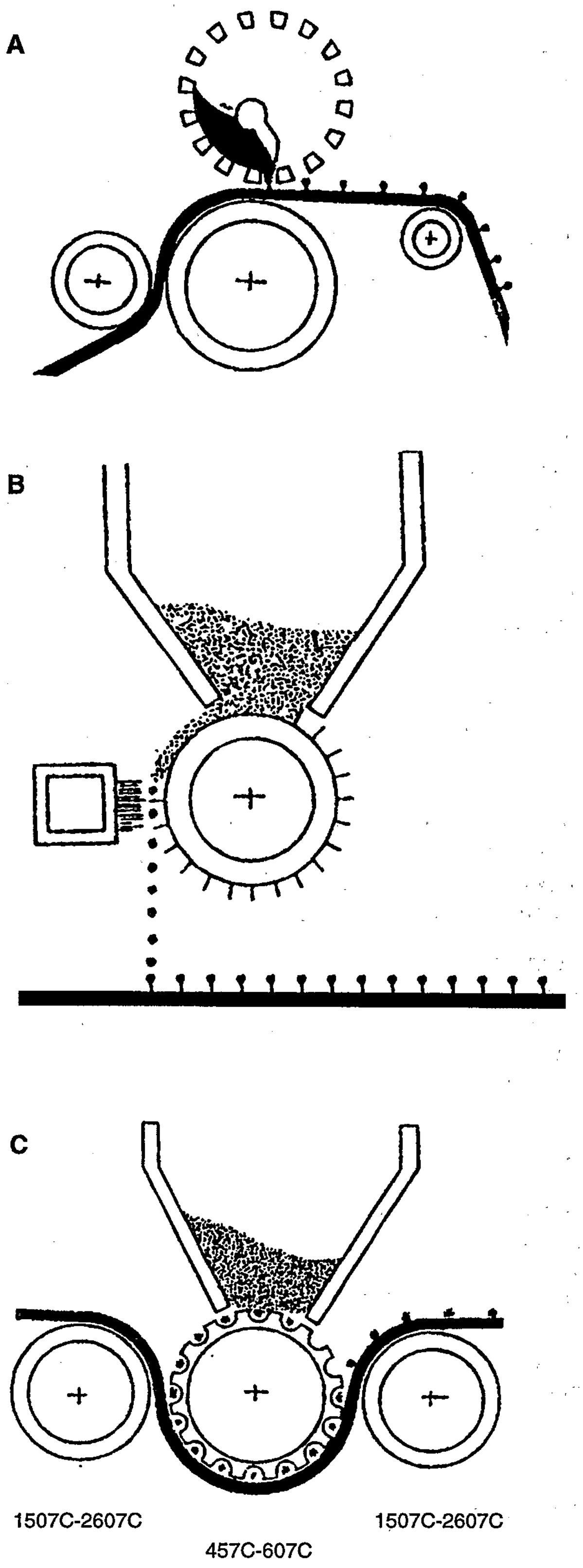

Figure 3-7. Schematic of (A) powder coating scatter, (B) paste point coating, and (C) powder paint coating using gravure roller (49).

rolls or batched in boxes, bins, or kiers for extended periods, ranging from 4 to 24 hours. Bleaching, desizing, resin finishing, and some types of dyeing can be done this way. The benefits usually take the form of energy savings (i.e., less steam use) and reduced boiler emissions. One example of an energy-saving dyeing process that some mills have adopted is low-temperature dyeing of nylon (50). This requires different dyeing assistants than the normal dyeing process.

3.11 Optimized Chemical Handling Practices

One of the most fundamental elements of any pollution prevention plan in the textile industry is optimization of chemical handling (15, 27, 43). Proper chemical handling procedures ensure that the right chemicals are used, that they are used in the correct amounts, that they are used in such a way as to minimize the amount of unreacted chemical that enters the waste stream, and that all wastes from processes involving chemicals are properly handled.

Good chemical handling does not occur by accident; it results from many preliminary planning steps, including:

- Attention to purchasing specifications.
- Packaging requirements.
- Chemical receiving, storage, and mixing.
- Proper worker training.
- Engineering controls such as automated chemical handling.

These planning steps are described in greater detail below.

3.11.1 Purchasing

Proper chemical handling begins with the establishment of procedures for ordering and purchasing chemicals. Vendors must be made partners in the pollution prevention program. During the prescreening and evaluation process for new chemicals, specifications and agreements between the vendor and the user must include details such as packaging, chemical constitution, and control of impurities. Appropriate methods for controlling incoming chemical quality must be formulated, based on the type of chemical, prescreening data available, and other factors.

In addition, open and regular lines of communication with the vendor must be established to report the results of QC tests. This serves the dual purpose of letting the vendor know that the chemicals are being tested and establishing the vendor's acceptance of the QC tests. If vendors are involved in establishing QC test protocols, they will have difficulty citing problems with the testing procedures as the basis for disputing any future quality problems.

3.11.2 Packaging

Textile operations commonly use several types of packaging, including:

- Bulk containers
- IBCs
- Drums
- Bags

The manner of packaging is important to reducing pollution and waste resulting from chemical handling. Chemicals should be purchased, handled, and transported in containers that are designed to minimize spills (15). In most cases, bulk containers or IBCs provide the best pollution prevention potential. Bagged chemicals and, to a lesser extent, drums are particularly susceptible to damage and spills (43).

If a spill occurs, the spilled material must not be washed down the drain but instead should be captured in wet/dry vacuum systems (15, 27, 43, 51). Further information on this subject is included in Sections 4.4, "Chemical Specialties," and 4.5, "Chemical Commodities."

3.11.3 Receiving

At least two people should receive each chemical shipment. This is especially important in bulk chemical deliveries, which can present serious problems if a problem arises during off-loading. For example, a simple problem such as a defective fitting can result in chemicals being sprayed on an operator or large amounts of chemicals being released. In addition, spills can generate a large amount of contaminated soil, which may require handling as hazardous waste, with associated expenses and liabilities. Every receiving area should be equipped with safety devices such as a shower, eyewash, and spill-absorbent material.

3.11.4 Storage

Chemicals should be stored according to manufacturers' recommendations and segregated according to type (e.g., oxidizer, reducer, acid, alkali, flammable). Bagged chemicals and other breakable types of packaging should be avoided. If they are used, they should be stored in well-protected areas. In particular, storage near high traffic areas should be avoided entirely, especially for bagged commodities such as salt and soda ash (15).

The facility design should include proper racks or other storage bins. Bulk tanks should have proper dikes, berms, or other spill containment mechanisms. Pallets of bags or drums should never be stacked on top of each other. In addition, forklifts should be properly equipped to handle each type of packaging. Extremely hazardous or offensive chemicals should be identified to warehouse handlers.

Shipping, storage, handling, and delivery systems should be optimized to reduce spill potential and automated to improve dosing accuracy (51). Storage areas should not have floor drains (15), but instead should have capabilities for dry capture (e.g., vacuum system). Recovered spilled material should be reclaimed if possible or segregated for separate treatment and disposal (51).

Storage areas should be regularly inventoried for obsolete chemicals. If proper receiving procedures are followed, the date of receipt and incoming QC testing will be marked on each container. From that mark, inventory personnel can determine the age of each item. Minimizing surplus chemicals reduces the potential for obsolete chemicals to become hazardous waste (43).

3.11.5 Mixing

All chemicals (process and nonprocess) should be accurately weighed, dispensed, and mixed in such a fashion as to avoid spills. Using the scoop or "dipperful" method of measuring has minor economic consequences but potentially major pollution consequences (15). Automatic metering and mixing systems ensure that mix recipes are always accurately prepared. This is vitally important because it enables the mill to experiment with different mix ratios and varying chemical quantities to assess the impact of changes in chemical use on product performance and pollution generation. The issue of proper scales and accurate calibration is discussed in Section 4.18, "Support Work Areas." Scales should be adequate for the purposes intended and regularly calibrated to ensure accuracy.

Moore (42) reports a case history in which a mill that processed nylon pantyhose was not in compliance with a city pretreatment ordinance on BOD, COD, and zinc. In the process of improving work practices, systems were introduced for accurately weighing all chemicals, as opposed to the previous practice of using a "dipperful" or "bucketful" (i.e., volumetric approximations). A zinc stripping agent was also eliminated from the chemical inventory. The result was complete compliance on all parameters.

All process equipment, including dyeing machines and mix tanks, should have fill levels marked for correct volume. Metering pumps should be calibrated, precise feed rates should be established for all processes, and workers should be trained to follow these process specifications. Instructions to employees must be precise, and employees must understand how to follow them. Also, proper equipment must be available to handle chemicals. A formal training program with regular refresher training is necessary to ensure success in chemical measuring, mixing, and handling. Having one employee train the next is not acceptable because this practice tends to encourage the passing on of bad habits from one generation of employees to the next (15).

Poor shade repeats are a major cause of economic loss and pollution in dyeing operations. On average, employees in a drug room or color kitchen make 300 weighings per day. Errors may arise from many sources, including sorption of moisture from the atmosphere, which may amount to a maximum of 20 percent error in dye weight (52).[4] Dry dispensing systems for powder dyes are available that are quick, easy, and accurate (see Figure 3-8). These 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. The system also includes hard automated container transport to and from the dispensing area (52).

If color is inaccurately dispensed, corrective additions must be made to the dyeing. This can not only increase the color use but also decrease color exhaust; require additional time, chemicals, and energy; and, in some cases, require stripping and redyeing. This is the costliest error of all in terms of economics and pollution. Inaccurate weighings are much worse in the drug room because steam and moisture are present, in addition to the abuse that production dye weighing scales receive compared with research laboratory scales. The manner of calibration and use of scales in weighing essential process chemicals deserves much closer attention.

Pasting procedures for dyes are not obvious and can significantly affect the quality of the work produced by the dyehouse. Each dye class has a specific pasteup procedure that must be followed for optimum results. Dye vendors readily supply proper pasteup procedures for specific dyes.

3.11.6 Worker Training, Expertise, and Attitudes

One vital piece of information that workers should be made aware of is which chemicals in that worker's area are potentially most harmful to the environment (e.g., metal-bearing dyes). The worker must be trained to be cautious about using these chemicals. Also, training must include correct procedures for pasting, dissolving, or emulsifying chemicals. These procedures should also be subject to closer auditing and recordkeeping.

3.11.7 Automated Chemical Systems

Perhaps the most significant pollution prevention achievement in textile equipment during the last 10

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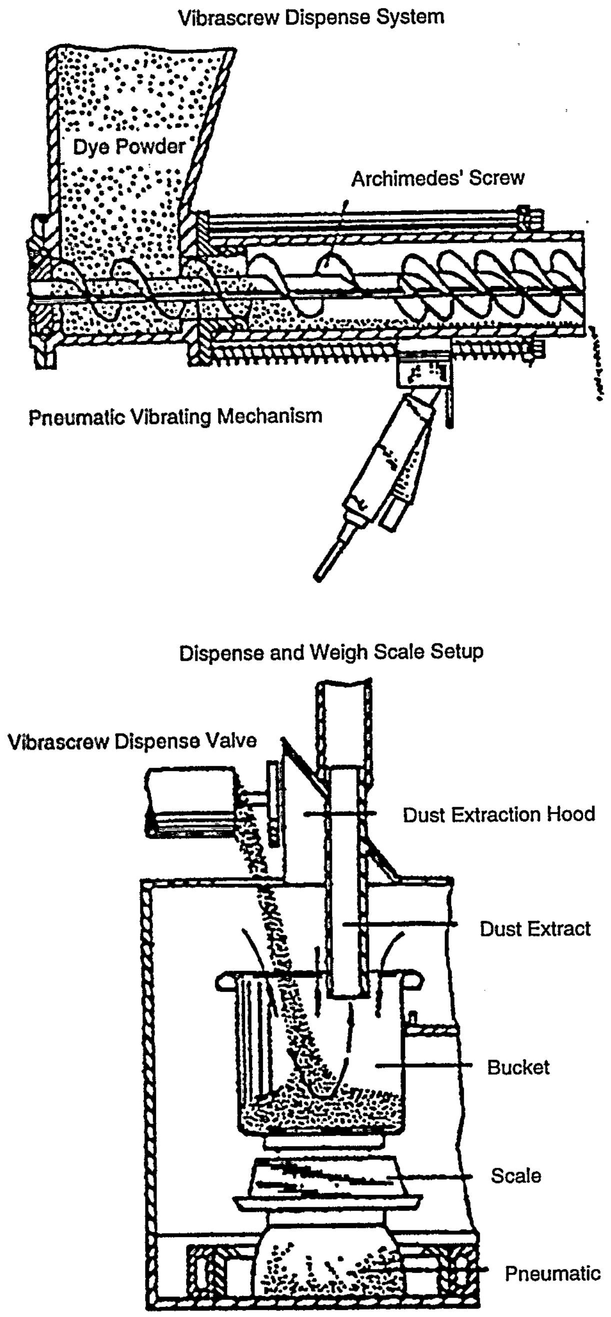
[4] Errors average about 4 percent.



Vibrascrew Dispense System

Dispense and Weigh Scale Setup

Figure 3-8. Vibrascrew dispense system (52).

years has been the introduction of automated color kitchens, bulk chemical systems, and dosing systems (see Sections 3.18.1, "Automated Mix Kitchens," 3.19, "New Equipment," and 4.11, "Printing"). These new systems not only reduce working losses from implement cleanup and disorderly work practices but also ensure that the exact amount of mix is made, reducing discards. These systems are particularly beneficial to continuous dyeing operations, printing, and finishing. By reducing startup and stopoff waste, they also make shorter runs on continuous equipment more economically feasible. A companion piece of equipment is the programmable dosing system, which can increase process efficiency greatly (27).

Computerized dispensing equipment cuts color waste and pollution (53). These systems integrate the functions of color computation (determining the exact amounts needed for the lot), color dispensing (measuring out each component of the mix or print paste), and delivery to the dyeing or printing machine (with robotics/hard automation). At least one carpet printing and dyeing company has integrated the function of a computerized dispensing machine with several other parts of the automated dyehouse control (weighing, reuse of recovered color) (53). Color reuse is done via a specially designed color reuse holding system.

3.12 Raw Material Prescreening (Before Use)

Chemical prescreening is widely recognized as an effective method for eliminating hazardous and offensive materials before they get into production processes (15, 17, 27, 43, 54). The purpose of prescreening is to determine:

- Chemical and mechanical alternatives.
- Proper use of the chemical.
- Proper training and equipment required for use.
- Incoming raw material QC test methods to be used and nominal values.
- Proper disposal and treatment methods.
- Potential environmental impacts.

3.12.1 Types of Chemicals

Textile chemicals may be classified into two categories: 1) commodities and 2) specialties. Commodity chemicals generally consist of known materials and are based on at least one relatively pure chemical substance. Specialties are proprietary mixtures of materials whose exact composition may not be known to the customer.

3.12.1.1 Commodities

Commodities used in textile mills include a wide variety of acids, alkalis, and oxidizing and reducing agents. Because these materials are of a known composition, prescreening is relatively straightforward. Prescreening of chemical commodities should be used to determine:

- Interactions with processes and substrates
- Reactions/interactions with other chemicals
- Recommended handling and application procedures
- Environmental effects

Because the materials are relatively pure and of known composition, the reactions and interactions are easy to gauge and the pollution characteristics are fairly well known. Therefore, mills have little difficulty establishing procedures for handling and for incoming raw material QC (see also Section 4.5, "Chemical Commodities").

3.12.1.2 Specialties

Unlike commodities, the composition of specialty chemicals may be unknown to the customer, and specialties are almost always mixtures of different chemicals. Thus, mills have difficulty determining the reactions and interactions with other process chemicals and substrates. The onus, therefore, falls on the vendor to provide information and assistance to the customer making the evaluation. The following is a list of typical evaluation parameters that mills should ask the vendor to supply:

- Percentage solids
- Proper manner of storage and handling
- Safety equipment required, including:
  - Personal safety equipment
  - Facility engineering controls
  - Spill control equipment
- Environmental characteristics, such as:
  - BOD (5-day and longer term)
  - COD
  - Aquatic toxicity rating
  - Polytoxicity, or other bioinhibition rating
  - Hazardous waste characteristics
  - Toxic Release Inventory (TRI) status
  - Priority pollutant content (identify)
  - Toxic/hazardous air pollutant content (identify)
  - Hazardous waste generation potential
  - Biodegradability
  - Metal content
  - Ignitability
  - Corrosivity
  - Reactivity
  - Toxicity
- Typical reactions
- Fire and spill procedures
- Proper manner of treatment and disposal
- Incompatibilities

Some of the preceding information is required to be provided on the material safety data sheet (MSDS) for the chemical product. In cooperation with the customer, however, the supplier should determine several other details. These include:

- Cost and performance in the site-specific application
- Availability of safer alternatives
- Proposed manner of use, including:
  - What will it be mixed with?
  - In what concentrations?
  - Who will handle it (level of expertise required)?
- Fate in the site-specific application, i.e., potential for:
  - Accumulation in the facility
  - Release to environment during processing
  - Release during consumer use

BOD Testing for Specialty Chemicals

The presence and accumulation of undegraded materials in waste treatment sludge is a pollution problem (54). Several BOD tests have been recommended for testing of specialty chemicals for undegraded materials. With mixtures such as specialty chemicals, different components degrade at different rates, so determining the ultimate BOD from a 5-day test (as is the case with commodity chemicals) is impossible. Therefore, longer term BOD tests are advisable. Achwal suggests a 14-day BOD test in which the percentage of degradation is determined and the specialty is classified as follows (54):

- If more than 80 percent degradation has occurred, the material is easily degradable.
- If 50 percent to 80 percent degradation has occurred, the material is moderately degradable.
- If less than 50 percent degradation has occurred, the material is difficult to biodegrade.

Moore recommends a 28-day BOD, with basically the same criteria for biodegradability.[5] For more information about specialty chemicals, see Section 4.4, "Chemical Specialties."

3.12.2 Evaluation Committee

In some companies, chemical prescreening is commonly administered by a committee comprising the following people:

- Plant nurse or industrial hygienist
- Production department manager
- Industrial engineer/environmental specialist
- Laboratory manager
- Chemist

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[5] See footnote 1.

- Legal representative
- Wage hour worker representative
- Purchasing agent

Although not all facilities employ individuals from each of these specialties, the list represents the range of skills and types of input that may be helpful when conducting prescreening evaluations.

3.12.3 Evaluation Policy

An evaluation should be performed on all chemicals, including process, maintenance, and cleaning chemicals as well as those brought on site by outside contractors. Prescreening should be a basic part of a mill's purchasing policy, inventory control, maintenance operations, housekeeping, production processes, and recovery/recycle/reuse programs. Trace impurities in raw materials should be identified and evaluated, if possible, because they can adversely affect product performance and can generate pollution (43).

3.13 Disinformation About Environmental Issues

A major trend of the 1980s and 1990s has been consumer preferences for "environmentally responsible" products. Manufacturers have responded by changing their production methods (in cases where their products were not very "green") and by making claims of environmental superiority for products they felt were produced in an environmentally superior manner. Recently, a backlash of criticism has arisen against the way in which products are evaluated and the way some companies tout the environmental benefits of their products.

The "environmental friendliness" of textile products has been the focus of some public discussion. Among the issues raised are the use of dyes and pigments that are harmful to the environment and the excessive use of chemicals for processing and finishing textiles. Some textile manufacturers have responded by misrepresenting their products with environmental claims developed through clever advertising and marketing strategies (47). For example, Mohr (47) cites efforts to promote the processing of raw cotton ("gray" or "green" cotton) directly into consumer products when in fact, the raw fiber is contaminated with natural pollutants that must be removed by scouring, bleaching, and other chemical-intensive actions to make it suitable for consumer use (47). Other manufacturers may make use of analytical tools such as product life cycle analysis in an irresponsible way to back up misleading environmental claims.

Textile manufacturers should be proactive about potential environmental charges that could be levied against their products and processes. The most effective strategy is to have in place a highly developed pollution prevention plan and a high level of expertise and awareness of pollution issues among workers and supervisors.

3.14 Scheduling Dyeing Operations To Minimize Machine Cleaning

In dyeing operations, startups, stopoffs, and color changes often result in losses of substrate, potential off-quality work, and chemically intensive cleanings for machines and facilities. Scheduling dyeing operations to minimize machine cleanings can have a considerable impact on pollution prevention.

Changes required by scheduling activities can generate significant amounts of waste for the textile mill. Machine cleaning is a significant contributor because machine cleaners are among the most toxic and offensive chemicals used in textile wet processing (15, 55). (For a more complete discussion of the losses associated with production stopoffs and changeovers, see Sections 3.8, "Maintenance, Cleaning, and Nonprocess Chemical Control," and 4.10, "Dyeing.") A well-planned dyeing schedule reduces the number of machine cleanings required and also the pollution that results from startups, stopoffs, and color changes.

Ultimately, the need for dye machine cleaning is contingent upon the sequencing of colors in the dyeing process. The ideal sequence, requiring the least amount of machine cleaning, is to run the same color repeatedly on a particular machine. The second-best dyeing sequence is to group colors within families (red, yellow, blue), then run the dyes within one color family from lighter to darker values and from brighter to duller chromas. When the darkest, dullest color of the family is reached, a thorough cleanup prepares the machine for a subsequent light, bright shade. Combining dye lots and scheduling dyeing production in this way prevents pollution by minimizing machine cleanings and mix dumps.

For scheduling of dyeing operations to become an effective pollution prevention measure, schedulers should understand the environmental impacts of their scheduling decisions. Schedulers are unlikely, however, to become experts on the impacts of scheduling on 1) process chemical discards, 2) chemical wastes, and 3) emissions factors of various production processes. Therefore, schedulers should receive some guidance making their scheduling decisions. At present, "smart" scheduling systems that can plan changeovers to minimize machine cleaning are not commercially available but are under development.[6] Once these are on the market, process engineers and schedulers will have the opportunity to control pollutants at the production scheduling and planning stage.

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[6] Stutz, G., and B. Smith, 1994. Personal communication between Gene Stutz and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

3.15 Standard Tests, Methods, and Definitions

One of the greatest needs in improving pollution prevention industrywide is the ability to transfer the successes of one plant to another and from other industries to the textile industry. Transfers of pollution prevention ideas and cleaner technologies produce successful results and require minimal cost and effort. Standardization of tests, terminology, and reporting formats is a useful tool for achieving successful transfer of information. Standardization also reduces potential disinformation and misunderstandings about processes and products. Some areas that should be standardized within a pollution prevention program, and if possible between pollution prevention programs, are:

- Audit protocols and reporting.
- Case history protocols and reporting.
- Aquatic toxicity testing and reporting.
- Quantifying treatability, offensiveness, and dispersability.
- Terminology related to biodegradability and other terms.
- Chemical and process alternative evaluation protocols.
- QC of incoming materials.

Modak reports that many international textile manufacturers are using the Austrian Textile Research Institute/Hohensteiner Institute protocol for substances called OTN 100 (24). The tests are carried out by gas chromatography/mass spectrometry (GC/MS), and the products are certified as passing the OTN 100 test.

One downfall of standardization is the negative impact it may have on creative thinking and innovation. If a pollution prevention audit or evaluation is reduced to an exercise in following a checklist or filling out a form, then the program runs the risk of becoming only a superficial activity with little importance to those involved. This is a serious matter and is the main reason why pollution prevention should be a grassroots, site-specific program, not a mandated, standardized paperwork exercise.

3.16 Consumer, Installer, and End-User Information

Consumer demand for specific products (e.g., insect-resistant wool products) is the ultimate driving force behind textile manufacturing. Unfortunately, many, if not most, consumers are unaware of the pollution the textile plant generates in an effort to satisfy consumer demand. In addition, consumers are often confused by "green" claims (see Section 3.13, "Disinformation About Environmental Issues") that are made in the absence of standard regulations and definitions (see Section 3.15, "Standard Tests, Methods, and Definitions"). As a result, consumers may express preferences for products with certain attributes or qualities with little or no knowledge of the pollution generated to produce those products. Consumers need to be educated about textile manufacturing processes and the pollution resulting from these processes in order to make better-informed choices in the marketplace.

Better-informed consumers can result in:

- Reduced demand for high-pollution products
- Improved life expectancy (durability) of textile products
- Less pollution from use, cleaning, and maintenance
- Better installation and use
- Enhanced postconsumer recycling of textile products

Consumers, however, should not bear all responsibility for a market that demands high-pollution products. Although many textile manufacturers have initiated effective pollution prevention within individual process lines, few, if any, have applied a global approach that broadly integrates pollution prevention from fabric designer to consumer.

Integration and coordination are the keys to maintaining pollution prevention all the way along the processing chain from raw material to yarn to fabric to textile product. Many of the difficulties of achieving global pollution prevention efforts have already been discussed. The basic dilemma is that pollution prevention efforts undertaken at one stage of processing may only benefit downstream operations. Unless they are all part of an integrated operation, no mechanism exists for upstream operations to recoup the costs or reap the benefits of any pollution prevention initiatives they may undertake.

Further difficulties arise when textile materials are combined with other raw materials to produce final consumer products (e.g., furniture). Often, textile manufacturers do not know which materials will be combined or in what manner they will be combined after they leave the mill. For example, in furniture upholstering, upholstery fabric can be combined with batting, fiberfill, open or closed cell foams, and stiffening innerliners. Problems arise when consumer product manufacturers lack good information about incompatible material combinations, especially those that could produce pollution such as indoor air emissions, sorption, and reemissions. This makes product design difficult for all involved.

Accurate, clear consumer information on product use with respect to aftermarket treatments, cleaning solvents, use conditions, installation and maintenance, and recycling is also needed. High and low polluting products (in terms of manufacturing) need to be accurately identified to the customer. In addition, better information on material combinations is needed. In short, a clear need exists to provide better information on product use, installation, and material combinations to all involved, including textile producers, consumer products manufacturers, and customers. Marketing is a crucial link in this chain. Some industries (e.g., pharmaceuticals) do an excellent job of informing consumers, and the textile industry can learn from these industries. In addition, the textile industry needs to emulate other successful techniques such as better technical product bulletins and product specifications. Providing this information would also help avoid certain common quality problems such as color bleeding of knit shirts with contrasting collars.

3.17 Segregation and Direct Reuse

One cornerstone of good waste management is that individual waste streams must be separately captured, segregated, and stored to maximize the potential for recovery, recycle, and reuse. This is true for waste streams from several textile processing operations including preparation, dyeing, printing, and finishing (see Sections 4.9, "Preparation," 4.10, "Dyeing," 4.11, "Printing," and 4.12, "Finishing," for more detailed descriptions).

For example, in printing operations, Malone suggests that, when producing many special customer colors, excess material and overproduced material should be held in inventory until a suitable use is found (18). The stored excess can be used as a component in a new color mixture (see Section 4.11, "Printing").

New machinery is available with built-in features that facilitate recovering and reusing waste streams. One example that can be widely applied in textile processing is the Scholl BLEACHSTAR. This machine has built-in facilities for waste stream segregation and capture (see Section 3.19, "Pollution Prevention Through New Equipment").

In addition, some facilities use multiple waste handling systems to segregate wastewater for more efficient reuse or treatment into:

- Noncontact cooling water.
- Stormwater from parking lot and roof drains.
- Cleanup water from machines, facility, and filter backwash.
- Process wastewater from preparation, dyeing, and finishing.

In the future, facilities and equipment will require even further segregation of wastewater. For example, highly colored or high salt content wastes can be better handled if separated from other waste streams. Reuse and treatment of these pollutants are expensive. Keeping these wastes separate from other wastes is essential to keeping the treated volume low.

3.18 Improved Process Control

In the past, control systems in textile operations involved the automation of existing manual methods. In many cases, these methods have been enhanced with attractive graphic displays and other aesthetic improvements, but the underlying control protocol remains the same as with the manual methods. A new generation of innovative control systems is being developed that actually uses more capabilities of microprocessors. Some are hard automated systems, and others employ sophisticated fuzzy logic or neural network control strategies. These are described in more detail in Section 3.19, "Pollution Prevention Through New Equipment," but are briefly mentioned here as well. Some examples are:

- Automated mix kitchens
- Chemical dosing systems
- Direct dyebath monitoring and control systems
- Real-time sensors and advanced control strategies
- Real-time multichannel adaptive control systems
- Scheduling and management systems

3.18.1 Automated Mix Kitchens

Automated mix kitchens are used for making print pastes and finish mixes, and for dye dispensing (both powder and liquid dyes). Laboratory systems are also available. These improve the speed and accuracy of dye and chemical dispensing, and eliminate a substantial amount of waste. For further information, see Sections 3.19, "Pollution Prevention Through New Equipment," and 4.18, "Support Work Areas."

3.18.2 Chemical Dosing Systems

Chemical dosing systems are similar to automated mix kitchens; however, they actually meter dyes or chemicals into the process. Dosing systems can produce many more dosing profiles and can be computer controlled and integrated with other dyehouse functions such as scheduling. For further information, see Sections 3.19, "Pollution Prevention Through New Equipment," and 4.10, "Dyeing."

3.18.3 Control, Automation, Scheduling, and Management Systems

Modern control systems typically control parameters such as:

- Air exhaust and moisture control from dryers

- Chemical feed or addition
- Cooling and heating
- Draining and filling
- Incident (tangle) alarm
- Pressure control, speed, flow, and temperature

These control systems follow a predetermined process routine and can be programmed with extreme accuracy. Pollution decreases with these systems because the improved control increases the likelihood of right-first-time processing. This saves time, energy, and chemicals, and facilitates chemical handling within the operation.

3.18.4 Real-Time Sensors and Advanced Control Strategies

One innovation that has occurred at the front end of many control systems is the adoption of rapid, accurate, real-time sensors. These enable the operator to monitor and evaluate important process parameters. In many systems, predictive models are embodied in the controls, which can make quick changes, adjusting operating variables to achieve the desired result. Some applications of these systems, which are discussed in Section 3.19, "Pollution Prevention Through New Equipment," are:

- Dryer efficiency and air pollution improvement
- Direct dyebath monitoring and real-time control

In these applications, traditional control strategies are replaced with innovative strategies that adaptively adjust in real time to compensate for uncontrollable parameters. This allows a better chance of right-first-time results despite raw material and other variations (55).

3.19 Pollution Prevention Through New Equipment

Equipment design, maintenance, and operation are essential elements of an effective pollution prevention program. During the last few years, certain new equipment concepts, as well as modifications to existing equipment, have appeared that directly contribute to the reduction of pollution from textile processing operations. Some of this equipment is mature and commercially proven, and is being readily adopted by textile mills as they replace older equipment. Other ideas are still unproven but show promise and deserve attention as attempts to bring them to a state of commercial usefulness progress.

3.19.1 Proven Commercial Technologies

The most notable proven, mature, commercial technologies are:

- Automated mix kitchens.
- Built-in bath reuse facilities on dye machines.
- Chemical recovery systems for caustic and size.
- Chemical dosing systems.
- Continuous knit dyeing ranges.
- Control, automation, and scheduling management systems.
- Countercurrent washing.
- Heat recovery systems.
- Humidity sensors and advanced controls for drying.
- Incinerator dryers.
- Low-bath-ratio dyeing systems.
- Mechanical finishing (e.g., compacting).
- Pad-batch dyeing machines for fiber-reactive dyes.
- Quick-change pads on continuous ranges.
- Transfer printing machines.
- Laser engraving of printing screens.
- Low add-on finishing.
- Waste reclamation systems for spinning.
- Water recovery systems.

3.19.1.1 Automated Mix Kitchens

Several manufacturers now offer automated mix kitchens for making print pastes and finish mixes. They also offer versions for dye dispensing of powder or liquid dyes in batch or continuous dye houses. In addition, similar systems are also available for the laboratory to improve speed and accuracy in color matching. The industry is beginning to adopt these systems and is using them in more sophisticated operations. In many cases, these systems connect directly to IBCs, and thus eliminate the potential for dye spillage, requirements for implement cleanup, and other polluting manual work practices. These systems also increase the accuracy of dispensing, and odd-sized mixes can be made to exactly accommodate varying lot sizes in continuous operations, thus reducing discards. For further information, see Section 4.18, "Support Work Areas."

3.19.1.2 Built-In Bath Reuse on Dye Machines

Several dyeing machine manufacturers offer machines featuring holding tanks that can store processing baths for reuse. In most cases, each machine has two or three of these holding tanks. These tanks accommodate reuse of preparation, dyeing, and wash baths, thus reducing water consumption. These machines are easily recognizable by the large holding tanks mounted beside the main kier. A sample configuration and a sample procedure for bleaching are shown in Figure 3-9.

A related configuration is the dual-kier system. Manufacturers have offered these systems for some time in package dyeing, and now offer them for piece dyeing machines as well. These systems allow processing bath to be pumped back and forth between two different dyeing kiers for reuse purposes.

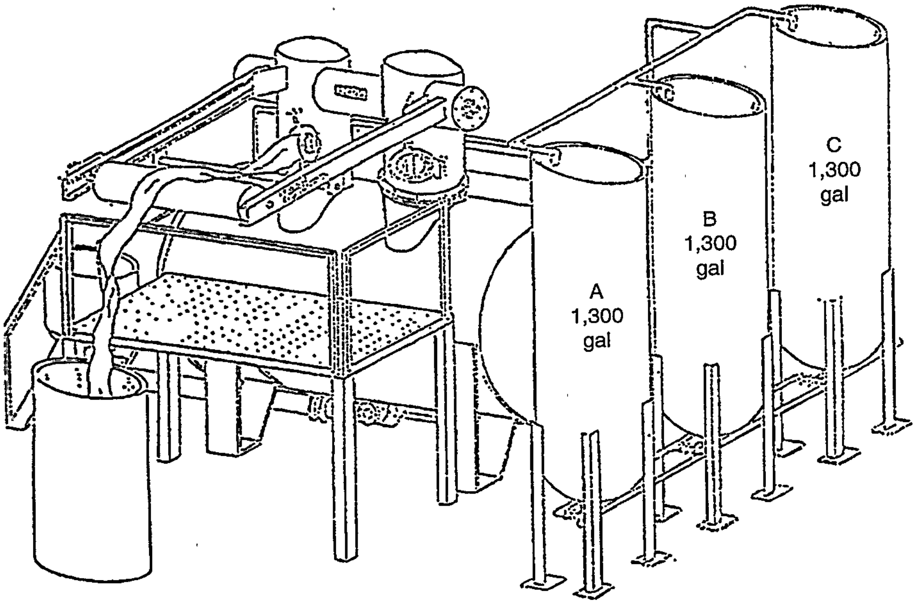
For further information on dyebath reuse, see Section 4.10, "Dyeing."

3.19.1.3 Chemical Recovery (Caustic and Size)

Caustic soda (sodium hydroxide) and certain warp size materials can be recovered for reuse with commercially available systems based on ultrafiltration, hyperfiltration, reverse osmosis, or evaporative recovery methods. Textile mills have adopted these systems but not as widely as would seem to be merited. Barriers to further use of recovery include logistical difficulties, and the need to segregate waste streams. In cases where mills do adopt these systems, the result can be outstanding cost and pollution savings. A schematic of the equipment for these recovery systems is shown in Figure 3-10. For further information on size and size recovery, see Section 4.7, "Slashing and Sizing."

3.19.1.4 Chemical Dosing Systems

Chemical dosing systems are somewhat similar to the automated mix kitchens discussed above in that they provide many of the same pollution prevention advantages. The function of these systems, however, is more than simply to weigh out the correct amount of material to make a mix. These chemical dosing systems meter the chemical into the dye process according to a specific dosing strategy. For years, dyers have manually added salt and buffers to dyeings according to specific chemical dosing versus time schemes. Dosing systems automate this function, make many more dosing schemes available, and can be computer controlled. This improves reliability of the dosing process, thereby increasing the replicability of results and the probability of



Example Procedure:

1. Bleach: Fill from Tank A; bleach; drain to pit.
2. Hot Rinse: Fill 650 gal from Tank B; drain to Tank A.
3. Hot Rinse: Fill 650 gal from Tank B; drain to Tank A; Tank A is full.
4. Warm Rinse: Fill 650 gal from Tank C; drain to Tank B.
5. Warm Rinse: Fill 650 gal from Tank C; drain to Tank B; Tank B is full.
6. Neutralize: Fill 650 gal from fresh water; drain to Tank C.
7. Final Rinse: Fill 650 gal from fresh water; drain to Tank C; Tank C is full.

Tanks A, B, and C are full and ready for next process.

Figure 3-9. Dyeing machine configured for dyebath reuse (56).

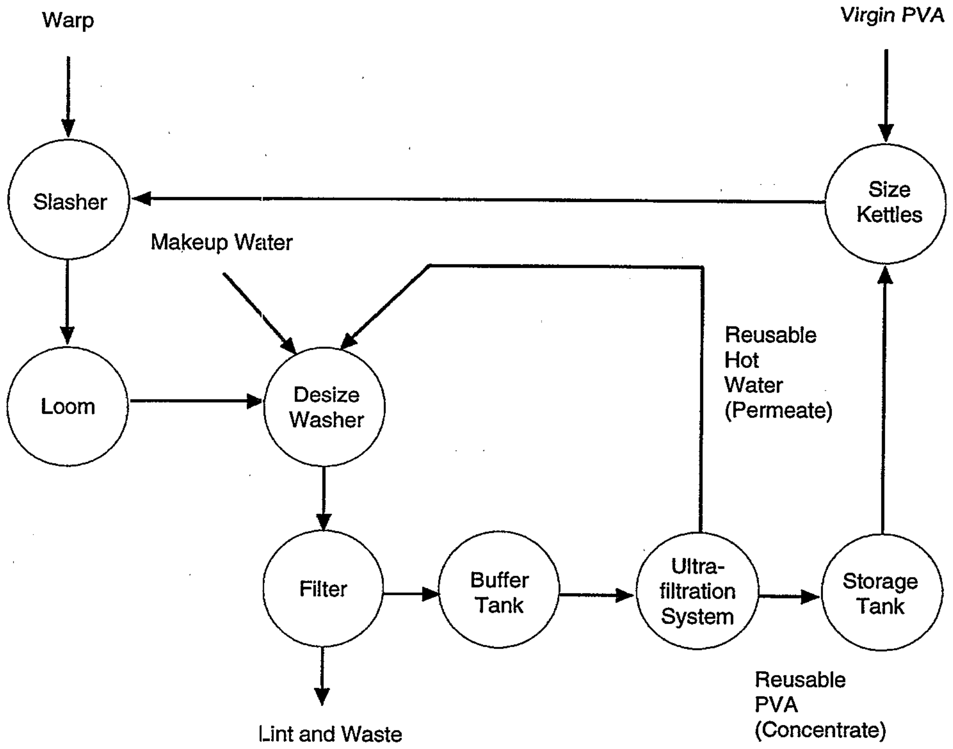


Figure 3-10. Schematic of PVA size recovery.

right-first-time dyeing. For further information about dosing systems, see Section 4.10, "Dyeing."

3.19.1.5 Continuous Knit Dyeing Ranges

Continuous dyeing offers certain pollution advantages compared with batch dyeing. One limitation of conventional continuous dyeing ranges, however, is their inherently high tension and therefore their inability to run knits. Several equipment manufacturers have recently introduced continuous knit dyeing ranges. These feature tensionless knit handling, dye application systems that avoid tubular edge marks, suitable guidance systems for knits, and other such features to overcome the limitations of continuous dye ranges. The ability to run knits by continuous dyeing methods presents many new possibilities, including the use of vat dyes for green shades (thus eliminating metal-bearing reactive dyes from formulas), elimination of salt from effluents, and increased flexibility for dye class selection. A diagram of a typical continuous knit configuration is shown in Figure 3-11.

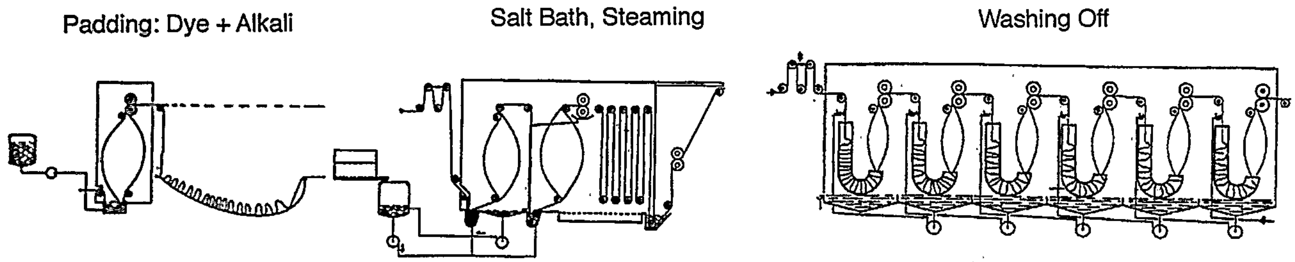
3.19.1.6 Control, Automation, and Scheduling Management Systems

One major change in the textile industry during the past 20 years has been improved process controls. Modern microprocessor technology enables each machine to be controlled according to a predetermined process specification. These systems perform tasks such as controlling:

- Air exhaust rate (ovens)
- Chemical feed or addition (dye machines, bleach ranges)
- Cooling
- Draining
- Filling (dye machines)
- Heating
- Incident (tangle) alarm
- Moisture control (dryers)
- Pressure control
- Speed or flow control
- Temperature

Once a predetermined optimized process is programmed into the controller, these and other tasks can be handled automatically, and the system reports to the supervisory computer all exceptions and other pertinent information about the process. One indication of the commercial impact of these new controllers is that the ITMA 1987 textile equipment show in Paris, France, comprised more companies showing controllers than companies showing dyeing machines. These controllers reduce pollution by improving:

- Probability of right-first-time processing
- Process conformance to standards
- Use of time, energy, and chemicals



Steps	Padding	Penetrating
Time	6 sec	60 sec
Temp.	20 - 30°C	
Pick-up	90 - 120%	

Levelling	Fixing
15 sec	75 sec
90	103
ca. 400%	90-120%

Rinsing		Soaping		Rinsing	
10 min	10 min	10 min	10 min	10 min	10 min
20	70	95	95	70	40
ca. 400%, after squeeze 140%					

Figure 3-11. Continuous dyeing of tubular cotton knits (57).

- Equipment operations audit
- Chemical handling practices

One such system is shown in Figure 3-12. It interfaces the management information system with dosing, blend water temperatures, dyeing machine control, report generation, automatic drug room, and other functions.

3.19.1.7 Countercurrent Washing

The practice of countercurrent washing is widely practiced in textile operations. This involves introducing raw water into the last of a series of washing steps, then circulating the wastewater from the last step to the next preceding step and so on up the line. In this way, the cleanest fabric is washed with the cleanest water, and the most contaminated fabric is washed with the least-pure water. This results in a huge water savings in multistep washing operations. For example:

Number of Washing Steps	Water Savings (percent)
2	50
3	67
4	75
5	80

Some washing equipment (i.e., horizontal washers) has the same inherent counterflow characteristics built into the design. In all washing steps, using the correct flow is essential. Excessive flow wastes water, and insufficient flow results in bad work.

Further information about countercurrent washing may be found in Section 2.2.7, "Water Conservation."

3.19.1.8 Heat Recovery

Many types of successful heat recovery systems have been developed, and the textile industry has started to adopt these systems widely in wet processing operations. The collection systems for water often feature underflow dams and other devices to stratify water before sending it to the heat exchanger. The recovered heat is useful in washing and fill water for the dye house.

3.19.1.9 Humidity Sensors in Drying

Dryer efficiency and air pollution are significant concerns with tenter frames and other drying devices (e.g., yarn dryers). Many important factors must be controlled, including the temperature of the dryer, the time of heating, the makeup air supply, and the humidity in the dryer. If the temperature is too high, undesirable dye and finish migration occur. If the temperature is too low, drying requires excessive time. Equally important is the humidity in the dryer. When the humidity is too high because of insufficient introduction of makeup air, moisture evaporates very slowly. If the makeup air is excessive, however, the humidity is very low and the drying is rapid, but excessive energy is required to heat the makeup air. Also, increasing the makeup air causes the oven exhaust to emit

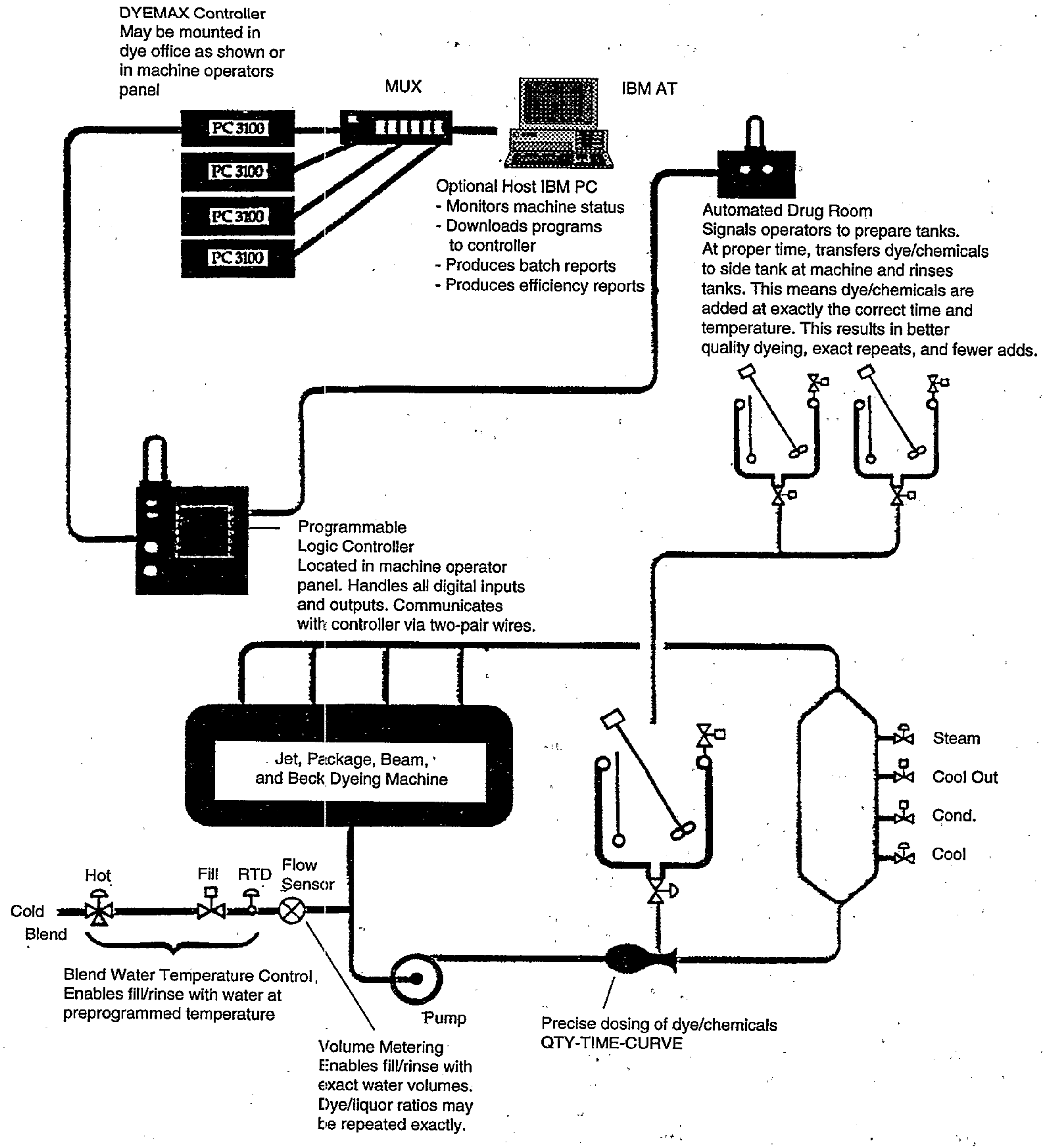


Figure 3-12. Automated process control system (58).

more air pollutants. Humidity monitors in the dryer provide real-time data to a system that controls exhaust dampers and makeup air to optimize dryer performance in terms of energy use, dye migration, and air pollution.

3.19.1.10 Incinerator Dryers

Another improvement in dryer efficiency is the use of incinerators or thermal oxidizers on the dryer exhaust to destroy contaminants in the discharge air stream. Heat can then be recovered from the exhaust gas and recycled into the dryer as preheated air.

3.19.1.11 Low-Bath-Ratio Dyeing Systems

One important parameter in batch dyeing is the bath ratio, or the ratio of the mass of the dyebath to the mass of the goods in the dyeing machine. The bath ratio varies greatly from one type of dyeing machine to another. In recent times, jet and package dyeing machines have been introduced with ever-decreasing bath ratios. In the 1960s, bath ratios of 12:1 were the norm. Some of the newest dyeing machines, called utra low liquor ratio (ULLR) machines, have bath ratios of 3:1 for synthetics and 5:1 for cotton. The machine shown in Figure 3-13 runs at 5:1 and below.

These low bath ratios have been accomplished through new engineering design concepts for the machines. The pollution prevention advantages of the lower bath ratio are less:

- Salt required for exhaust dyeing on cotton
- Dyebath chemical required
- Unfixed dye at lower bath ratio
- Energy required to heat up dyebaths
- Time required to fill and drain machine
- Water used

One vendor's cost comparison of low-bath-ratio jets with other dyeing machines is given in Table 3-16. The higher productivity and lower water, steam, and chemical costs produce savings estimated at $0.0835 per pound dunning polyester/cotton and 100 percent cotton (56). Based on 100,000 pounds per week production running 52 weeks per year, the total annual savings amount to $.0835 x 100,000 x 50 = $417,500.

In addition, some machines (air jets) use air, not water, as the transporting mechanism. These machines were introduced in 1975, but the early models were not successful. The latest is the then AIRFLOW, which reportedly can run at bath ratios of 2:1 or less.

Further information on low-bath-ratio dyeing may be found in Sections 2.2.2, "Discharge of Electrolytes," and 4.10, "Dyeing."

Table 3-16. Estimated Savings With ULLR Dyeing Equipment (56)

Parameter	Conventional Equipment	ULLR Equipment	Change	Percent Change
Bath ratio	10:2	5:1	—	—
Productivity	282.77	316.39	33.62	11.9
Cost Factors				
Water	0.0189	0.0119	–0.007	–37.0
Steam	0.0161	0.008	–0.0081	–50.3
Electricity	0.0052	0.0052	0	0.0
Direct labor	0.0309	0.0277	–0.0032	–10.4
Chemicals	0.138	0.0774	–0.0606	–43.9
Supplies	0.0089	0.0088	–0.0001	–1.1
Overhead	0.0424	0.0379	–0.0045	–10.6
Total	0.2604	0.1769	–0.0835	–32.1

3.19.1.12 Mechanical Finishing (Compacting)

Several methods exist for providing desired end-use performance in terms of shrinkage control, softness, width, yield, and other factors without using chemical finishes. A typical method is compacting, a process that preshrinks fabrics to a stable configuration, thereby eliminating the need for cross-linking resins, which contain formaldehyde. Compactors have been widely adopted in the textile industry and are very reliable for both knits and wovens. Several types of machines are

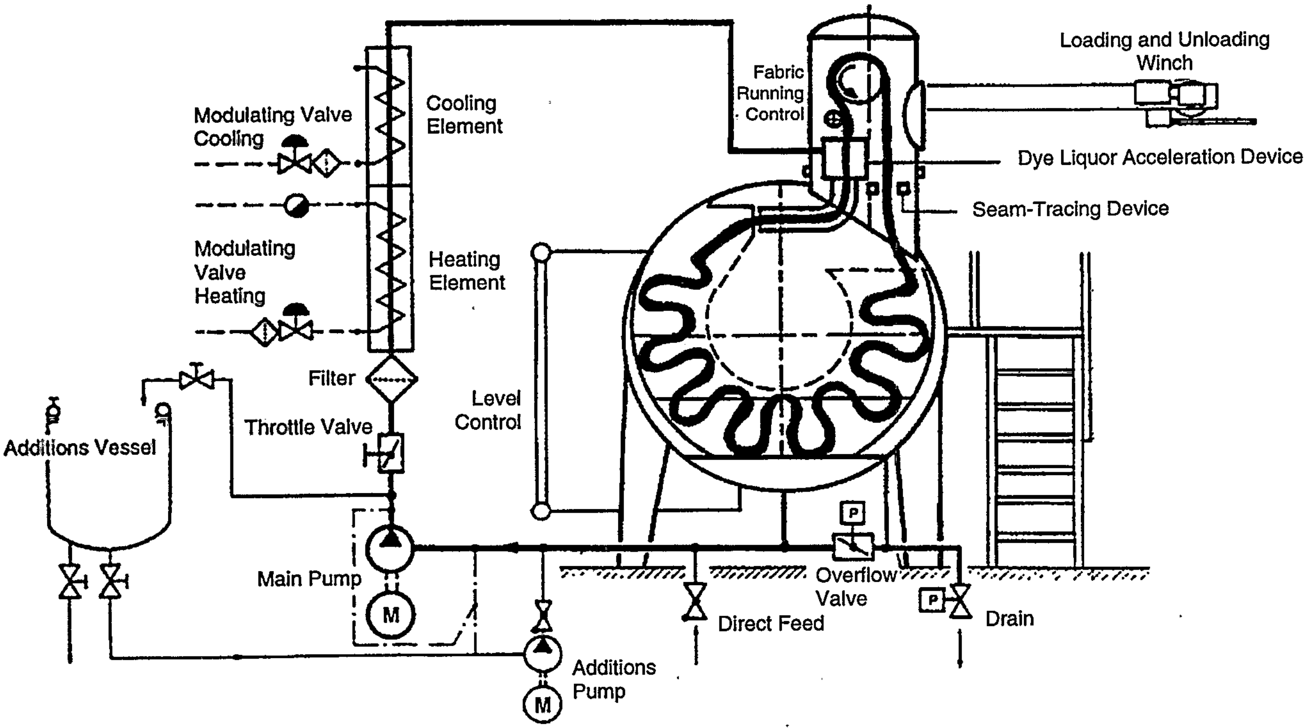


Figure 3-13. ULLR piece dyeing (56).

available, employing rubber belts or sets of rolls with differential speeds. A diagram and explanation of the rubber-belt type is found in Figure 3-14. For further information on mechanical finishing, see Section 4.12, "Finishing."

3.19.1.13 Pad-Batch Dyeing of Fiber Reactives

The most popular method of batch dyeing of cotton, especially cotton knits, is fiber-reactive dyes. These have the disadvantage of producing excessive color and salt in wastewater when applied by batch methods. The pad-batch dyeing system eliminates these problems, and allows knits to be dyed semicontinuously with fiber reactives, but without salt, and increases fixation typically well above 90 percent. This method uses special padders and tubular knit guiding and handling equipment to ensure even dyeing without distortion or stretching of the knit fabric. Equipment configurations resemble the continuous knit ranges in Figure 3-11. For further information on pad-batch dyeing, see Section 4.10, "Dyeing."

3.19.1.14 Quick-Change Padders on Continuous Ranges

One major limitation of continuous dye ranges is the cost of stopoff, startup, and color changes. Generally, a certain amount of fabric must be sacrificed before achieving a steady state of running. Also, some dye solution must be discarded from lines, pumps, and pad troughs. This causes time loss, pollution, and expense. To minimize such losses, several manufacturers now offer quick changeover pads, which have very small volumes and can drop down and swing away from the fabric path to facilitate rapid dumping and cleaning. Schematics showing how these systems operate are shown in Figure 3-15. Further information may be found in Section 4.10, "Dyeing."

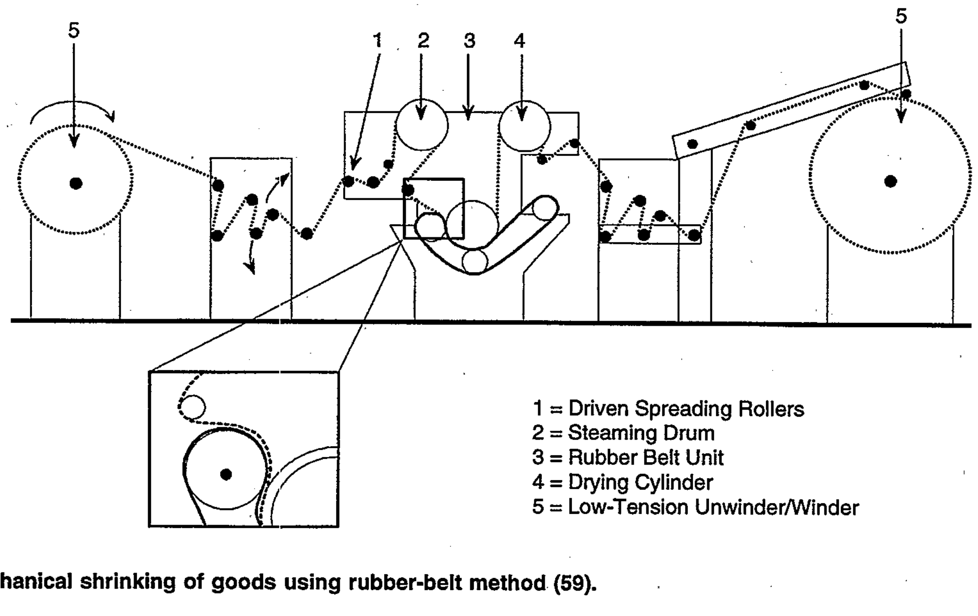
3.19.1.15 Transfer Printing

Similar start-up and stop-off losses associated with pattern or color changes occur in the printing process. One way to avoid these losses for printing of disperse dyes on polyester is through transfer printing. This technique prints the disperse dye onto a paper substrate, then transfers the dye under high temperature and pressure onto the polyester fabric by sublimation. Overall, this method accounts for approximately 6 percent of all printing done today worldwide (61).

Transfer printing offers many advantages, including:

- Color changeovers are essentially instantaneous.
- Short runs are not a problem.
- Paper printing is more efficient than fabric printing.
- Cloth and paper are both preinspected, avoiding off-quality printing.
- Textile mills can start printing with minimal capital outlay.
- Cost per unit of fabric printed is lower.

Transfer printing equipment is simple, consisting of only a heated cylinder and a blanket or other means of maintaining contact between the fabric and the paper. The limitation of the system is that it only works for disperse dyes. A diagram of a transfer printing machine is shown in Figure 3-16. For further information on transfer printing, see Section 4.11, "Printing."



1 = Driven Spreading Rollers
2 = Steaming Drum
3 = Rubber Belt Unit
4 = Drying Cylinder
5 = Low-Tension Unwinder/Winder

Figure 3-14. Mechanical shrinking of goods using rubber-belt method (59).

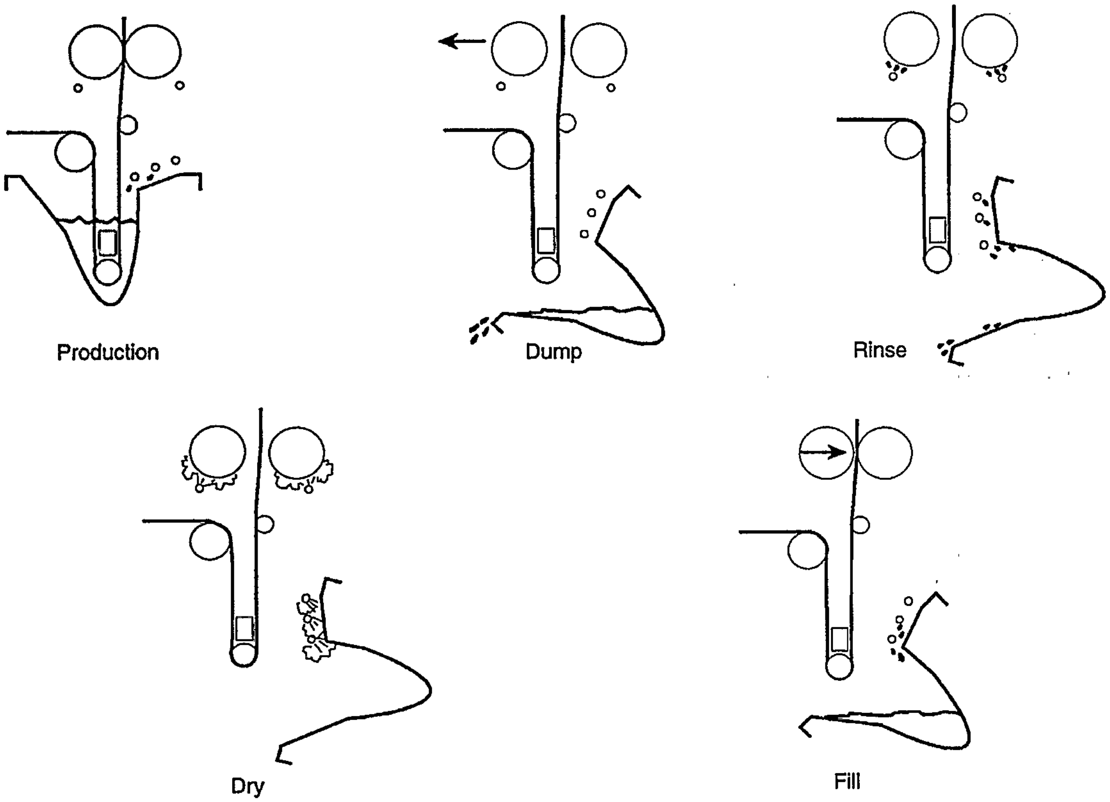


Figure 3-15. Quick-change S-roll pad to reduce startup, stopoff, and changeover losses (60).

3.19.1.16 Laser Engraving of Printing Screens

Conventional methods of print screen making involve photographic processes, manual film making, registration verification, and, finally, working with lacquer-coated screen material to produce a rotary screen. New laser engraving techniques allow for direct digital scanning (or on-screen design) of patterns, thus avoiding toxic photographic silver residues. The quality of the screens is also better. A typical setup includes a digital scanner, CAD workstation, and the engraver, which uses a helium-carbon dioxide laser. Several systems have been installed in the United States in recent years.

3.19.1.17 Low Add-On Finishing

Several types of low add-on finishing machines are available. All types apply a very low amount of finish solution to the fabric, thus reducing energy and chemical use. Some of the more popular methods are (40):

- Ultra high extraction with vacuum
- Sprays
- Foams
- Kiss rolls

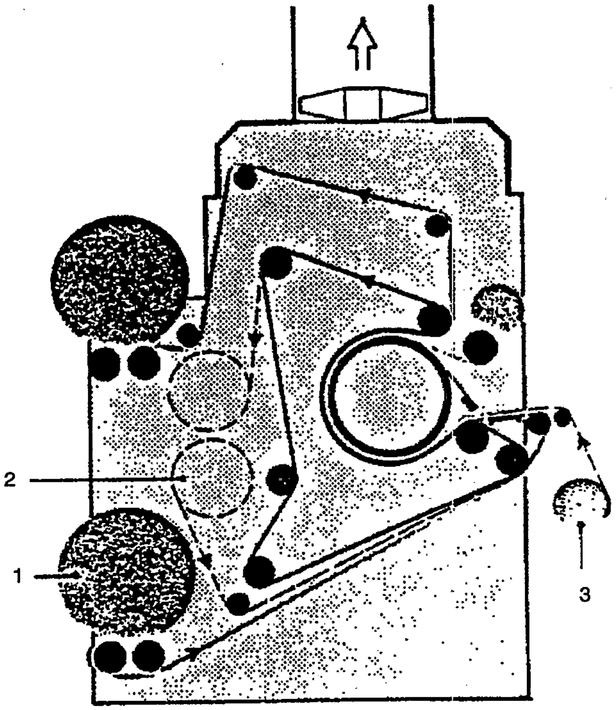
Vacuum extraction is used in many ways to reduce pollution in textile wet processing operations. The most simple way is to reduce the water content of fabric before it goes into a drying process. Reducing the moisture mechanically by vacuum reduces the heat energy required to dry the fabric. This means faster dryer speeds and lower costs. Also, finishing at lower WPU levels offers many advantages, including reduced chemical use. Other applications related to pollution prevention include the ability to avoid dragout and carryover of processing solutions from one processing step to the next. This can, for example, increase the efficiency of washing. High-extraction, low-carryover process step separations generally prevent pollution. Tests of the EVAC system of vacuum finishing showed that for a given crease recovery angle performance, fabrics show less strength loss using the vacuum-extracted finishing method. The vacuum-extracted finishing samples had lower formaldehyde release for the same level of performance, and fewer chemicals were used than in conventional finishing (62).

The EVAC vendor reported trials showing impressive results. For example, Table 3-17 shows the results obtained in one trial. The test showed that equal or better shrinkage control could be obtained using low add-on, wet-on-wet finishing, with lower chemical and energy use.

Foam finishing uses air to dilute the water in a chemical solution, thus lowering the WPU of the fabric and the energy required for drying. Foams can be somewhat hard to control, but they are useful in certain applications. Carpet dyeing and certain backcoating operations are done with foam. A typical foam setup is shown in Figure 3-17 for foam finishing of tubular knit fabrics.

High extraction for moisture removal before drying is shown in Figure 3-18. It uses a high-velocity steam jet plus vacuum to blow out the excess moisture.

For more information on low add-on finishing, see Section 4.12, "Finishing."



1. Textile
2. Protective Paper
3. Transfer Paper

Figure 3-16. Transfer printing of disperse dyes on polyester (61).

Table 3-17. Results of Tests on Knit Finishing System Using Vacuum Technology[a]

	Shrinkage percentage (length × width)		
Fabric	**Untreated**	**Low Add-On**	**Conventional**
Interlock(k)[b]	15 × 4	6 × +2[c]	6 × 3
Jersey(k)	12 × 2	7 × +1	8 × 3
Sheeting(w)[d]	8 × 3	2 × 0	2 × 1
Twill(w)	11 × 0	3 × 0	3 × 1

[a] Tyndall, M. 1989. Memorandum from Mike Tyndall, Cotton, Inc., Raleigh, NC, summarizing results of tests of the EVAC Ultraknit trial (May 8).
[b] k = knit.
[c] + = growth.
[d] w = woven.

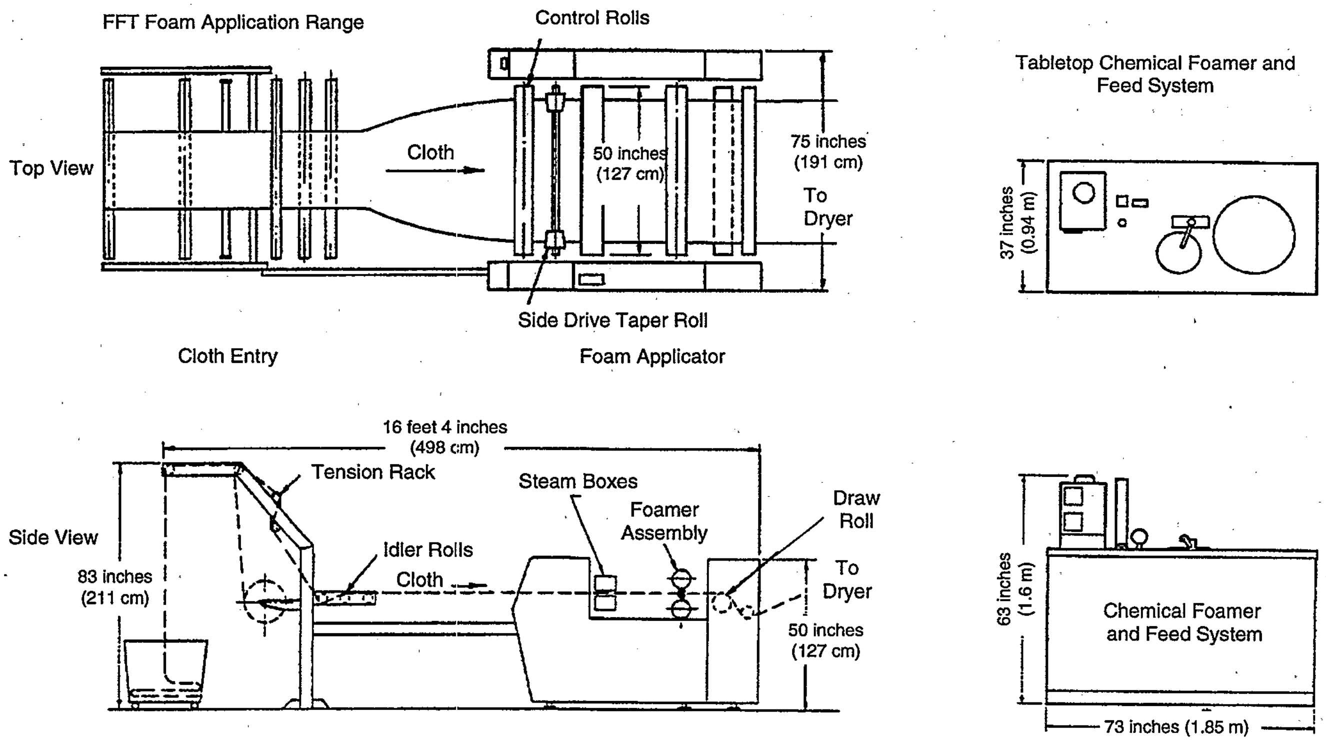


Figure 3-17. Foam finishing for low add-on (63).

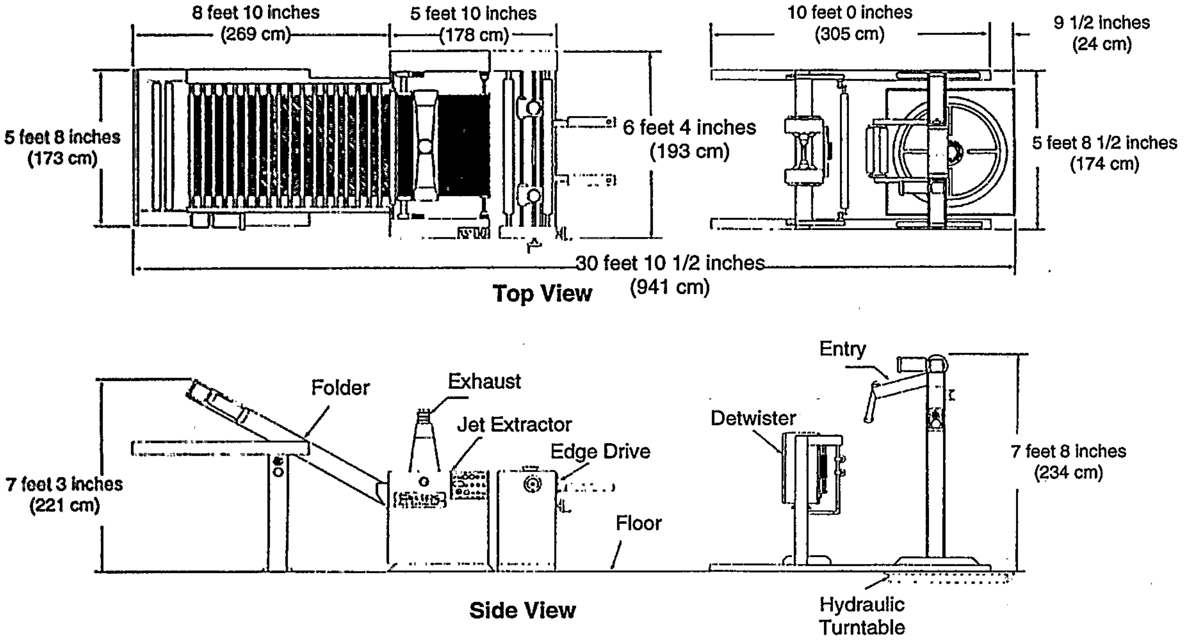


Figure 3-18. High-extraction removal before dyeing (64).

3.19.1.18 Waste Reclamation in Spinning

Part of every cotton spinning operation involves the removal of undesirable impurities, trash, and tangled fiber masses from the raw cotton stock. In the past, this nonreworkable waste was discarded. Now, systems are available to collect it at its sources and reprocess it to recover lint. The recovered lint is recycled into other cotton spinning operations, while the approximately 1.5-percent residual trash can be sold for reuse in padded mailing envelopes or compressed into extremely high-density fuel pellets for boilers. For further information, see Sections 4.2, "Fiber," and 4.8, "Fabric Formation."

3.19.1.19 Water Recovery

Many systems are available that can recover water from waste streams. The size and chemical recovery systems described previously in this section recovered water as a side benefit. Filter-based decolorization systems also can recover water in a reusable form. Other systems for renovation of dyeing wastewater use ozone or chlorine.

3.19.2 Emerging Technologies

Many new technologies have been proven at the pilot scale but have yet to be fully adopted by industry. Some will no doubt be more successful than others. These technologies show promise, however, and their commercial development should be monitored.

The most notable emerging technologies include:

- Direct dyebath monitoring and control systems
- Real-time adaptive control systems
- Electrotechnologies
- Ink-jet printing
- Supercritical fluid dyeing
- Ultrasound dyeing

3.19.2.1 Direct Dyebath Monitoring and Real Time Control

Traditional textile process control strategies are based on defining an optimized process, then controlling the machinery and services to conform as closely as possible with that process specification in terms of parameters such as time, temperature, and machine speed. In textile dyeing, for example, the fishbone diagram in Figure 3-19 shows that the dyer cannot control many of the variables. The traditional approach has been to accept the resulting shade variations and to compensate for product variances by segregating each dye lot, rather than mixing it with others (65).

New control strategies have been developed that adaptively adjust the process in real time to compensate for uncontrollable parameters, thus arriving at the desired result despite anomalies such as those that occur in raw materials and utilities. This control system is based on real-time adaptive dynamic control of the process, using real-time data, and accurate prediction of final dyebath

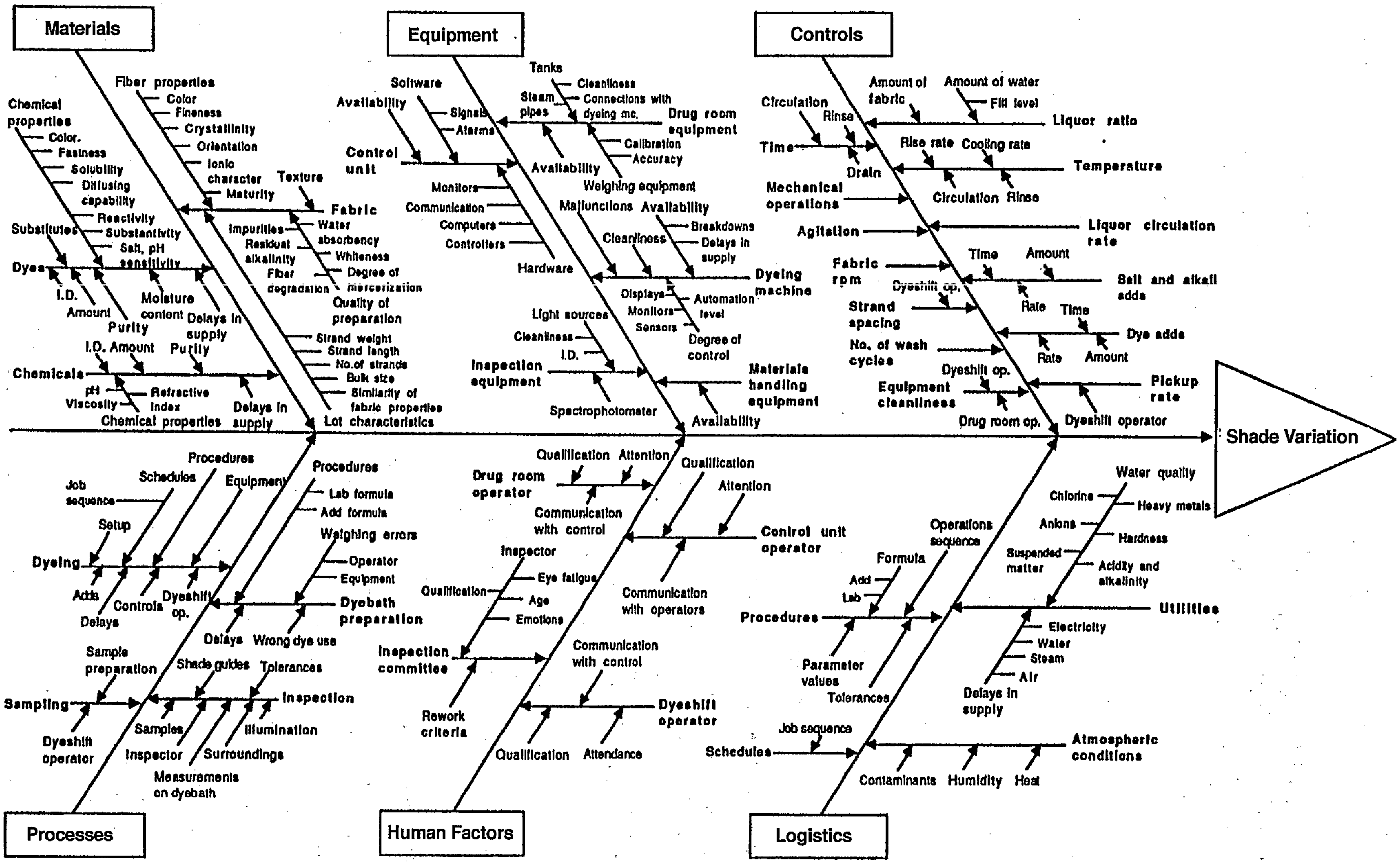


Figure 3-19. Cause-effect diagram for shade variation in batch dyeing (66).

exhaustion based on the dyebath state at any given time. The control system then determines an optimized predicted process necessary to reach the standard target.

One particularly useful parametric control model for that purpose is the standard Langmuir kinetic model based on the sorption and desorption rate constants (k_a and k_d respectively), a parameter related to dye sites or dyeing capacity of the fiber (S), and solution and fiber concentrations of dye at any time (c^s and c^f respectively):

$$dc^f/dt = -dc^s/dt = [k_a c^s (S-c^f)] - [k_d c^f] \qquad \text{(Eq. 3-6)}$$

Process control strategies based on the above parametric model have been highly successful for real-time control of processes involving individual dyes. Given the necessary parameters, which are estimated in real time from the progress of the dyeing itself, the control algorithm determines conditions and time at which a desired percentage exhaustion will be reached. Data from ordinary production dyeings can be used to construct predictive models of dye process behavior, including, for example, temperature dependance of the above parameters for individual dyes. In this way, real-time adaptive control models can be developed without extensive test dyeings on production machinery.

3.19.2.2 Ink-Jet Printing

Commercial units are being offered for ink-jet printing, in which droplets of dye solution are directed toward specific spots, thus forming a pattern (67). The method is not yet commercial but holds promise as an emerging technology. The need for photographic screen-making and most color mix kitchen activities are eliminated. Significantly fewer chemicals are required, and pattern/color changes are simple. This method produces virtually no cleanup waste. Ink-jet printing is a well known method in document printing, and it can easily be applied to textile fabrics too.

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Chapter 4
Pollution Prevention in Specific Textile Processes

4.1 Introduction

This chapter identifies pollution prevention opportunities in specific textile processes or operations. The chapter roughly follows the stages of textile manufacture. It begins with several sections covering raw material handling and use, including issues related to raw fiber production and processing, dye selection and use, as well as chemical specialties and commodities. Subsequent sections cover yarn formation, slashing and sizing, fabric formation, textile preparation, dyeing, printing, finishing, and cutting and sewing operations. Additional sections go beyond the textile mill to address issues related to installation of textile materials, aftermarket treatment of textiles, consumer care issues, globalization of pollution prevention, and pollution prevention in support work areas.

Each section discusses environmental issues for that particular part of the operation and identifies relevant pollution prevention opportunities. A particular effort is made to relate environmental problems in each phase of operations to other stages of production, both upstream and downstream, and to highlight the connection between operating practices in one part of the operation and pollution problems elsewhere. A major theme of this chapter is the need for a broader, more global approach to pollution prevention, as summarized in Section 4.17, "Globalization of Pollution Prevention."

4.2 Fibers

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.2, Fibers (General)		
Residues from agriculture, synthesis, and/or other upstream operations	Incoming raw material QC	Air and water pollution results during scouring (see Section 4.9.1.3) and heated operations (see Section 4.12)
4.2.1.1, Cotton		
Natural waxes and oils	Not preventable	Removed in scouring (see Section 4.9.1.3)
Metals	Avoid use of metal-based agricultural chemicals; otherwise, generally not preventable	Removed in scouring (see Section 4.9.1.3)
Agricultural chemical residues	Minimize use of agricultural chemicals in favor of nonchemical methods	Generally present in very low levels; of little concern in normal operations
Lubricant residues from harvesting	Use water-based lubricants and cleaners, not petroleum oils	Use of water-based cleaners and lubricants is a widespread practice
4.2.1.2, Wool		
Oil and grease	Not preventable	Removed in scouring
Pesticides	Conservative use and maximized use of nonchemical pest control methods	Practices vary greatly among growth areas
4.2.2, Synthetic or Regenerated Fibers		
Fiber finishes	Optimum control of finish add-on and proper selection of finish components	Generally trade secrets Add-on levels vary Volatile and hazardous components sometimes used A source of water and air toxics
Unreacted or improperly reacted polymer synthesis or regeneration residues	Optimized reaction process and method in fiber regeneration or polymerization	Includes many materials such as monomers, oligomers, metals, degradation products, solvents, and coagulants

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
Additives	Optimum control of add-on and proper selection of additives	Trade secrets, often applied with varying add-on levels, also often containing hazardous components
4.2.3, Fiber Pollution Prevention Strategies		
Residues from fiber manufacture	Incoming fiber QC and producer participation in global pollution prevention approach	Residues are removed or vaporized during scouring or heat treatment operations
Packaging wastes	Use of recyclable bale wrapping, straps, and ties	Widely practiced; vendor participation is required

A wide variety of contaminants may already be present in fibers when they arrive at the textile mill. During processing, when the fabric (or yarn) is heated or scoured, potential contaminants can be released into the water and air as pollutants. Because of the massive amounts of fiber used in textile manufacturing, even trace contaminants can produce large amounts of pollutants. In addition to the air and water pollutants released, a considerable amount of packaging waste, such as bale wrap materials, is generated (see Section 1.2.3 for a discussion of these solid wastes).

Many textile operations lack an incoming quality control (QC) system for fibers. Some operations test cotton fibers for physical properties such as micronaire, length, strength, color, and nonlint content. Few if any mills test for contaminants, however, and almost no mills test synthetic fibers, despite the variability and pollutant potential of synthetics.

Richardson (1) discusses the importance of checking incoming fibers for impurities and residues from previous processing. Standard fiber-extraction tests for water-, enzyme-, and solvent-extractable materials are available for testing incoming fiber (2). These methods can detect oils, fats, waxes, spin finishes, lubricants, starches, and other contaminants. Standard test methods also can be easily adapted to detect specific contaminants by simply performing the appropriate tests on the extracts obtained. Traditional effluent tests such as those for detecting biological oxygen demand (BOD) and chemical oxygen demand (COD) as well as chemical-specific tests can be used, in addition to high-performance liquid chromatography (HPLC) and gas chromatography/mass spectrometry (GC/MS) for organics, and inductively coupled plasma (ICP) for metals. Most commercial wastewater laboratories can perform these tests at reasonable costs.

4.2.1 Natural Fibers

Natural fibers are acquired from animal, mineral, and plant sources (see Table 4-1). Several types of contaminants are found in natural fibers, and all have the potential to create significant pollution problems. Table 4-2 identifies the contaminants found in natural fibers along with a brief description of the resulting pollution problems. For example, waxes and oils from animal-derived fiber can contribute to BOD, COD, as well as fats, oil, and grease (FOG), and pesticide residues can contribute to aquatic toxicity. Metals can accumulate in sludges or in the treatment system itself, causing potential long-term problems.

As shown below, natural fibers exhibit great variability in quality and extent of contamination and thus should receive attention in any pollution prevention program. A comprehensive incoming raw material QC program is highly advisable to detect and control these contaminants before they become serious pollution problems.

4.2.1.1 Cotton

Cotton is by far the most commercially significant natural fiber in the United States. Cotton's relative ease of production and its applicability to a wide variety of textile products contributes to its popularity. Cotton production, however, may use chemicals such as pesticides and herbicides, and these may remain as a residue on raw cotton fibers that reach the textile mill. Modak (3) has reported that raw cotton contains pesticides, fertilizers, and defoliants. Tests of cotton performed from 1991 to

Table 4-1. Natural Fiber Sources

Animal	Mineral	Plant
Wool	Asbestos	Cotton
Silk	Glass	Flax
Other hair fibers	Metallic	Hemp
Alpaca	Copper	Jute
Camel	Steel	Linen
Cashmere		Ramie
Horse		
Llama		
Mohair		
Rabbit		
Vicuna		

Table 4-2. Natural Fiber Contaminants and Associated Pollution Problems

Contaminant	Resulting Pollution
Natural waxes and oils	BOD, COD, FOG
Metals	Aquatic toxicity, treatment system inhibition, accumulation in sludge
Agricultural residues	Aquatic toxicity
Lubricant residues arising from harvesting and processing	BOD, COD, FOG

Table 4-3. Results of Pesticide Residue Sampling in Cotton From Growing Regions Worldwide (4)

	Pesticide (TLV for vegetable foodstuffs in mg/kg)								
Source	Total DDTs (1.0000)	Lindan (0.5000)	HCB (0.1000)	Qunitozen (1.0000)	Dicofol (2.0000)	Methoxychlor (10.0000)	Endosulfan (30.0000)	Tetradifon (1.5000)	Total Limit MST (1.0000)
Argentina	—[a]	0.004	—	—	—	—	—	—	0.0040
Argentina	—	0.002	—	—	—	—	—	—	0.0020
Australia	0.031	0.002	—	—	—	—	—	—	0.0330
Columbia Acala	—	0.002	—	—	—	—	—	0.024	0.0260
Côte d'Ivoire	—	—	—	—	—	—	—	—	0.0000
Greece	0.037	0.005	—	—	—	—	—	—	0.0420
Israel	—	0.006	—	—	0.022	0.168	—	—	0.1960
Mali	0.014	0.002	—	—	—	—	—	—	0.1600
Mexico	—	—	—	—	—	—	—	—	0.0000
Mexico-Mante	—	—	—	—	—	—	—	—	0.0000
Paraguay	0.041	0.002	—	—	—	—	—	—	0.4300
Peru del Cerro	0.009	0.003	—	—	—	—	—	—	0.1200
Peru-Pima	0.075	0.002	—	0.002	—	—	—	—	0.0790
Sudan-Rahad Acala sg	—	0.001	—	—	—	—	—	—	0.0010
Sudan-Shambat	—	0.002	—	—	—	—	0.107	—	0.1090
Syria	—	0.003	—	—	—	—	—	—	0.0030
Tadzhikistan ELS rg	0.046	—	—	—	—	—	—	—	0.0460
Chad	—	0.002	—	—	—	—	—	—	0.0020
Turkey	—	0.004	—	—	—	—	—	—	0.0040
Turkey	0.027	0.004	—	0.006	—	—	—	—	0.0370
Turkey Hatay	—	0.003	—	—	—	—	0.02	—	0.0230
Turkmenistan	—	—	—	—	—	—	—		0.0000
Turkmenistan ELS rg	0.059	—	—	—	—	—	—	—	0.0590
United States: Arizona	—	0.0008	0.0002	—	—	—	—	—	0.0010
United States: California	—	0.006	—	—	—	—	—	—	0.0006
United States: MOT	—	0.004	—		—	—	—	—	0.0040
United States: Pima	—	0.005	—	—	—	—	—	—	0.0050
United States: Pima	—	0.0007	—	—	—	—	—	—	0.0007
United States: Texas	0.008	0.0007	0.0003	—	—	—	—	—	0.0018
Uzbekistan	—	0.004	—	—	—	—	—	—	0.0040
Uzbekistan ELS rg	—	—	—	—	—	—	—	—	0.0000
Zimbabwe Albar	0.019	—	—	—	—	—	—	—	0.0190
Zimbabwe Delmac rg	0.008	0.003	—	0.006	—	—	—	—	0.0170

[a] Not detected.

1993 and reported by the Bremen Cotton Exchange in Germany, however, reported only trace levels of pesticides in cotton samples from around the world, including the United States (see Table 4-3). All these levels were below the threshold limit value (TLV) for foodstuffs, and they represent little concern, unless an agricultural production upset or spill occurs (4).

Analysis of raw cotton fiber indicates the presence of high BOD and COD, as well as copper, tin, and zinc. Table 4-4 shows the levels of these pollutants in both Delta and California cottons (5). Tests for other metals, including arsenic, cadmium, chromium, mercury, lead, selenium, and titanium, found them all to be below ICP detection limits. German testing found most metals to be nondetectable, with the exception of zinc, which was still below the "pollutant-free certification" limit (4).

Smith and Rucker (6) reported on a series of tests involving neutron activation of different cotton samples. The following metals were present in cotton fibers after the fibers are spun, woven, and prepared: titanium, manganese, magnesium, copper, vanadium, aluminum, chromium, cesium, zinc, and cobalt (see Table 4-5).

Studies of processing solutions in textile operations (6) have also shown that the metal content (iron, copper, zinc, and manganese) in these solutions exceeds the metal content in raw water (see Table 4-6). Fibers or previously added materials (e.g., warp sizes) introduce these metals into the processing solutions.

Reducing or eliminating metal contaminants in cotton processing wastewater involves testing incoming fibers and avoiding use of those contaminated with metals. This requires a global pollution prevention approach not usually seen in textiles. The spinning mill should perform the incoming QC step to eliminate metals in effluent from the finishing mill. Elements of such an approach are discussed further in Section 4.17, "Globalization of Pollution Prevention."

Table 4-4. Presence of BOD, COD, and Metals in Cottons (5)

Pollutant in Extract	Delta Cotton (ppm)	California Cotton (ppm)
BOD	514	848
COD	956	1,693
Copper (Cu)	0.048	0.050
Tin (Sn)	0.003	Not detected
Zinc (Zn)	0.223	0.315

Table 4-5. Metals Present in Prepared Cotton (6)

Metal	Sample I (ppm)	Sample II (ppm)
Titanium (Ti)	2.11	<0.5
Manganese (Mn)	0.140	0.104
Magnesium (Mg)	1.632	1.741
Copper (Cu)	2.29	3.16
Vanadium (V)	0.070	0.032
Aluminum (Al)	33.91	29.45
Chromium (Cr)	0.095	0.142
Cesium (Cs)	0.0076	0.0083
Zinc (Zn)	7.38	7.35
Cobalt (Co)	0.017	0.0024

Table 4-6. Metals Content of Raw Water and Textile Processing Solution (6)

Metal	Average Raw Water Concentration (ppm)	Average Processing Solution Concentration (ppm)
Fe	0.1	1.5
Cu	0.02	0.25
Zn	0.11	1.49
Mn	0.01	0.03

4.2.1.2 Wool

Wool is another significant commercial natural fiber. The main concerns with wool processing are FOG and aquatic toxicity arising from pesticide residues on raw wool. Pesticides are applied directly to sheep to reduce parasitic infestation, and these residues are released into wool-processing wastewater during preparation and dyeing (7).

Wimbush (8) reported that a specific agricultural residue, pentachlorophenol (PCP), was found at levels as high as 100 parts per million (ppm) in consumer products such as wool carpets. PCP causes indoor air pollution and respiratory distress in humans and pets. Because of the lipophilic nature of chloro-organic pesticides such as PCP, they tend to become associated with natural oils in the wool and are removed with those oils in wool scouring operations (7).[1] Several alternative pesticides can be used in place of PCP, but all have negative consequences for downstream waters (7).

Harmful PCP levels in consumer textile products are, in some cases, too low to be quantified accurately using traditional methods. In a test of 140 wool carpets, Wimbush (8) found that 123 (88 percent) had a PCP content below 5 ppm. Of the remainder, 3 were in the 5- to 10-ppm range, 11 were in the 11- to 50-ppm range, and 3 contained more than 50 ppm.

Careful prescreening of raw wool fibers for PCP residues is necessary. Interestingly, in carpets with high PCP levels, PCP was found primarily in the jute or polypropylene backings, not in the wool pile. Of 28 raw wool fiber samples from carpet, 19 had measured levels of PCP below 5 ppm and none had levels above 50 ppm (see Table 4-7). When 81 samples of carpet material other than raw wool were tested (e.g., jute, cotton, polypropylene, latex carpet components), 19 of 81 samples had PCP levels above 5 ppm and 10 had levels above 50 ppm (see Table 4-8).

Sampling data suggest that some countries are more knowledgeable about the effects of PCP and thus more restrained in the use of these chloro-organic pesticides. Shaw (7) sampled wool from the countries responsible

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[1] In some cases, lanolin, which is used in cosmetics, can be removed from the scoured-off oils (7). Chloro-organic pesticide residues in the oils, however, can render the recovered lanolin, and other oils from the wool, unsuitable for cosmetic use (7). Lanolin refiners have found ways to remove the pesticides to levels below 1 ppm, but even that level is undesirable in consumer skin care products.

Table 4-7. PCP Levels in Wool Carpet (8)

PCP Level (ppm)	Number of Samples (%)
<5	19 (68)
5 to 50	9 (32)
>50	0 (0)
Total sampled	28 (100)

Table 4-8. PCP Levels in Carpet Components Other Than Wool (7)

PCP Level	Number of Samples (%)
<5 ppm	62 (77)
5 to 50 ppm	9 (11)
>50 ppm	10 (12)
Total Sampled	81 (100)

Table 4-9. Organochloride Pesticide Levels Detected in Samples From Different Wool-Producing Regions (9)

Country of Origin	Average Level Detected (ppm)
Australia	0.091
Europe	4.46
New Zealand	0.01
South Africa	3.19
South America	162.5

for most of the world's raw wool production and found the highest chloro-organic pesticide levels in South American wools (see Table 4-9). Wools from Australia and New Zealand exhibited the lowest levels. Many countries have adopted regulatory controls on the use of chloro-organic pesticides, and in those countries pesticide levels in rivers that run through sheep-producing areas have dropped by more than 50 percent (7).

Because of the extremely high variability of pesticide residues in raw wool, a comprehensive raw material testing protocol is necessary for pollution prevention. Industry standards, such as the Woolmark carpet certification system, have been set up to require proper raw material prescreening. This certification system requires that all incoming raw materials be tested to ensure that they do not contain PCP above the regulatory level or 5 ppm. To receive the Woolmark certification, all raw materials must pass this test.

To aid in the detection of PCP, several rapid, effective HPLC analytical procedures for testing raw wool and other carpet components for PCP have been developed. These tests replaced more time-consuming, less sensitive tests. HPLC has high sensitivity and the equipment, although not part of a standard textile mill laboratory, is readily available in most areas. This technique allows testing of many samples fairly quickly and inexpensively (7).

4.2.2 Synthetic and Regenerated Fibers

Synthetic and regenerated fibers comprise a wide variety of manmade fibers, as well as some regenerated natural fibers. These are shown in Table 4-10.

Synthetic fibers may contain several types of impurities that are imparted to the fibers during fiber manufacturing. These impurities exist in the fibers before they reach the textile manufacturer and fall into the categories of finishes, polymer synthetic by-products, and additives. Table 4-11 lists some of these contaminants.

Table 4-10. Synthetic and Regenerated Fibers

Synthetic	Regenerated
Acetate	Rayon
Triacetate	Viscose
Acrylic	Rubber
Aramid	Chitin
Modacrylic	Chitosan
Polyamide (nylon)	
Polyethylene	
Polypropylene	
Polyester	
Saran	
Spandex	

The three main concerns associated with wet processing of fibers contaminated with impurities are:

- Aquatic toxicity
- Metals
- BOD and COD

Smith (10) tested several textile mill effluents which showed significant aquatic toxicity, and identified many organic compounds and metals. In another study (5) many of the same organic compounds, as well as several metals (As, Cd, Cr, Cu, Hg, Pb, Se, Ti, and Zn), were identified in synthetic fiber extracts. These organic compounds (of varying toxicity), which were identified in mill effluents and also in fiber extracts, are listed by fiber type in Table 4-11. The synthetic fiber extracts also exhibited high BOD and COD as shown in Table 4-12.

In the preceding table, the COD:BOD ratio of the acrylic extract is very high, indicating the potential for pass-through during treatment and subsequent discharge to the environment. At this time, no toxicity data exist for these extracts, but tests are underway (5).

Many impurities found in synthetic and regenerated fibers are intentionally applied as part of proprietary spin finishes. These finishes are added to fibers for lubrication and to impart other desirable properties such as

Table 4-11. Impurities Associated With Synthetic Fibers

Finishes
- Antistatic
- Lubricant

Polymer Synthesis By-Products
- Unreacted monomers
- Low-molecular-weight oligomers (e.g., trimer)
- Residual catalyst

Additives To Facilitate Processing
- Antistatic agents
- Lubricants
- Humectant
- Others

Table 4-12. Contaminant Levels in Synthetic Fiber Extracts (11)

Fiber Extract	COD (ppm)	BOD (ppm)	BOD/COD
Acrylic	1,139	155	7.3
Dacron polyester	271	88	3.1
Nylon	6,417	1,803	3.6
Trivera polyester	319	92	3.5
Wool	13,470	3,322	4.1

static electricity control. In almost all cases, the finishes must be removed to ensure uniform penetration of the fabric by dyes and other finishes and to avoid reaction or precipitation with dyes and finishes. If left on the fiber, volatile components of spin finishes can produce toxic air emissions when vaporized by high-temperature processes such as drying, heatsetting, thermofixation, and curing ovens. To prevent these emissions, spin finishes must be scoured from fibers before dyeing and finishing. Although this scouring process eliminates the air pollution problem, it replaces it with a water pollution problem because the scouring water is ultimately discharged into the wastewater.

The compounds in Table 4-13 are found not only in process wastewater from synthetic fiber dyeing and finishing operations, but also were detected in synthetic fiber extracts (5, 10). Metals extracted from synthetic fibers are shown in Table 4-14 and include As, Cr, Cu, Pb, and Zn. Not all of these were detected in all four synthetic fiber types tested. Only Cu and Zn were detected in the Trivera and acrylic samples; Cu, Pb, and Zn were present in the Nylon 6 samples; while As, Cr, Cu, and Zn were detected in the Dacron sample (5).

Table 4-13. Compounds Typical of Synthetic Fiber Extracts

Dacron
- Tetra hydro 2,5 dimethyl cis furan
- Methyl isobutyl ketone
- 3 methyl cyclo pentanone
- Hexanone
- Diethyl ketone
- Dodecanol
- Alcohols (C_{14} and C_{18})
- Esters of C_{14} - C_{24} carboxylic acids
- Hydrocarbons (C_{14} - C_{18})
- Carboxylic acids (C_{16} - C_{24})
- Phthalate esters (many)

Trivera
- Tetra hydro 2,5 dimethyl cis furan
- Ketones (several similar to Dacron above)
- Alcohols (C_{12} - C_{18})
- Carboxylic acids (C_{12} - C_{18})
- Esters of carboxylic acids (C_{12} - C_{18})
- Phthalate esters (several)
- Hydrocarbons

Acrylic
- Hydrocarbons (several C_{15} - C_{18})
- Esters of carboxylic acids (C_{17} - C_{22})
- Alcohols
- Phthalate esters
- N,N dimethyl acetamide
- Other nitrogenous compounds

Nylon 6
- Diphenyl ether
- Hydrocarbons (C_{16} - C_{20})
- Carboxylic acids (C_{14} - C_{18}) and dicarboxylic acids
- Esters of carboxylic acids (C_{10} - C_{18})
- Alcohols (C_{20} - C_{22})
- Other nitrogenous compounds

Table 4-14. Metals Concentrations in Extracts From Synthetic Fibers (ppm) (5)

	Metal				
Fiber	As	Cr	Cu	Pb	Zn
Trivera	bdl[a]	bdl	0.033	bdl	0.117
Dacron	0.061	0.011	0.03	bdl	0.075
Acrylic	bdl	bdl	0.025	bdl	0.087
Nylon 6	bdl	bdl	0.034	0.01	0.148

[a] bdl = below detection limit of ICP.

4.2.3 Pollution Prevention Strategies

The above review of pollution problems illustrates the potential benefits of incoming fiber QC and greater disclosure of potentially harmful impurities and additives (i.e., spin finishes). Many fiber contaminants are metals and organics, which are undesirable in wastewater and can cause air pollution. Some of these impurities are produced during polymerization of synthetic fibers, while others are intentionally added to control the surface and electrical properties of fibers. Many of these impurities can interfere with downstream processing and quality, and create pollution problems.

Because of the extremely high volume of fibers used in textile processing and the great variability in contamination, a comprehensive incoming fiber QC program is essential for synthetics. Some fiber companies, notably Cotton Incorporated, have endorsed standard testing methods for fibers and have actively worked to ensure that the fiber user and the producer (farmer) exchange information for QC. In synthetics, such global pollution prevention efforts have not yet evolved. Mills can still set up good incoming fiber QC, however, based on performance testing, statistical sampling, and analysis of extractable materials to identify potential pollution problems before they arise. Purchasing specifications should include specific requirements for factors such as metals, aquatic toxicity, and extractables (e.g., spin finish levels), as well as specific packaging requirements to reduce solid wastes (see Section 1.2.3, "Solid Wastes," for a discussion of fiber packaging materials).

4.3 Dyes

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.3, Dyes (General)		
Color	Proper dye selection, optimization of handling, optimization of dye process for maximum dye exhaust in batch dyeing, improved audit and employee training for identified dyes	
Aquatic toxicity	Identifying toxic dyes and providing special handling, worker training, auditing, spill response/control	
Metals	Dye selection, handling	
Undesirable degradation residues	Dye selection, handling	
Packaging	Using IBCs or returnable containers	
Obsolete dyes	Proper inventory control	
General	Involving dye vendor/supplier in pollution prevention activities at the mill level	Insist on identification and disclosure of environmental information on dyes
4.3.1, General Background		
General	Properly inform dyers and dye handlers concerning the technical aspects of dye use	Vendor/supplier must be involved to provide information for proprietary products
Salt	Select cotton dyes that require minimum amounts of salt, and optimize salt for each recipe	See dyeing (see Section 4.10 for further information)
Wastewater (high volume of water)	Optimize dyeing and washing operations	
Color	Proper dye selection	
	Optimum handling, auditing, and employee training	
	Optimization of dye process for maximum dye exhaust in batch dyeing	
Metals	Dye selection, handling	
Air emissions	Auxiliary chemical selection and handling	
	Optimum process and drying conditions	
4.3.2, Dyes and Dye Processes		
Water	Equipment maintenance, employee training, process optimization, waste stream segregation for reuse and many other methods of water conservation	Very high hydraulic loads result from dyeing and especially afterwashing
Salt	Selecting cotton dyes that require minimum amounts of salt, and optimizing salt for each recipe	
Metals	Dye selection, handling	
Color	Optimum handling, proper dye selection, optimum dye process for maximum dye exhaust in batch dyeing	No general, across-the-board method of color treatment exists, so pollution prevention is very important
Organic chemical wastes from spent chemical dyeing auxiliaries	Process optimization, chemicals selection, substitution of "better" chemicals, process modification to eliminate the need for chemicals, alternate processes	See also Section 4.5, which gives more detail on chemical selection and use

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
Air emissions	Process optimization, chemicals selection, substitution of less volatile chemicals, process modification to eliminate the need for volatile chemicals, alternate processes	Highly dependent on the type of dyeing process
4.3.3 through 4.3.3.10, Applications Classes of Dyes		
Dyestuff wastes with associated color, metals, aquatic toxicity, etc.	Better understanding of batch dyeing processes	Dye selection, framed in the perspective of the role of affinity and reactivity, with comparisons of alternative dye classes
4.3.4, End-Use Classes of Dyes		
Dyestuff wastes with associated color, metals, aquatic toxicity, etc.	Dye selection, handling	Dye selection in this section is framed in the perspective of end-use (design) product specification
4.3.5, Environmental Classes of Dyes		
Dyestuff wastes with associated color, metals, aquatic toxicity, etc.	Dye design and selection	Dye selection in this section is framed in the perspective of the chemistry of the dye and the intermediates from which it is synthesized (i.e., the design of the dye itself)
4.3.6, Pollution Prevention for Dyes		
Dyestuff wastes with associated color, metals, aquatic toxicity, etc.	Raw material prescreening procedures	

Significant opportunities exist for preventing pollution in textile dyeing operations. This section describes important characteristics of textile dyes that relate to pollution prevention and serves as background to other sections of this document (e.g., Section 4.10, "Dyeing"). In addition, this section presents pollution prevention strategies for use in selecting dyes, evaluating dye alternatives, and modifying work practices. The following list summarizes briefly the main pollution prevention ideas presented in this section.

- Handle and use all dyes in a conservative manner.
- Arrange processes to ensure maximum dye exhaust and fixation, and minimum waste from spent processing baths.
- Always deal with suppliers who are knowledgeable and responsible/reputable.
- Prescreen all dyes before use by reviewing all available environmental information.
- Insist that suppliers identify all dyes and provide information on their environmental fate and impacts. Avoid using dyes if inadequate information exists about their safety, metal content, degradability, or safety of the aerobic and anaerobic degradation products.
- Identify dyes that are highly toxic, metal bearing, etc. Establish procedures for proper handling and spill response, and train workers.
- Inform designers, schedulers, and customers of the environmental burden of problem dyes, and recommend safer alternatives. Those involved in specifying colors and hues may not realize environmental consequences of their choices.
- Understand the application classes and subclasses of dyes, and use this information as well as an understanding of site-specific features and limitations (e.g., equipment, control systems, and facility layout) to design efficient processes.
- Select dyes with the highest fixation efficiency.
- For exhaust dyeing, select dyes with high affinity, if possible, especially where the bath ratio of the dyeing equipment is high.
- Select dyes and dye combinations with the highest probability of right-first-time dyeing in the specific use setting.
- Perform statistical sampling and routine dye quality control checks to ensure environmental quality and performance.
- Keep in mind that pollution prevention extends to both dye selection and dye process operation. Further information on dye process considerations, found in Section 4.10, "Dyeing," should be reviewed.

4.3.1 General Background

Textiles are dyed using a wide range of dyestuffs, techniques, and equipment. Most dyeing is performed either by the finishing division of vertically integrated textile companies, or by specialty dyehouses that operate on a commission basis or that purchase greige goods and finish them before selling them to apparel and other product manufacturers. Dyes used by the textile industry are largely synthetic and are derived from coal tar and petroleum-based intermediates. Some naturally occurring dyes, derived from animal or plant sources, are also used but are relatively unimportant commercially. Most dyes are considered chemical specialties because of their low volume and high price, although a significant proportion are produced in commodity volumes. Dyes are sold as powders, granules, pastes, and liquid dispersions and solutions, with concentrations of active ingredients ranging typically from 20 to 80 percent.

Dyes are applied to fibers or fabrics in a variety of ways and impart their color via different mechanisms, which are described below. A variety of auxiliary chemicals are used during dyeing to assist in dye absorption and fixation into the fibers.

Important factors in dye selection include type of fiber and machine, product end-use application, and customer demands or preferences. Historically, the environmental impact of dye selection, application, and use has not been a major consideration. Until recently, dyers had little access to information concerning the environmental impact of dyes, and as of 1984, the chemical composition of at least half the dyes used in the industry was estimated to be unknown (12). During the last 40 years, however, more information on the environmental consequences of dyes has become available, and dye manufacturers have substantially eliminated hazardous dyes from their product lines while actively searching for safer substitutes. To the extent that more environmentally benign dyes are consistent with customer needs and product quality, dye manufacturers seek to offer dyes that provide water and energy savings, reduce pollution, and increase efficiency in dye and chemical use as well as raise productivity.

Dye use presents several environmental concerns that should be addressed through pollution prevention:

- Dyeing operations are water-intensive.
- Cellulose dyeing uses massive amounts of salt.
- Dyes contain metals such as copper, nickel, chromium, mercury, and cobalt. In some dyes, these metals are functional (i.e., they form an integral part of the dye molecule); however, in most dyes, metals are present as impurities (see Section 2.2.5, "Metals"). For example, mercury is used as a catalyst in the manufacture of certain dyes and is often present as a trace residue. Metals are difficult to remove from wastewater and may pass through the effluent treatment system or become part of the wastewater sludge.
- Water from spent dyebaths and dye rinse operations contains unreacted or unfixed dyes, and effluent discharge containing these compounds may be highly colored. Because color can interfere with the transmission of light in receiving waters, high doses of color can interrupt photosynthesis and aquatic life. Color can also interfere with ultraviolet (UV) disinfection of treated wastewater. The primary concern about effluent color at discharge concentrations, however, is its undesirable aesthetic impact on receiving waters. Aesthetic concerns about textile mill effluent have led to increased regulatory attention at the local level.
- Dye rinse water and spent dyebaths contain numerous auxiliary chemicals, such as salt. Important individual chemicals contained in these wastes are addressed in other sections of this document (e.g., Sections 2.2.2, "Discharge of Electrolytes," 4.4, "Chemical Commodities," 4.5, "Chemical Specialties," and 4.7, "Slashing and Sizing").
- Dyeing contributes to air emissions, although air concerns are related more to the types of dyeing processes and to the chemical auxiliaries used than to the specific dyes selected. For example, batch dyeing of disperse dyes may be performed on atmospheric machines that operate with the aid of dye carriers. These carriers include aqueous emulsions of chemicals that may volatilize during subsequent heatsetting, drying, or curing stages.

4.3.2 Dyes and Dye Processes

Textiles are dyed using batch and continuous processes. In batch dyeing, a certain amount of textile substrate, usually 100 to 1,000 kilograms, is loaded into a dyeing machine and brought to equilibrium, or near equilibrium, with a solution containing the dye. Because the dyes have an affinity for the fibers, the dye molecules leave the dye solution and enter the fibers over a period of minutes to hours. Auxiliary chemicals and controlled dyebath conditions (mainly temperature) accelerate and optimize the action. The dye is fixed in the fiber using heat and/or chemicals, and the tinted textile substrate is washed to remove unfixed dyes and chemicals.

In continuous dyeing processes, textiles are fed continuously into a dye range at speeds usually between 50 and 250 meters per minute. To be economical, this may require the dyer to process 10,000 meters of textiles or more per color, although specialty ranges are now being designed to run as little as 2,000 meters economically. Continuous dyeing processes typically consist of dye application, dye fixation with chemicals or heat, and washing. Dye fixation on the fiber occurs much more rapidly in continuous dying than in batch dyeing.

In batch dyeing, the objective is maximum exhaust and fixation of the dye to minimize carryover of unfixed dye into the washing stages. The maximum dye exhaust achievable is related to the affinity of the dye for the fiber and the bath ratio, as expressed in the following (13):

$$E = K/(K + L) \qquad \text{(Eq. 4-1)}$$

where:

E = exhaust, which ranges from 0.50 to 1.00 (50- to 100-percent exhaustion) in commercial operations (14)

K = dye affinity, which ranges from 50 to 1,000 for various dye/fiber combinations

L = bath ratio, which ranges from 5 to 50 for various machines[2]

(See Figure 4-1.)

In the following expression, K is a partition coefficient, the ratio of the concentration of dye in solution to the concentration of dye in the substrate at equilibrium, i.e.,

$$K = c^f/c^s \qquad \text{(Eq. 4-2)}$$

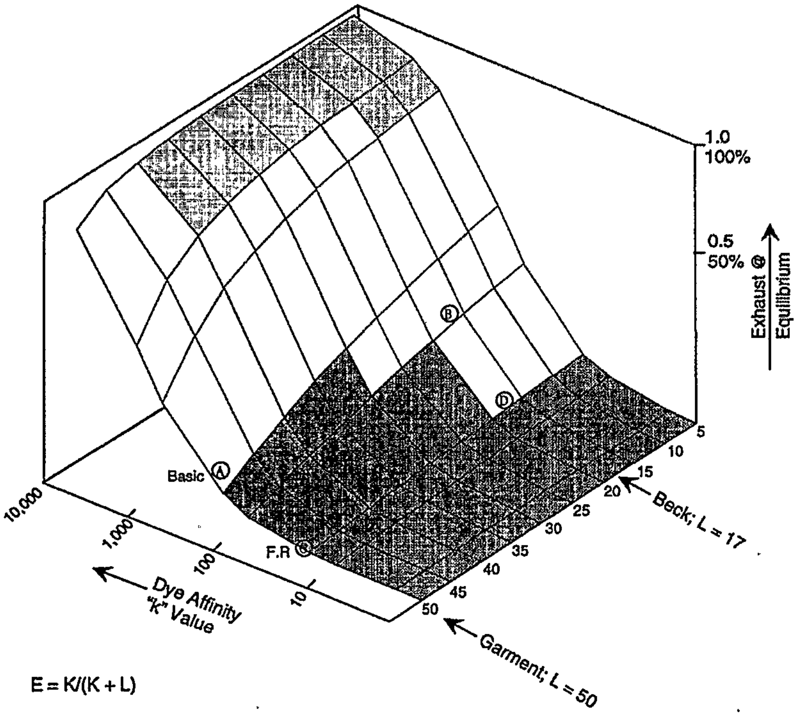
where:

c^f = concentration of dye in fiber at equilibrium
c^s = concentration of dye in solution at equilibrium

According to Equation 1, when the bath ratio increases, exhaustion decreases and more color is discharged. This effect is more pronounced with low affinity dyes (i.e., when K is low). When K decreases, more dye remains in the solution and the color in the wastewater increases, especially if L is high. This highlights the importance of affinity. To reduce color in wastewater, the dyer should select higher affinity dyes (i.e., with high K values). When running low affinity (low K) dyes, short bath ratios are essential.[3]

Different dye classes exhibit different affinities depending on the type of fiber. Even within dye classes, individual dyes can show large affinity variations. Thus, generalizing about exhaustion associated with specific dye classes, and especially with specific dyes, is difficult. Dye vendors, however, can identify the higher affinity class members for dyers. With this caveat in mind, some typical exhaustion/fixation levels for various dye classes are given in Table 4-15.

As shown in the table, users of cellulose dyes have the greatest problems with poor exhaustion and fixation characteristics. Further, the popular fiber reactive dyes lead the list in terms of poor fixation, except for recently introduced, improved reactive dyes for cotton, which exhibit a higher degree of fixation. The same conclusions are reflected in



E = K/(K + L)

Examples:
Basic Dyes K = 700
Fiber Reactive K = 50
Beck L = 17
Garment Dyeing L = 50

A. Basic on Garment
B. Basic on Becks
C. Fiber Reactive on Garment
D. Fiber Reactive on Becks

Figure 4-1. Relationship between dye exhaust and affinity.

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[2] Note that affinity is based on equilibrium concentrations wheras exhaust is based on amounts or mass of dye. Therefore, K (affinity) does not depend on L, but E (exhaust) does.

[3] When dealing with fiber reactive dyes, however, hydrolysis does not significantly effect affinity. High affinity hydrolyzed dye is difficult to wash off. Susceptability to hydrolysis is a factor regarding color in the wastewater for fiber reactive dyes.

Table 4-16, which presents data on color values for approximately 20 different combinations of dyes, fibers, and dye machines.

Although much information in this section concerns batch dyeing, continuous dyeing also has specific dye requirements. In general, dyes with low affinity are favored in continuous dyeing for two reasons:

- To prevent "tailing" from occurring during a run. Tailing is often attributed to undesirable exhaustion of the padding solution.
- To make washing off the unfixed color easier.

Easy washoff is essential in continuous dyeing. Dyes with low affinity, by definition, wash off more easily (if not fixed). To achieve consistent shade repeats and level (even) dyeings, each dye in a recipe must have application properties (i.e., fixation rate) similar to all other dyes in the recipe.

Some dyes are sensitive to specific water contaminants (e.g., hardness, iron, copper, chlorine, tannic acid, and

Table 4-15. Exhaustion/Fixation Levels for Various Dye Classes (14)

Class	Typical K[a]	Typical Fixation (%)	Fibers
Acid	130	80 to 93	Wool
Azoic	200	90 to 95	Cellulose
Basic	700	97 to 98	Acrylic
Direct	100	70 to 95	Cellulose
Disperse	120	80 to 92	Synthetic
Premets	470	95 to 98	Wool
Reactive	50	50 to 80	Cellulose
Sulfur	50	60 to 70	Cellulose
Vat	130	80 to 95	Cellulose

[a] The typical K is computed by assuming a bath ratio of 17:1 (typical for becks) and solving for $K = EL/(1-E)$, where E is on a 0-to-1 scale. For acid dyes, the dye exhausted is typically 87 percent, or $E = 0.87$. Solving $E = K/(K + L)$ for K results in $K = L/(H - E) = (17)/(0.13)$ or 130. Therefore, at equilibrium the concentration of dye in the fiber will be 130 times greater than the concentration of dye in the bath for a dye that exhausts 87 percent at 17:1 bath ratio.

Table 4-16. Wastewater Color Values From Various Dye/Substrate/Dye Method Combinations (15)

Dyeing No.	Dye Class	Substrate	Method	ADMI[a] Color	Apparent ADMI Color	TOC (mg/L)	BOD (mg/L)	pH	Cl^- (mg/L)	Suspended Solids (mg/L)	Dissolved Solids (mg/L)[b]
1	Vat	Cotton	Exhaust/Package	1,910	—	265	294	12	190	41	3,945
2	2:1 Premetallized	Polyamide	Exhaust/Beck	370	—	400	570	7	nil	5	1,750
3	Disperse	Polyester	Atmos./Exhaust	315	—	300	234	8	33	39	914
4	After coppered direct	Cotton	Exhaust/Beck	525	1,280	135	87	5	520	41	2,763
5	Reactive	Cotton	Exhaust/Beck	3,890	—	150	INT[c]	11	9,800	32	12,500
6	Disperse	Polyamide carpet	Exhaust/Beck	100	—	130	78	8	28	14	395
7	Chrome	Wool	Exhaust/Beck	3,200	—	210	135	4	33	9	1,086
8	Basic	Polyacrylic	Exhaust/Beck	5,600	12,000	255	210	5	27	13	1,469
9	Disperse	Polyester carpet	Exhaust/Beck	215	315	240	159	7	27	101	771
10	Acid	Polyamide	Exhaust/Beck	4,000	—	315	240	5	14	14	2,028
11	Direct	Rayon	Exhaust/Beck	12,500	—	140	15	7	61	26	2,669
12	Developed	Rayon	Exhaust/Beck	2,730	—	55	12	3	130	13	9.8
13	Disperse/Acid/Basic	Polyamide carpet	Exhaust/Beck	210	720	130	42	7	10	8	450
14	Disperse	Polyester	High-Temperature Exhaust	1,245	—	360	198	10	1,680	76	1,700
15	Sulfur	Cotton	Continuous	450	—	400	990	4	42	34	2,000
16	Reactive	Cotton	Continuous	1,390	—	230	102	9	57	9	691
17	Vat/Disperse	Cotton/polyester	Continuous	365	1,100	350	360	10	167	27	2,292
18	Basic	Polyester	Atmospheric/Exhaust	1,300	2,040	1,120	1,470	5	17	4	1,360
19	Disperse/Acid/Basic	Polamide carpet	Continous/Kuster	<50	190	160	130	7	22	49	258
20	Azoic	Cotton	Exhaust/Package	2,415	—	170	200	9	7,630	387	10,900

[a] ADMI = American Dye Manufacturers Institute.
[b] Mostly salt.
[c] INT = high salt or reactive.

aluminum) (11). This is a significant consideration because background levels of these contaminants in process water fluctuate considerably from season to season, location to location, and mill to mill. Different mills that produce a similar product in two different locations, or at different times of the year, sometimes use different dyes and dyeing methods to account for variations in water quality.

4.3.3 Characteristics of Dyes

Textiles are dyed using many different colorants, which may be classified in several ways (e.g., according to chemical constitution, application class, end-use). The primary classification of dyes is based on the fibers to which they can be applied, and the chemical nature of each dye determines the fibers for which the dye has affinity. Table 4-17 lists the major dye classes and the types of fibers for which they have an affinity. The dye classes commonly used in the textile industry are described in further detail below.

4.3.3.1 Acid Dyes

Acid dyes are water-soluble anionic compounds applied to nylon, wool, silk, and some modified acrylic textiles in an acidic medium. Some acid dyes are also used for coloring food and paper. They exhibit little affinity for cellulosic or polyester fiber. Colors generally are bright, and the material exhibits good to excellent fastness properties. Acid dyes have one or more sulfonic or carboxylic acid groups in their molecular structure. The dye-fiber affinity is the result of ionic bonds between the sulfonic acid part of the dye and the basic amino groups in wool, silk, and nylon fibers.

Table 4-17. Dye Classes and Fibers for Which They Have Affinity

Dye Class	Fibers
Acid	Wool and nylon (polyamide)
Azoic	Cotton and cellulose (see naphthol)
Basic	Acrylic, certain polyesters
Direct	Cotton, rayon, and other cellulosic
Disperse	Polyester, acetate, and other synthetics
Fiber reactive	Cotton and other cellulosic, wool
Food dyes	Not used in textiles, similar to acid dyes
Mordant (obsolete)	Natural fibers (must pretreat with metals)
Naphthol (azoic)	Cotton, rayon, and other cellulosic
Optical brighteners	Various (also called fluorescent brighteners)
Pigment	All (requires binders, just like painting)
Solvent	Synthetic, rarely used in commerce
Sulfur	Cotton and other cellulosic
Vat	Cotton and other cellulosic

Mordants can be used to improve wetfastness and perspiration fastness of acid dyes, although shades tend to be duller. Mordants include Cr, Sn, Cu, and Al. Because of environmental concerns surrounding mordants, their use in acid dyeing in the United States has essentially ceased.

4.3.3.2 Azoic Dyes

Azoic dyes, also known as naphthol dyes, are used on cellulosic fibers (particularly cotton) but may also be applied to rayon, cellulose acetate, linen, jute, hemp, and sometimes polyester. Azoic dyes are made up of two chemically reactive compounds, which are applied to the fabric in a two-stage process. The reaction of the two compounds in the fiber produce the colored azo chromophore. During dyeing, the azoic dye forms inside the fibers.

The Colour Index (CI) refers to the components used in azoic dyeing as CI Azoic Coupling Components and CI Azoic Diazo Components. The coupling components are mostly derived from β-naphthol and are available in powder or liquid form, while the diazo components are available as free bases (fast color bases) and diazonium salts (fast color salts). The depth of shade is determined by the extent to which the coupling component is absorbed when the diazo component is applied to the fiber.

Azoic dyes produce bright and dark shades of yellow, orange, red, maroon, navy blue, brown, and black. The dyes exhibit good lightfastness and fastness to peroxide and other bleaches. They can be applied in a variety of ways (i.e., continuously or using yarn, jet, beck, or jig dyeing processes). Use of azoic dyes has declined over the years, however, because of application costs and concerns about the possible presence of carcinogenic naphthylamines in the effluent.

4.3.3.3 Basic (Cationic) Dyes

Basic dyes were the first synthetically manufactured dye class. They were initially used to dye silk and wool (using a mordant), but they exhibited poor fastness properties. Modified basic dyes were developed and are now used exclusively to color synthetic fibers such as acrylic, modacrylic, and modified nylons and polyesters, in which their fastness is acceptable. Basic dyes are rarely used on natural fibers, both because of their poor light- and washfastness and because of the need for mordants.

Basic dyes have limited water solubility and are applied in weakly acidic dyebaths. Ionic bonds are formed between the cation in the dye and the anionic site on the fiber. As a class, basic dyes are among the brightest dyes available. In addition, they have unlimited color range and good fastness properties (except in natural fibers, as noted above). Good preparation (scouring) is necessary to remove the surface additives applied for knitting and weaving. Basic dyes are strongly bound and do not migrate easily; therefore, temperature must be used to carefully control exhaustion to ensure level dyeing.

Basic dyes exhibit high aquatic toxicity, as shown in Tables 2-28 and 2-29, but when applied properly, they exhaust nearly 100 percent. Problems are more often attributable to improper handling procedures, spill cleanup, and other upsets.

4.3.3.4 Direct Dyes

Direct dyes are water-soluble, anionic compounds used extensively for coloring paper but also for dyeing cotton, rayon, linen, jute, hemp, silk, and nylon fibers, as well as mixtures of fibers and leather. The term "direct dye" refers to the fact that these dyes can be applied directly to cellulosics without mordants. The dyes are absorbed into hydrophilic fibers as the fibers expand in the water solution. Sodium chloride or sodium sulfate salts are added to the dyebath to counteract the slightly negative charge that cellulosics have in aqueous solution. The molecular structure of direct dyes is narrow and flat, permitting these molecules to align with flat cellulose fibrils, where the dye molecules are held in place through Van der Waals forces and hydrogen bonds. Fixatives, which react with the dye, are generally added to hold the dye molecules in place and improve colorfastness.

Although direct dyes yield bright, deep colors, they vary greatly in lightfastness. They are widely used to color cellulosic materials including those that need high fastness (e.g., upholstery and drapery fabrics). Also, they are limited in washfastness and their ability to withstand exposure to moisture (e.g., perspiration) unless the fabric is aftertreated with a chemical fixative in a common procedure called afterfixing. Direct dyes are more economical than reactive or vat dyes, but their use has declined in recent years as reactives with superior end-use properties have risen in popularity. They are beneficial from a pollution prevention standpoint, however, because direct dyes use low amounts of salt and other offensive materials, compared with reactive dye.

4.3.3.5 Disperse Dyes

Disperse dyes have a very low water solubility, so they are applied as a dispersion of finely ground powders in the dyebath. The particles dissolve at low concentrations in the aqueous dyeing medium but transfer into the synthetic fiber polymer because of their higher solubility in the substrate. High temperatures and superatmospheric pressures are sometimes used for application. This reduces the need for chemical accelerants (e.g., dye carriers), which are required at lower temperature.

Disperse dyes are used for oleophyllic fibers (polyester and other synthetics) that do not accept water-soluble dyes. They are used largely for synthetic fibers, mainly polyester but also cellulose acetate rayon (also called regenerated cellulose fibers), nylon, and acrylic fibers. For polyesters, disperse dyes offer a full shade range. Because of the limited buildup properties and poor washfastness in dark shades, however, disperse dyes are used mostly to obtain pastel shades in nylons and acrylics. Disperse dyes tend to have good fastness to light, perspiration, laundering, and dry cleaning. They also have good crocking resistance.

4.3.3.6 Fiber Reactive Dyes

Fiber reactive dyes are water-soluble, anionic dyes that provide high wetfastness and require relatively simple dyeing methods. They are mainly used for dyeing cellulosic fibers such as cotton and rayon but are also sometimes used for wool, silk, nylon, and leather. Fiber reactive dyes have largely replaced direct, azoic, and vat dyes and are the largest dye class (in commercial value) in the United States. Because of the bright shades available—particularly orange, scarlet, and turquoise—they are popular choices for color fashion apparel.

Fiber reactive dyes form covalent chemical bonds with the fiber and become part of the fiber, giving excellent fastness properties. Because of their solubility, leveling takes place rapidly before fixation, which provides flexibility in dye application methods. To exhaust the dyes, however, large amounts of salt are generally necessary, and substantial amounts of dye can remain unfixed at the end of the process. After dyeing, the fabric is afterwashed with an anionic surfactant to remove unreacted dye.

Environmental concerns about fiber reactive dyes focus on color and salt, two pollutants that are receiving increased attention. The relatively low fixation efficiency of the dyes results in effluent color, which is not easily removed in treatment systems. Decoloration of the effluent is difficult because of the low level of aerobic biodegradation and/or adsorption of the dye color onto activated sludge during treatment. Large amounts of salt are used to exhaust the dyes, and some jurisdictions are tightening salt limits to levels that may be difficult to meet because conventional treatment systems are not effective in removing salt.

Some improvements in fixation of fiber reactive dyes have been made, particularly with the introduction of bifunctional reactive dyes. Bifunctional dyes have two reactive groups, which increases the efficiency of dye fixation. Low-bath-ratio equipment can also be used to reduce salt requirements, and pad-batch dyeing using cold reactive dyes that require no salt is a viable alternative to consider (see Section 4.10, "Dyeing").

4.3.3.7 Mordant Dyes

Mordant dyes are used mainly in wool dyeing, although they also are used to dye silk and nylon and to print wool, silk, and cellulosic fibers. In general, mordant dyes have fair to good fastness properties. These dyes usually contain a ligand functionality capable of reacting strongly with salts of aluminum, chromium, cobalt, copper, nickel, or iron to give differently colored metal complexes. Mordants are now used infrequently in the United States because of concern about toxic metal salts in the effluent.

4.3.3.8 Pigments

Pigments differ from dyes in that they:

- Remain insoluble during application
- Have no affinity for the fibers
- Require binders
- Do not react with the fibers

Little penetration of the color into the substrate occurs with pigments. Instead, pigments are usually mixed with a vehicle that hardens upon drying, forming an opaque coating. Pigments are used extensively in textile printing (see Section 4.11, "Printing").

4.3.3.9 Sulfur Dyes

Sulfur dyes are mainly used for dyeing cotton and rayon substrates. They may also be used for dyeing blends of cellulosic and synthetic fibers, including nylons and polyesters, and are occasionally used for dyeing silk.

The synthesis of sulfur dyes is based on the reaction at high temperature of organic compounds containing nitro and amino groups with sulfur or sodium sulfide. The dyes contain sulfur both as an integral part of the chromophore and in polysulfide pendant chains.

Sulfur dyes are reduced with sodium sulfide to a water-soluble form before application to the fiber. In reduced form, sulfur dyes are soluble and have an affinity for cellulose. Sulfur dyes color by absorption, like direct dyes, but with exposure to air they oxidize to re-form the original insoluble dye inside the fiber. This makes them very bleach fast to oxidizing bleaches (e.g., peroxide) and resistant to removal by washing.

Sulfur dyes have good to excellent washfastness and moderate to good lightfastness. They are relatively inexpensive compared with other dyes. Although they encompass a broad shade range, sulfur dyes are mostly used for dark shades because lighter shades have poorer resistance to light and laundering. The shade range for sulfur dyes includes brick reds, browns, burnt oranges, and blacks. Sulfur dyes tend to be dull compared with other classes. Deep indigo denim colors are often obtained by applying indigo dyes over a sulfur "bottom." In recent years, use of sulfur dyes has decreased in the United States because of environmental concerns (sulfide residues) associated with the manufacturing process. Some newer sulfur dyeing options, based on low-sulfide reducing agents, are discussed in Section 4.10, "Dyeing."

4.3.3.10 Vat Dyes

Vat dyes are the oldest and among the more chemically complex dyestuffs. They are used most often for dyeing and printing cotton and cellulosic fibers, and for end-uses that require good fastness properties, such as toweling, industrial uniforms, military uniforms, and tenting. Although most commonly used for cottons and cellulosics, they can also be applied to nylon and polyester/ cellulosic blends and are sometimes used for dyeing wool and acetate.

Vat dyes have excellent fastness properties when properly selected and are often used on cotton and cellulosic fabrics that will be subjected to severe conditions of washing and bleaching (e.g., sewing threads). Vat dyes can be used on all fibers except those sensitive to alkalis.

Vat dyes are applied by exhaust or continuous methods. They are either supplied in water soluble reduced "leuco" form or reduced with a reducing agent such as sodium hydrosulfite. Then they are allowed to migrate into the fiber by an exhaustion process (for batch dying) or by steaming (for continuous dyeing). When this migration into the fiber is complete, the substrate is rinsed to remove surface dye, then the dye is oxidized back to its water insoluble form within the fiber. The result is a dyeing of very high fastness to washing.

Vat dyes offer a good range of colors, but shade ranges are generally dull.[4] Because of this, preparation, including bleaching and mercerizing, is important. Mercerizing helps the dyer achieve deeper shades and produce adequate cover on raw cotton. Vat dyes are insoluble in water but are readily soluble in alkaline solution. Vat dyes can be applied by continuous methods or by exhaust dyeing procedures.

4.3.4 End-Use Classes

Dyes are also classified according to their end-use properties, most notably their fastness under a variety of end-use conditions, such as light, laundering, crocking, dry cleaning. These properties, as they relate to the intended end-use of the textile product, are taken into account during dye selection by the laboratory dyer, who formulates the dye recipe for production use.

The consideration of applications, end-uses, and costs explains why the laboratory dyer selects specific dyes when matching a particular shade for a customer. Virtually every shade is custom matched to the exact color

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[4] Vat dyes can produce bright greens without metals, which is a problem with other classes for cotton.

the customer requests, although customers generally have little knowledge of the environmental consequences of their selections. For maximum pollution prevention, the dyer should encourage the customer to consider more environmentally friendly dyes. Often, a slight change in hue or brightness requirements allows selection of different dyes and colorants that could potentially eliminate significant environmental problems (e.g., metals in wastewater). This underscores the need for the dyer and the designer to be aware of both the product and the environmental performance aspects of textile dyes. These globalization issues are discussed further Section 4.17.3.2.

4.3.5 Environmental Classification

Several textile dyes, and even some food dyes, have been investigated and found to be carcinogenic (16). Close study of the dyes has revealed that carcinogenicity is linked to specific types of dye intermediates or metabolites, such as benzidines.

Whaley (12) examined many dyes for evidence of hazardous nature, based on their molecular structure. Of 1,460 dyes examined, the structures were found or known for 585 dyes, or approximately 40 percent of the total. Based on an assessment of likely reduction degradation products, 55 percent of these known dyes were predicted to be hazardous, and 13 percent were predicted to be uncertain in terms of safety (see Figure 4.2 for a general overview, and Table 4-18 for a specific breakdown of dyes by color class).

Since 1984, a concerted research effort has been made to develop dyes based on safer intermediates. Some safer intermediates, along with the older, traditional mutagenic intermediates, are shown in Figure 4-3. The old intermediates were adopted many years ago, before development of the numerous tests now available to determine environmental effects. Responsible dye manufacturers have eliminated offending colors from their product lines; however, the widespread use of apparently harmful dyes even as late as the early 1980s indicates the need for the dyer to be vigilant when selecting dyes and to use care in handling all dyes.

Responsible manufacturers now consider the environmental impact of the dyes they produce, in addition to their traditional considerations of economy, high wetfastness, and high tinctorial value (17). Dyestuffs can be synthesized based on safer intermediates. One strategy for

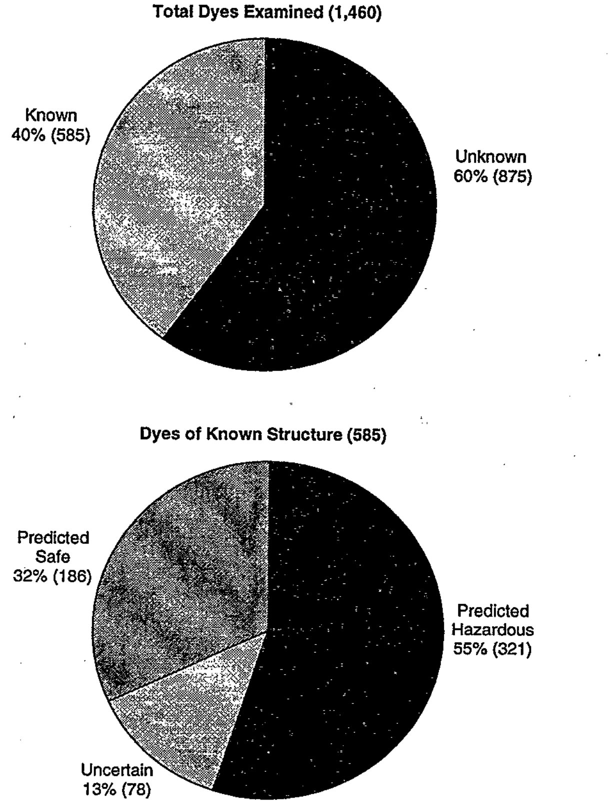

Figure 4-2. Predicted hazardous nature of dyes (1984).

Table 4-18. Predicted Hazardous Nature of Dyes; All Dyes Except Vats, Sulfurs, Foods, and Brighteners (1984) (12)

Colors	Total Known[a]	Safe (of Known)	Uncertain (of Known)	Hazardous (of Known)	Percent Hazardous (of Known)	Unknown
Yellows	87	39	16	32	37	190
Oranges	54	15	6	33	61	98
Reds	140	47	19	74	53	214
Violets	49	18	7	24	49	40
Blues	98	41	13	44	45	179
Greens	27	10	0	17	63	20
Browns	24	2	1	21	88	94
Blacks	35	9	8	18	51	36
Azoics	71	5	8	58	82	4
Totals	585	186	78	321	55	875

[a] Sixty percent of structures were undisclosed and thus could not be evaluated.

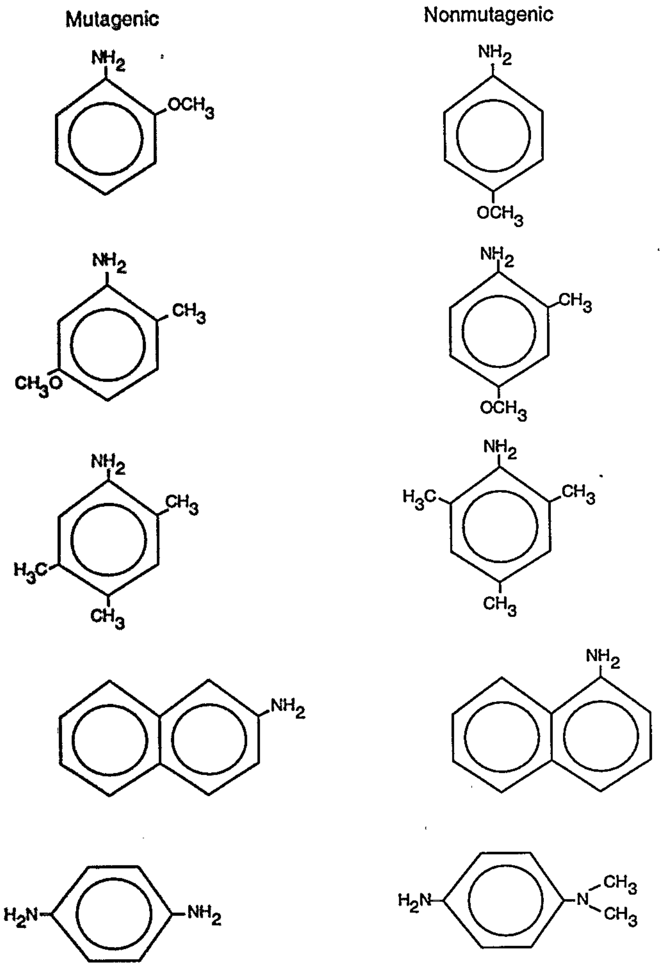

Figure 4-3. **Some mutagenic dye intermediates and nonmutagenic alternatives (12).**

azo dyes is to increase the size of the alkoxy group ortho to the azo linkage (18).

4.3.6 Pollution Prevention Measures

As a pollution prevention measure, every dyer should work only with responsible and knowledgeable suppliers; insist on complete identification of all dyes and chemicals, as well as full environmental impact information; be conservative in the handling and use of all dyes and chemicals; and arrange processes to ensure maximum utilization and minimum waste from spent processing baths and handling. Dyers should follow established principles for the safe handling of dyes.

Dye manufacturers should help dyers consider environmental factors when selecting dyes by providing more information concerning the ingredients of their products.

A dyer should evaluate dyes from an environmental point of view according to the following factors:

- Safety of the dye and its metabolites.
- Aquatic toxicity.

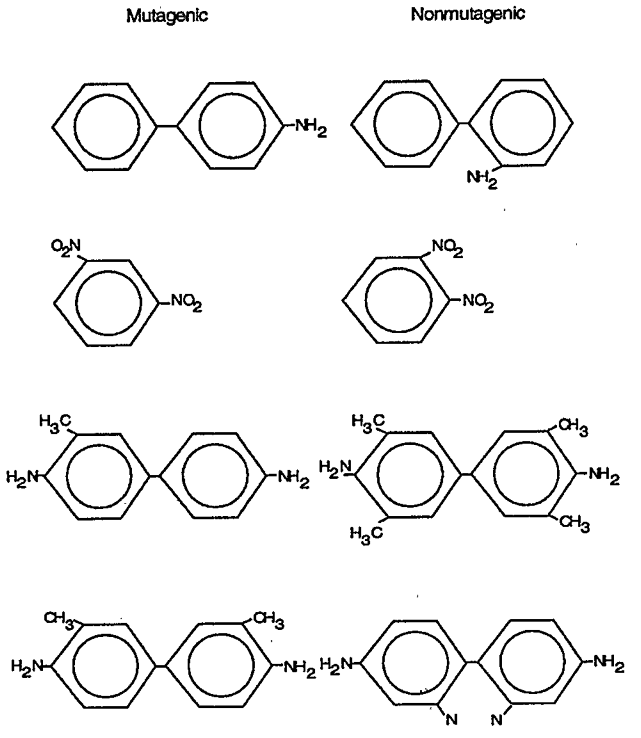

Figure 4-3. **Some mutagenic dye intermediates and nonmutagenic alternatives (12) (continued).**

- Metal content.
- Ability to be decolorized, degraded, or treated by biological degradation, chemical destruction, sorption, or precipitation.
- Toxicity of degradation products.
- Propensity to produce hazardous wastewater treatment sludges.
- Exhaustion typically achieved in a dyeing process.

The need for better disclosure of dye structures and properties is obvious. Although dye manufacturers are increasingly aware of the need to provide more information, future trends may not bode well for better disclosure of dye ingredients and environmental impacts, given the need to protect proprietary business information. In the past, many dyes have been classified by chemical structure and applications factors in the CI. The CI is a dual classification system for dyes in which the dyes are grouped according to chemical class (with a CI constitution number when the chemical structure is known for each chemical compound) and use or application class (with a CI generic name for each dye, whether made by one or several manufacturers). The CI is the standard means of identification for textile dyes. The CI generic name is derived from the application class to which the dye belongs, the shade or hue of the dye, and a sequential number, all of which gives clues about the possible environmental effects of the dye.

This indexing system seems to be coming to an end because many of the major dyestuff companies have withdrawn their support. In the future, dyes will become more proprietary, like specialty products, with an associated loss of information for the user. In the future, lack of information will make evaluation of pollution problems, substitutions, and other aspects of the dye selection process even more difficult for textile mills because they will know even less about the chemical constitution and structure of the dyes that they are using.

Dyers must rely on vendors for environmental information on dyes, but, in the final analysis, dyers must carefully evaluate environmental and other claims about dyes using their own site-specific processes, equipment, and experience.

4.4 Chemical Specialties

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.4, Chemical Specialties (General)		
All pollution types resulting for specialty chemical auxiliary use (e.g., water, air, hazardous and solid wastes)	Understanding of the types and roles of chemical auxiliaries in textile processes, possible alternatives, and the importance of prescreening and raw material QC	Further details for specific specialties of highest importance in pollution prevention are in the sections that follow (4.4.1 through 4.4.3.2)
4.4.1, Proprietary Nature of Chemical Specialties		
All pollution types resulting for specialty chemical auxiliary use (e.g., water, air, hazardous and solid wastes)	Better information exchange between chemical supplier and user (mill), sources of information, prescreening and incoming QC	
4.4.2, Types of Chemical Specialties		
All pollution types resulting for specialty chemical auxiliary use (e.g., water, air, hazardous and solid wastes)	Better understanding of the types and uses of processing assistants	An example is given; complete description of all types and uses of textile specialty processing assistants is beyond the scope of this or any other single document; important specialties are reviewed in the following sections
4.4.2.1, Warp Size		
BOD, COD	Understanding of alternatives, consequences of selection, possibility of recovery	Removed size is generally wasted to the desize operation (see Section 4.9.2.1)
Aquatic toxicity	Understanding of alternatives, consequences of selection	Explained in Sections 4.7 and 4.9, "Sizing and Preparation"
4.4.2.2, Permanent Press Finishes		
Formaldehyde	Formaldehyde-free alternatives	Further information is in Section 4.12, "Finishing"
4.4.2.3, Softeners		
General pollution from softener use, especially aquatic toxicity and air emissions	Understanding of available types of softeners, their respective performance characteristics, and selection criteria	See also Section 4.12, "Finishing," for further information
4.4.2.4, Builders		
General pollution from the use of builders, including formaldehyde	Understanding of available types of softeners, their respective performance characteristics, and selection criteria	See also Section 4.12, "Finishing," for further information
4.4.2.5, Surfactants		
General: all types of pollutants from surfactants	Better understanding of the types, occurrences, and uses of surfactants, as well as their special properties	Several types (cationic, anionic, noinionic, amphoteric) are discussed. Their properties (both performance and pollution) are discussed and sources are identified
BOD, COD	Surfactant selection	Tables of BODs are given
Aquatic toxicity	Surfactant selection; better testing methods	Comparison of various types for raw waste and treated waste toxicity are explained
4.4.3, Pollution Prevention		
Warp size	Reduction of the need for warp size through fabric design, loom selection, and loom operating speed	A global issue; the gains in wet processing must be balanced against the losses in weaving
BOD from warp size	Size selection	A global issue; the gains in wet processing must be balanced against the losses in weaving

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
Aquatic toxicity from warp size	Size ingredients control; better understanding of the performance and environmental consequences of size additives	Removed and wasted at desizing operation (see Section 4.9.2.1)
BOD from surfactants	Surfactant selection	
Aquatic toxicity from surfactants	Surfactant selection, avoiding cationics in particular; chemical prescreening	Includes case histories
4.4.4, Other Pollution Prevention Measures		
All types of pollution from chemical specialty use	Use of mechanical, not chemical, remedies for process and/or equipment inadequacies	Case histories are included
	Avoiding overuse of specialty processing assistants; reduction of chemical specialty use	Specific pollutants are identified in the description of processes in which the specific specialties are used
	Getting better information from vendors and using MSDS information	
	Chemical prescreening and incoming specialty raw material QC	
	Understanding measures of treatability	
Cleaning up and packaging wastes	Bulk purchases and returnable IBCs	Avoid drums and bags if possible

The textile industry uses several thousand chemical specialties, each designed to accomplish a specific purpose in processing and finishing operations. The selection and use of these chemical specialties has a considerable impact on the amounts and types of pollutants generated at textile facilities. This section reviews the types of chemical specialties used, discusses their pollutant impacts, and describes strategies for their selection and use that can minimize the amount of pollution generated.

Most textile wet processing operations use chemical specialties, but the major specialty-consuming operations are sizing, scouring, bleaching, dyeing, printing, and finishing. Vendors offer a wide array of chemical specialties for use in these processes. A recent list compiled by The American Association of Textile Colorists and Chemists (AATCC) contained more than 5,000 proprietary specialty products in 100 categories. An industry consisting of approximately 175 companies marketed these chemicals (19). The major categories of chemical specialties used in textile processing include surfactants; warp sizes; thickeners; and finishing chemicals such as water and soil repellents, durable press finishes, and flame retardants. A complete list of categories from the *AATCC Buyers Guide* (19) is shown in Table 4-19.

Chemical specialties represent one of four major sources of pollution in textile wet processing operations. Other sources include dyes and pigments, chemical commodities (including incoming water), and incoming substrates. Chemical specialties represent a pollution prevention challenge, primarily because they are used in so many operations and because knowledge of their constitution is limited by their mostly proprietary formulations. Considering the large quantities of chemical specialties consumed by the textile industry, relatively little information is available concerning their pollutant characteristics.

The use of chemical specialties is so widespread in textile manufacturing that techniques for preventing pollution from their use are discussed throughout this document. Other sections of this manual that deal with chemical specialties are: Section 2.2.5, "Metals," 3.5, "Chemical Alternatives," 3.7, "Incoming Raw Material Quality Control," 3.11, "Optimized Chemical Handling Practices," 4.7, "Slashing and Sizing," and 4.12, "Finishing," among others. This section provides an overview of chemical specialties and discusses, in-depth, those specialties not covered in other sections. The main points made concerning chemical specialties in this section are:

- Pollution prevention for chemical specialties is important but difficult to implement because of proprietary formulations and the difficulty of obtaining information about environmental effects.
- The selection and specification of chemical specialties is essential to the overall pollution prevention strategy because of the wide range of environmental impacts that could result from different proprietary formulations.
- QC of chemical specialties is important because low-quality chemicals, or variability in chemical quality, can result in greater pollution or in batches of low-quality goods.

4.4.1 Proprietary Nature of Chemical Specialties

Chemical specialties used in processing generally comprise proprietary blends of low-cost commodity chemicals. These blends are sold at specialty prices because of the vendor's expertise, not only in mixture composition but also in applying the products to solve site-specific processing problems. For this reason, the formulations almost always are considered proprietary. Although by law the vendor must supply a material safety data sheet (MSDS), specialty formulators are not required to reveal

Table 4-19. Categories of Proprietary Chemical Specialties in the Textile Industry (19)

Accelerators
Acids, fatty
Acids, inorganic
Acids, organic
Adhesives
Antichlors
Anticreasing agents
Antifoaming agents
Antifume agents
Antimicrobial agents
Antioxidants
Antislip finishing agents
Antistatic agents
Atmospheric fading protective agents
Binders for fabrics, yarns
Binders for pigments
Bleaching agents
Bleaching assistants, stabilizers, and catalysts
Builders, detergent
Carriers, dye
Catalysts
Chelating agents
Coating agents and assistants
Coning and winding lubricants
Corrosion inhibitors
Crease-resisting finishing agents
Curing assistants
Degreasing agents
Degumming agents and assistants
Deliquescents
Deodorants
Depitching agents
Desizing agents
Detergents and assistants
Discharge printing agents and assistants
Dispersing agents
Dulling agents
Durable press agents
Edge binders
Emulsifying agents and assistants
Enzymes
Fixing agents for dyes
Flame retardants
Foam inhibitors
Foaming aids
Fulling agents and assistants
Fumigants
Fungicides
Gas fading inhibitors
Germicides
Gums
Hand builders
Hygroscopic agents, humectants
Insecticides and insect repellents
Iron stains, agents for prevention and removal
Kier boiling agents and assistants
Levelling chemicals
Loading agents
Lubricants for textiles
Mercerizing assistants
Mildew preventatives
Milling agents
Mordants and metallic salts
Moth resisting agents
Nonslip finishes
Nonwoven binders
Odorants, odor-masking agents, and deodorants
Oil repellents
Oxidizing agents
Paint and tar removers
Penetrating agents
Polymers
Printing assistants and catalysts
Protective agents for wool and silk in wet processing
Reducing agents
Resins
Resists, dye
Retarding agents
Rewetting agents
Rubbing fastness, agents for improving
Rust preventatives
Scouring agents and assistants
Scrooping agents
Sequestrants
Shrinkage controllers (other than anticreasing agents)
Silver-fish repellents
Sizing agents
Slip-proofing agents
Soaping agents for prints and dyeing
Soaps
Softeners
Soil release/stain release finishes
Solvents, formulations
Scouring agents
Spinning agents
Spotting agents
Stripping agents and assistants, dyes
Stripping agents and assistants, finishes
Surfactants
Tar removers
Thickeners
Throwing oils
Tints, fugitive
Ultraviolet absorbers/light stabilizers
Water repellents
Water softeners and normalizers
Water treatment agents
Waxes
Weighting agents
Wetting agents
Whitening finishes, fluorescent
Winding lubricants
Wool scouring agents and assistants

specific information to mills about pollutants generated by the specialty. This greatly complicates mills' efforts to identify and reduce their use of problem chemicals.

The proprietary nature of specialty formulations is a complex issue. Although the vendor wishes to keep formulations secret to protect commercial interests, the mill may need information about the chemical to prepare for spills, disposal, treatment, reporting, and compliance. Proprietary formulations are now a major pollution prevention problem for mills.

One solution is for the mill to insist on the necessary information during the prescreening process, which will ensure that the mill understands pollution issues associated with a particular chemical before it begins using it (see Section 3.7, "Incoming Raw Material Control"). Although some vendors may hesitate or refuse to provide formulation and environmental effects data, others realize the increasing need to provide safe, effective chemicals and to be forthcoming with information about the chemicals in order to make the sale.

For pollution prevention purposes, the two most important pieces of information about chemical specialties are 1) the disclosure of pollutant information, including potential incompatibility with other materials, and 2) better, more accurate aquatic toxicity data (20). The importance of this information is discussed further below.

4.4.2 Types of Chemical Specialties

The major chemical specialty categories in the textile industry are shown in Table 4-19. Essentially all areas of wet processing in a textile mill use some of these chemical specialties. Surfactants are used in most wet processing operations. Finishing involves treating natural and synthetic fibers with chemical specialties to transform those fibers into yarn for use as is, or for weaving or knitting the yarn into fabrics.

Typical finishing recipes for cotton and cotton blends use a combination of the following chemical specialties:

- Cross-linking resin and its required catalyst.
- Softener.
- Wetting or penetrating agent.
- Sewing lubricant.
- Handbuilder (stiffener).
- Functional additives (e.g., water repellent, flame retardant).

Specific chemical specialties used in finishing include:

- Oils, waxes, and fats.
- Starches and polymers.
- Tints.
- Esters (butyl stearate, tridecyl stearate, oleates, palmitates, laurates, trimethylolpropane trispelargonate, pentaerythritol tetrapelargonate, di(2-ethylhexyl) adipate, azelates, and sebacates).
- Polyoxyalkylene glycols and poly(oxyethylene-oxypropylene) ethers.
- Silicone and modified silicone fluids.
- Emulsifiers (anionic, nonionic, cationic, and amphoteric).
- Antistatic agents (anionic, nonionic, and cationic).

Data on the sales of textile chemicals indicate the relative importance of each chemical specialty category. As shown in Table 4-20, dyes and dyeing auxiliaries make up the bulk of chemical sales, but other specialties also are purchased in substantial quantities.

The classes of chemical specialties are too numerous to describe completely in this manual. The sections that follow cover the major categories. Specific problems related to the generation of wastes from chemical specialties, or to the processes in which chemical specialties are used, can be found elsewhere in this manual.

4.4.2.1 Warp Sizes

Table 4-20. Chemical Sales to the Textile Industry (21)

Category	Sales: Millions of 1987 Dollars	Sales: Percent
Dyes and auxiliary products	859	57.6
Surfactants	177	11.9
Sizes and thickeners	159	10.7
Water and soil repellants	101	6.8
Durable press resins	94	6.3
Flame retardants	39	2.6
Other textile chemicals	62	4.2
Total	1,491	100.0

Size is a chemical mixture applied to warp yarns to improve the strength and bending behavior of the yarn's fibers, thereby preventing breakage during weaving operations. Size is removed from fabrics after weaving has been completed in a companion process called desizing, which can generate high pollution loads in textile effluent.

The three main types of size currently used are:

- *Natural products (starch):* Starch, derived mainly from potatoes and corn, is the most common size and is used mainly for cotton products and other natural fibers.
- *Fully synthetic products:* Synthetic sizes include polyvinyl alcohol (PVOH or PVA), polyvinyl acetate (PVAc), polyacrylic acid (PAA), and polyester.
- *Semisynthetic products (blends):* Semisynthetic sizes or blends include modified starches, starch ethers, starch esters, carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC), and starch-ether and starch-esters.

In addition to the chemicals listed above, size mixtures normally include additional auxiliary chemicals that are added to improve weaving performance, enhance stability of the size or the sized yarn, and distinguish between sizes, among other uses.

Starch desizing contributes high BOD loadings to effluent compared with synthetic desizing. Typical starch sizes have 5-day BODs of 500,000 ppm to 600,000 ppm, while the BODs of alginates and modified starches range from 100,000 ppm to 500,000 ppm (11). Synthetic sizes contribute much lower BOD loadings than starches, ranging from 10,000 ppm to 30,000 ppm. These BODs are approximately 15 to 60 times lower than those for starch. If the synthetic size is recycled, BOD loadings drop even farther, resulting in an overall reduction of more than 99 percent compared with starch (11). Synthetic sizes contribute lower BOD loadings because they are not biodegradable. Consequently, they are more likely to pass through wastewater treatment systems to be discharged to the environment than starches. At this time, the total size consumption in the

United States is about one-third recoverable. Of the one-third that is recoverable, only about one-third of that is actually recovered, or about 10 percent of the total size used.

Auxiliary components in the size mixture also can affect BOD levels. Humectants, lubricants (waxes and oils), antistatic compounds, biocides, glycerine, and wetters can generate up to 10 or 15 percent of the total BOD load. Of these auxiliary components, humectants and lubricants contribute the most to BOD load, typically accounting for 2 to 5 percent of the total (11).

Auxiliary chemicals added to the size mixture can also result in toxicity. For example, surfactants and biocides, which are commonly used, can add to aquatic toxicity. This issue is discussed further in Sections 4.7, "Slashing and Sizing," and 4.9, "Preparation."

4.4.2.2 Permanent Press Finishes

Cotton, rayon, and other forms of cellulose and blends that contain these fibers usually require finishing with a reactive agent to cross-link adjacent cellulose chains. This step immobilizes the fibers, reducing shrinkage and improving bending properties (e.g., crease recovery).

Many types of reactive cross-linkers exist. Currently, the products of choice for cross-linking cellulose are N-methylol compounds, which are produced by reacting urea with formaldehyde and other additives. In application and use, N-methylol cross-linkers can release formaldehyde.

The most widely used cross-linker for textiles is dimethylol dihydroxy ethylene urea (DMDHEU). This agent usually reacts with cellulose under high temperatures in the presence of a Lewis acid catalyst such as magnesium chloride. When properly used, applied, and cured, formaldehyde release from fabrics treated with DMDHEU is minimal. A few commercially available nonformaldehyde cross-linkers eliminate formaldehyde release completely. These cross-linkers (e.g., DMeDHEU) are considerably more expensive than DMDHEU and, therefore, have never been widely used in the U.S. textile industry.

4.4.2.3 Softeners

Finish recipes (which incorporate softeners) often are made up in the same way that they were many years ago, without regard for environmental considerations (22, 23). A wide variety of softeners exist, including natural and synthetic compounds (24). The main types of softeners are fat, petrochemical, and silicon based (25).

The performance of each type of softener varies, and each has advantages and disadvantages (24, 25). Fatty acid softeners are biodegradable (24), while both paraffin and polyethylene softeners are nonbiodegradable (24). Quaternary types *have high aquatic toxicity (24).* Mineral oil and paraffin wax softeners are still used although these types of softeners smoke when heated, producing air emissions from dryers (22, 23). Polyethylene glycol (PEG) and polyethylene oxide (PEO), on the other hand, do not produce volatile organic compounds (VOCs) during drying and curing. Reactive silicone softeners are very well fixed and do not wash off of the fiber, whereas most other types wash off during home laundering of the textile products (24).

4.4.2.4 Builders

Functional materials applied to textiles to improve their softness or feel are known as builders or handbuilders. These materials include N-methylol film-forming reactive materials (e.g., trimethylol melamine, urea formaldehyde), natural polymers (e.g., starches, alginates, gums), and synthetic polymers (e.g., PVA) (25).

Acrylic handbuilders and stiffeners can replace formaldehyde-based N-methylol handbuilders (22, 23). Acrylics are good substitutes in many applications. The use, however, of acrylate monomers, especially their manufacture, is linked to other pollution problems. The alginates, starches, and modified starches are the least harmful environmentally, but they also have high BOD and often produce high levels of total suspended solids (TSS), which are difficult to remove or settle.

4.4.2.5 Surfactants

Surfactants are used in the formulation of almost all chemical specialties, including:

- Penetrants and wetting agents.
- Solvent and nonsolvent scouring compounds.
- Lubricants and antistats.
- Oil and wax emulsifiers.
- Dispersants for all types of specialties.
- Emulsification systems for many of water-insoluble processing assistants (e.g., lubricants, dye carriers, softeners).

A working knowledge of surfactants is important for production workers and supervisors for several reasons:

- Surfactants are widely used in textile manufacturing for a variety of purposes.
- The behavior of surfactants often is substantially different than might be expected based on experiences with other "normal" chemicals.
- Surfactants are one of the main causes of aquatic toxicity and BOD in textile wastewater.

- Because of the many different types of surfactants available, selecting the correct surfactant for a particular function requires a good understanding of performance and pollution issues.

Fortunately, the wide variety of surfactants available facilitates the selection of less-polluting alternatives (26). Unfortunately, this information is often unavailable to the typical mill production supervisor.

The four basic classifications for textile surfactants are 1) nonionic, 2) anionic, 3) cationic, and 4) amphoteric (13). Overall, anionic and nonionic surfactants account for over 90 percent of total consumption, as shown in Table 4-21 (27).

Based on these data, most pollution prevention efforts focus on the largest volume surfactant categories, nonionic and anionic surfactants. Nonionic surfactants dissolve in water without forming ions, while anionic surfactants dissolve to form negative ions. Cationics, however, exhibit extremely high aquatic toxicity. Most textile mills avoid using cationic surfactants because of their incompatibility with more widely used anionic surfactants.

The four basic categories of surfactants are described in more detail in the sections that follow. Examples of the major product types are provided for each.

Nonionic

Nonionic surfactants have many advantages, including excellent compatibility in most processing situations, good wetting and rewetting, good emulsification, and excellent oil solubility. Nonionic surfactants also are good components of oil emulsifiers. The disadvantages of nonionic surfactants include temperature sensitivity (cloud point), low alkali tolerance, low electrolyte tolerance, possible harshening of cellulosic fibers, and possible dye spotting and/or crocking of disperse dyes from residual surfactants (28). In addition, surfactants generally generate large amounts of foam, which may or may not be desirable in specific situations. Alkylphenol ethoxylate surfactants are one of the largest groups of nonionic surfactants used, accounting for more than 400 million pounds per year in the United States (29). Of this, 82 percent (approximately 330 million pounds) is ethoxylated nonyl phenol, of which about 80 to 90 million pounds are treated and discharged to rivers each year (29).

Table 4-21. Consumption of Surfactants in Textiles (27)

Type	Percent of Total
Anionic	59[a]
Nonionic	33
Cationic	7
Amphoteric	1
Total	100

[a] 34 percent synthetic and 25 percent natural soaps.

Four examples of common nonionic surfactants are:

- *Alcohol ethoxylates:* Derived from ethylene (easily degraded), propylene, butylene (more difficult to degrade), or vegetable triglycerides (easy to degrade). They are known by acronyms such as AE (alcohol ethoxylate) or LAE (linear alcohol ethoxylate). These surfactants are used as emulsifiers, wetters, or scouring agents.
- *Alkylphenol ethoxylates:* Derived from propylene (most often containing a branched nonyl) or butylene (containing a branched octyl), and known by acronyms such as APEO (alkylphenol ethoxylates), or NPE (nonylphenol ethoxylate). Decomposition products of APEOs are phenols, which are toxic to aquatic organisms such as fish. Used as an emulsifier, wetter, or scour.
- *Tertiary thiol ethoxylate (TTE):* Used as an emulsifier, wetter, or scour.
- *Diethanol cocoamide (DEC):* Used as a scour, lubricant, and softener, as well as in dyeing.

Anionic

Anionic surfactants commonly consist of sulfates, sulfamates, sulfonates, sulfosuccinates, phosphate esters, methyl taurines, carboxy methylates, and metallic and amine soaps. Four examples of anionic surfactants are:

- *Alkylbenzene sulfonates:* Linear and branched compounds; only the linear biodegradable compounds currently are used, and the treated effluent from processes using these compounds have no known adverse environmental effects. Used as penetrants, dispersants, and wetting, scouring, and foaming agents. Example: dodecyl benzene sulfonic acid (DDBSA).
- *Alcohol ethoxysulfates:* Linear and branched compounds; only the linear biodegradable compounds currently are used. Used as penetrants, dispersants, and wetting, scouring, and foaming agents. Example: sulfated ethoxylated alcohol (SEA). These are ethylene-oxide based, like AE, and demonstrate all of the desirable properties of nonionics but because they are anionic, they do not exhibit cloud point and other problems associated with nonionics. They are sometimes called cryptononionics.
- *Naphthalene sulfonic acid (NSA):* Used as a dispersant for disperse dyes.
- *Sodium lauryl sulfate (SLS):* Used in scouring, afterwash.

Anionic surfactants generally are used as rapid wetters, dispersants, emulsifiers, coemulsifiers, lubricants, and scouring agents. They also can be used as compatibilizers, anticoprecipitants, and components in carrier emulsion systems (28).

Anionic surfactants have several advantages, including:

- Good oil emulsification
- Good dye dispersibility
- Excellent wetting and rewetting speeds
- Low cost

Disadvantages include:

- Calcium and magnesium sensitivity with sulfate surfactants.
- Incompatibility with cationics.
- High foam level.
- Carryover from processing steps that can affect dye yield in basic or cationic dyeing.

Cationic

Cationic surfactants are relatively uncommon in textile processing. One exception is fiber finishing, where cationic surfactants are used as accelerators in weight reduction of polyester fibers by caustic treatment methods (28). Cationic surfactants also account for as much as 12 percent of all fabric softeners used (30). Cationics lower the surface tension of water and assist in emulsion, dispersion, and foam stabilization (31). Two examples of cationic surfactants are:

- *Alkyl dimethyl benzyl ammonium chloride (ADBAC):* An antistatic agent. Also used as a softener and lubricant for cloth.
- *Tallow amine ethoxylate (TAE):* Used in dyeing and antistatic treatments, or as a decoupler.

Both of these surfactants exhibit very high aquatic toxicity.

Amphoteric

Amphoteric surfactants are not used widely in today's textile operations, except in specialized situations that require wide ranges of compatibility. Amphoterics can be used in alkaline or acid media and in combination with either cationic or anionic surfactants. They exhibit excellent lubricant, corrosion inhibition, and wetting action properties and provide a protective colloid to facilitate silk and wool processing. Amphoterics are used in scouring and dyeing of protein fibers to prevent chafing, crack marks, and crow's feet (28). Nonetheless, amphoterics are expensive, and some forms are not heat stable so they cannot be used at elevated temperatures. Amphoterics have few advantages compared with other less expensive surfactants. An example of an amphoteric surfactant is *coamphocarboxy propionate (CCP), which* is used for scouring wool and silk.

Surfactant Uses

Surfactants are used in almost every textile process, beginning with fiber formation. Surfactants are applied to fiber for lubricity, antistatic properties, or other purposes. Surfactants are also used in processing solutions for specific purposes such as stabilization of an emulsion or dispersion. Surfactants perform a variety of functions in many textile processes, including (11, 26, 29, 31):

- Lubrication processes
- Spin finishing
- Desizing
- Scouring
- Mercerizing
- Bleaching
- Wet finishing
- Foam finishing
- Dyeing
- Foam dyeing
- Printing

Surfactants are used in wet processing to ensure complete wetting and penetration of processing solutions (13). In addition, surfactants can serve as dispersing agents, emulsifiers, bath detergents, foaming agents, and levelers. Besides applications in which surfactants are added directly to a substrate, many textile processes use water-insoluble processing assistants that are applied from aqueous emulsions. Essentially all chemical specialties thus contain surfactants to improve their solubility and dispersibility and to suspend water-insoluble materials in processing baths. This is particularly important because any precipitation of insoluble material is likely to lead to spots or other defects, as well as equipment fouling.

Surfactant Pollutant Properties

Surfactants may be transferred to the textile wastewater or remain behind as a residue on fibers, yarns, or fabrics. Examples of surfactant-containing residues found on textile substrates include oils and waxes on natural fibers, spin finishes on synthetic fibers, winding emulsions on yarn, coning oils, yarn finishes, knitting oils, and warp sizes (13). Further discussion of surfactant residues may be found in Section 4.2, "Fibers."

In major textile producing countries, textile manufacturing consumes approximately 10 percent of all surfactants. Ultimately, 70 percent of these surfactants are discharged in wastewater (27). Kravetz reported that surfactants have been found in raw textile waste at concentrations of approximately 50 ppm to 200 ppm (26). Other studies of raw textile wastewater have found concentrations of specific surfactants at 1,780 parts per billion (ppb) to 2,400 ppb (29). The concentration of surfactants in treated effluent depends on the amount of degradation that occurs during treatment (13, 26).

Surfactant Biodegradability

Surfactants are a major source of aquatic toxicity in textile wastewater. To reduce toxicity of wastewater, surfactants must be either eliminated from use or degraded via biological treatment. Textile mills concerned with effluent toxicity should consider pollution prevention approaches for reducing surfactant use. Surfactant substitutions in textile processes can have a beneficial effect on wastewater treatability, as well as residual aquatic toxicity after treatment.

The treatability and degradability of surfactants has been a major topic of study in the textile industry over the last few years. Kravetz et al. (32), Kravetz (26), Moore et al. (31), Huber (30), Achwal (27), and Naylor (29) have all published data related to this, as have the Chemical Manufacturers Association (CMA) and the U.S. Environmental Protection Agency (EPA).

Kravetz (32) studied three types of nonionic ethoxylate surfactants for degradability (i.e., LAE, alkyphenol (AP), and TTE). In bench-scale tests, LAE was degraded 70 percent and reportedly was harmless to the environment following treatment. AP passed through the treatment systems, as did TTE, and were degraded only 25 percent to 30 percent (32). Later work by Kravetz attributed variable degradability of surfactants to the hydrophobe part of the molecule, that is, the more linear the molecule, the greater its degradability. Branched hydrophobes are less degradable than linear hydrophobes, and aromatic materials are even less degradable (13).

The failure of some surfactants to degrade completely can result in problems such as foaming in the receiving waters and aquatic toxicity. AP was found to degrade much more slowly at low temperatures (e.g., 8°C) than at room temperature, whereas LAE was far less dependent on temperature (32).[5] In general, laboratory studies confirm that AP degrades slowly and that intermediate forms of AP reportedly are more toxic than undegraded AP in some cases (29).

Recently, an industry group of major surfactant suppliers studied the fate of AP in the real-world environment by measuring AP concentration in raw textile wastewater and in 30 rivers, using special chromatographic analytical techniques capable of low-level concentration measurement (ppb). AP from textile operations was found to degrade between 94 and 97 percent in real-world waste treatment systems (29). This degradation level was far greater than that reported in bench-scale tests previously conducted (26, 31, 32). In wastewaters with AP concentrations of approximately 2 ppm, the degradation level in treated effluent was immeasurably low in approximately 70 percent of the samples. Based on worst-case scenarios of discharge locations and low-water flows, almost all in-stream concentrations were below the no-observable-effect concentration (NOEC) (29).

Despite the differences exhibited in laboratory studies and real-world treatment systems, no published evidence currently exists to show that AP is more degradable than LAE. The issue of biodegradability is closely related to the BOD and COD of the materials, as discussed below.

Surfactant BOD and COD

BOD_5 values have been published for a variety of detergents, individual surfactants, and scouring and dyeing assistants, as shown in Tables 4-22 and 4-23. Incomplete surfactant biodegradation within the 5-day time limit of the standard BOD test results in a large variation in BOD_5 results among different surfactant types. The COD test with dichromate is more rapid and consistent; therefore, the COD is higher than the BOD_5 and shows less variability. One measure of biodegradation potential is the ratio of COD to BOD_5. If a surfactant biodegrades completely in 5 days, the ratio is close to 1:1. As the extent of biodegradation decreases, the ratio increases (11).

Table 4-22. BODs of Detergents and Surfactants: Product 5-Day BOD (ppm) (11)

All detergent	40,000
Dreft detergent	49,000
Igepal (alkyl phenol EO)	40,000
Igepon AP-78 (sodium isothoinate oleate)	1,210,000
Igepon T-77 (sulfonamide)	1,660,000
Isodecyl alcohol 6 EO (Epilsophogene DA 63)	100,000
Ivory Snow	1,220,000
Lauryl sulfate	1,250,000
Merpol B (alcohol sulfate)	440,000
Neodol 25-3-S (alcohol EO sulfate)	570,000
Neodol 25-7 (12-15 C alcohol/7 EO)	450,000
Neodol 45-7 (14-15 C linear alcohol/7 EO)	650,000
Nonyl pehol 10 EO (Igepal CO630)	24,000
Orvus K (ammonium lauryl sulfate)	1,560,000
Parval (fatty amide soap)	50,000
Rome soap flakes	1,220,000
Sandopan TLF (sulfonated fatty amide)	50,000
Santomerse 3 (sodium alkyl aryl sulfonate)	90,000
Saponite (solvent scour)	830,000
Sulfanol KB (sodium alkyl aryl sulfonate)	0
Sulfonated castor oil	520,000

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[5] Sasser, P.E., and B. Smith. Personal communication between P.G. Sasser, Cotton, Inc., Raleigh, NC, and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC (July 29).

Sulfonated vegetable oil	590,000
Syndet (amide detergent)	120,000
Tallow	1,520,000
Tallow soap	550,000
Tergitol 15-S-7 (11-15 C secondary alcohol 7 EO)	150,000
Triton 770 (alkyl aryl polyester sulfate)	90,000
Triton 771 (polyester sulfate)	50,000
Triton X-114 (isooctyl phenol EO)	100,000
BP solvent	940,000
Duponol C (lauryl sulfate)	1,250,000
Duponol D (alcohol sulfate)	450,000
Duponol RA (wetter)	330,000
Duraline (solvent scour)	160,000
Ethofat C/15 (fatty acid/EO)	1,000,000
Ethofat C/60 (fatty acid/EO)	220,000
Ethomid HT/15 (amide/EO)	1,000,000
Ethomid HT/60 (amide/EO)	90,000
Extol XP Special	700,000
Iberscour	530,000
Igepol CA-630 (wetter)	130,000
Igepol CA conc.	70,000
Iversol (solvent scour)	600,000
Kierpine Extra (sulf. oils)	610,000
Kreelon 8D (sodium alkyl aryl sulfonate)	50,000
Kreelon 8G (sodium alkyl aryl sulfonate)	230,000
Kyro AC (fulling)	120,000
Merpol B (alcohol sulfate)	440,000
Monotone A	200,000
Naccosol A	20,000
Nacconol NR	0 to 40,000
Nacconol NRSE	0
Nekal NF	120,000
Nevtronyx 60D	0
Orvas Neutral Granules	30,000
Parval (fulling)	50,000
Pine Oil	1,080,000
Pluronic F68 (polyglycol ether)	120,000
Rinsol	720,000
Sandozol KB (sulf. vegetable oil)	150,000
Solpinol Special	700,000
Solvent A	250,000
Solvent GTS	410,000
Solvent T	250,000
Solvex	10,000
Special Textile Flakes	1,120,000
Strodex	120,000
Supertex E	250,000
Syndet	120,000
Syntholite #100	100,000
Triton 770	90,000
Triton W30	500,000
Ultrawet DS	0
Ultrawet 35K	0
Xylol Scour Special	420,000

Table 4-23. BOD of Dyebath Auxiliary Chemicals: Product Five-Day BOD (ppm) (11)

Anthomine (wool dyeing)	90,000
Carbopen (penetrant)	20,000
Dyes (various)	0 to 100,000
Dyes (sulfur)	Approx. 100,000
Dyes (disperse)	Approx. 30,000
Dyes (direct)	Approx. 80,000
Dyes (azoic)	Approx. 20,000
Azoic couplers (β-naphthol)	100,000
Formopon (hydro/formaldehyde strip)	270,000
Gluconic acid and lactone (vat)	520,000
Glucose corn syrup (vat)	530,000
Lanazin tip (albumin derivative)	90,000
Fluorescent brightener (leucophor)	330,000
Metachloron (fix)	0
Peregal OK	20,000
Rexan O (EO leveler)	20,000
Sodium acetate (buffer)	320,000
Sulfoxite (strip)	270,000

Nonbiodegradable surfactants such as high COD-to-BOD_5 ratio detergents are a problem because they are likely to pass through treatment systems. The best choices for biodegradable surfactants are those with ratios in the 2:1 to 6:1 range (33). Some researchers advocate a top limit of 5:1. Ratios above 5:1 represent surfactants that are difficult to degrade and should be avoided. This approximation applies not only to surfactants but also to textile specialties and waste streams in general (11). The Organization for Economic Cooperation and Development (OECD) test 301D, "Ready Biodegradability," may also be used to calculate BOD:COD ratios. International standards state that a BOD_{28}:COD ratio greater than 60 percent (based on nonaqueous activities) is readily biodegradable.

Aquatic Toxicity of Surfactants

The Clean Water Act requires acute and chronic toxicity tests to be performed on waste treatment plant effluent. Surfactants can contribute greatly to aquatic toxicity. Some nonionic surfactants are known to kill fish in the ppm range and produce chronic effects in the 0.1 ppm to 1.0 ppm range.

To a large extent, the choice of surfactants can control the toxicity of raw textile wastewater (31). Surfactants vary in aquatic toxicity as well as treatability, depending on specific features of their molecular structure. Knowledge of molecular structures, therefore, enables the processor or chemical specialty manufacturer to select surfactants with lower aquatic toxicity that are more amenable to degradation in treatment systems. Because eliminating all surfactants from textile processing is impossible, those that are less toxic and more treatable should be selected (33). Another important point to realize is that surfactants are often used as emulsifiers or dispersants in specialty products that contain significant nonaqueous components. These nonaqueous components contribute to aquatic toxicity and therefore deserve attention as well (see Section 4.4, "Chemical Specialties").

In one bench-scale study, AP was degraded approximately 25 percent, while under similar conditions, LAE was degraded 100 percent. Although LAE has higher aquatic toxicity ($LC_{50} = 2$ ppm) than AP ($LC_{50} = 13$ ppm) before treatment, treated effluents showed substantial toxicity for AP but no toxicity for LAE. Because LAE is more degradable and has higher BOD than AP, more rapid oxygen uptake and more waste sludge production would occur per unit time, but pass-through potential would be less. Table 4-24 summarizes surfactant toxicity data from a number of studies. Moore et al. (31) reported that aquatic toxicity is related to the hydrophilic lipophilic balance (HLB) of the surfactant. He also determined that water hardness contributes to aquatic toxicity in surfactant solutions.

In addition to the data presented in Table 4-24, the aquatic toxicity of cationic materials in general (48- to 96-hour LC_{50} for various aquatic species) is high, between 0.6 ppm and 2.6 ppm, with the NOEC ranging from 0.05 ppm to 0.5 ppm (30).

4.4.3 Pollution Prevention

Because chemical specialties are so ubiquitous and often cause high aquatic toxicities, high BOD levels, and other pollution problems, all facets of chemical specialty use must be examined. Particular operations that require attention include chemical handling and storing, chemical auditing, automated dispensing, chemical substitution, container reuse, dyebath reuse and other processing changes, and optimal process chemical choice, among others. Many of these options are discussed in other sections of this manual. The following sections discuss particular process areas and specific chemicals.

4.4.3.1 Sizing

Significant reductions in pollution can be achieved by carefully selecting the type of warp size, optimizing sizing operations, and instituting size recycling. Proper fabric design, loom selection, and operating speeds, as well as careful control of the size mixture and add-on level present the need for excessive amounts of size. In this case, pollution prevention activities must take place within one unit operation while another unit operation enjoys the benefits (see Section 4.17, "Globalization of Pollution Prevention," for more information).

Table 4-24. Aquatic Toxicity of Surfactants

Class	Type	LC_{50} (ppm)	Reference
Nonionic	TTE	17.32	31
		28.4	32
	DEC	2.4	31
	LAE	5.4	31
		0.8	32
		0.5 to 150	34
	AP	12.5	31
		2.9, 1.6	32
		1.3 to 1,000+	34
Anionic	DDBSA	19.9	31
	NSA	Not reported	
	SLS	27.8	31
	SEA	20.2	31
		0.4 to 400	34
Cationic	ADBAC	11.9	31
	TAE-15 mol EO	4.1	31
	TAE-15 mol EO	66.1	31
Amphoteric	CCP	159.1	31

Selection of the most appropriate size for a given operation is complicated, partly because of the many different sizing materials that are available to the textile manufacturer. Different fiber types, weaving looms, cost requirements, pollution characteristics, and other factors need to be balanced when selecting a size.

Choosing synthetic sizes can result in large reductions in pollution. Synthetic sizes have inherently lower BOD levels than natural sizes, and can be recycled and reused. By moving from a high-BOD starch to a low-BOD synthetic that can be reused, BOD output can be reduced by nearly 100 percent. Several warp size alternatives to starch are available, such as PVA, CMC, PVAc, PAA, and polyester. These materials differ considerably in their BOD and COD content, as well as the degree to which they are degraded during desizing. PVA and CMC are low-BOD, recoverable sizes that should be considered as alternatives to starch.

During size selection, the nature of additives in the size mixture also should be considered. Surfactants and biocides in starch mixtures contribute to BOD, and their use should be examined in light of the facility's overall pollution prevention goals. Additives can also interfere with the recyclability of sizes (see Section 4.7, "Slashing and Sizing").

4.4.3.2 Surfactants

Until recently, AP was the preferred nonionic surfactant for several reasons (27). The wetting and emulsification performance of AP in textile processes is excellent, and the cost is competitive. Also, many municipalities compute sewer charges using a formula based in part on the BOD content of wastewater, providing an incentive for industries to seek out the lowest BOD surfactants. AP-type surfactants generally have BODs in the range of 20,000 ppm to 200,000 ppm (11).

In light of studies showing aquatic toxicity in treatment residues from AP, however, attitudes regarding surfactant selection have changed (27). The German Association of Textile Auxiliary, Tanning Agent, and Detergent Manufacturers voluntarily ceased production of AP-containing products on January 1, 1992, and now suggests that LAE be substituted in formulations (7). Most experts agree that selecting the most degradable surfactants is necessary to solve aquatic toxicity problems (32). At this time, the best known pollution prevention practice is to replace AP with LAE. Research into better substitutes continues (7).

As discussed in Section 4.4.2.5, a practical guide for evaluating chemical specialties is the ratio of COD to BOD, which indicates the ability of the chemicals to biodegrade. Criteria such as OECD 301D for evaluating ready biodegradability of products or waste streams have been discussed previously in Section 4.4.2.5. Another important procedure is to avoid the use of extremely toxic cationic surfactants, which often are found in lubricants and fabric softeners (30). If no substitute is available, then handling, storage, and use of cationic surfactants should be carefully controlled and proper training, auditing, application procedures, and work practices should be established.

Case History: Surfactants

The City of Mount Airy in Surry County, North Carolina, operates a trickling filter treatment system for 14 textile mills and a population of 7,600. Effluent from this system was found to be high in aquatic toxicity, containing potentially toxic levels of copper, zinc, and surfactants, especially APs.

The City of Mount Airy requested that each textile mill review its use of APs, and substitute, eliminate, or optimize/reduce the use of these surfactants. Within 60 days, the toxicity of effluent from the treatment system decreased substantially. This decrease was attributed primarily to the substitution of LAE for AP. Before industrial source reduction efforts, toxicity (48 hours LC_{50} static daphnid bioassay) was 51 percent. Following changes in the types of surfactants used at the mills, toxicity was reduced to a level of greater than 90 percent. Effluent from the treatment system then regularly passed North Carolina Department of Environmental Management Ceriodaphnia pass/ fail minichronic bioassay tests (13). Similar analyses were performed in the towns of Reidsville and Concord, North Carolina, with similar results (see, for example, Diehl and Moore [35]).

4.4.4 Other Pollution Prevention Measures

In many cases, chemical specialties are used to compensate for inadequacies in equipment or substrate design. For example, dyebath lubricants are used to prevent abrasion, creasing, and cracking during dyeing when the cloth is incompatible with the dyeing machine's fabric transport system. Often, a change in the running speed or the temperature of a process can eliminate such problems without the need for chemicals. As a general rule, mechanical alternatives should always be evaluated before adding chemicals to a dyebath.

Chemical specialties also are often used to correct problems or deficiencies caused by other materials. For example, defoamers are used to suppress foam that results from the addition of inappropriate wetting agents. In addition, bath stabilizers often are added to prevent bath precipitation when incompatible chemical specialties are mixed together. A better strategy in each case is to remove the chemical that is causing the problem or replace it with a better product, rather than simply adding more chemicals to the bath.

Moore (36) reported a typical example of this issue in a hosiery mill. The facility processed nylon pantyhose and was out of compliance with a publicly owned treatment works (POTW) pretreatment ordinance for BOD, COD, and zinc. Vendor information and MSDSs were reviewed, and conditions that necessitated chemical specialty use were identified and corrected. The mill reduced its use of chemical specialties by 70 percent in the acid dyeing process and by 33 percent in the disperse dyeing process. Overall, the mill reduced chemical specialty use from 11 percent to 5 percent on weight of goods (owg). The end result was a 40-percent reduction in BOD and COD and elimination of the zinc problem (36).

4.4.4.1 Obtaining Information

Users of chemical specialties must request and review all information about chemical specialties before using them at the mill. At this juncture, the supplier has an incentive to supply the information required to complete the sale. Further, unless users request pollutant information, suppliers might not realize that customers value the availability of low-polluting products that perform well in their operations.

To facilitate access to information about chemical specialties, databases currently are being set up to provide users with information about chemical composition, while maintaining vendor confidentiality. A consortium of textile companies, chemical suppliers, and fiber suppliers, along with the North Carolina Department of Environmental Management, is sponsoring the development of one such database at North Carolina State University. The potential for reducing pollution through the use of certain chemical specialties will be evaluated based on information about the chemical commodities constituents of these specialties. The database is under development, and data collection from the standard literature is underway (37).

4.4.4.2 Selecting/Prescreening Chemicals

Textile mills traditionally have used performance, cost, and vendor support as the main criteria for evaluating new chemical specialties. Now, however, the textile industry is increasingly interested in reducing its use of chemical specialties and finding less-polluting alternative chemicals or cleaner technologies. The incentive for seeking less-polluting chemicals and technologies varies and can include regulatory compliance, worker protection, community or shareholder relations, or participation in voluntary chemical use reduction programs.

Users of chemical specialties often find that vendors are reluctant to reveal pollutant information about such products. This reluctance is not necessarily because the vendors believe the information might reflect negatively on their product. Although environmental testing is required for most new chemicals or new applications of existing chemicals, many manufacturers do not have systems in place to supply this information to vendors at the sales and marketing level, where customers are most likely to request the information. Vendors are realizing, however, that environmental awareness at the sales and marketing level and the availability of environmentally friendly products are market advantages today.

Textile mills that have existing chemical specialty prescreening programs should review their programs to ensure that they fully consider environmental effects of the chemicals. If no prescreening program is in place, the checklist below, which describes a prescreening protocol that several companies use successfully, can be used (11):

- Cost and performance.
- Hazardous waste characteristic (ignitability, toxicity, corrosivity, reactivity, flammability).
- Priority pollutant status (the list of 126 chemicals) (see Table 2-25).
- Listed 33/50 chemicals.
- Availability of safer alternatives.
- Biodegradability.
- Heavy-metal content.
- Percentage solids.
- Potential for accumulation in the facility.
- Potential for release to the environment.
- Indoor air pollution potential.
- Hazard potential when mixed with other chemicals.
- Hazardous and toxic air pollutants.
- Proposed manner of use.
- Ultimate fate of the chemical.
- Hazard potential to the customer.
- Who will handle the chemical.
- How the chemical will be used (other chemicals to be mixed with, concentrations).
- Whether the user requires special safety equipment.
- Spill procedures, incompatibilities, etc.
- Type of packaging (returnable, bulk).

Various authors have suggested several specific prescreening criteria and, although mills should not rely on these criteria alone to satisfy their environmental goals, the criteria might be helpful in cases where more detailed information is not readily available. One recommended criterion, for example, is to select chemicals that are at least 90 percent biodegradable in activated sludge treatment systems (38). A second method is to compare the COD to BOD ratio (11). This number should be between 2:1 and 5:1 for typical chemical specialties. Higher numbers indicate that the materials are more likely to resist biodegradation and pass through waste treatment systems. Three OECD methods are also useful in these evaluations: 301D for biodegradability, 209 for biomass impact, and 202 for daphnia toxicity. Databases (e.g., Aquatox) for these data are being introduced for commercial use.

Chemical specialties also should be screened for the presence of any 33/50 chemicals. Under its 33/50 Program, EPA has asked industry to voluntarily reduce its use of 17 chemicals on the Toxics Release Inventory (TRI) by 33 percent by 1992 and 50 percent by 1995. The 33/50 chemicals found in textile operations include 1,1,1-TCE (spot remover), perchloroethylene (dry cleaning), and methyl ethyl ketone (MEK)/methyl isobutyl ketone (MIK)/toluene/xylene (latex coating operations) (39).

A prescreening evaluation for new chemicals can be done effectively by a committee that includes the following (11):

- Nurse or hygienist.
- Chemist.
- Production department manager (where the chemical will be used).

- Safety officer.
- Waste treatment system operator.
- Others as appropriate.

Involving the vendor in the prescreening process is also important because the vendor has information about the product that the mill does not. The vendor, however, does not control the use conditions of the chemical or handling practices. The mill must discuss the intended application of the chemical with the vendor so that the vendor can anticipate any potential problems. For more information on this as a global approach, see Section 4.17, "Globalization of Pollution Prevention."

4.4.4.3 Maintaining Incoming Chemical Quality Control

The quality of chemical specialties can vary from batch to batch, and variations in quality can have a significant effect on process conditions, environmental releases, and final product quality (1). The customer should work with vendors to set acceptable guidelines for the purity and content of chemical specialties before purchase (1). After deciding to adopt a chemical, the mill must establish a regular program of quality control verification to ensure that chemical quality requirements are being met. Each shipment should be checked when it is received.

Once prescreened and approved for use, samples of incoming chemicals should be tested to ensure consistency (11). Because chemical specialties are generally of unknown composition, the suggested tests are not chemical-specific. Developing specific tests for each chemical specialty mixture is not realistic in a commercial textile setting. The following checklist describes an incoming chemical QC protocol (11):

- Permanently mark the date that the drum/container was opened as a visual verification that the test was done and as an aid in detecting aged chemicals.
- Check pH with pH meter or pH paper and record (for aqueous products).
- Check viscosity with Zahn cup and record.
- Check density with hydrometer and record.
- Determine percentage solids by evaporation in an oven and record.
- Note color and clarity visually and record.
- Note odor and record.
- Check conductivity with handheld conductivity meter and record (for aqueous liquids).
- Check index of refraction with handheld refractometer (for clear liquids) and record.
- Compare data with previous history and vendor's standard values.
- Enter the data on a control chart for display.
- Keep carefully documented records for each chemical on a long-term basis.
- Retest drums that have been open for a long period.
- Review all data with the vendor.

All incoming QC data should be reviewed with the vendor, even if no problem is indicated. Reviewing data accomplishes two important functions:

- Builds rapport and acceptance of test data, which will be valuable if a problem arises.
- Alerts the vendor that the customer is testing incoming materials and establishes acceptance criteria for those materials.

4.4.4.4 Selecting Packaging

One crucial area to cover with the vendor during prescreening is to ensure that packages will be returnable without being cleaned on site. Offsite cleaning transfers chemical wastes back to the production facility, which presumably is better able to handle wastes than the textile mill. Chemical specialties should be purchased in returnable, reusable containers, preferably IBCs (40). Returnable IBCs or bulk purchases eliminate waste packing materials and may provide other benefits, such as:

- Reduced spillage
- Reduced handling costs
- Reduced packaging waste
- Reduced worker exposure to chemicals
- Simplified inventory
- Reduced cost of chemicals that are bought in bulk
- Savings in storage space (IBCs are stackable)

If IBCs are not available or purchasing them is not practical and drums or bags must be used, the mill should follow the recommendations below.

When purchasing chemicals in drums, returnable containers should be specified, and the vendor should be required to accept unwashed drums for return. Eliminating the need to wash each drum before pickup prevents a significant amount of wastewater pollution at the textile facility.

Many chemicals are purchased in bags (e.g., salt, TSP, TSPP, soda ash, warp size). Bags are a constant source of breakage and spillage, and disposing of them is nuisance. They cannot be stored near high traffic areas or wet locations. They also must be moved around on skids, which tend to break, and handling bags requires a significant amount of labor. Whenever possible, mills should specify a preference for IBC packaging rather than bags (all chemicals listed above are available in IBCs as well as bags).

4.5 Chemical Commodities

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.5, Chemical Commodities		
Salt	Understanding the role of salt in cotton dyeing and low-salt process alternatives	
Water (hydraulic load)	Understanding the role of water in various processes and how to select and design equipment and process, alternatives for low water use	
Acids and alkalis	Understanding the role of pH and alkalinity in various processes, and alternatives	
General reduction of high-volume pollution from commodities	Understanding the role of commodities in various processes, and alternatives	Further information is in various sections on the processes themselves
	Handling of commodity chemicals, especially the use of bulk systems	Special maintenance procedures are required for safely operating bulk chemical systems, and these are identified; case histories are given
Low-level offensive wastes originating from commodities	Incoming raw material QC for low-level impurities in high-volume raw materials	Metals in fibers, toxic agricultural residues, etc., are examples

Many types of commodity chemicals are used in textile manufacturing. Most notable are acids, alkalis, electrolytes, oxidizers, organic solvents, and reducing agents. Other high-volume raw materials include raw water and fiber. Some of these high-volume inputs are discussed in the following sections: Sections 2.2.2, "Discharge of Electrolytes," 2.2.7, "Water Conservation," and 4.2, "Fibers."

Commodities are used in extremely large quantities in textile processing; in some cases, the weight of commodities may be as high as the weight of the goods being processed. For example, the raw materials required by a 100,000-pound-per-day mill producing fiber reactive dyed and finished cotton-woven fabric could include the following top six commodity materials:

Raw Material	Quantity (pounds)
Water	10,000,000
Cotton fiber	100,000
Salt	80,000
Acid and alkali	15,000
Peroxide	2,000
Silicate	3,000

In addition to potential environmental problems associated with commodity chemicals themselves, the mill must be concerned with contaminants that may be present in commodities. Because of their volumes, the presence of impurities at the ppm level in commodities can be a significant problem. For example, an average zinc level of 1 ppm in the commodities listed above would contribute 1 pound of zinc to the effluent every 10 days. Because of the potential for this kind of pollution, commodities must be screened for low-level impurities and must be purchased from "pure" sources. Low-level impurities in commodity chemical inputs have not been comprehensively evaluated. Some data are available for fibers, however (see Sections 4.2.1 and 4.2.2).

4.5.1 Commodities Versus Specialties

Unlike specialties, commodities are chemicals of known composition and are sold based on market supply and demand conditions. Because their chemical composition is known, incoming QC tests can be directed toward the actual chemical nature of the commodity, as opposed to the generic screening protocols recommended in Section 4.4, "Chemical Specialties." To prevent pollution, tests should focus on impurities in the commodity. These impurities are the result of source contamination or limitations of the manufacturing processes used to produce the commodity and serve no useful purpose in the textile process.

4.5.2 Types of Commodities

Table 4-25 presents some of the most common commodities used in textile operations, including:

- Acids (mineral)
- Acids (organic)
- Alkalis
- Buffering salts
- Electrolytes
- Oxidizers
- Reducing agents

Table 4-25. Examples of Commodity Chemicals Used in Textiles

Commodity Category	Examples	Uses
Acids (mineral)	Hydrochloric acid Sulfuric acid Phosphoric acid Boric acid	Neutralization Stripping of resin finish Repair work/stripping dyes
Acids (organic)	Formic acid Acetic acid Oxalic acid Citric acid	pH control in many processes Catalyst in resin curing
Alkalis	Caustic Soda ash Trisodium phosphate Sodium bicarbonate Ammonia Sodium meta silicate Potassium ortho silicate Sodium pyrophosphate Borax Disodium phosphate	pH control in many processes Activator for peroxide bleach Activator for fiber reactive dyes Neutralization Mercerization
Buffering salts	Monosodium phosphate	pH control (nonvolatile)
Electrolytes	Sodium chloride (common salt) Sodium sulfate (Glauber salt) Magnesium sulfate (Epsom salt) Salt brine (25% sodium chloride solution)	Promote exhaustion of cellulosic dyes
Oxidizers	Peroxide Sodium chlorite Sodium hypochlorite Percarbonate Perborate Periodate Permanganate (obsolete—rare) Dichromate (obsolete—rare)	Bleach Stripping agent for dyes (repair)
Reducing agents	Sodium hydrosulfite Bisulfite Thiosulfate Thiourea dioxide	Stripping agent for dyes (repair) Afterclearing disperse dyes

4.5.3 Quality Control for Incoming Commodities

A good pollution prevention program includes commodity chemical prescreening and testing of incoming raw material shipments. Usually, the mill can easily check the strength or activity of incoming commodity chemicals (41). Tests for that purpose, however, do not reveal the presence of offensive impurities or contaminants, such as heavy metals. Most textile mills do not have the equipment to perform quantitative tests for low-level impurities in high-volume commodity raw materials.

In many cases, however, the material can be dissolved in distilled water (for salts), neutralized (for acids and alkalis), or reacted (for oxidizers or reducers), and the resulting solutions can be tested for metals using sensitive qualitative-analysis spot tests. Spot test methods are summarized in the literature (41) and are presented in detail in Section 3.7. In addition, many contract laboratories run metals analyses using atomic absorption (AA) or inductively coupled plasma (ICP) techniques for reasonable prices.

4.5.4 Bulk Systems/Automated Dispensing

Many textile operations use bulk storage tanks and automatic dispensing systems for commodity chemicals because of the high volumes used and the price advantage of buying in bulk. The use of bulk systems helps prevent pollution by reducing small-scale spills, handling losses, implement cleanup wastes, container washing, and fluid disposal.

Switching from manual to automated bulk systems involves a tradeoff, however. With manual dispensing systems, the maximum spill that could reasonably be expected to occur is usually 55 gallons (one drum) or less. With automated systems, the potential for a spill of thousands of gallons is present, although the likelihood of a spill is lower.

The pollution prevention strategy for manual systems is to improve packaging, train workers, and emphasize housekeeping. Switching to bulk handling systems requires that mills provide training for workers and develop and enforce spill prevention and spill response procedures, to minimize the risk of spills. Further considerations include:

- Sound engineering design of bulk systems, including segregation of tanks by chemical type; selection of proper line and tank metallurgy; pumps and check valves; tank containment systems providing good secondary (berm) containment; automatic timeout/shutoff on demand pumps; lockout/tagout provisions; and alarms.
- Careful installation.
- Clear labeling and identification of tanks.
- Strong preventive maintenance programs for system components and equipment such as pumps, pipes, sight glasses, supports, and valves. Frequent and thorough safety audits.
- Spill control planning.
- Worker training.
- Proper notification of community emergency response units.
- Proper control and policies regarding deliveries including no off-loading except during normal working hours; two people present during off-loading; safety shower and eyewash at the off-loading point; and no bulk delivery truck washing allowed on site.

Sales of commodity chemicals are very competitive, so to get business, commodity vendors often provide a bulk tank (as well as design specifications for installation) either for free or for a modest charge. This service is a good pollution prevention opportunity for the mill because commodity vendors have high levels of expertise in bulk handling of their products. Vendors often have hotlines or helplines, and some even offer onsite environmental and safety inspections of installations.

Below are examples of problems that have occurred at mills that lack a pollution prevention strategy for commodities:

- A 1,000-gallon peroxide tank ruptured and spilled its contents because an installer did not put the specified check valve in the delivery line. Process material backed up into the tank resulting in rapid decomposition of the peroxide.
- A driver went to sleep in the cab of his oil delivery truck and the tank overflowed. Because no overfill alarm was present, and only one person was on site during off-loading, the problem was not detected until too late.
- A delivery hose came loose from its coupling, spraying the driver with chemicals. No plant employee was present during off-loading. The driver had to go and search for a shower. By the time he returned, 700 gallons of material had sprayed onto the ground, resulting in a very expensive cleanup. The spill occurred because only one person was present during off-loading, a safety shower was not present at the delivery point, and the hose coupling was not properly maintained.
- A driver pumped catalyst into a reactant tank and ruined 4,000 gallons of resin because the tank was not properly labeled. Although expensive chemicals were ruined, the consequences could have been much worse.

4.6 Yarn Formation

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.6, Yarn Formation (General)		
General for all types of pollution resulting from yarn formation	Understand processes, process flows, and alternatives, as well as fiber alternatives	Waste control in spinning is very advanced because spinning is a major cost factor
Reworkable fiber waste	Recycle within process	
Nonreworkable waste (e.g., packaging waste, trash, hard waste)	Select reusable packaging types, then recycle	
	Identify causes of waste and educate employees, maintain equipment, etc., to eliminate or minimize these causes	
4.6.1, Yarn Formation Process		
Process waste	Segregate, recover, reuse, develop markets, and sell	

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
Controllable-cause waste	Identify causes of waste (worker error, off-specification raw materials, equipment malfunction, housekeeping, improper procedure), then take remedial action	
Packing materials and other solid waste (e.g., bale wrap, cones, tubes, straps)	Involve suppliers as discussed in Section 1.2.3	
Chemical additives	Having global perspectives	These are removed in wet processing (see Sections 4.9 and 4.17 for more information)
4.6.2, Types of Waste Associated With Spinning		
Trash (nonlint)	Use improved raw materials (from agriculture)	
	Use better cotton varieties and better ginning procedures	
Sweeps, fly, and invisible waste	Identify causes of waste (worker error, off-specification raw materials, equipment malfunction, housekeeping, improper procedure), then take remedial action	
	Train workers	
	Improve waste collection and handling	
Reworkable waste	Improve waste collection and handling using vacuum capture at the source	
Hard waste	Identify causes of waste and educate employees, maintain equipment, etc., to eliminate or minimize these causes	
Packaging	Use reusable cones, yarn cases, pallets, and bale wrap	Requires supplier coordination and global views
	Use clear plastic shrink wrap, not opaque cardboard yarn cases	

This section describes pollution prevention opportunities in yarn formation operations. The discussion is limited to pollutants and contaminants formed or released during spinning. Methods to address pollution associated with raw fiber contamination are discussed separately in Section 4.2, "Fibers," as are the pollution prevention opportunities associated with synthetic fiber formation.

4.6.1 Yarn Formation Processes

4.6.1.1 Continuous Filament Yarns

Filament yarns are continuous forms in which the length of the fiber is essentially infinite, resulting in the yarn's structural strength and integrity. A single continuous filament yarn may typically have as few as one (monofilament) or as many as several hundred filaments. Table 4-26 contains examples of fibers that are typically used in filament form, including a wide variety of manmade polymers, some regenerated natural fibers, as well as silk and a few other natural fibers.

Manmade filament is formed by liquefying the polymer, extruding it through an opening of appropriate size and shape, and resolidifying it into a solid continuous filament yarn. The liquid state may be either a melt or a solution. Fibers that are melted and extruded resolidify through cooling. Alternatively, the polymer may be dissolved to bring it to a liquid state for extrusion, then resolidified by either immersing it in a coagulating bath (wet spinning) or evaporating the solvent (dry spinning). In either case, residual solvents or components of the coagulation bath can be present in the continuous filament yarn. After the spinning process, the yarn then undergoes one or more postextrusion processes, such as annealing, drawing, crimping, texturizing, finishing, and winding. This is depicted in Figure 4-4.

Spun synthetic fibers can include residues from numerous sources, including:

- Polymerization (e.g., monomer, trimer, oligomer, catalyst).
- Melt additives (e.g., delusterants, colorants).
- Extrusion auxiliaries (e.g., surfactants).
- Natural fiber regeneration (e.g., solvents).
- Fiber derivitization (e.g., xanthates).
- Fiber finishing (e.g., antistatic agents, weighter).

Table 4-26. Fibers Typically Used in Filament Form

Synthetic	Regenerated	Natural
Acetate	Rayon	Silk
Triacetate	Chitosan/Chitin	
Acrylic	Rubber	
Aramid		
Modacrylic		
Polyamide (nylon)		
Polyethylene		
Polypropylene		
Polyester		
Saran		
Spandex		

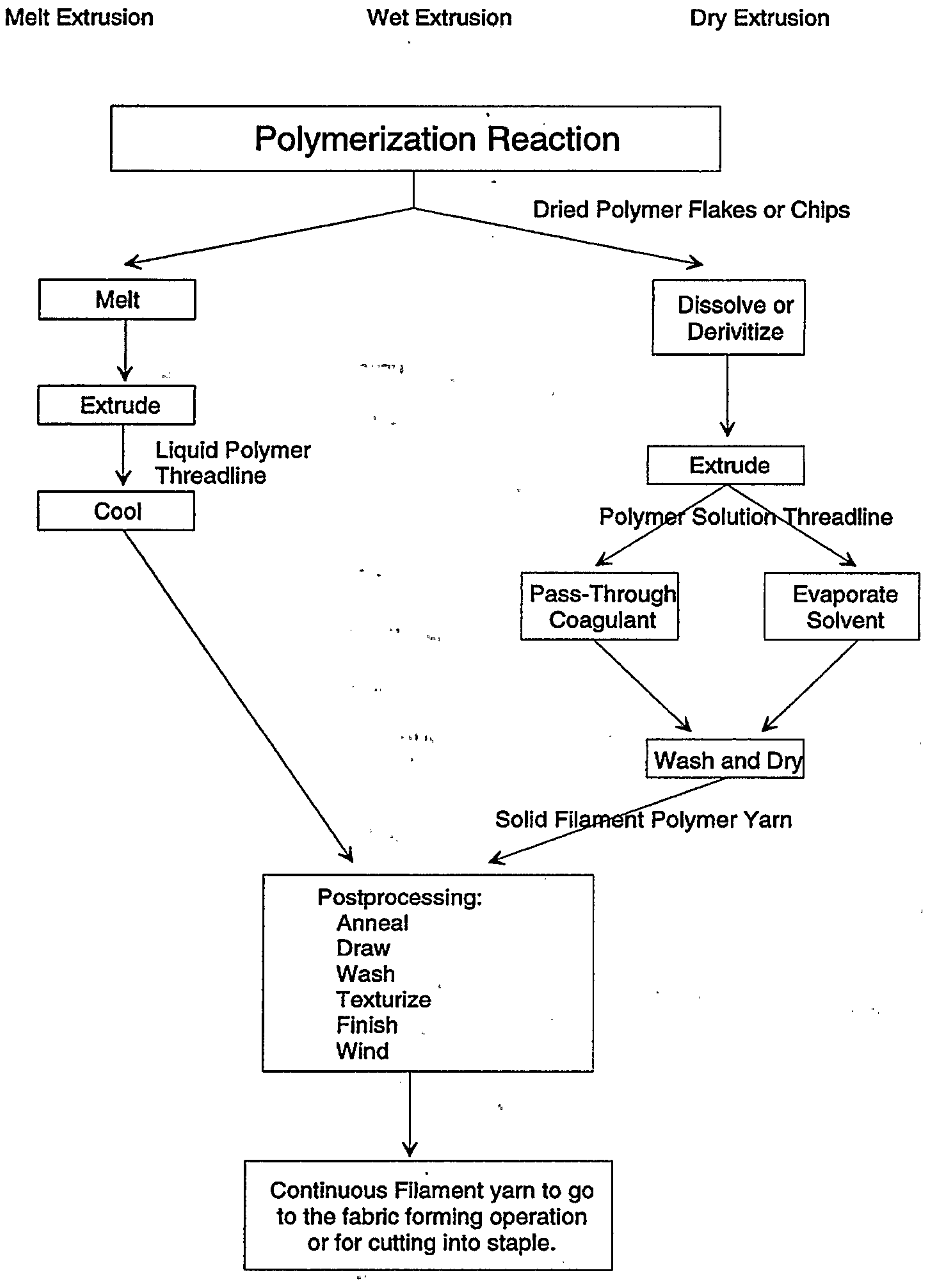

Figure 4-4. Production sequence for synthetic continuous filament yarn production.

- Tints (e.g., for identification).
- Winding (e.g., mineral oil, wax).
- Other postextrusion processing (e.g., lubricants, humectants).

All of the postextrusion processes listed above are part of the fiber manufacturing process, covered in Section 4.2, "Fibers."

Filament yarn can be cut into staple of any desired length and can be spun on various spinning systems detailed below.

4.6.1.2 Spun Yarns

The spinning process takes natural fibers with a finite length and combines them to produce a yarn with superior strength and structural integrity properties. Synthetic or regenerated filament fibers are often cut into shorter lengths so they can be blended with natural fibers and spun into yarn, or to improve their tactile properties in an effort to emulate natural yarns. For example, filament polyester is often cut to 1.5-inch length for blending with cotton staple in polyester/cotton blended spun yarns. Acrylic is often cut into longer length to emulate the tactile properties of wool. These finite-length forms of fiber are called staple. The typical length of wool fibers ranges from 2 inches to 12 inches (special varieties up to 18 inches), and cotton fibers range from 0.8 inches to 1.4 inches.

Spinning provides spun yarns with structural integrity and strength. This is achieved by aligning the individual fibers in a parallel direction and inserting a precisely controlled amount of twist into the yarns to cause individual fibers to bind together through interfibrous frictional forces. The methods of controlling staple fiber orientation, alignment, cleaning, evenness, and twist are highly length dependent; thus, staple fibers of widely differing lengths are not compatible for spinning together. In cotton/wool blends, for example, the wool must be cut to a length similar to the cotton staple length to facilitate processing. Thus, two spinning systems are used: long staple spinning (woolen and worsted system) and short staple spinning (cotton system). Short staple spinning is by far the most prevalent type. The two systems differ greatly in several details. Figures 4-5 and 4-6 show the typical steps in each production sequence, and the paragraphs below highlight the differences.

4.6.1.3 Long Staple Spinning

Long staple yarn production includes wet processing steps interspersed with dry processing steps (see Figure 4-5). This division between wet and dry processing distinguishes long staple from short staple spinning; no wet processing occurs in short staple spinning until the yarn is desized, scoured, and bleached at the finishing mill. Information specific to long staple systems is therefore covered in Section 4.12, "Finishing." This is appropriate because scouring, dyeing, and finishing of wool are commonly done when wool is in the form of raw stock fiber, sliver, tops, as well as yarn and fabric. Section 4.12 includes a major subsection on wool wet processing.

Many of the same pollution prevention techniques presented below for short staple are equally applicable to the dry steps in wool spinning.

4.6.1.4 Short Staple Spinning

The majority of yarn in the United States is produced using short staple spinning. Figure 4-6 shows the steps in the short staple spinning process. Pollution prevention in this process primarily focuses on three items:

- Fiber waste from cleaning and other processing operations.
- Packaging wastes.
- Additives such as tints, antistatics, and lubricants that are applied during spinning and that must later be removed.

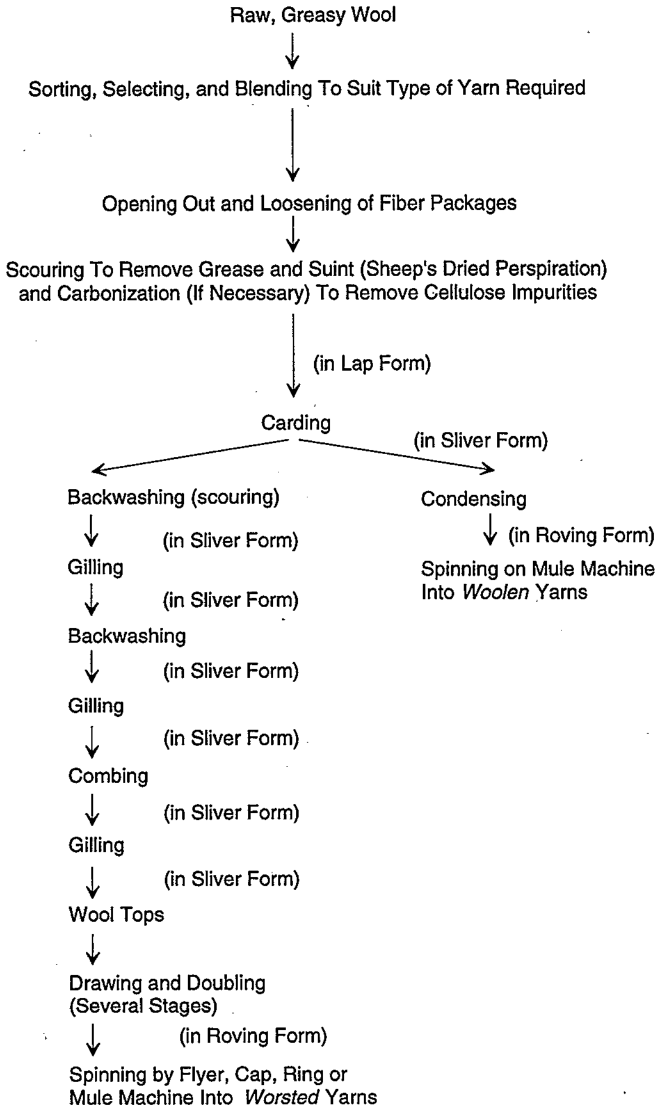

Figure 4-5. Stages in the manufacture of yarns for long staple spinning (42).

Most fiber waste comes from cotton processing because cotton is less pure than synthetics upon arrival at the mill. Trash, immature fibers, and other impurities must be removed from cotton before processing. In other respects, however (e.g., packaging waste), cotton and synthetics are similar in terms of process waste.

Spinning operations have already achieved dramatic improvements in waste reduction, mainly for economic reasons. Successful waste reduction is a common feature of commodity operations (e.g., yarn spinning), where raw material cost and utilization are closely related to profitable performance. The opposite is true with very high value-added products (e.g., coated fabrics), where raw material cost and waste are minor overall factors. The economic incentive to conserve and reuse raw materials is extremely low, and the economic incentive

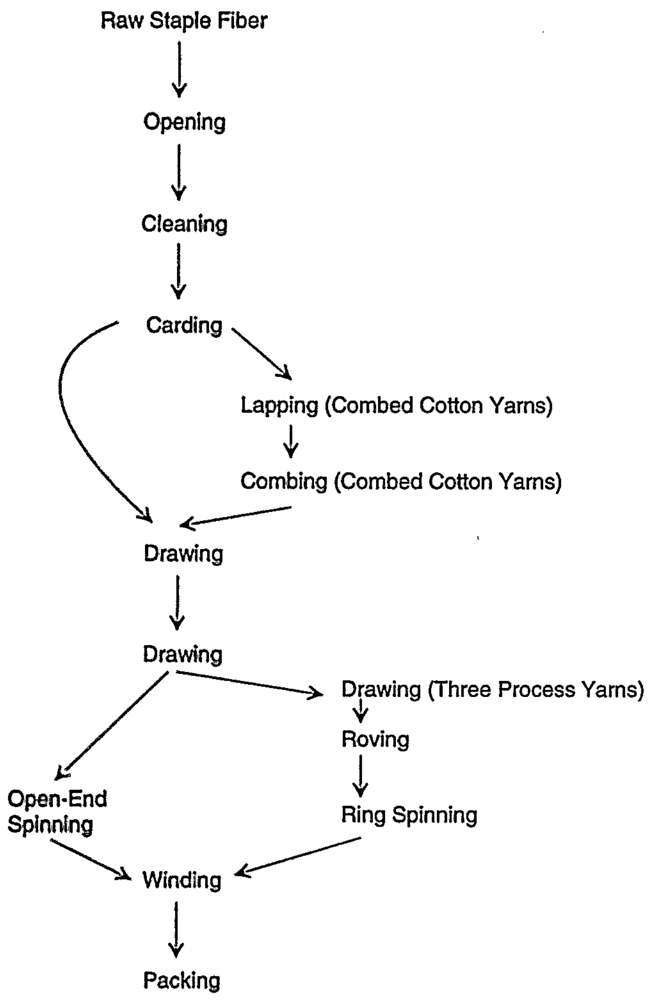

Figure 4-6. **Stages in the manufacture of yarns for short staple spinning.**

to make the best product regardless of cost or waste is much greater.

Although most mills have extensive waste minimization programs, spinning still generates a substantial amount of waste. A 1986 U.S. Department of Energy study estimated that the total amount of fiber waste in the United States from polyester and cotton spinning operations is 45 million pounds per year (43). In one company with six spinning operations, the waste was equivalent to 70 bales of fiber per day (44). According to a survey of fiber waste in spinning mills, over 40 percent of this waste is controllable using management practices described in this section (44).

4.6.2 Types of Waste Associated With Spinning

Although spinning operations generate many types of waste, the main categories are (45):

- Process waste.
- Controllable-cause waste.
- Solid wastes such as packing materials (notably polypropylene bale wrap) and bale straps (plastic or metal).

4.6.2.1 Process Waste

Process waste is related to the manner in which staple fibers are processed during spinning. This waste can be further characterized according to its potential for reuse:

- *Reworkable waste:* Refers to good, clean fibers that can be fed directly back into the opening line through a designated waste hopper. These fibers originate from nearly every process in the spinning mill. They are collected, delivered to waste containers or air handling systems, then returned to the opening line. These fibers have their full value, and standard practice in nearly every spinning mill is to have at least one waste hopper for reworkable wastes in the opening line.
- *Nonreworkable waste:* Is generally produced in cleaning processes (e.g., opening, cleaning, carding). It also may contain various amounts of soiled or damaged reworkable waste.
- *Hard waste:* Refers to yarn that has been sized. These fibers are very difficult to open and reuse in the normal spinning process.

Most mills employ efficient recovery and reuse systems for reworkable wastes, and many also find suitable reuse opportunities for other types of process waste.

4.6.2.2 Controllable-Cause Waste

Controllable-cause wastes are those attributed to upsets or departures from normal operating procedures, such as (44):

- Worker error or mistake, or failure to follow procedures.
- Rejected materials, off-specification materials, and failed QC.
- Equipment malfunctions.
- Poor housekeeping.
- Improper method or procedure.

Such wastes are considered controllable because they can be avoided through closer attention to factors such as equipment maintenance, operating conditions, and QC procedures.

4.6.2.3 Solid Waste

Solid packaging wastes include bale wrap, cones, cases, and strapping. These wastes are discussed later in this section and in Section 1.2.3, "Solid Wastes."

4.6.2.4 Additives

In addition to the wastes discussed above, another important issue for spinning operations is chemicals that are added during spinning and that can affect operations later in the production process. Additives such as tints and lubricants are often applied in the spinning operation with implications for later stages of the production process (e.g., during preparation for printing, dyeing, finishing). Additives are discussed under the processes in which they are removed (e.g., Section 4.9, "Preparation") and in Section 4.17, "Globalization of Pollution Prevention."

4.6.3 *Pollution Prevention in Short Staple Spinning*

The amount of waste generated from short staple spinning depends on the cotton grade used as input and the intended quality level of the spun yarn. To produce good yarn, the nonlint content (trash) of the raw fiber must be removed, and, as part of the process, a certain amount of lint is also removed. Over the years, the nonlint content of raw cotton has decreased significantly. Before 1960, the waste content of raw cotton averaged from 2 percent for the best grades, such as strict good middling (SGM), to over 10 percent for lower grades, such as strict good ordinary (SGO) (45). As the nonlint content in the raw cotton has decreased, the amount of nonreworkable waste generated in spinning has also declined.

The decrease in the nonlint content of raw cotton is partially due to mechanical harvesting machines, which became popular in the 1950s to 1960s. These machines reduced the nonlint content in cotton by automating aspects of the cotton picking process. Lint cleaners also have been added to gins over the years. These "fine" cleaners remove small particles of waste after the lint and seeds are separated in the gin stand. Before seed/fiber separation, cleaning was very inefficient, and only the largest trash particles (e.g., stems, leaves) could be removed. After the separation of lint from seeds, the lint cleaners can remove finer trash efficiently. Most gins now have one to three stages of these fine cleaners, which remove more trash, and thus give reduced nonlint content for the fiber bales going to the spinning mill.

The nonlint content of the raw cotton itself has declined through improved agricultural and ginning techniques, including the development of better strains of cotton. Figure 4-7 shows historical data on the nonlint content of various cotton grades from the 1950s through 1986.[6]

Cleaning waste is fiber deliberately removed from the raw cotton at the spinning mill to increase the quality of the cotton stock and thus obtain the desired yarn properties. Most of this originates from opening, cleaning, carding, and combing and may amount to between 5 percent and 20 percent of the raw fiber (44). In U.S. mills with good waste control, 5 percent is the typical upper limit.

Sweeps, fly, and invisible (unaccounted) waste amounts to 1.5 percent in the best mills but may range as high as 9 percent in poorly operated mills. The rest of the waste results from neglect, old equipment, or poor work practices (44).

In addition to improving the raw cotton itself, process engineering has led to other changes that have reduced spinning mill waste. The elimination of such processes as pickers, roving in the rotor spinning process, and winding as a separate process has prevented waste. In addition, major improvements have been made in opening, cleaning, carding, drawing, and spinning. Sophisticated waste handling systems are now available to capture waste using vacuum and pneumatic handling.

The net result is that nonreworkable waste generation from spinning processes has steadily declined, as follows.[7]

1930s	15 percent
1950s	10 percent
1990s	3 to 5 percent

Spinning mills now typically produce between 3 percent and 5 percent nonreworkable waste, depending on the grade of cotton they run and the product they make. Modern reclamation equipment can reclaim some lint from this nonreworkable waste, ultimately yielding 1.5 percent or less waste to discard. Many mills do better than the 1.5-percent figure, while a few of the worst mills are in the 2.0-percent range. All waste, except for "hard" waste, can be reused internally if properly reprocessed (44).

An ever-increasing ability to reuse and recycle waste has accompanied increased waste reduction. Markets have developed for various waste products, and separation techniques for reprocessing nonreworkable waste now can recover most of the waste as reusable lint.

The state-of-the-art pollution prevention technique for handling nonreworkable waste is to collect it using vacuum capture at its source. Capture and recovery points include lost ends in roving or sliver, air handling filter systems, cards, draw frames, carding and cleaning waste, and comber noils. This waste is carried by air to a system that separates lint from nonlint. The amount of recovered lint depends upon the cotton grade. Of the 3 to 5 percent total waste, typically only 1.5 percent actually survives as nonlint waste to be discarded. The recovered lint (fiber) is fed back into lower quality products, or at a very low level into the same product opening line. The 1.5 percent that is trash is sold for several other reuse applications. One example is padded mailing envelopes, which are often stuffed with this material. An-

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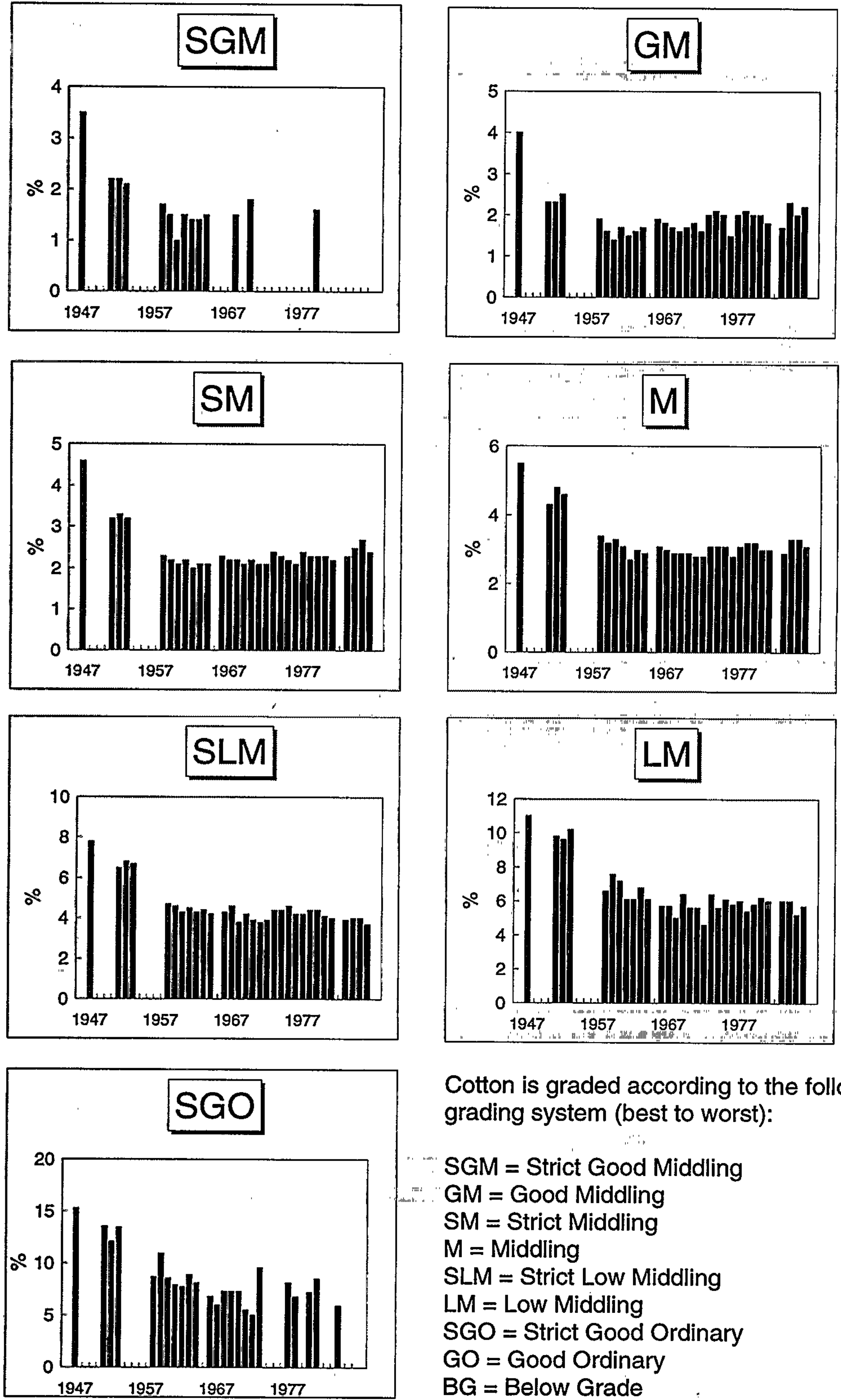
[6] See footnote 5.

[7] See footnote 5.



Cotton is graded according to the following grading system (best to worst):

SGM = Strict Good Middling
GM = Good Middling
SM = Strict Middling
M = Middling
SLM = Strict Low Middling
LM = Low Middling
SGO = Strict Good Ordinary
GO = Good Ordinary
BG = Below Grade

Figure 4-7. Average percent Shirley Analyzer nonlint content of white cotton grades (see footnote 5).

other common reuse opportunity is to compress the material using a two-stage hydraulic ram system into extremely high-density cylindrical pellets about 2 inches in diameter and 2 inches long to use as boiler fuel.

4.6.4 Other Waste Issues

In addition to the fiber waste discussed above, two other waste issues are important in spinning operations:

- Additives added during spinning that must be removed later.
- Solid packaging waste.

Additives (e.g., tints, lubricants) are often applied in the spinning operation and affect later preparation stages (printing, dyeing, finishing). Methods for managing these are discussed under the processes in which they are removed (e.g., Section 4.9, "Preparation") or in Section 4.17, "Globalization of Pollution Prevention."

Solid packaging wastes, including bale wrap, cones, cases, and strapping, are discussed in Section 1.2.3, "Solid Waste." Because of large volumes, mills should use plastic reusable cones to minimize waste from these sources and should reuse yarn cases. An even better solution than reusable yarn cases is the palletized shrinkwrap form of yarn packaging, which allows workers to see the yarn through the plastic shrinkwrap. When workers can see the yarn, they tend to handle it more carefully, thus reducing the amount of dirty and damaged yarn, and associated waste.

4.7 Slashing and Sizing

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.7, Slashing and Sizing (General)		
Polymeric sizes in general	Global views Size add-on optimization (use minimum required amount) Incoming raw material QC Minimization of discards Equipment maintenance Proper storage, handling, and employee training Facility design Solid capture; housekeeping	Reduction of size add-on at weaving (and perhaps loss of weaving efficiency) ensures pollution reduction at the desizing operation
BOD, COD	Selection and handling of size	Reduction at the slashing operation and at the desizing operation
Metals	Incoming raw material QC	
Air and water toxics	Incoming raw material QC	
Fiber lint and yarn waste	Segregation, capture, and reuse for fuel	
Packaging	Supplier involvement; purchasing specification for reusable IBC or bulk packaging	Avoid bags
4.7.1, Unit Process Description		
General polymeric size pollution	Understanding of the function and applications of warp size Improved process control of temperature, speed, add-on, tension, and moisture (dryness) Facility design (e.g., mix kitchen, pumps, mix tanks, and scales) Equipment design, maintenance, and operation QC improvement and prevention of loom stops	
4.7.2, Warp Size Types and Properties		
Polymeric sizes in general	Global views Size add-on optimization (use minimum required amount) Incoming raw material QC Minimization of discards Equipment maintenance Proper storage, handling, and employee training Facility design Solid capture; housekeeping	Reduction of size add-on at weaving (and perhaps loss of weaving efficiency) ensures pollution reduction at the desizing operation
BOD, COD	Selection and handling of size	
Metals	Incoming raw material QC	
Air and water toxics	Incoming raw material QC	
Fiber lint and yarn waste	Segregation, capture, and reuse for fuel	

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
Packaging	Supplier involvement; purchasing specification for reusable IBC or bulk packaging	Avoid bags
4.7.3, Desizing		
BOD (starch)	Process alternatives, including oxidative or acid desizing	
Size (synthetic)	Segregation and recovery for reuse	
4.7.4, Identification of Wastes and Pollutants		
Size packaging materials	Buying in bulk or IBCs; work practices; monitoring/auditing packaging materials	
Unused portions of mixes	Proper planning and scheduling; monitoring/auditing dumps	
Equipment clean up	Planning and scheduling; teflon-coated dry cans to reduce fouling; better process monitor/control; monitoring/auditing cleaners	
BOD	Alternative size materials and auxiliaries; proper mill conditioning and controls to reduce the need for additives	
Aquatic toxicity	Alternative recipes; monitoring/auditing and reducing machine cleanup events; proper mill conditioning and controls; timely scheduling from weaving to desizing to reduce the need for biocides; incoming material prescreening/QC	
Fiber lint and yarn waste	Bar code tracking to improve efficiency and reduce waste; monitoring/auditing these wastes	
Size itself	Segregation for recycle and recovery; proper size selection; better process control and add-on monitor; proper fabric design to reduce the need for size and weighter; work practices; audits	Global views are important; changes in sizing practice produce pollution reduction at desizing operations; correct risk/benefit determination is important

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
General	Maintenance; monitoring; control and optimization of processes	

Warp size (or size) is a chemical mixture applied to fibers that will undergo weaving (but not knitting) operations. Size improves the strength and bending behavior of yarn, allowing weaving operations to continue with less breakage and fewer stoppages than would be the case with untreated fibers. Size is applied only to the warp (lengthwise) yarns because they are under the most mechanical stress in weaving operations; the weft yarn is not coated with size. The operation that applies size to the yarn is termed slashing. Warp yarns for cotton and cotton blends have 10 to 15 percent (by weight of goods) added as size, while filament synthetics require 3 to 5 percent by weight of sizing. Size is removed from the fabric when the weaving operation is complete, in an operation called desizing, and this can contribute high pollution loads to textile effluent.

Many opportunities for pollution prevention exist in warp sizing operations.

- Modern weaving machines run at high speeds and therefore place extreme demands on yarns in the loom. Proper warp sizing is a crucial factor in fabric quality and in preventing loom stoppages, which lower weaving efficiency. For effective pollution prevention, a slashing operation must look beyond weaving performance to the desizing operation and the pollution contributed by size at that stage. A global attitude about size is required for pollution prevention because the size will be removed at another location. Mills should remember that everything that is put on as size will eventually become waste, so they should be conservative in using and specifying size. Size add-on should be monitored and correlated with actual production performance. In many cases, size use may be reduced without affecting the desired results in the weaving operation.
- QC of incoming raw material is important for size. Mills should implement checks for metals, toxic organics (e.g., biocides), and other potential contaminants. Only the correct amount of size mix should be prepared to avoid dumping unused portions. Similar styles should be scheduled to run sequentially to avoid unnecessary cleaning of size tanks and other equipment, as well as excessive discards of unused size. Excessive and unnecessary additives in size mixes should be eliminated. If additives are used, only those that will not produce toxic or offensive waste streams during desizing should be selected.

Slasher and mix area equipment should be maintained to avoid leaks and spills. Add-on levels should be carefully monitored and controlled to use the minimum amount of add-on necessary to accomplish the task.

- Fiber lint and yarn waste should be segregated. Packaging should be reduced by specifying bulk or IBCs for size. Mix kitchens, slashers, and work areas should be monitored for proper chemical handling and work practices. Conditions in the weave room or storage areas should be controlled to avoid problems. Facilities should be designed so that pipes from the mix kitchen to the size boxes are of minimum length to minimize the quantity discarded during changeover and cleanup. Only nontoxic, safe cleaning agents should be used to clean equipment such as tanks, pumps, lines, size boxes, cans, and lease. As much waste as possible should be captured in solid form for landfill or other appropriate disposal (not disposed of down the drain). Machine cleaning supplies should be accounted for, and the required frequency and severity of cleaning for slasher and mix area components (containers, utensils, mix tanks, pumps, lines, working area) should be monitored. Employees should be trained in proper cleaning procedures.

Size serves no long-term purpose on the fabric, only a transitory purpose for weaving. Every year, the textile industry uses and discards huge quantities of warp size. In the United States, consumption is estimated at approximately 200 million pounds per year.[8] Less than 10 percent of this is recycled; the rest is disposed of in the effluent stream. This makes size disposal one of the largest industrial waste streams in U.S. manufacturing.

Size mixes have different properties, so size selection is a crucial step in achieving the desired results in weaving and size removal operations. Important properties of sizing compounds are the swelling temperature and the water solubility. With the introduction of high-speed air-jet weaving machines, size drying speeds are also important. These machines have made high-speed, high-pressure, low-wet-add-on sizing ranges popular and resulted in the introduction of low-viscosity, high-solids size formulations.

4.7.1 Unit Process Description

To ensure proper performance of yarns in a loom, stiffening agents and lubricants are added to the warp yarns. The size improves the toughness of the yarn and improves its bending behavior. As a result, abrasion, fuzzing, static buildup, stretch, breaking, creep, entanglements, shedding of lint, and other undesirable events are suppressed in the weaving process. Modern weaving machines run at high speeds and place extreme demands on the yarns in the loom. Proper warp sizing is a crucial factor in attaining final fabric quality and in preventing loom stops, which lower weaving efficiency.

Warp size is added to a sheet of warp yarns using pad/dry techniques in a large range called a slasher, which comprises:

- A yarn creel with very precise tension controls.
- A yarn guidance system.
- A sizing delivery system, usually involving tank storage and piping to the size vessels.
- One or more dips of the yarn sheet in size solution.
- Drying of yarns on hot cans or in an oven.
- A lease that separates yarns from a solid sheet back into individual ends for weaving.

In addition, sizing operations require ancillary equipment such as a mix kitchen with scales, mix tanks, pumps, and plumbing, as well as a precise slasher control system, which usually features temperature, speed, density, tension, and moisture monitors.

4.7.2 Warp Size Types and Properties

Size is a mixture of primary and auxiliary chemicals. The subsections below describe the chemical makeup of typical size mixtures.

4.7.2.1 Primary Component of Size

The type of size used depends on the yarn type, weaving process (e.g., loom type, speed) and historical tradition and experience in the textile facility. Three main types of size are currently used:

- *Natural products (starch):* Starch is the most common natural size and the most common size overall. It can be derived from a variety of substances, but corn and potatoes are preferred. Starch is used mainly for cotton products and other natural fibers.
- *Fully synthetic products:* Synthetic sizes include polyvinyl alcohol (PVOH or PVA), polyvinyl acetate (PVAc), polyacrylic acid (PAA), and polyester (WD).
- *Semisynthetic products (blends):* Semisynthetic sizes or blends include modified starches, starch ethers, starch esters, carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC), and carboxymethyl starch (CMS).

See Table 4-27 for a listing of sizes used for various fibers and Table 4-28 for a more detailed classification of size types. Table 4-29 lists environmental advantages

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[8] Robinson, G., and B. Smith. Personal communication between George Robinson, DuPont Company, Charlotte, NC, and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

Table 4-27. Sizing Materials Used for Filament Yarns (28)

Fiber Type	Basic Size
Nylon	Polyacrylic acid PVA
Glass	PVA Dextrins Amylose derivatives Blends
Acetate	Stymer (styrene-maleic anhydride copolymer) Gelatin
Viscose rayon	PVA Amylose derivatives CMC Blends
Polyester	Acrylic copolymers Alkali-soluble polyvinyl acetate Linear polyester

Table 4-28. Categorization of Spun Yarn Sizing Materials (28)

- **Starches: Corn, Potato, Tapioca**
  - Unmodified—pearl
  - Acid-modified, 20-60 fluidity
  - Oxidized, several fluidities
  - Dextrinized (British gum)
  - Derivatized
    - Acetate
    - Hydroxyethyl ether
    - Acrylate
    - Styrene
  - Cross-linked
  - Cationic
  - High amylose
  - Low amylose (waxy)
- **PVA**
  - Fully hydrolyzed
  - Partially hydrolyzed
- **Other**
  - CMC
  - Blends
  - Other polymers

Table 4-29. Environmental Advantages and Disadvantages of Alternative Synthetic Sizes (37)

Size	Advantages	Disadvantages
CMC	Can reuse solutions	Supports mildew
	Washes off with cool water	Cost
PVA	Good adhesion	Cost
	Tough films	
	Can mix with starch	
	Washes off easily with hot water	
PAA	Washes off with alkali	Cost
	Good adhesion to nylon and synthetics	
	Can control stiffness by copolymerization	
WD	Good adhesion to polyester	Cost
	Washes off with very hot water	Can precipitate and cause spots

and disadvantages of alternative starches. Specific types of size used in textile weaving are described below.

Starch

Starch is the most common primary size component, accounting for approximately two-thirds of all size chemicals used in the United States (130 million pounds per year). Starch offers good performance on natural fibers and is often used in a blend with synthetic sizes for coating natural and synthetic yarns. A major problem with starch size is the inability to reuse or recycle the size because of degradation of the starch to various sugars during the desizing process.

Polyvinyl Alcohol

PVA accounts for much of the remaining size consumed in the United States (70 million pounds per year). PVA offers excellent mill performance when processing polyester/cotton goods and pure cotton fabrics and washes out completely to facilitate uniform dyeing. The strength, adhesion, viscosity, and other properties of PVA are affected by the degree of hydrolysis (the percentage of acetate groups replaced by hydroxyl groups). PVA can be used as size in either 100-percent pure form, or in blends with natural sizes such as starch. A typical blend formulation contains 50 to 95 percent PVA, depending on the type of fabric used and other processing parameters. For spun yarn, high-viscosity PVA is used to bind the surface fibers and coat the yarn with a continuous film to suppress neps. In this application, a fully hydrolyzed PVA/starch mixture is usually employed. For filament fibers, low-viscosity partially hydrolyzed PVA is used to penetrate the yarn to prevent fiber splitting and breaking.

Sodium Carboxymethylcellulose

CMC is an anionic polyelectrolyte that is soluble in either cold or hot water. The U.S. industry uses approximately 5 million pounds of CMC per year. CMC size is used primarily for polyester/cotton and polyester/rayon blended yarns. For sizing pure synthetic fibers such as polyester, competing sizes provide better adhesion, stronger film, less shedding, and less sensitivity to moisture than CMC size. CMC and acrylics might compete with PVA, but these sizes do not provide the necessary strength for all applications. Also, at high humidities, CMC sizes do not perform as well as other alternatives.

Hydroxyethylcellulose

HEC size is available in water-soluble or alkali-soluble grades with a range of properties including wide-ranging solution viscosity. Alkali-soluble HEC is used in textile sizing, although in negligible quantities.

4.7.2.2 Size Auxiliary Chemicals

Sizes generally consist of mixtures of the above primary chemicals plus additional auxiliary chemicals added to improve weaving performance, enhance the stability of the size or sized yarn, distinguish between sizes, and for many other purposes.

Auxiliaries used in sizing mixtures include:

- *Adhesives and binders:* To assist in binding the size to the yarn. Examples: natural gums (locust bean gum, tragasol, but not starch), gelatin, soya protein, casein, acrylates, PVA, CMC.
- *Antistatic agents:* To suppress static in high speed weaving.
- *Antisticking agents:* To reduce fouling of dry cans and guide rollers. Examples: waxes, oils, sulfated tallow, pine oil, kerosene, Stoddard solvent.
- *Biocides (preservatives):* To improve shelf life of woven goods. Example: orthophenyl phenol (OPP).
- *Defoamers:* To suppress foam in locations where process water is very soft. Example: zinc and calcium chloride, light mineral oil, isooctyl alcohol but not silicones.
- *Deliquescents:* To protect against overdrying. Example: zinc and calcium chloride, polyalcohols (PEG), glycerine, propylene glycol, diethylene glycol (DEG), urea.
- *Emulsifiers, dispersants and surfactants:* To stabilize size mixtures during application and assist in desizing operations. Example: nonionic ethylene oxide compounds.
- *Humectants:* To protect against drying.
- *Lubricants and softeners:* To improve the bending and frictional characteristics of the yarns. Examples: fats, waxes, oils, tallow, sulfated tallow, butyl stearate, glycerine, mineral oil.
- *Penetrants:* To assist in penetration of size on filament yarns but not spun yarns.
- *Release agents:* To facilitate removal of size during desizing.
- *Thinning agents:* To increase penetration (similar to penetrants). Examples: enzymes, oxidizers, perborates, persulfates, peroxides, chloramides.
- *Tints:* To identify warps.
- *Weighters:* To increase the density of woven yarn. Example: clay.

Lubricants are grouped in two general classes: saponifiables and unsaponifiables. The unsaponifiable lubricants are considered the best friction reducers and include crude-scale paraffin wax and refined paraffin wax. Removal of these during desizing, however, requires added surfactants, which have high aquatic toxicity (see Section 2.2.6, "Aquatic Toxicity"). Saponifiables include fats and fatty components such as fancy tallow, hydrogenated tallow glycerides, and fatty esters. These compounds can also be used as emulsifiers for the unsaponifiables.

Any of these additives that are present in the size mixture will later be removed in wet processing (preparation, desizing, and scouring), and thus all of these materials will appear in waste streams from desizing operations. Undesirable materials (e.g., zinc salts, OPP) are generally not used on domestic goods but regularly appear in imported fabrics. This is an important point in the process at which to perform QC for raw material screening in textile operations (see Section 3.12, "Raw Material Prescreening Before Use").

4.7.3 Desizing

The desizing process produces a high-volume waste stream. Desizing waste deserves attention because essentially all size chemicals that are removed enter the waste stream, and the amount of chemicals removed during desizing is significant. Typically, 6 percent or more of the weight of the goods is added as size, only to be removed and discarded in the desizing operation.

Desizing of starch is usually performed using enzymes to solubilize the starch, followed by thorough washing of the fabric to remove the size and desizing chemicals. Alternative procedures include the use of acids or oxidizers to degrade the starch. These procedures are not as common as the use of enzymes because of the potential for cotton fiber damage. Acid desizing hydrolyzes the starch, rendering it water soluble. Enzyme desizing uses animal or vegetable enzymes to decompose starch to a water-soluble form. Because the starch is degraded, recycling is impossible; therefore, the desizing waste must be disposed of in the effluent.

Synthetic sizes are usually removed with hot water washes, although alkali is sometimes used to increase solubility. The removal process does not degrade synthetic sizes, so they can potentially be recovered for reuse as a sizing agent.

4.7.4 Identification of Wastes and Pollutants

Sizing and desizing operations contribute to BOD and aquatic toxicity in different amounts, depending on the exact makeup of the size mixtures the mill uses. Additional wastes associated with sizing and desizing include size packaging, dumps of unused size mixtures, and equipment cleaning wastes.

4.7.4.1 BOD

Starch desizing contributes relatively high BOD loadings to the effluent compared with synthetic desizing. Typical starch sizes have 5-day BODs of 500,000 to 600,000 ppm, while alginates and modified starches have BODs of 100,000 to 500,000 ppm (11). Table 4-30 lists BODs of various sizes, and Table 4-31 reports BODs of a range of size materials. Synthetic sizes contribute much lower BOD loadings than starches, ranging from 10,000 to 30,000 ppm. These BODs are approximately 15 to 60 times lower than for starch, lowering the BOD by well over 90 percent. If the synthetic size is recycled, BOD loadings drop even lower for an overall reduction (compared with starch) of over 99 percent (11).

Table 4-30. BODs of Various Warp Sizes (11)

Size	BOD (ppm)
PVAc	10,000
PVOH	10,000-16,000
PVOH/CMC (3:1)	17,500
CMC	30,000
HEC	30,000
Starch/PAA (5:4)	295,000
Alginate	360,000
Starch ether	360,000
Starch/PVOH (5:1)	405,000
Starch	470,000

Table 4-31. BODs of Various Size Materials (11)

Size Material	BOD (ppm)
Ahco nylon wax size	340,000
B-2 gum (starch dextrins)	610,000
Brytex gum 745 (starch)	610,000
CMC	30,000
Elvacet (PVA)	10,000
Elvanol 72-60 (PVOH)	10,000-16,000
Globe Easyflow starch	650,000
Hydroxyethyl cellulose (HEC)	30,000
KD gum (starch)	570,000
Keofilm No. 40 (starch)	50,000-550,000
Morningstar starch	470,000
Nicol starch	570,000
Pearl (cornstarch, No. 173 and PT)	500,000
Penrod gum 300 (hyroxy starch ether)	360,000
RTC gum (starch-urea)	120,000
Starch No. 450	460,000
Sodium alginate	360,000
Wheat starch	550,000
Ambertex M (starch paste)	20,000

Auxiliary components of the size mixture can also affect BOD levels. Humectants, lubricants (waxes and oils), antistatic compounds, biocides, glycerine, and wetters contribute up to 10 or 15 percent of the total BOD load from size mixtures. Of these, humectants and lubricants contribute the most, typically 2 to 5 percent of the total (11). Typical BODs and aquatic toxicities for additives are found in Table 4-32.

4.7.4.2 Toxicity

Toxicity contributions derive mainly from the auxiliary chemicals added to the size mixture. Surfactants and biocides commonly add to aquatic toxicity.

4.7.4.3 Other Wastes

In addition to the size/desize chemicals removed from textiles, sizing and desizing operations generate additional wastes that deserve attention, including:

- *Packaging materials for size:* Size is commonly shipped to the textile mill in 80-pound bags. Based on the amount of size that weaving operations consume, these bags can constitute a major solid waste source. In one operation, three slashing units consumed over 37,000 bags of size per year.
- *Dumps of unused portions of size mixes:* Size batches are mixed in the amount needed for the upcoming production run. Occasionally, excess size is mixed or goes unused. Because starch-based size mixtures cannot be stored, excess may be dumped hot to the sewer.
- *Machine cleaning and maintenance:* Cleaning and maintenance of sizing equipment may be performed with solvent-based cleaning agents. Wastes from

Table 4-32. BOD and Aquatic Toxicity of Warp Size Additives (11)

Additive	BOD (ppm)	Toxicity LC_{50} (ppm)
Surfactants	10,000 to 1,000,000	<1 ppm to 28 ppm
Urea	90,000	>1,000 ppm
Glycerine	640,000	>1,000 ppm
Oils and waxes	100,000 to 1,500,000	Varies
Biocide	Test fails	High
DEG	60,000	>1,000 ppm

cleaning and maintenance operations include materials such as wipes, rags, and discarded filters.

- *Fiber lint and yarn waste:* Desizing operations scour fabric to remove sizing chemicals and may remove substantial amounts of lint and yarn waste.

4.7.5 Pollution Prevention Measures

Pollution prevention measures for sizing and desizing operations focus on proper fabric design, operating equipment to minimize sizing requirements, selection of appropriate size chemicals, proper size mixing, and proper worker training/attitude.

Sizing is one example where pollution prevention activities must be undertaken within one unit operation (sizing) while another unit operation (desizing) enjoys the benefits (i.e., reduced pollution). This can be especially challenging in situations where the same company does not perform both the sizing and the desizing, though even within companies, difficulty may arise in achieving cooperation between departments on pollution prevention issues. In these situations, a proper pollution prevention strategy should stress documentation of policies and practices, communication among departments or between companies, and incentives. This extends to globalization of the pollution prevention strategy requiring better information exchange between consumers, designers, managers, and suppliers, as discussed in Section 4.17.3.2.

4.7.5.1 Size Selection

Significant reductions in pollution are achievable through careful selection of the warp size mixture. Determining the most appropriate size for a particular weaving operation is complicated, partly because of the multitude of different sizing materials that are available to the textile manufacturer. Different fiber types, weaving looms, cost requirements, fabric designs, and pollution characteristics are just some of the factors the manufacturer needs to balance in selecting a size.

The most accurate means of evaluating a size formula involves in-plant testing. Certain sized yarn characteristics can indicate overall weavability, including elasticity, elongation, tensile strength, resistance to abrasions, continuity, and consistency. These can be accurately evaluated by testing samples in the laboratory, following test procedures developed by organizations such as the Institute of Textile Technology.

The mechanical and operational characteristics of the sized yarn must be considered as only part of the overall selection requirements. Cost of the size is an important element, and the polluting characteristics must also be considered. A size that has inherently low pollution, or a size that can be recycled or reused, should be given high priority, *in addition to mechanical and cost* considerations.

Two large gains in pollution reduction come from choosing synthetic sizes with inherently lower BOD levels and sizes that have the ability to be recycled and reused. The combination of moving from high-BOD starch to a lower BOD synthetic that can be reused can reduce BOD output by nearly 100 percent. Several warp size alternatives are available, as noted above (i.e., starch, PVA, CMC, PVAc, PAA, and polyester). These materials differ considerably in their BOD and COD content, as well as the degree to which they are degraded during desizing. PVA and CMC are low-BOD, recoverable sizes and hence should receive serious consideration as alternatives to starch.

As is the case with surfactants (see Section 4.4.2.5) some high BOD sizes tend to be easy to treat and some low BOD sizes are more likely to pass through waste treatment systems. Unlike low BOD surfactants, undegraded, low BOD warp sizes (e.g., PVOH) that pass through waste treatment systems have relatively little harmful effect on the environment. With warp sizes, therefore, it is not as clear which type is preferable. The consideration is the use of a natural, renewable, biodegradable material (i.e., starch) versus a synthetic material that can be recovered (but usually is not in practice).

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 pollution prevention goals. Additives can also interfere with the recyclability of sizes.

4.7.5.2 Size Recycling/Recovering

Recovery of synthetic (PVA) size can be performed using membrane filtration equipment such as that shown in Figure 4-8. Size recovery is not widely practiced in the textile industry, however, for a variety of reasons. A few successful size recovery systems are currently in operation, but these systems can recover only certain types of sizes, notably PVA. As indicated, PVA accounts for approximately one-third of total size consumption in textiles. The bulk of size used is starch, which degrades during desizing and cannot be recovered.

Currently, less than one-third of all PVA is recovered. Several technical and business barriers prevent further recycle, including the practice of mixing PVA with sizes that inhibit recovery, the high expense of shipping recovered PVA concentrate solutions, high capital cost of recovery equipment, commingling of goods containing different sizes at the desizing plant, and lack of understanding of recovery potential.

Thus, for several valid reasons, the textile industry makes limited use of size recovery. This is equivalent to thousands upon thousands of tons of intentionally created waste, making it (in addition to water, salt, and cutting room waste) one of the highest volume waste materials in textile manufacturing, and perhaps all United States manufacturing. To increase size recycling requires 1) removing logistical and technical barriers to recycling and reclamation of sizes, 2) providing more incentives for recovery, 3) developing fabric-forming machines and processes that require minimal amounts of sizes, and 4) designing yarns and fabric structures that require less size and lubricant to produce.

Nonintegrated mills face substantially greater barriers to recycling size because sizing and desizing operations occur at different firms. Reusing or recycling requires the sizing and desizing mills to coordinate activities, including information transfer (e.g., types of size applied, quantities recycled) and physical activities (e.g., transport of goods, quality testing, financial arrangements). The benefits of recycle accrue to the desizing facility, which recovers a waste that has economic value, while the costs accrue to the sizing facility, which absorbs the higher costs of size reformulation.

4.7.5.3 Chemical and Process Alternatives

Numerous auxiliary chemicals may be added to the size mixture, including adhesives, binders, antistatic agents, antisticking agents, biocides, defoamers, deliquescents, emulsifiers, dispersants, surfactants, lubricants, softeners, thinning agents, tints, and weighters. These additives can contribute significantly to BOD, COD, aquatic toxicity, and the volume of wastes associated with sizing and desizing operations. Reported BOD values and aquatic toxicities of several additive materials are summarized in Table 4-32.

In most cases, these additives are added to overcome or prevent the occurrence of specific problems that may arise during slashing, weaving, or storage. Often, addressing these concerns using mechanical or other nonchemical means may be possible, thus avoiding the use of chemical additives. For example:

- Air-conditioning and humidification systems can prevent static electrical buildup, thereby eliminating or reducing the need for antistatic agents.
- Teflon-coated dry cans and guide rollers are widely used and help reduce fouling, thus avoiding the need for antisticking agents and toxic machine cleaners.
- Timely movement of goods into wet processing (desizing) operations eliminates 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.
- Using moisture monitors and implementing advanced process control reduces or eliminates the need for deliquescents to protect against overdrying. If deliquescents must be used, zinc salts should be avoided.
- 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 minimal residual alkalinity in incoming yarns.
- Evaporation barriers on size boxes eliminate surface skinning and the associated need for deliquescents, stabilizers, emulsifiers, dispersants, and surfactants.
- Sizing recipes should be based on proper polymer molecular weights and concentrations to achieve the proper viscosity, thus 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 ensure production of the desired weight fabric, eliminating the need for weighters.

Organizing production activities as indicated above can reduce or eliminate the need for additives. This in turn

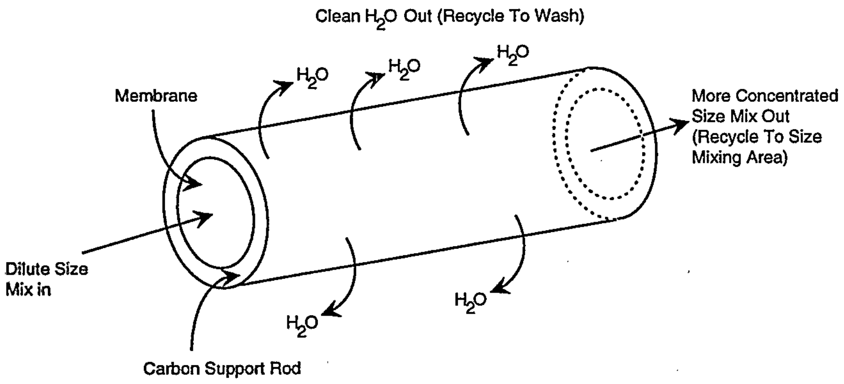


Figure 4-8. PVA size recovery system.

may facilitate the implementation or operation of size recovery systems, reduce BOD and aquatic toxicity in desizing wastewater, and reduce waste from sizing operations.

4.7.5.4 Raw Material Control in Sizing

QC of incoming raw materials is an important element of an overall facility pollution prevention strategy. Specific steps should be taken to minimize the pollution contribution of sizing and desizing operations.

Incoming warp size (and yarn) should be tested for the presence of toxic contents, notably zinc and biocides. Textile mills should seek higher purity, raw size materials at every opportunity. Mill personnel should perform prescreening and shipment checking of size using established procedures.

If possible, mills should purchase size in bulk or semibulk IBCs to avoid excessive packaging waste in the form of bags, pallets, and skids. In addition to generating wastes, the traditional 80-pound bag is extremely prone to breakage during transport, storage, and delivery to the mix kitchen. Improper cleanup of spill from these packages is a major source of BOD from yarn manufacturing and slashing operations. Proper employee training and resources should be provided to alert employees to the pollution impacts of improper cleanup. Proper equipment should be provided for cleaning up spilled size, including vacuums that can recover the maximum amount of material. Too often, spilled size is washed down the drain.

If bags are used, procedures should be established for handling and storing them in a way that allows for recycling. Methods to avoid container breakage via alternate packaging, handling, storing, and use as well as proper methods of cleaning up spilled size should be an important focus for employee training.

4.7.5.5 Monitoring Size and Add-On

Analytical methods are available for determining the size contents of yarns and fabrics (see the *AATCC Technical Manual* [2]). Size add-on should be the minimum 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 can be reduced without significantly affecting production operations.

Analytical methods are also available for determining the nominal contents of size mixtures. In addition, samples from size mixes can be tested for metals. Anything (including components of the size mixture and impurities) that is put on the fabric during the slashing operation will later be removed and become a pollutant.

4.7.5.6 Scheduling

A major source of pollution from slashing operations is dumping of unused mix. By their nature, many size mixes have essentially zero shelf life and cannot be reused if allowed to sit. Production planning is thus essential to eliminate mix dumping. Size requirements should be estimated carefully to avoid mixing of excessive amounts of size. Pipe and pump volume should be kept to a minimum to avoid waste from the plumbing that connects the mix kitchen to the size boxes. Therefore, having the mix kitchen as close to the slasher(s) as possible is important. Further gains can result from reducing the size of the mix boxes as much as possible. Finally, the frequency of style and size mix recipe changes should be minimized to reduce waste from changeovers. Efforts should be made to use the same size recipe on as many different styles as possible, then to group production accordingly.

4.7.5.7 Work Practices

Slashing operations by their nature often appear disorderly and sloppy. To significantly reduce the contribution of slashing to pollutant loads requires training and the development of proper worker attitudes toward pollution prevention.

4.7.5.8 Waste Auditing Procedures

Pollution prevention waste auditing procedures that can be followed include:

- Auditing mix kitchens, slashers, and work areas for proper chemical handling and work practices (by methods which are described in a general section on orderly work practices).
- Focusing on orderly work practices, proper use of implements, avoiding spills, repairing leaks, proper cleanup, and correct disposal of chemical residues.
- Accounting for machine cleaning supplies and monitoring the required frequency and severity of cleaning for slasher and mix area components (containers, utensils, mix tanks, pumps, lines, working area).
- Noting problems with specific size mixtures, fabrics, or running conditions.
- Counting and monitoring size bags and other size packing materials (e.g., skids).
- Auditing the incidence of damaged and broken bags, skids, pallets, and other containers.
- Auditing, measuring, and tracking of dumped, unused portions of size mixes (a major cause of pollution from these operations).
- Weighing and monitoring of fiber, lint, and scrap yarn waste.

4.7.5.9 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 pollution prevention but also to proper slasher operation. Mix kitchen equipment maintenance, including mix tanks, stirrers, implements, scales, pumps, and piping, is essential. Maintenance, cleaning, and other nonprocess chemicals should be evaluated for aquatic toxicity.

4.8 Fabric Formation

The following table introduces pollutants and waste streams discussed in this section, as well as pollution prevention activities suggested for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.8, Weaving and Knitting (General)		
Packaging waste from yarn supply	Standardized, reusable packaging	
Yarn and fabric scraps	Monitoring/auditing; automated handling	
Fabric waste (off-quality)	Maintenance of looms and knitting machines; optimization of fabric design and machine selection	CAD systems are useful in designing fabrics for specific machines
Machine lubricants	Optimization of use; evaluation of alternative lubricants	
Latent defects causing off- quality in later processing	Automated detectors for holes and other defects	Proper design reduces the need for chemical finishing later
4.8.7, Carpet Formation (Tufting)		
Carpet scraps	Minimize size for dyeheader testing and flammability testing; minimize changeover/runout areas	
Yarn scraps	Establish yarn waste goals; monitor/audit yarn waste	
Seam cut outs	Use butt seams, not lap seams	
General fibrous waste	Train workers to develop proper attitudes; establish goals; assign individual responsibility	
Edge trims	Pay better attention to width control to reduce the need for salvage trimming	

4.8.1 Fabric Formation Unit Processes

Textile fabrics are formed primarily by knitting or weaving processes. A few commercially significant specialty processes such as nonwoven and braiding exist, but these are less important than weaving and knitting. One other important fabric process is carpetmaking, which forms carpet in several ways, such as weaving and tufting.

Fabric formation produces relatively little waste compared with other processing steps such as spinning or finishing. The main waste is the packaging in which yarn is received, such as cardboard tubes, cases, and cones. This waste can be reduced by specifying reusable packaging such as shrinkwrap pallets and plastic, reusable tubes. Fabric formation also produces small quantities of fibrous materials as waste (e.g., waste yarn, rags, and fabric scraps). Richardson (46) reported studies of various types of fabric in which standardizing yarn package sizes reduced waste.

Automated handling and inventory systems for yarn and fabrics are available that provide for automatic weighing in and out of yarn and fabric, thus accurately tracking waste. These systems were useful in long-term auditing of fiber/yarn/fabric waste from fabric manufacturing operations.

4.8.2 Pollution Prevention in Weaving

High-speed weaving machines place great demands on yarn and size materials. Several alternative types of size can be used (see Section 4.7, "Slashing and Sizing"), which differ in their properties, including pollutant potential. The typical size add-on varies among operations, so the BOD potential from the desizing operation must be viewed not only in terms of the BOD (or COD) of the size material, but also in terms of how much size is commonly used (47). Although warp size is a major pollutant in finishing mill wastewater, the needs of the weaving operation continue to be the main consideration in size selection. An important step toward pollution prevention in weaving operations is to take a more global view of size use. Mills need to consider not only the weaving efficiency of a size but also its pollution potential in the desizing operation. Upgrading of loom mechanisms and reduction of speeds may be necessary to run warps without warp sizes or lubricants (46). This results in somewhat lower efficiency and production for the weaver but achieves great savings in pollution at the slashing and desizing operations (46).

The selection and use of size materials, as noted above, is crucial. Another consequence of size selection is the potential for recovery of the warp size in the desizing operation. Barriers to size recovery include mixing of sizes by the weaver and geographic separation of the weaver and the desizer (47).

A further opportunity for preventing pollution comes through the use of vacuum extractors rather than thermal evaporation to dry water-jet-woven fabrics. This saves energy, associated air emissions, and boiler ash production (46). The recovered water from vacuum extraction can be reused in the size kitchen if the weaving facility performs sizing on site.

4.8.3 Pollution Prevention in Knitting Operations

Although knitting operations are generally not considered a significant pollution source, several aspects of knitting operations can affect pollution in downstream operations. These include:

- Fabric quality factors
- Lubricant use, including incoming yarn QC
- Fabric design factors

4.8.4 Fabric Quality Factors

Fabric quality is important in two ways. First, off-quality fabric (e.g., with holes, dirt, barre) becomes waste at the end of the process. Beyond this, however, the processing efficiency of knit fabrics at the finishing mill necessitates that incoming fabrics be of high quality. Efficient rope bleach ranges for knits, for example, consume less water, energy, and chemicals than batch preparation methods for knits. But these systems do not function as well if the knit tube has holes or major defects. The newer machines feature controlled fabric ballooning and better fabric transport but are dependent on a well-constructed knit tube to operate properly (48). Most knit guiders used in inspection and finishing operations do not function properly if the goods contain excessive holes or major fabric defects.

4.8.5 Lubricant Use

Machine lubricants can contaminate knit goods and be removed to wastewater during subsequent downstream processing. Moore reported a study in which BOD and COD from a knit scouring operation were significantly reduced by controlling the quality and contents of the incoming yarn and lubrication of the knitting machines in the knitting operation (36). The incoming knitting yarn was screened by standard test methods for extractable content. In addition, the amount of knitting oil used for the knitting machines was controlled (36). These pollution prevention steps brought the mill's scouring system into compliance without costly waste treatment system construction.

4.8.6 Fabric Design Factors

The importance of properly considering product properties at the design and raw material selection stage is emphasized in Section 3.2, "Design-Stage Planning for Facilities, Processes, and Products." Computer-aided technical (in addition to aesthetic) design of knit fabrics can ensure correct yield and shrinkage of knit goods, thus reducing or eliminating the need for chemical finishing. Proper yarn selection and careful processing can ensure proper weight, width, shrinkage, and spirality of the final product without chemical finishes. Yarn selection and knitting machine setup, as well as essentially tensionless handling of fabric, are crucial to ensuring that fabric ultimately achieves its relaxed equilibrium configuration. A final configuration that meets customer specifications eliminates the need for chemical finishes (49).

Often, textile mills achieve the above design criteria but fail to implement the necessary measures in the knitting room. Important considerations include proper scheduling and setup of knitting machines for each style. Most often, problems arise when production demand exceeds the capacity of the machine group best suited for the particular style. Compromises are often made with the decision to knit on alternate machines, accepting the probability that chemical resins (with formaldehyde) will be necessary to stabilize the fabric at the customer's specifications.

4.8.7 Pollution Prevention in Carpetmaking

Carpet formation also deserves attention in terms of pollution prevention. Carpet waste amounts to 2 percent of the total annual production of 900 million square yards, or 18 million square yards of waste per year (50). The dollar value of this waste is about $100 million. One carpet manufacturing operation that produced about 8 million yards of carpet annually had more than $500,000 in waste per year, as shown in Table 4-33 (50).

A careful cost analysis of a typical carpet operation shows that reducing waste by 2 percent would increase pretax profits by 26 percent (50). Pollution prevention activities that were implemented in carpet manufacturing include the following:

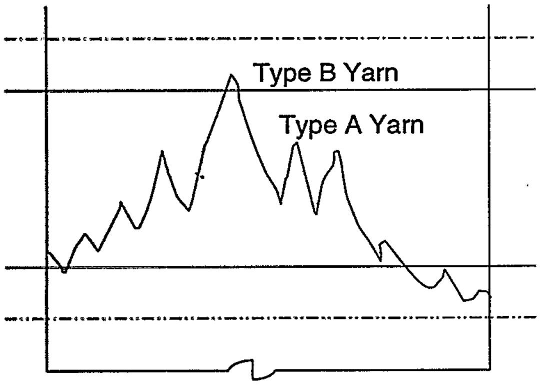
Table 4-33. Amounts and Value of Waste in Carpet Manufacturing (8 Million Square Yards per Year Facility) (50)

Type of Waste	Annual Value ($)
Backing selvage	96,000
Mitter selvage	92,000
Backing seams	71,000
Seam trim	53,000
Other trim, selvage, and samples	190,000
Miscellaneous	10,000
Total	512,000

- Tufting dyeheader samples (i.e., yarn QC check) are typically a yard or more. Carpetmaking operations cut 1,175 of these each year. This can be reduced to 8 inches for a savings of 80 percent, or $23,000 per year.
- Tufting yarn changeovers (e.g., merge, pattern, type) occur by "runout," which can be minimized as shown in Figure 4-9. By reducing runout to minimum distance, the average savings were 25.3 inches of carpet. At a frequency of 300 times per year, the value was $41,000.
- Failure to adhere to established yarn waste standards accounted for 1,200 pounds annually of excess waste yarn, with a value of $14,000.
- Converting from lap to butt seams in carpets reduced seam waste by 50 percent (see Figure 4-10), thereby saving $70,000.
- Better worker training and attention to cutting, especially in producing straight cuts, reduces trimming before seaming. Average savings were over 4 inches per seam, or $17,000 per year.
- Minimizing trim saved $5,000 annually.
- Minimizing test samples can also reduce waste. For example, flammability tests require 12- x 12-inch samples. Cutting oversized samples (i.e., 17- x 17-inch), plus other oversized samples for testing, wasted $12,000 of material.
- Better training and attention to width control in tufting and printing saved an average 3.4 inches on all carpets produced, for an annual savings of $91,000 in one operation. In another, excessive selvage trim was reduced 3.23 inches, resulting in an annual savings of $228,000.

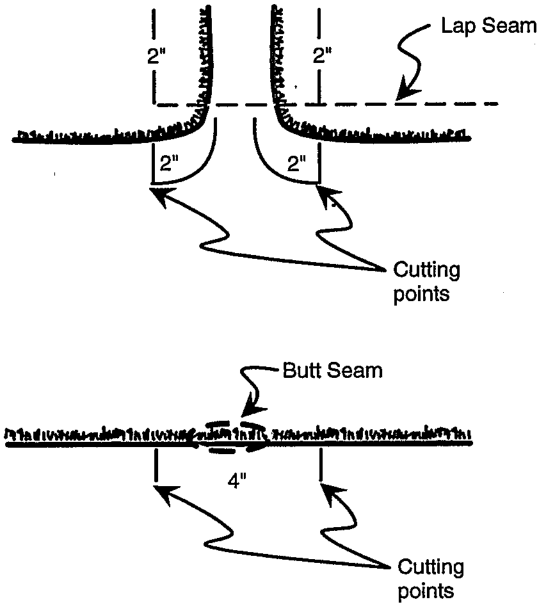
Palmer reported that the key pollution prevention steps in carpet operations include (50):

- Selecting one person with technical qualifications and authority to coordinate all pollution prevention activities.
- Establishing goals from sources such as literature, other mills, and trade associations.
- Studying waste reduction opportunities.
- Reporting waste quickly in an understandable way and highlighting expectations.



The broken lines represent typical cut marks, and the area between the broken and solid lines represents waste that can be avoided.

Figure 4-9. Potential waste savings from reducing runout from dye samples (50).



Converting to butt seams reduces waste by 50 percent. Total waste per lap seam is 8 inches; the total per butt seam is 4 inches.

Figure 4-10. Potential waste savings in converting to butt seams from lap seams in carpet (50).

4.9 Preparation

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.9, Fabric Preparation		
Water	Reuse and countercurrent use; flow optimization	Continuous processes lend themselves better to recycle/reuse
Alkalinity	Recycle/recovery (sometimes possible)	
BOD and COD	Testing incoming greige goods	Global approach to additives is important
Metals and other toxics	Testing incoming goods for contaminants	
Surfactants (aquatic toxicity)	Selecting degradable types; avoiding cationics	

General	Right-first-time production; optimized processes; good process and product QC; automated process controls, such as titrators and chemical feed systems	Latent defects are often not observed until problems arise in later processes
Desizing pollutants	See Section 4.7 table above	

Most cloth routinely undergoes one or more finishing processes after it emerges from the manufacturing process. These include:

- Cleaning the cloth before finishing
- Improving texture and hand
- Colorization (specifically, dyeing and printing)
- Inspection and QC

This section deals with fabric preparation, the first two steps in the above finishing sequence.

Most fabric that is dyed, printed, or finished must first be prepared, with the exception of denim and certain yard-dyed knit styles. Because preparation is a universal process, and techniques are relatively uniform across most of a mill's production, preparation is usually the highest volume single process in a mill and hence an important area for pollution prevention.

In preparation, the mill removes contaminants that interfere with dyeing, printing, and finishing (20). If fabrics contained no contamination upon arrival for wet processing, preparation processes would be unnecessary. About half of all the pollution and a significant amount of the wastewater from textile wet processing could be prevented (20). The main pollutants from preparation are water, alkalinity, BOD, COD, and small amounts of offensive materials such as metals and surfactants (11, 27).

Preparation is crucial to every subsequent process in the textile mill, but it is underrecognized as a source of quality and pollution problems. Preparation often receives little attention from managers and technicians, who are concerned with "more important" problems such as bad dyeing, printing, and finishing work (which themselves are caused by poor preparation). Because visually observing poor preparation when it occurs can be difficult, poorly prepared work generally goes unnoticed and is subject to further processing, which inevitably reveals latent defects in preparation. This results in more costly finishing and dyeing reworks, off-quality production runs, excess pollution, and other problems (51). In effect, the preparation process sets an upper limit on quality that cannot be improved in later processes.

One key to pollution prevention is right-first-time production, and the key to right-first-time production is complete, consistent preparation. In an attempt to ensure right-first-time production, many standard quality evaluation tests for prepared fabric have been developed, as well as process tests to control preparation parameters (e.g., concentration of caustic, peroxide). Automated control systems also are available to monitor preparation variables. These include automatic titrators, chemical feed control systems, and other such systems.

Any pollution prevention program, especially one aimed at water conservation, would benefit from a thorough audit of preparation procedures, and a study of state-of-the-art preparation equipment appropriate to the cloth styles being produced. This section discusses sources of pollution from textile preparation and identifies relevant pollution prevention strategies.

4.9.1 Preparation Processes

Greige goods must undergo a series of preliminary cleaning treatments before the finishing mill applies any functional finishes or before they move on to dyeing and printing. These preliminary treatments include desizing, scouring, bleaching, and singeing. Following cleaning and scouring, most cloth is in a relaxed condition and must be straightened and brought to its proper configuration before it undergoes further finishing steps. This is particularly important for finishes meant to impart surface design or color. Also, treating cloth to make it more stable or chemically reactive is advantageous because it makes subsequent chemical finishes more permanent. These processes include heatsetting and mercerizing.

4.9.1.1 Continuous Versus Batch Preparation Processes

Most mills can use uniform preparation processes for the entire range of products they produce. Economics, as well as pollution control, thus favor continuous rather than batch preparation processes (52). Although continuous preparation is more common, quite a few mills still prepare goods (especially knits) batchwise on dyeing machines. The usual justification for not preparing goods continuously is complexities in scheduling, handling, and other factors. Some of these other factors include the high capital cost and the capacity required for high productivity of knit preparation equipment. Low-volume knit operations often cannot justify the cost of this equipment given the volume of material they have to process. In addition, continuous preparation and dyeing schedules must be coordinated to ensure that goods do not sit around wet for a long time. If knit goods must be dried for storage, the economic loss is great because of the high cost of drying. Finally, storing and tracking goods through continuous preparation and dyeing is more complicated than simply loading goods into one machine and doing both processes sequentially on the same machine.

Mills using batch preparation may find that pollution prevention considerations provide sufficient incentive to consider switching to continuous preparation and/or finishing. Unlike batch processes, continuous operations provide greater segregation for recycle and reuse of waste streams.

4.9.1.2 Desizing

Sizing materials are applied to warp yarns before they are woven into cloth. The sizing materials form a protective coating over the yarns and prevent chafing or breakage during weaving. Chemicals used as sizing agents may be divided into two categories: 1) water-soluble sizes, such as PVA and 2) water-insoluble sizes, such as starch. Oils, waxes, and other additives are often used in conjunction with sizing agents to increase the softness and pliability of the yarns (see Section 4.7, "Slashing and Sizing").

Manmade fibers are generally sized with water-soluble sizes that are easily removed by a hot-water wash or in the scouring process. On the other hand, natural fibers such as cotton are most often sized with water-insoluble starches or mixtures of starch and other size materials. Enzymes are used to break these starches into water-soluble sugars, which are then removed by washing before the cloth is scoured. Removing starches before scouring is necessary because they can react and cause color changes when exposed to sodium hydroxide (alkali) in scouring.

Bacteria in waste treatment can easily attack water-soluble sugars, which are the by-product of desizing. Water-soluble sugars are very degradable and have a high BOD. As a result, desizing of starch-sized fabrics often accounts for more BOD than all other processes in the finishing mill combined (11).

Many of the pollution concerns associated with sizes are discussed in Section 4.7, "Slashing and Sizing." To prevent pollution in desizing, the least-polluting alternative is to use, then recover and recycle, synthetic sizes. A prerequisite for this is that the weaver and the finisher must be in close geographic proximity.

In addition to geographic considerations, the weaver and the finisher must have a joint interest in pollution prevention. This is because the recovered size does not directly benefit the finisher, or vice versa. Therefore, a more global pollution prevention strategy or perspective must be developed to facilitate size recovery and reuse. Vertically integrated operations, where the weaving and finishing occur within the same organization, greatly facilitate this strategy. Nevertheless, not all integrated operations that are able to take advantage of size recovery do so. One reason for this is that size recovery equipment is expensive and only economically feasible in high-volume operations. On the other hand, some weavers and finishers, not connected through the corporate chain, cooperate to use and recover synthetic size.

4.9.1.3 Scouring

Scouring is a cleaning process that removes impurities from fibers, yarns, or cloth. The impurities include lubricants, dirt and other natural materials, water-soluble sizes, antistatic agents, and fugitive tints used for yarn identification.

Scouring uses alkali to saponify natural oils, and surfactants to emulsify and suspend nonsaponifiable impurities in the scouring bath. The specific scouring procedures, chemicals, temperature, and time vary with the type of fiber, yarn, and cloth construction. Two main pollution prevention principles must be addressed for scouring:

- Incoming greige goods may contain contaminants and should undergo testing and QC (see Section 4.2, "Fiber"). Any goods containing toxic or offensive contaminants (e.g., pentachlorophenol on wool, metals on cotton, toxic spin finishes on synthetic) should be rejected because subsequent wet processing releases these pollutants into the wastewater or air.
- Surfactants used in desizing should be easily degradable. These types of surfactants can be identified by their low COD:BOD ratios and high BOD values. See Sections 2.2.5, "Metals," and 4.4, "Chemical Specialties."

4.9.1.4 Bleaching

Bleaching is a chemical process that eliminates unwanted colored matter from fibers, yarns, or cloth. Bleaching decolorizes colored impurities that are not removed by scouring and prepares the cloth for further finishing processes such as dyeing or printing.

Several different types of chemicals are used as bleaching agents, and selection depends on the type of fiber present in the yarn, cloth, or finished product and the subsequent finishing that the product will receive. The most common bleaching agents include hydrogen peroxide, sodium hypochlorite, sodium chlorite, and sulfur dioxide gas. Hydrogen peroxide is by far the most commonly used bleaching agent for cotton and cotton blends, accounting for over 90 percent of the bleaching agents used in textile operations. Peroxide is an environmentally benign chemical because it is easily treatable and decomposes into water and oxygen during treatment.

The bleaching process involves several steps:

1. The cloth is saturated with the bleaching agent, activator, stabilizer, and other necessary chemicals.

2. The temperature is raised to the recommended level for that particular fiber or blend and held for the amount of time needed to complete the bleaching action.
3. The cloth is thoroughly washed and dried.

The bleaching agent, temperature, and processing time must be carefully controlled to avoid damage to the fiber, or severe losses in strength may occur.

Pollution from bleaching stages normally is not a major concern. In most cases, scouring has removed impurities in the goods, so the only by-product of the peroxide reaction is water. Aside from chemical handling issues and water conservation (covered in other sections), little effort is required to reduce pollution from bleaching. Of course, maintaining high efficiency and quality ensures right-first-time production and reduces reworks in later processes.

4.9.1.5 Singeing

Singeing is a dry process used on woven goods that removes fibers protruding from yarns or fabrics. These are burned off by passing the fibers over a flame or heated copper plates. Singeing improves the surface appearance of woven goods and reduces pilling. It is especially useful for fabrics that are to be printed or where a smooth finish is desired. Singeing has essentially no pollutants associated with it other than small amounts of exhaust gases from the burners.

4.9.1.6 Mercerizing

Mercerization is a chemical process for cotton and cotton/polyester goods that increases their dyeability and luster, and improves appearance. The yarn or cloth is treated under tension at room temperature with a 20-percent caustic solution. After treatment, the caustic is removed by several washes, also under tension. Remaining alkali may be neutralized with a cold acid treatment followed by several more rinses to remove the acid.

Mercerizing can generate substantial amounts of high pH alkali (about 20 percent owg). This waste stream can be recycled through evaporative caustic reclamation systems, but this is rarely practiced because the systems are expensive and require a large volume to justify the capital cost. Another reuse opportunity is to recycle the alkali into the scouring process.

4.9.1.7 Heatsetting

Heatsetting is a dry process used to stabilize fabrics with a high content of synthetic polymers. When manmade fibers are heatset, the cloth maintains its shape and size in subsequent finishing operations, as long as it does not encounter temperatures higher than the setting temperature. The cloth is stabilized, or set, in the form in which it is held during heatsetting (e.g., smooth, creased, uneven). Thus, heatsetting is widely used to impart a variety of textural properties to manmade fibers. These properties include interesting and durable surface effects such as pleating, creasing, puckering, and embossing. Heatsetting also gives cloth resistance to wrinkling during wear and ease-of-care properties attributed to improvements in resiliency and in elasticity.

In the manufacture of synthetic fibers, proprietary spin finishes often are used to provide fiber lubrication and other desirable properties, such as static electricity control (20). These spin finishing agents contain volatile components that are vaporized during heatsetting (20). Several pollution prevention strategies can help avoid this:

- From 50 to 80 percent of the air in gas-fired heatsetting frames can be recirculated, thereby burning up contaminants as they pass through the gas flames. This of course does not work on steam tenters. This strategy is best implemented by real-time monitoring of humidity in the heatset area and appropriate damper control.
- Improved or more aggressive scouring may remove these finishes from the goods before heatsetting. This may trade an air pollution problem for a water pollution problem, however, because the spin finishes will be removed with wastewater from scouring operations. Wastewater treatment, however, may be capable of degrading these pollutants to some degree to reduce their impact, whereas volatilization releases them entirely to the atmosphere (see Section 4.2, "Fibers").
- Heatsetting should be done after dyeing (not in greige). After dyeing, the spin finish is removed from the air and transferred into water where it can be more easily treated.
- Incoming synthetic goods (or fiber, if possible) 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. The chemical content can be determined by analyzing the extract by infrared or any of several chromatographic methods (e.g., GC, HPLC). Mills should follow up on this analysis by developing a fiber purchasing specification based on the monitoring results.

4.9.2 Summary of Pollution Prevention Strategies for Preparation Pollutants

Preparation is essential to obtaining good results in subsequent textile finishing processes. Many of the pollutants from preparation result from removal of previously applied contaminants and upstream processing residues, and these can be passed on to subsequent stages if preparation is poor. QC of incoming raw materials (including substrate, fiber, yarn, and fabric) is thus one of the most crucial elements of a pollution prevention strategy. QC must include testing for offensive or hazardous materials.

The sections below identify important pollution prevention considerations for the main categories of pollution found in preparation.

4.9.2.1 Water Reduction in Preparation

Preparation procedures should be thoroughly audited for chemical use and handling, equipment condition, and in-process quality verification. Mills should study and evaluate the state-of-the-art preparation equipment appropriate to the styles they are producing. Water conservation is covered in detail in Section 2.2.7, "Water Conservation."

4.9.2.2 Alkalinity

Preparation processes generally are carried out in a range of pH conditions: from neutral to highly alkaline conditions. As a result, the pH of preparation wastewater is frequently above 11. NPDES and POTW pretreatment regulations generally require an upper pH limit of 9 or 10; thus, alkaline waste streams from preparation should be reused wherever possible. A typical scheme is shown in Figure 4-11 (53). In general, and especially for cotton, no substitutions are available for alkalinity in scouring and bleaching, so the high pH cannot be eliminated by any process alternative.

4.9.2.3 Biological Oxygen Demand

Most of the BOD in textile preparation comes from sizes, knitting oils, and natural impurities that are removed from the greige fabrics. Table 4-34 (11) shows typical BOD levels from preparation processes. Because most BOD from preparation comes from upstream residues (e.g., knitting oils), little can be done in the preparation process itself to reduce BOD. Although mills are often tempted to use surfactants with low BODs to reduce pollution load and associated POTW surcharges, they must do so with great caution to avoid introducing processing materials that pass through waste treatment systems and cause aquatic toxicity in the effluent or sludges. This is discussed further below and also in Sections 2.2.6, "Aquatic Toxicity," and 4.4, "Chemical Specialties." The best pollution prevention strategy for BOD is to use, recover, and reuse synthetic sizes. This can reduce BOD as well as dissolved or suspended solids in effluent.

4.9.2.4 Aquatic Toxicity

Surfactants, which cause much of the aquatic toxicity from textile operations, are a minor source of offensive wastes produced during preparation. AP surfactants are not completely degradable in typical waste treatment

Table 4-34. BOD From Preparation Processes (11)

Process	Pounds of BOD per 1,000 Pounds of Production
Singeing	0
Desizing starch	67
Desizing starch mixed size	20
Desizing PVA or CMC	0
Scouring	40-50
Bleaching with peroxide	3-4
Bleaching with hypochlorite	8
Mercerizing	15
Heatsetting	0

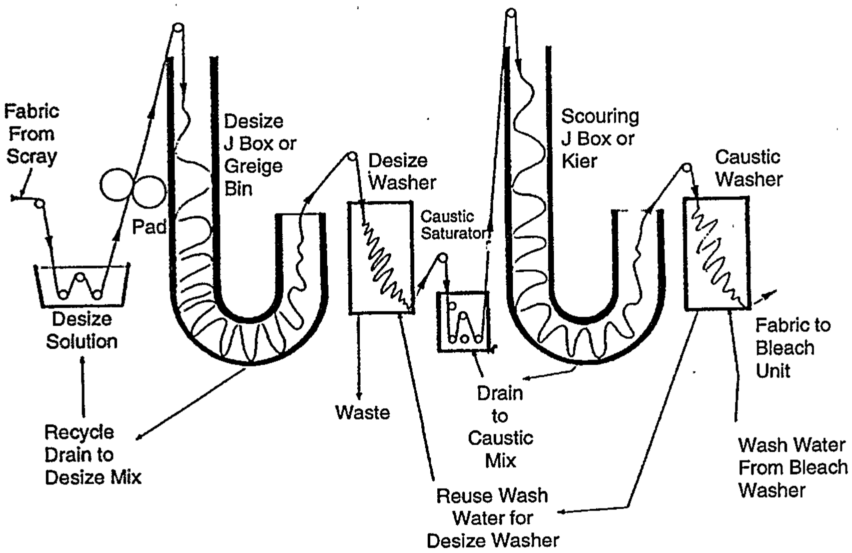


Figure 4-11. Reuse of alkaline waste streams from desizing and scouring operations (53).

systems, and even if degraded, the degradation residues are phenols, which are toxic to fish (22, 23). Other types of surfactants, such as LAE, are less toxic (22, 23). Degradable surfactants should be favored over nondegradable ones despite their extremely high BOD values.

When purchasing commodity surfactants, mills can easily assess the surfactants' aquatic toxicity potential. If the surfactant is part of a proprietary compounded specialty, however, the responsibility for assessing toxicity rests with the formulator (22, 23). In practice, mills often have difficulty obtaining toxicity information for proprietary chemicals.

The toxicity of surfactants is discussed in Sections 2.2.6, "Aquatic Toxicity," and 4.4, "Chemical Specialties," as are the difficulties of obtaining information concerning environmental impacts of surfactants and other specialties.

4.9.2.5 Metals

Metals originate in the incoming fabrics. The types and amounts of metals found in textile fibers and fabrics are covered in detail in Section 2.2.5, "Metals." To reduce the potential for releasing metals to wastewater during preparation, mills should test and monitor incoming greige goods as part of their QC and pollution prevention program.

4.9.3 Pollution Prevention Through Equipment Selection and Use

Several types of scouring/bleaching equipment or equipment modifications are available that can reduce or minimize pollution from preparation operations. These include:

- Countercurrent washing
- Low-bath-ratio batch bleaching with bath reuse built in
- Continuous horizontal washers
- Continuous knit bleaching ranges
- Combined single-stage processing

4.9.3.1 Countercurrent Washing

Countercurrent washing equipment can be retrofitted to any multistage continuous washing operation, whether it is installed for dyeing, printing, or in this case, preparation. Continuous preparation ranges run the fabric through three consecutive stages that progressively clean the fabric: desizing, scouring, and bleaching. Each stage comprises a process bath, a dwell time, and a washing step. As the fabric progresses through the three steps, various impurities are removed. Because of this, the washwater from the final stages contains few impurities and can be reused as feed for previous processing stages instead of being dumped from washers. Figure 4-10 depicts a countercurrent washing setup (53).

Countercurrent washing equipment is applicable to a variety of operations and fabrics. It is common in modern mills and is becoming more common in older mills as these mills upgrade and update their equipment. Although countercurrent washing equipment has low operating costs and offers pollution and energy savings, it has a fairly high capital cost. This may make some mills slow to change to this equipment.

Often, water flows in washing are excessive. Flow optimization makes a good companion activity to the installation of countercurrent washing.

4.9.3.2 Low-Bath-Ratio Kier Bleaching Systems

Low-bath-ratio kier bleaching systems reduce wastewater volume. A typical example of such equipment is the Scholl AG BLEACHSTAR ultra-low-liquor bleach range (54), designed for a wide range of knit fabrics. The machine features holding tanks for storage of scouring and bleach baths. These counterflow tank systems facilitate easier bath reuse (54). The washwater 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. In this way, each bath is used three times and the ultimate water use is only about 0.8 gallons of water per pound of cloth from an average of 4.5 to 6.0 gallons (54).

4.9.3.3 Continuous Horizontal Washers

Continuous horizontal washers can conserve energy and water. The process, as shown in Figure 4-12, is to spray clean washwater on the top (final) pass of fabric as it makes a series of horizontal traverses upward in the machine (13). The unprocessed fabric enters at the

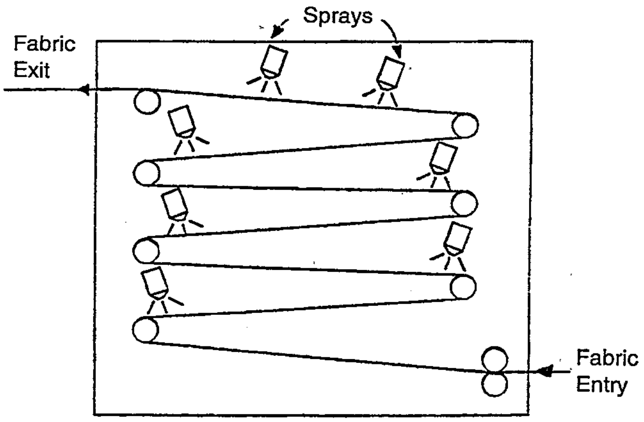


Figure 4-12. Horizontal washer configuration (13).

bottom traverse, and the water enters at the top. These vertical spray washers reduce water and energy use as well as improve quality and captured suspended solids for dry disposal.

4.9.3.4 Continuous Knit Bleaching Ranges

Many textile companies use continuous knit bleaching ranges, which have significant pollution prevention advantages, one of which is water conservation (11). Until the early 1980s, continuous knit preparation machinery was limited in the styles that it could run. Many knit styles exhibited rope marks, crows feet, creases, and cracks if continuously prepared. That changed with the introduction of efficient rope bleach ranges for knits, based on jet-dyeing principles. These ranges consume less water, energy, and chemicals than batch preparation methods for knits (48).

More recent models of continuous knit ranges have been improved mechanically as well as in flexibility of production capacity. A significant change was the introduction of lower capacity machines for smaller operations (48). Previous models were so large that small operations (those processing under 100,000 pounds per week) could not justify them economically. The new machines also feature inherent countercurrent water use, reduced ballooning of the fabric, better fabric transport, better chemical metering systems, fabric sensors to ensure proper dwell time, better filtering of the baths, and better controls (49).

4.9.3.5 Combined Single-Stage Processing

Combining scouring and bleaching also can save energy and water. In addition, a cold pad-batch method can be used at room temperature for long desizing, scouring, and bleaching cycles (12 hours overnight).

The single-step, cold-batch method of desizing minimizes energy and water use and maximizes productivity in desizing (47). Bleaching and scouring are combined, and all preparation is carried out in the single-step, cold-batch process (47). Recipes for desizing are given in Table 4-35 (47). The composition of most proprietary stabilizers can be estimated. Figure 4-13 compares the performance of the three desizing methods on various types of sizes (47).

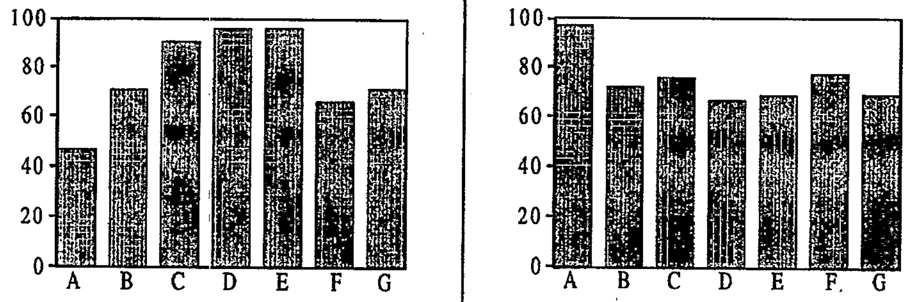
4.10 Dyeing

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.10, Dyeing		
Toxicity: metals, salt, surfactants, organic processing assistants, cationic materials	Process alternatives, modification, and optimization; optimum auxiliary selection and use; substitution of mechanical for chemical process facilitation; machine cleaning and scheduling	
Air emissions: VOCs	Chemical selection	See Sections 2.2.3 and 4.4
Color	Work practices; maximized exhaustion and fixation	Fiber reactive dyes are the primary problem area
BOD and COD	Chemical substitution; substitution of mechanical for chemical process facilitation	
Sulfide	Chemical alternatives	Applies to sulfur dyes
General: acidity/alkalinity, water	Equipment selection (low bath ratio); optimized and well-controlled processes for maximum right-first-time production; avoidance of mix discards; use of automated chemical dispensing; training; maintenance; minimized chemical specialty use	
Special experimental techniques for general application	Dyebath reuse; experimental techniques (e.g., waterless SCF dyeing and ultrasonics)	

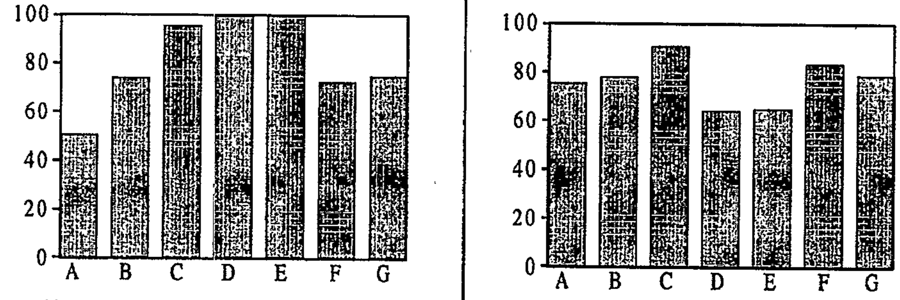
This section describes opportunities for furthering pollution prevention efforts in textile and finishing mills through dyeing process specification, dyeing equipment selection and operation, and other work practices related to textile dyeing.

Some dyers may have less latitude than other types of textile processors in specifying less polluting dyeing processes, because much dyeing is done by commission dyehouses according to the customer's specifications. Persuading customers of the need to modify the product may be difficult in this case because no immediate benefits will accrue to them. Textile product manufacturers, however, are increasingly interested in the "life-cycle" environmental impacts of their products and are seeking ways to reduce this impact. Information in this section will help the commission dyer appeal to the customer's desire for products with reduced life-cycle



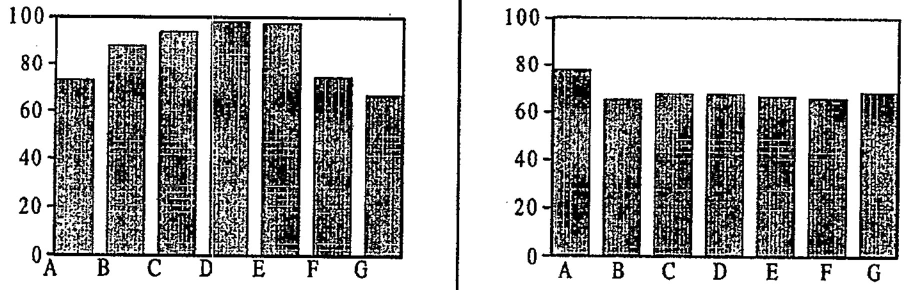
a. Size removal (%) by low-level hydrogen peroxide.

b. Consumption (%) of hydrogen peroxide—size removal by low-level hydrogen peroxide.



c. Size removal (%) by high-level hydrogen peroxide, low pick-up.

d. Hydrogen peroxide consumption (%)—size removal by high-level hydrogen peroxide at low pick-up.



e. Size removal (%) by high-level hydrogen peroxide at high pickup.

f. Hydrogen peroxide consumption (%)—size removal by high-level hydrogen peroxide at high pickup

Figure 4-13. **Comparison of three alternative desizing methods on different types of size. A= natural starch; B = modified starch; C = CMC; D = PVOH (low viscosity); E = PVOH (medium viscosity); F = acrylic; G = PES (47).**

Table 4-35. Alternative Recipes for Desizing Processing Baths (47)

Recipe Details	Add-On Level
Recipe 1: Low-level hydrogen peroxide with low pickup	
Hydrogen peroxide 35%	45 g/kg
Caustic soda 100%	20 g/kg
Stabilizer X	12 g/kg
Leonil EBL-X	15 g/L
(65% pickup)	
Recipe 2: High-level hydrogen peroxide with low pickup	
Hydrogen peroxide 35%	60 g/kg
Caustic soda 100%	20 g/kg
Stabilizer 82-X	15 g/kg
Leonil EBL-X	15 g/L
(65% pickup)	
Recipe 3: High-level hydrogen peroxide with high pickup, using a special stabilizer	
Hydrogen peroxide 35%	60 g/kg
Caustic soda 100%	20 g/kg
Stabilizer 82-X	15 g/kg
Leonil EBL-X	15 g/L
(100% pickup)	

impacts, and foster an awareness of these impacts among all customers. This is discussed further in Section 4.17, "Globalization of Pollution Prevention."

For dyers working in vertical operations, the benefits of pollution prevention accrue to the organization as a whole. This section assists the dyer in identifying the benefits associated with pollution prevention, including:

- Reduced dye and chemical costs
- Reduced water consumption
- Reduced energy consumption
- Improved product quality
- Improved process reliability

4.10.1 Introduction to Dyeing Processes

Modern textile dyeing is a complex operation that requires the dyer to be knowledgeable in many different areas: fibers and their physical and chemical properties, dye chemistry and dye application techniques, construction methods used for yarns and fabrics, and many fastness, quality control, and economic considerations for the finished product. The fundamentals of dyeing practice, however, are relatively straightforward. Textiles may be dyed during any of four stages of production, using either batch or continuous techniques. The stage of production chosen for dye application and the type of process selected depend on the desired results, the relative costs of different dyeing methods, available materials, demand considerations, and other factors.

4.10.1.1 Dyeing at Various Stages of Production

Textiles may be dyed in fiber form (before spinning), as spun yarns (after the finished material has been woven or knit), or, in the case of apparel, in garment form after cutting and sewing.

Fiber Dyeing

Fibers may be dyed before they are spun into yarns or woven or knit into textile fabrics. In stock dyeing, the raw fiber is dyed in large kiers. Irregularities in shading are overcome when the fibers are blended into yarn. In top dyeing, fibers are shaped into lightly twisted rovings, or tops, before dyeing. Uniform colors are attained in both dyeing methods.

Yarn Dyeing

Textiles may be dyed in yarn form before they are used to weave or knit a pattern or design into the cloth. The three methods for batch dyeing yarn are skein dyeing, package dyeing, and beam dyeing.

Skein dyeing is used for large, bulky, or delicate yarns. The yarn is formed into loose coils, called hanks or skeins, which are then immersed in a large, open dyebath. Dye penetration is good because the yarn is distributed loosely in the bath.

In package dyeing, yarns are wound onto perforated tubes or springs, stacked on perforated rods, and placed in a pressurized tank. Dye is pumped through the rods and ultimately through the yarn package. The liquid is recirculated until the proper color is achieved. Package dyeing is somewhat quicker than skein dyeing because it forces the dye through the yarn under pressure. Package dyeing is preferred for dense, small, highly twisted yarns, whereas skein dyeing is preferred for large, loose, bulky yarns, especially wool and acrylic.

The beam dyeing process is similar to the package dyeing process except that yarns are wound on a perforated warp beam. The advantage of beam dyeing is that following drying, the beams can be moved directly to slashing and then onto the loom, when they are needed for weaving. Yarns can also be continuously dyed either on a slasher or on a continuous range, using a technique known as chain dyeing.

Cloth or Piece Dyeing

Piece dyeing involves the dyeing of woven or knit cloth and may be accomplished by batch or continuous processes. The choice between batch and continuous dyeing usually depends on such factors as fabric construction, cost considerations, the dye classes chosen (and their applicability to batch or continuous equipment), the minimum lot size required for economical running, and the availability of equipment. Generally, except for dye jobs involving less than 1,000 meters of cloth, most woven material is dyed by continuous processes. Most knit cloth, on the other hand, is dyed by batch methods because it cannot withstand the tension of the continuous range.

4.10.1.2 Batch Versus Continuous Dyeing

In continuous dyeing, textile materials are fed continuously into a dye range at speeds of roughly 50 to 250 yards per minute. For any color, continuous dyeing is less expensive, has lower labor requirements, and generates less waste for long runs of 10,000 yards of more. Continuous dyeing processes usually consist of dye application, dye fixation with chemicals or heat, and washing.

For short runs, batch dyeing is generally more economical because of the higher startup and stopoff costs associated with continuous dyeing. In batch dyeing, a given amount of textile material is loaded into a dyeing machine and brought to equilibrium, or near equilibrium, with a dye-containing solution. The dyes have affinity for the fibers, which causes the dye to leave the dye solution and enter the fibers over a period of minutes to hours. Use of chemicals and controlled temperatures accelerate and optimize the exhaustion of the dye. Dye is then fixed in the fiber using heat and/or chemicals, and the textile material is washed.

A third type of dyeing, known sometimes as semicontinuous dyeing, applies dyes continuously but fixes and washes the material batchwise. Pad-batch dyeing, the best known semicontinuous process, is described later in this section.

4.10.1.3 Rope Versus Open-Width Dyeing

Dyeing machines can be classified into two types: rope and open width. With rope dyeing machines, the fabric is transported through the machine in a loosely collapsed form resembling a rope. In open-width dyeing, the fabric is maintained in a flat and open condition at all times. The main fabric dyeing machines are classified as follows:

Machine	Configuration
Beam	Open
Beck	Rope
Continuous	Open
Jig	Open
Jet	Rope
Pad-batch	Open

The most popular rope dyeing machines are jets, followed by becks. The most popular open-width dyeing machines are beams, followed by jigs and pad-batch. The choice of rope versus open-width dyeing depends on the fabric's ability to withstand the mechanical demands involved in the two methods. Rope dyeing has the potential for abrasion of fabrics as well as permanent creases, cracks, and streaks. Open-width dyeing applies tension to fabrics and thus has the potential to form edge marks and creases in tubular knit goods. Jet dyeing machines (for rope dyeing) have been engineered to be more gentle and can handle most styles of goods. Thus, jets have emerged in the United States as the dominant batchwise piece dyeing machines (see Figure 4-14).

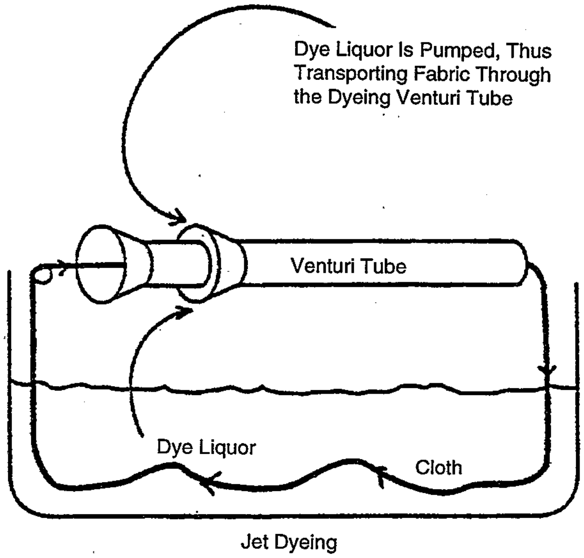


Figure 4-14. Schematic of jet dyeing machine.

4.10.2 *Pollutants Associated With Dyeing*

Many pollutants are associated with the dyes and chemicals used in dyeing processes. These may originate from the dyes themselves (e.g., toxicity, metals, color) or derive from auxiliary chemicals used during the dyeing process (e.g., salt, surfactant, levellers, lubricants, alkalinity). Pollutant impacts are also associated with chemicals used during dyeing equipment maintenance and cleaning.

Dyeing contributes most of the metals and essentially all of the salt and color in effluent from textiles operations, and these are priority areas for pollution prevention. Wagner (14) reports that dyeing consumes 8 percent of the water and contributes 5 percent of the BOD in a typical cotton finishing operation.

Some common aquatic pollutants associated with dyeing processes are presented in Tables 4-36 and 4-37. Table 4-36 outlines the types of pollutants associated with dyes of various types, while Table 4-37 shows the BOD contribution to waste of various auxiliary chemicals associated with each of the major dye classes.

Table 4-36. Types of Pollutants Associated With Various Dyes (55)

Class	Fiber	Type of Pollution
Direct dyes	Cotton	Salt Unfixed dye Copper salts Cationic fixing agents
Reactive dyes	Cotton	Salt Alkali Unfixed dye
Vat dyes	Cotton	Alkali Oxidizing agents Reducing agents
Sulphur dyes	Cotton	Alkali Oxidizing agent Reducing agents Unfixed dye
Chrome dyes	Wool	Organic acids Unfixed dye Metals Sulfide
1:2 Metal complex dyes	Wool	Organic acids Metals
Acid dyes	Wool	Organic acids Unfixed dyes
Disperse dyes	Polyester	Reducing agents Organic acids Carriers

Dyeing also contributes to air emissions. Many volatile chemicals are used in dyeing, and these are reviewed more thoroughly in Sections 2.2.3, "Toxic Air Emissions," and 4.4, "Chemical Specialties,"

Modern batch dyeing processes use enclosed machines that operate at superatmospheric pressures above the boiling point of water. These machines have reduced the need for chemical specialties such as dye carriers and have contained many fumes and vapors that the former atmospheric (open) machines released. These volatile materials, however, now have a tendency to either be forced into the substrate or discharged with the wastewater. In the former case, the organic chemical residues from dyeing tend to volatilize during the subsequent drying, heatsetting, and curing (or finishing) operations performed on the substrate. In the latter case, the volatiles tend to be stripped from the wastewater systems during secondary activated sludge biological aeration treatment (see Section 1.2.1, "Air Pollutants").

In continuous dyeing (and printing), the fabric usually goes through one or more cycles of wetting and drying as it progresses down the range, and the fabric repeatedly undergoes high-temperature thermofixation processes. In these stages, any volatile components of the dyeing process solutions are volatilized in the range. Because of the high temperatures in thermofixation ovens, even relatively nonvolatile materials (e.g., urea) can be vaporized.

4.10.3 Pollution Prevention in Specific Dyeing Situations

This section describes pollution problems and recommended prevention measures applicable to selected dyeing situations that involve certain combinations of dyes and fibers. These situations cover most of the important pollution problems—and thus represent pollution prevention opportunities—that occur within dyehouse operations.

4.10.3.1 Acid Dyes for Wool and Nylon

Acid dyes are the major class of dyes used for wool and nylon in the United States. Bath exhaustion with acid dyes, if performed properly, can reach 90 percent or greater. Aside from premetalized dyes, which constitute only a small portion of total dye use, the main concern about acid dyeing is the BOD contribution of acetic and formic acid and the low pH (in the range of 3 to 7). Sudden variations in wastewater pH can produce shock loads to the biological processes in wastewater treatment systems and contribute high aquatic toxicity (1).

Many acid dyes contain metals as part of the dye structure. Work is underway to develop acid dye replacements for premets, which would contain iron instead of the more harmful cobalt, nickel, lead, chromium, or zinc (56). This 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.

4.10.3.2 Chrome Dyeing for Wool

According to Shaw (7), approximately 70 percent of wool dyed in Europe uses heavy metals, mainly chrome. Low-chrome alternatives have been under development since 1976. Results show reductions of chrome in effluent from about 155 ppm (for conventional dyeing) to levels of 33 ppm, 8 ppm, and near 0 ppm for pH control, fresh bath, and thiosulfate methods, respectively (57). U.S. discharge regulations require essentially zero discharge of chrome.

Duffield et al. (57) provide several pollution prevention recommendations to reduce chrome discharges from chrome wool dyeing:

- If the dyebath is not completely exhausted before chroming, the bath should be drained. This prevents mixing of dyeing and chroming solutions.
- The optimum pH for maximizing dye chroming is in the range of 3.5 to 3.8. This can be attained using formic acid instead of acetic or other acids, which may inhibit exhaustion of the chromate ion.
- Only the minimum required amount of chrome should be added to the bath.

Table 4-37. **BOD of Dyeing Auxiliaries (ppm) (11)**

Class	Fiber	Machines	Chemicals	BOD Contribution to Waste
Acid	Wool Nylon	Stock Skein Package Jig Beck Jet Beam	Surfactant Leveler Retarder Acid Dye Lubricant Salt	Moderate (varies) Varies (may exhaust) Varies Low Low Varies (may exhaust) Nil
Basic	Acrylic Other Polymers	Stock Package Beck Jet Beam	Surfactant Leveler Retarder Acid Dye Lubricant Salt Carrier	Moderate (varies) Varies (may exhaust) Varies Low Low Varies (may exhaust) Nil Varies (may exhaust)
Direct	Cellulose	Stock Package Jet Beck	Alkali (weak) Surfactant Retarder/Leveler Salt Lubricant Fixative Dye	Nil Varies (moderate) Varies (moderate) Nil Varies (may exhaust) Low (exhausts) Low
Disperse	Synthetic	Stock Package Beck Jet Beam	Acid (weak) Dispersant Dye Carrier Lubricant Reductive/Afterscour	Low High High (dispersant) High (varies) Varies (may exhaust) Moderate to high
Fiber reactive	Cellulose (wool)	Stock Jig Jet Beam Beck Skein	Alkali (strong) Salt Dye Dye Lubricant Soap-off	Nil Nil Nil Nil Varies (may exhaust) Moderate (varies)
Naphthol (sulfur vat)	Cellulose	Any	Reducers/Oxidizers Dye Lubricant Buffer	Varies greatly

- The dyer should follow a time-temperature cycle that is optimum for chrome dyeing, such as that diagrammed in Figure 4-15. This figure depicts a low-temperature chrome dyeing technique running at 90°C. Thiosulfate is added after chroming to destroy residual dichromate.
- Raising the temperature to between 98°C and 100°C results in better chrome utilization and lower chrome residual. A 7.5-percent anhydrous sodium sulfate solution must be used to ensure even chrome treatment at these temperatures. An alternative is to add chrome, wait 10 minutes, and then lower pH to 3.5 to 3.8.

Further data illustrating the benefits of optimized chrome techniques are shown in Table 4-38.

The discussion above relates to dyeing processes in which the dyer adds chrome separately to the bath. Other wool dyeing processes use dyes that contain chrome in the dye molecule, and several pollution prevention techniques are available for these as well.

For 1:1 metal complex dyes, alternatives are available that reduce chrome residues from typical levels of 5.4 ppm to 1.3 ppm (e.g., the Neolan P class from Ciba) (57). Sulfamic acid is used instead of sulfuric acid to provide better pH control during heating with these dyes. For 1:2 metal complex dyes, the techniques under investigation include use of chemical specialty assistants, better chemical dosing and temperature controls, and dyeing above the boiling point under pressure (57). Using these methods, exhaustion increased by an average of 32.8 percent in one case and 8.7 percent in another (57).

Chromium is a very offensive pollutant and should receive maximum pollution prevention attention. In addition to dyebath effluents, other sources of chrome in the dyehouse may include spillage from handling, implement cleanup, drum washing, and incorrect weighings. Pollution prevention measures include special worker training, identification of problem dyes, better recordkeeping, and auditing of chromium use.

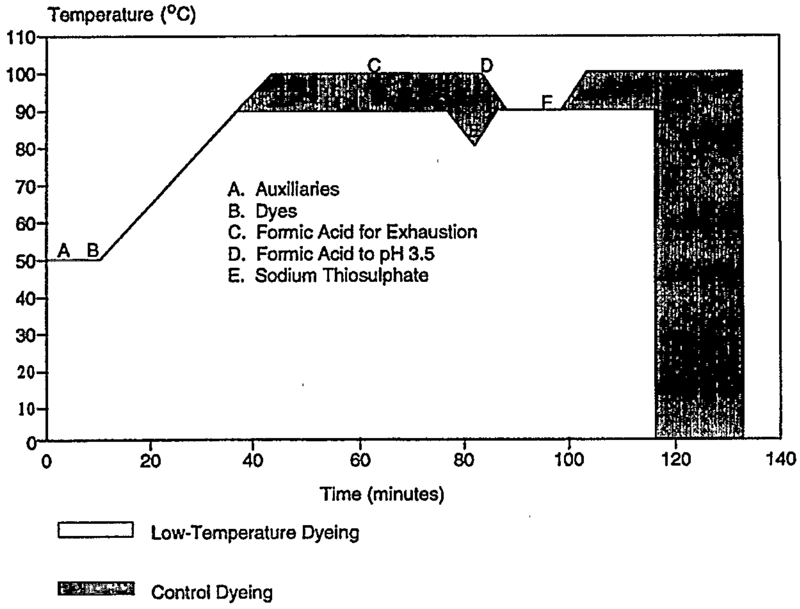


Figure 4-15. Low-temperature chrome dyeing, time/temperature profile (56).

Table 4-38. Dyebath Chromium Residues With Optimized Chroming (57)

Chroming Metals	Residual Chromium (mg/L)
Control dyeing black	66
Control dyeing navy	83
Black 98°C, Lyocol CR (Sandoz)	1.68-3.50
Navy 98°C, Lyocol CR (Sandoz)	1.00-4.30
Black 90°C, thiosulphate	3.00-6.00
Navy 90°C, thiosulphate	2.50-3.50

4.10.3.3 Basic Dyes for Acrylic and Polyesters

Basic dyes are water soluble and have extremely high affinities for acrylic and basic dyeable polyester. Shades are brilliant, costs are low, and the dyebaths exhaust essentially 100 percent. As cationic materials, basic dyes tend to exhibit high aquatic toxicity if present in wastewater (58). Assuming good spill management and dyeing practice, however, very little dye should carry over to the effluent stream because of the high exhaust percentage. Pollution prevention recommendations for these dyes therefore focus on proper handling and spill control (see Sections 3.11, "Optimized Chemical Handling Practices," and 4.18, "Support Work Areas").

4.10.3.4 Disperse Dyes for Polyester, Acetate, and Other Synthetics

Dyeing of polyester and polyester/cotton blends commonly includes an afterclearing step. Afterclearing is the process of treating disperse dyed polyester fabrics with a reducing solution containing typically 2 percent sodium hydrosulfite and 2 percent sodium hydroxide owg at 90°C for 30 to 45 minutes. Residual hydrosulfite produces immediate oxygen demand (IOD) in the effluent.

Afterclearing sometimes is unnecessary and a waste of water, chemicals, and time (59). On properly dyed 100-percent polyester, for example, afterclearing should not be necessary for most shades. With blends, subsequent drying, heatsetting, and curing steps may cause disperse dye migration from the polyester to the cotton, from which it washes off in the washfastness test. Clearing the polyester before heat treatments is often inconsequential to the final result if the dye is prone to migrate (as are, for example, virtually all disperse red dyes).

New ester-type disperse dyes have been introduced that can be aftercleared with alkali alone and that do not require any reductive afterclearing agent. These dyes are based on the diesters thiophene and benzodifurone, which are cleared using only alkali (with no hydrosulfite). In addition, the dyes based on benzodifurone resist thermomigration, especially in red shades (59).

4.10.3.5 Fiber Reactive Dyes on Cotton and Other Cellulosics

Fiber reactive dyeing of cotton and other cellulosics cannot achieve the high fixation level of other fibers, which in wool and synthetics are typically in the range of 90 percent or higher (60). To maximize fixation, fiber reactives require the use of large quantities of salt, typically up to 100 grams per liter. Even with high levels of salt added and the use of new bifunctional reactive dyes, fixation in typical batch dyeing processes usually remains below 70 to 80 percent. This results in the discharge of large amounts of color to the wastewater.

When applying fiber reactive dyes to cotton, some unfixed, hydrolyzed reactive dye remains in the fiber to be washed off. The washing off process requires substantial amounts of water. One alternative is to limit the amount of washing and then fix the remaining dye (22, 23). In addition to the standard fixing agents for use in this situation (dicyanodiamide [DCY]/formaldehyde), several new cationic polymeric fixing agents are available that are more efficient when used with fiber reactive dyes. These agents, now in standard use in package dyeing, can easily be used in fabric machines as well.

Pad-batch dyeing is an important alternative for fiber reactive dyeing on cotton and blends and is described in detail later in this chapter. Pad-batch dyeing has been widely recognized as an attractive alternative in terms of pollution prevention and energy efficiency (11, 54).

4.10.3.6 Low Sulfide Reducing Agents for Sulfur Dyeing

Because of their extreme resistance to washing off, sulfur dyes are preferred if the ultimate in fastness is required (e.g., black sewing threads top stitched on white fabric). They are also completely resistant to the normal perborate, chlorine, and peroxide bleaches. The drawback is that the shade range is limited—mostly dull, dark, and earth tones.

When initially introduced in the late 1800s, sulfur dyes were reduced in the dyehouse by boiling the dye with soda ash and sodium sulfide to render them soluble (61). Then, in reduced form, they were applied to cotton, then reoxidized later in the process to produce fast dyeings. A by-product is foul-smelling sulfur dioxide (61). A later advance was the introduction in 1936 of prereduced/presolubilized sulfur dyes, thus eliminating the need for on-site reduction processes. In the 1990s, new types of sulfur dyes have been introduced that feature lower sulfide content, which lowers sulfide discharges to mill effluent as well as hydrogen sulfide odors in the mill and in the waste treatment system. The chemical nature of the proprietary reducer is not revealed, but it appears from the MSDS information to be an organosulfur reducing agent (61).

Glucose or sugars from corn can also be substituted for sulfide-containing reducing agents (3). In one case, using alternative reducing agents lowered the sulfide concentration from 30 ppm to 2 ppm in the effluent. A small increase in BOD resulted but was easily handled by the waste treatment system, whereas the sulfide waste was not amenable to treatment. The zone settling velocity in the clarifiers improved as a result of the decrease in sulfide, thus increasing waste treatment efficiency. Odors also decreased. Operating costs did not increase, and the cost savings for avoided purchase of sulfide removal equipment was estimated at $20,000. Waste treatment efficiency improvements were valued at $30,000 per year. The corn sugars were obtained as a waste product from the corn starch industry, which saved the starch manufacturer $12,000 in waste treatment expansion and $2,400 in operating expense annually.

4.10.4 Batch Dyeing Pollution Prevention Measures

Best management practices for pollution prevention in dyeing processes begin with careful dye selection. Desirable features of a batch dye include: 1) high fixation, 2) low toxicity, 3) absence of metals, 4) appropriateness for the intended end-use, 5) correct and compatible application properties, and 6) high probability of right-first-time production. Dye selection is discussed more thoroughly in Section 4.3, "Dyes."

Major pollution prevention techniques available to batch dyers include low bath ratio dyeing, particularly ultra-low-liquor-ratio (ULLR) dyeing, and use of automated chemical and dye dosing systems.

4.10.4.1 Ultra-Low-Liquor-Ratio Dyeing

In dyebaths, some chemicals act on the bath and are normally measured according to the bath volume. Among these are salt, pH control, acid/alkali, dyebath lubricants, and dispersing agents. Other chemicals, such as dyes and softeners, act on the fabric and are measured based on the weight of goods. Recently, a distinct trend has developed toward reduced bath ratio dyeing among mills interested in pollution prevention and energy conservation. Low-bath-ratio dyeing can save energy and dyebath chemicals because energy and chemical use in dyeing is generally a function of the bath volume, not the amount of fabric.

The terminology of dyeing distinguishes between those chemicals whose quantities are based on the amount of bath and those whose quantities are based on the amount of fabric. The terms on weight of bath (owb) and on weight of goods (owg) are often used. An important relationship for the dyer is:

$$\text{owb} = \text{owg}/L \qquad \text{(Eq. 4-3)}$$

where L is the bath ratio, or, conversely,

$$\text{owg} = \text{owb} * L \qquad \text{(Eq. 4-4)}$$

An example of the effect of bath ratio can be found in Section 2.2.2, "Discharge of Electrolytes," where the salt required for different machines at different bath ratios has been tabulated.

Unfortunately, many operations use cost systems that base all chemicals and dyes owg for accounting reasons.

When bath ratios change (e.g., when low-liquor-ratio dyeing is adopted) the chemicals that should be owb are then incorrect. This leads to frequent confusion among managers and accountants, and sometimes even among dyers. Therefore, a recommended pollution prevention practice for batch dyeing is to determine whether each chemical in the process should be owg or owb and to ensure that everyone understands the distinction—and its importance for pollution prevention.

Table 4-39 shows normal bath ratios for several dyeing machines. ULLR dyeing, one form of low-bath-ratio dyeing, has the following advantages:

- Decreased water consumption and associated cost savings (reduction in water purchases, reduction in effluent volume requiring treatment).
- Decreased consumption of bath chemicals (see sample calculation for salt in Section 2.2.2). ULLR dyeing can reduce salt requirements by 80 percent compared with beck dyeing and by 60 percent compared with conventional jet dyeing (59).
- Increased fixation of dyes (see Section 2.2.1, "Color Residues" on the relation between fixation and bath ratio) (59).
- Reduced cycle times because of quicker machine drains and fills and more rapid heating and cooling.
- Decreased energy requirements for heating the dyebath, which in turn lead to reduced steam and boiler use, reduced fuel consumption, and fewer emissions to the atmosphere from combustion.

In some fabric dyeing machines, ULLR techniques have lowered bath ratios from 30:1 to 5:1, and in some cases bath ratios have gone as low as 3:1. Both jet and package dyeing machines use short and compact piping and low-volume pumps, and have better space utilization of substrate in the kier (62). At this level of moisture in the machine, almost no water is free. The cloth itself inherently takes up about two to four times its weight in water, and the pipes, pumps, kier, and sumps of the machine take up the rest. Below the ratio of 5:1, insufficient water is present to keep the pumps "wet."

Table 4-39. Normal (Conventional) Bath Ratios (13)

Process	Machine	Bath Ratio
Continuous	Pad at 100% wet pickup	1:1 (e.g., pad-batch)
Exhaust	Beck	17:1
	Jet	12:1
	Jig	5:1
	Beam	10:1
	Package	10:1
	Paddle	40:1
	Stock	12:1
	Skein	17:1
	ULLR jet or package[a]	3:1 or 5:1

[a] Low-liquor-ratio dyeing machines are often cited as a method of reducing the volume of dye waste to be treated (22, 23, 54, 62). In fact, most water used in dyeing is used for washing not as part of the dyebath itself. The correlation between bath ratio and water use, therefore, is not as close as it may appear.

ULLR Dyeing Machines

Jet dyeing and package dyeing are commonly used for low ratio dyeing (see Figure 4-14). In jet dyeing, fabric is placed in a closed tubular system. A jet of dye solution is supplied through a venturi to transport the cloth through the tube. Turbulence created by the jet aids in dye penetration and prevents the fabric from touching the walls of the tube. Jet dyeing machines that rely on air transport or foam have also been available for some time. Older machines have proven uneconomical because of the energy required to maintain the necessary air flows, but energy requirements have lessened in newer models, such as the Then Airflow (63). Package dyeing machines are also used in low ratio dyeing. In package dyeing, the yarn remains stationary, and the dyebath is pumped through the machine cylinder.

Dye Selection for ULLR Dyeing

Dye selection for batch dyeing standard processes is discussed in Section 4.3, "Dyes." ULLR dyeing requires consideration of these factors, plus additional factors. The need for additional considerations arises because the dyebath is much more concentrated due to the decrease in water in the ULLR system, as shown below:

Bath Ratio	Dye Concentration (owg)	Dye Concentration (owb)
Conventional (20:1)	1.0 percent	0.05 percent
ULLR (4:1)	1.0 percent	0.25 percent

Thus, for the same concentration owg, the ULLR machine has five times more concentrated dye in the bath. Under these conditions, additional dye selection considerations should include (59):

- High solubility (even in the presence of salt).
- Good leveling (because little water is present to assist in dye migration).
- Good washing off.
- Very good right-first-time dyeing performance.

Suitability for ULLR dyeing also requires low interaction with other dyes, low interaction with auxiliaries, and high shear stability because the dye bath is pumped through the machine at high rates. At high concentrations, dyes tend to aggregate, which affects solubility and kinetic dyeing behavior.

Costs of ULLR

ULLR techniques involve reduced liquor ratios in the dyebath, but simply reducing the amount of water in the dye bath is not sufficient. Without further modification, lowering the water level in the machine may cause pump cavitation or poor fabric movement through the dye chamber. Because of this, ULLR concepts generally cannot be retrofitted onto existing dyeing machines. Specially designed ULLR jet or package machines must be used that feature a kier with a different configuration, size, and shape from that found on a normal jet. All of the pumps and pipes are low-volume versions. The installation cost for a typical ULLR jet with a capacity of 30,000 pounds per week is around $1 million. This translates into a $20- to $40-million investment for a typical large dyehouse interested in converting to ULLR dyeing. Given the long life of dyeing equipment (20 years), the high capital cost of ULLR dyeing machines discourages replacement of still-valuable existing dyeing equipment (59).

4.10.4.2 Automated Dosing Systems

Dosing systems meter chemicals to dyebaths automatically, as opposed to the practice of manual chemical addition. For years, dyers have added salt and alkali to direct and fiber reactive dyes, typically in portions of one-quarter, one-quarter, one-half. Microprocessor-controlled dosing systems extend that concept to continuous dosing with a variety of profiles, such as constant rate or variable rate. Some systems now under development (though not yet commercially available) can even sense dye exhaustion as it occurs and adjust the dosing profile of salt and alkali accordingly (64).

Automated dosing systems can be optimized to deliver the right amount of the right chemical at just the right time. This additional control improves the efficiency and reliability of chemical reactions in the dyebath, ensuring more consistent and reproducible results. In addition, these systems avoid the tendency to overuse environmentally harmful chemicals, which may pass through treatment systems unreacted or react to produce undesirable byproducts. Dosing systems also reduce handling losses and equipment cleanup. Automated dosing systems are commercially available and are being adopted throughout the textile industry. A companion technique to automated dosing is the automated color kitchen, which is discussed in Sections 4.10.5.2 and 4.18.

4.10.5 Continuous Dyeing Pollution Prevention Measures

In continuous dyeing (and printing), the key pollution prevention goals should be to:

- Maximize dye fixation.
- Minimize washoff.
- Avoid discards and machine cleaning waste during startup, stopoff, and changes of color and style.

Dye fixation is accomplished with steam, dry heat, or chemical reaction, and the ovens, steamers, and chemical pads in the continuous operation deserve close attention and optimization for each recipe. High affinity for dyes, which is so important in batch dyeing (especially at long bath ratios), is not required for continuous dyeing. In fact, high-affinity dyes cause problems in continuous dyeing, such as tailing and difficult washing, which requires excessive water.

4.10.5.1 Improvements in Continuous Dye Ranges

Continuous dyeing ranges offer certain inherent pollution prevention advantages, such as no exhausted dyebath to discard, high levels of fixation, the ability to reuse washwater in countercurrent operation, reduced use of chemical specialties, and the elimination of salt for dyeing cotton. Continuous dyebath ranges have drawbacks, however, and their use has been limited in the past. For example, knits cannot normally be dyed in continuous processes because they cannot withstand the high lengthwise tension. Other limitations of continuous dyeing are the lot size restrictions mentioned above, the discharge of leftover mixes and pad baths at stopoff and color changeovers, and the high pollution potential of the cleaning agents.

Continuous ranges have steadily improved in recent years, however, and limitations to their use are slowly disappearing. Continuous dye ranges with short plumbing runs, small pipes and pumps, and small pad-bath troughs can reduce discarded mixes because all padding liquors in the pumps, pipes, and pads are discarded when a new color is started. Many modern continuous dye ranges have low stopoff losses and other desirable features as described above. This not only reduces pollution for shades that are run on continuous ranges but also allows smaller lots to be run economically on the less-polluting continuous systems. Increased use of continuous knit dyeing ranges will result in a corresponding decrease in pollution because continuous dyeing is generally less polluting than batch dyeing, especially for longer runs (48).

4.10.5.2 Automated Color Kitchens

One of the most significant pollution prevention developments in textile equipment during the last 10 years has been the development of the automated color kitchen. Automatic color mixing and batching reduces working losses from cleanup and disorderly work practices, and also ensures the correct amount of mix is made every time, thus reducing discards. This applies particularly to continuous dyeing operations, printing, and finishing. Reducing startup and stopoff waste also makes shorter runs on continuous equipment more economically feasible (13). Further information about color kitchens appears in Section 4.18, "Support Work Areas."

4.10.5.3 More Efficient Washing

Washing operations consume most of the water used in textile wet processing, and water conservation is, in large part, related to proper control of washing. Important aspects of washing are discussed in depth in Section 2.2.7, "Water Conservation." Continuous dyeing machines can be made more water efficient through the use of flow restrictors, which control water volume. In addition, countercurrent washing and recycle of clean water are important features of continuous dyeing and printing operations (46).

4.10.6 General Pollution Prevention Measures

This section discusses general pollution prevention techniques that are applicable to both batch and continuous dyeing. The most important general pollution prevention strategies for dyeing operations, based on a computer simulation model of dyeing processes, include (65):

- Operating at the lowest possible bath ratio. This leads to reductions in direct operating costs, water and chemical use (because chemicals are added as a percentage of water volume), energy use (less liquor to heat or pump), and less effluent discharge (lower volume being treated and lower chemical concentrations). The cost of dyes remains essentially the same because dyes are added as a percentage of the weight of the fabric.
- Minimizing strip/redye procedures.
- Avoiding shading additions.

4.10.6.1 Minimize Use of Auxiliaries

Numerous auxiliary chemicals are used in dyebaths to improve the efficiency of the dyeing process (see Section 4.3, "Dyes"). Selecting dye auxiliaries that do not interfere with dye exhaustion can improve the process reliability of dye operations (66). Dyebath auxiliaries typically contain surfactants that reduce dye fixation, however, and this contributes to color in the wastewater. Use of auxiliaries should be minimized, not only to save the pollution associated with the chemical itself but also to increase color yield, which in turn produces more consistent shade repeats and fewer reworks with less pollution.

Auxiliaries are often added to compensate for inadequacies in process, equipment, or substrate design. One way to reduce the need for auxiliaries is to optimize processes and machinery to decrease such variation. This improves the reliability and efficiency of the process and minimizes the generation of pollutants (46). If auxiliary chemicals are used in dyeing, care should be taken to control dispensing by accurately weighing all dyes and chemicals.

4.10.6.2 Right-First-Time Dyeings

Without question, the most effective pollution prevention practice is "right-first-time" dyeing. Corrective measures such as reworks, redyes, stripping, shade adjustments, top-ups, or adds are chemically intensive and have a much lower chance of achieving desired quality than right-first-time dyeing (65, 67). In most cases, the greatest costs in reprocessing are the costs associated with dyes and chemicals. Studies have shown that the cost of dyeing can increase by as much as 30 percent when dye additions are required (68). Right-first-time dyeing leads to increases in productivity and more efficient use of fixed capital and labor, which increases profitability. Using data from the United Kingdom, Glover and Hill (65) showed that a 10-percent improvement in right-first-time production can produce a 1.7-percent decrease in product waste and a $2.00 reduction in cost per 100 kilograms of fabric dyed.

Much of the success of efficient, right-first-time dyeing hinges on good fabric preparation. Proper fabric preparation results in higher fixation and less repair work. Poor preparation is a major cause of reworks and dye corrections. Fabric preparation is reviewed in more detail in Section 4.9, "Preparation."

4.10.6.3 Improved Dye Fixation

Improved dye fixation is an important key to pollution prevention in the dyehouse (14). Mills can improve fixation and reduce chemical requirements overall by mercerizing cotton yarn or fabric during the preparation process, thus increasing dye uptake and reducing the need for chemical accelerants (69). Mercerizing can therefore reduce the amount of dye needed to achieve a given shade and decrease the amount of color in the wastewater. The tradeoff is that mercerization uses highly concentrated (22 percent) sodium hydroxide, which is a pollution concern. The exact shade used in the dye process is key to the decision of whether to mercerize.

4.10.6.4 Pad-Batch Dyeing

Pad-batch dyeing is a cold method used for dyeing cellulosics (mainly 100-percent cotton and polyester/cotton blends) that can achieve large reductions in pollution, energy requirements, and costs. The basic technique is to saturate the prepared fabric with a premixed dye liquor and pass it through a padder, which forces the dyestuff inside the fabric for greater penetration while removing excess dye solution. The fabric is then stored, or batched, on rolls or in boxes for 4 to 12 hours. Typically, the batches are covered with a plastic film to prevent carbon dioxide absorption and water evaporation. While in batching, the dyestuff reacts with and penetrates the fabric, resulting in even, consistent color. After the reaction is complete, the fabric is washed.

Pad-batch dyeing offers several advantages over conventional dyeing processes:

- No salt or chemical specialty agents are needed. Eliminating these chemicals reduces waste as well as chemical and wastewater treatment costs.
- More efficient use of dye leaves less color in the wastewater and reduces water and energy consumption. Wagner (14) reports fixation ratios for pad-batch dyeing of 92 to 97 percent compared with 42 to 80 percent for reactives at a 10:1 exhaust dyeing bath ratio.
- Dye quality is more consistent. Compared with rope dyeing, pad-batch dyeing can attain more even color absorbency, greater colorfastness, and much lower defect levels (when the fabric is correctly prepared). High-reactivity dyes used in pad-batch dyeing have rapid fixation and stability, resulting in shade reliability and repeatability. With highly reactive dyes, cleanup is easy and frequent shade changes present little problem.
- Pad-batch dyeing can be used on wovens or knits in many constructions. Certain tubular knit styles may develop edge marks at the fold, but new methods in development will reduce this problem in heavyweight styles (52).
- The simplicity and flexibility of the system allow for use of available equipment—becks, beams, and continuous equipment for washing (63).
- Pad-batch dyeing requires a low capital investment and offers overall cost savings, in dyes, chemicals, labor, water, and other areas.

The following checklist serves as a reference to avoid some of the problems common to pad-batch dyeing:

- *Maintain good alkali control:* The generally accepted method is to mix the required amount of dye in 80 percent of the total necessary water, then mix the alkali into the other 20 percent. A dual-piston pump feeds the dye and alkali through a static line mixer in a 4:1 ratio to create the proper mix in the pad trough. This metering must be accurate and calibrated on a regular basis.
- *Keep good data on bath ratios:* This facilitates adjusting exhaust dye recipes. If the dyer has good information about the dyes being used, the formulas can be adjusted to compensate for bath ratio.
- *Prepare fabric well:* Effective preparation is necessary to obtain consistent dyeing side-to-side and end-to-end. The fabric should be scoured and/or bleached with a residual pH of 7 or slightly less, and all residual alkali, starch, and knitting oils must be removed (11).
- *Maintain good temperature control:* Feed only cold fabric to the pad to avoid temperature increases. Hot weather may necessitate keeping the mix cool by using a cooling jacket or by feeding plain ice into the mix.

Dye Requirements

Pad-batch dyeing requires highly reactive "cold dyeing" fiber reactive dyes. Table 4-40 contains a list of dyes that have gained prominence (13).

Table 4-40. Examples of Dyes Used in Pad-Batch Dyeing (11)

Dye	Manufacturer
Altafix CX	Atlantic
Cibacron F	Ciba
Drimarine K	Sandoz
Intracron C	C & K
Levafix E(A)	Mobay
Procion MX	ICI
Remazol	Hoechst
Sumafix	Wright

Equipment Requirements

The equipment needed for pad-batch dyeing includes a padding unit; a batcher or material handling system; a dye/alkali mixing device; A-frames, storage racks, and storage boxes; and a washoff device (beam, beck, continuous).

Cost Comparison

Smith (13) compared the capital and annual operating costs of pad-batch systems with those of conventional exhaust dyeing based on becks. Table 4-41 shows this comparison. Capital costs of the pad-batch equipment are less than one-third the cost of comparable becks, and operating costs (excluding dyes) are approximately one-fifth. Table 4-42 compares the dye chemical costs and reveals that pad-batch costs are generally lower, by as much as 40 percent.

Sommerville (52) developed economic models of dyehouse costs for running 100-percent cotton and cotton/polyester blends on batch, continuous, and pad-batch equipment. The models incorporate knowledge of the labor, equipment, power, steam, and chemical costs associated with each method of dyeing. Simulated runs of various load sizes were performed to calculate total costs and costs per pound for each

Table 4-41. Cost Comparison of Pad-Batch Dyeing Machines With Conventional Exhaust Dyeing Machines (13)[a]

Description	Cold-Dyeing Reactives on Cotton Pad-Batch/ Two-Beam Washoff Stands	Conventional Exhaust Dyeing 100% Cotton (19 Becks)
Capital Costs		
Dye pad for knits, two-beam washoff stands	$160,000	
19 atmospheric becks, 1,000-lb capacity each		$570,000
Installation (estimated to be 30%)	$48,000	$171,000
Operating Costs		
Labor costs	$79,560	$256,360
Fuel costs	$52,000	$272,000
• Extra drying	$48,300	
Water costs	$8,700	$98,500
Dye costs (see Table 4-42)	Varies	Varies
Chemical costs		
• Salt	$0	$337,840
• Alkali	$19,112	$82,820
Total Costs		
First-year capital and operating costs (exclusive of dye costs)	$415,672	$1,450,680
Subsequent yearly operating costs (exclusive of dye costs)	$207,672	$1,047,520

[a] Assumes processing of 193,050 lb per week of 100% cotton.

Table 4-42. Comparison of Typical Dye Costs for Pad-Batch Versus Beck Dyeing (13)[a]

Color	Pad-Batch (¢/lb)	Beck Dyeing (¢/lb)
Powder blue	30	40
Dark red	50	63
Bright yellow	35	50
Bright red	48	75
Bright blue	55	70
Light blue	37	58
Dark green	46	70
Navy	30	53

[a] Assumes use of cold reactive dyes for exhaust dyeing.

method to determine the lot sizes over which various techniques are most competitive. The following general observations were made:

- *Batch:* For batch dyeing (jig, beck, jet), the costs per pound decrease with lot size until machine capacity is reached. Processing additional fabric, however, requires adding another machine. The cost curve for batch techniques is thus characterized by a series of steps.
- *Continuous:* As lot size on the continuous range increases, the cost per pound of fabric drops sharply and levels off to a fairly constant value. For short lots, the costs associated with downtime and changes become a significant component of total costs.
- *Pad-batch:* In pad-batch dyeing, the cost per pound of fabric increases very little as lot size decreases. Downtime costs are minor and contribute little to the overall cost per pound.

Figures 4-16 and 4-17 show cost-curve comparisons for pad-batch versus jet dyeing and pad-batch versus continuous dyeing. Costs per pound for pad-batch are lower than for continuous ranges for runs of up to approximately 4,500 pounds mainly because of the high downtime costs of the continuous process. For all three batch processes examined (jet, beck, and jig), pad-batch dyeing was more economical over the entire range of load sizes.

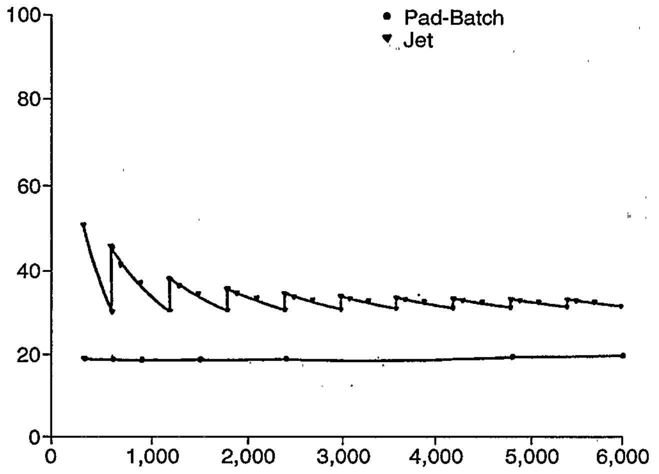


Figure 4-16. Cost curves comparing pad-batch dyeing and jet dyeing (52).

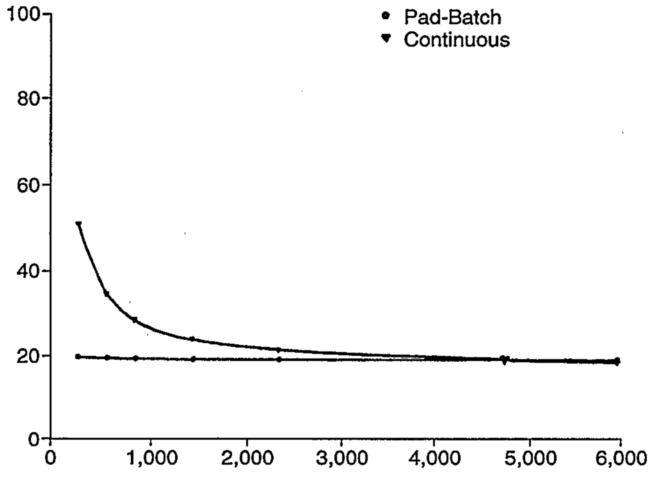


Figure 4-17. Cost curves comparing pad-batch dyeing and continuous dyeing (52).

4.10.6.5 Dyebath Reuse

Dyebath reuse is the process by which exhausted hot dyebaths are analyzed for residual colorant concentrations, replenished, and reused to dye further batches of material (70). Dyebath reuse provides a pollution alternative that is less costly than constructing a pretreatment system (e.g., for urban-based dyehouses that lack space for pretreatment) and reduces the volume of effluent and pollution concentrations in the effluent (71). Both dyebath reuse and construction of pretreatment facilities can accomplish many of the same goals (e.g., reducing BOD/COD loadings and flow); however, dyebath reuse may be a more attractive choice because of its lower cost. Dyebath reuse generally requires a smaller capital outlay than pretreatment systems and offers a return on the investment in the form of dye, chemical, and energy savings that pretreatment systems do not offer. Dyebath reuse principles can be applied to dyebaths and bleach baths.

Dyebath reuse carries a higher risk of shade variation because impurities can build up in the dyebath and decrease the reliability of the process. If product quality standards are high, then dyebath reuse may be risky. In addition, some dyeing systems are more amenable to dyebath reuse than others. Dyebath reuse can be reliably used on dyes that exhaust quantitatively (e.g., acid dyes on nylon, basic dyes on acrylic).

Some equipment manufacturers are providing built-in holding tanks to store spent baths. One model (SCHOLL BLEACHSTAR) has three holding tanks to allow reuse of processing baths or washwaters. Other models have pairs of kiers connected to facilitate the pumping of processing baths from one machine to another, either for reuse purposes or to ensure shade consistency on double-sized loads.

The four basic steps to dyebath reuse are discussed below.

1. *Save the just-exhausted dyebath:* Two alternatives are available for saving exhausted dyebaths. In the first option, the dyebath is pumped to a holding tank (or to a second identical machine), while the product is rinsed in the same machine in which it was dyed. When the rinsed product is removed, the dyebath is returned to the dye machine. With the second option, the product is removed from the exhausted dyebath and placed in another machine for rinsing. This option requires no holding tanks or pumps; however, the product receives additional handling, and an additional machine is needed for rinsing. For each of the above methods, the dyebath should be cooled with a noncontact cooling water system. Contact cooling water would dilute the dyebath and would increase the amount of chemicals needed for reconstitution.
2. *Analyze the dyebath for residual chemicals:* Most auxiliary chemicals do not exhaust to a significant degree during the dyeing process. Makeup quantity is about 10 percent because of the amount lost by absorption to the product. Some auxiliaries, however, exhaust or are lost in the dyeing process and need to be replenished more fully. Unexhausted dyestuffs must be analyzed to determine the exact quantities remaining in the dyebath to ensure the proper shade in the next dyeing cycle. Dyebath analysis can be performed using a spectrophotometer and/or guidelines based on specific production experience. Equipment for this is readily available at a cost of under $10,000. Unexhausted dyestuff is measured by solution coloristic techniques, sometimes using extraction techniques if the bath is turbid. Extraction solvents include 1-octanol for basic and acid dyes and toluene for disperse dyes. The procedure and equipment for analyzing dye from the dyebath are described in Table 4-43.

Table 4-43. Dyebath Analysis Equipment and Procedures (11)

Equipment Requirements	Quantity
25-mL graduated cylinder	2
25-mL sample (separatory) funnel	2
20-cc glass syringe	2
Ring stand and rings	1
Cotton stand and rings	1
Table salt	1 lb
Solvent	4 L
Sample cells	4
Total estimated cost	Under $500

Procedures

1. Add 2 mL (25 g) of salt, 25 mL of exhausted dyebath, and 25 mL of solvent such as 1-octanal or toluene in succession in a clean separatory funnel.
2. Place stopper in funnel and shake vigorously for 3 seconds. Allow contents to separate for 3 seconds. Shake vigorously again for 3 seconds. (This mixing action results in extraction of dyes from the dyebath water into the solvent.)
3. Place funnel on ring stand and allow for distinct separation of salt (bottom layer), water (middle layer), and solvent with dyes (top layer). Solvent layer may appear cloudy because of water in the solvent.
4. Remove stopper. Open the stopcock and allow the salt and water layers to drain out to the sink or receptacle. Close stopcock.
5. Place two cotton balls in a clean, dry syringe. Drain solvent layer from funnel into syringe.
6. Allow solvent to pass through cotton balls in syringe to absorb any remaining water, and collect in a clean, dry sample cell as it leaves the syringe.

3. *Reconstitute the dyebath:* Before the dyebath can be reused, water, auxiliary chemicals, and dyestuffs needed for the next dyeing cycle must be added to the bath. Water is added to replace what was lost to evaporation or to the product. Auxiliary chemicals are added in proportion to the water added. The amount of auxiliaries can be estimated; quantities do not need to be exact. Finally, the amount of dyestuff to be added is calculated by subtracting the dye quantities in the exhaust dyebath from recipe quantities for the next dye shade. For some types of dyes (acids, basics, direct, and disperse), exhaustion is governed by thermodynamic and kinetic laws, which essentially do not alter the dyestuff. Other types of dyes (fiber reactive, naphthol, sulfur, vat) undergo chemical reaction and are rendered insoluble, reacted, or entrapped in the fiber in a chemically different form. Dyebath reuse history with these dyes is not as extensive, but reuse may still be feasible.

4. *Reuse the dyebath:* With exhaust dyeing, the bath temperature may be higher than the temperature in a new dyebath. The starting temperature should be checked to avoid spotting and levelness problems. In most cases, the loss of heat during storage and the cooling caused by addition of water are sufficient to drop the dyebath temperature to an adequate level. Time and energy can be saved by starting the next dyeing at the highest possible temperature consistent with desired product quality.

Dyebath Reuse Applications

The process described above has been used for many fibers and dyestuffs. Table 4-44 shows full-scale applications (13). Specific case histories have been reported in the literature for acid/nylon, basic (cationic)/Nomex, and disperse/nylon (11).

Table 4-44. Dyebath Reuse Applications (72)

Product	Fiber	Dyestuff	Dye Machines
Knit fabric	Polyester	Disperse	Jet
	Cotton	Reactive or direct	Beck
	Polyester/Cotton	Disperse/Reactive or direct	Beck
Yarn package	Polyester	Disperse	Package
	Polyester/Cotton	Disperse/Reactive or direct	Package
Socks	Nylon/Spandex	Acid	Paddle
Pantyhose	Nylon/Spandex	Disperse/Acid	Beck
Carpet	Nylon	Disperse/Acid	Beck
	Polyester	Disperse	Beck
Woven fabric	Aramid	Basic	Jet
Skein	Acrylic	Basic	Skein

Maximizing Dyebath Reuse Benefits

If properly controlled, dyebaths can be reused for 15 or more cycles (the range is 5 to 25). For maximum dyebath reuse benefits:

- Use dyeclasses that undergo minimal changes during the dyeing process, including:
  - Acid dyes for nylon and wool
  - Basic dyes for acrylic and certain copolymers
  - Direct dyes for cotton
  - Disperse dyes for synthetic polymers

  (Vat, sulfur, and fiber reactive dyes are difficult to work with.)
- Reuse the dyebath to repeat the same shade, with the same dyes and equipment, on the same fiber. Reuse of a dyebath to produce a darker or lighter shade with the same dyestuff on the same fiber is also possible. In general, however, adding new colorants to the dyebath increases the degree of difficulty in dyebath reuse.

Costs and savings of dyebath reuse, per dyeing machine, are given in Table 4-45.

Table 4-45. Typical Costs and Savings for Dyebath Reuse per Dye Machine (13)

Description of Cost/Savings	Value
Total Costs	
Lab and support equipment	$9,000
Machine modifications, tanks, pumps, pipes	$15,000 to $25,000
Annual operating costs	$1,000 to $2,000
Total Savings (Annual)	
Dyes and chemicals	$15,000
Water	$750
Sewer	$750
Energy	$4,500

Limits to Dyebath Reuse

Dyebath reuse is limited by fabric impurities that are not removed during preparation and by impurities that accumulate from dye diluents, salt buildup, steam contaminants, emulsifier systems, and surfactants. These limitations tend to be insignificant at first but become a major concern after many reuse cycles (perhaps 20). In addition, specialty dyeing assistants and other materials essential to the dyeing process may be lost by several mechanisms. These include losses to vaporization from open dyeing machines, exhaust onto the fabric, chemical reaction, and dye liquor carryoff by the substrate. These losses may vary from 10 percent upward and may vary between components of a blended chemical specialty. To ensure best results, dyeing assistants must be carefully screened for reuse performance. Bath (exhaust) dyeing is used for small lots, short runs, and fast turnaround times. Dyebath reuse requires close scheduling, which may limit the flexibility needed for bath dyeing.

4.10.6.6 Water Reuse

Water reuse is becoming more prevalent and at least one dyehouse in Germany produces 20 tons per day of dyed knit with zero effluent water (60). With proper dyebath compositions, dyeing in a "standing bath" is possible (i.e., dyeing many lots in the same bath rather than using a new bath for each). This has the potential to save up to 60 percent on water consumption and total organic carbon (TOC) load in the effluent (60). Several conventional dyehouses in the United States operate without any special treatment equipment and achieve partial process and noncontact cooling water recycle of up to 30 percent. Also, several dyers in the United States dye multiple lots in the same bath. In almost all cases, these dyers are dyeing noncritical products, such as work gloves or hosiery that do not have extremely high quality standards. The savings of time, chemicals, pollution, and energy in these cases are substantial. (Section 2.2.7, "Water Conservation," describes water use in detail.)

4.10.6.7 Better Controls

Improved dyeing machines have features that facilitate right-first-time dyeings, such as accurate process conditions (e.g., pressure sensors, chemical feeds). Also, improved controllers are available to accept and interpret these data, enabling the operator to improve existing control protocols and implement entirely new control strategies. These are reviewed in Section 3.18, "Improved Process Controls."

4.10.7 Emerging Pollution Prevention Technologies

Several pollution prevention techniques are emerging from pilot and laboratory studies and may receive increased attention in the coming years. Among these is supercritical fluid (SCF) dyeing, which uses carbon dioxide (CO_2) as the fluid medium for disperse dyeing on synthetics. No water or pollution is associated with the SCF process. Also, the CO_2 evaporates without any applied heat, yielding energy savings (60). SCF application in textile dyeing is presently being researched; large-scale commercialization is likely several years away.

4.11 Printing

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.11, Printing		
Suspended solids	Clean up properly; avoid discards by proper scheduling and planning	
Hydrocarbons, VOCs and PRs	Use polymer print pastes (not varsol based) and other nonvolatile alternatives	
Water	Reuse; use countercurrent washing	
Color	Train workers to encourage good work practices; clean screens	
Solvents	Clean up properly; avoid excessive machine and screen cleaning by proper scheduling and by dry capture procedures	
Ammonia nitrogen	Avoid urea (steam can often be used as a substitute)	
Aquatic toxicity	Avoid excessive machine and screen cleaning by proper scheduling and by dry capture procedures; avoid use of metal-based dyes	
Foam	Arrange processing so that excess foam is recovered, not dumped; avoid process stopoffs	
General	Maintain equipment properly; use automated chemical systems; examine printing alternatives (e.g., transfer, ink jet, xerography); involve customers at the design stage	

Printing, like dyeing, is a method for applying color to a fabric. Whereas dyeing is best suited for solid coloring of fabrics or for applying simple geometric patterns, printing can be used to apply intricate patterns or designs. Printing generally is limited to prepared fabric, although with some methods, printing may be done before the cloth is manufactured. Dyeing can be done on fibers, yarns, or cloth after they have been woven or knit.

In printing, the color, which is usually in the form of a paste, is deposited on the fabric using a variety of machinery and techniques. The fabric then is treated with steam, heat, or chemicals to fix the color. Localized application of color requires careful cloth preparation to ensure optimal absorption of the print paste without spreading. Print pastes also must be formulated carefully to ensure proper flow properties during application (thixography) and to ensure they remain in place from application until drying (73).

4.11.1 Printing Techniques

The major commercial printing methods are:

- *Pigment printing:* Pigment printing is a common method used with all fabric types. Pigments and binders are padded onto the fabric and then cured. Like continuous pigment dyeing, pigment printing is a cheap, simple process. It produces printed fabrics with color, fastness, and other properties that are adequate for many end-uses.
- *Wet printing:* Wet printing uses fiber reactive dyes for cotton or sometimes other types of dyes, depending on the fibers being printed. The dyes are fixed by steam, dry heat, or chemical reaction, similar to continuous dyeing. Because wet printing uses pigments without binders, the cloth is softer and has better color fastness than pigment-printed fabrics, especially in the case of darker colored shades of fabric.
- *Discharge printing:* Discharge printing creates patterns on fabrics by removing color. A dischargeable dye is first padded onto the fabric to produce a solid color material. The discharge or stripping/bleaching agent then is applied to the cloth, producing "discharged" areas that show the underlying solid-color material. Discharge printing is chemically similar to the afterclearing process in dyeing.
- *Carpet printing:* Special techniques are used to print carpets, including foam, spray, and ink drop methods.

Tables 4-46 (a) and (b) show results from a recent survey of printing worldwide and indicates the prevalence of various printing methods and dye classes in different parts of the world (74). As seen, rotary screen printing is the most common printing technique used in North America, and pigment dyes are the most common type of dye used.

4.11.2 Pollutants Associated With Textile Printing

Textile printing, like dyeing, generates varying amounts and types of pollutants. Table 4-47 presents the main pollutants associated with printing and identifies their sources. Printing produces high BOD and COD loads only if preparation operations (scouring) are done on site. Information on preventing pollution from preparation operations is covered in Section 4.9, "Preparation."

Print application consumes less water and produces less BOD than preparation operations such as desizing, scouring, and bleaching. Provost (76) reported that, in a typical print plant, printing contributed only 6 percent of BOD to the total pollutant load and accounted for 7 percent of water consumption (see Table 4-48). Print washing, on the other hand, uses more than one quarter of the total water in the mill but produces only 1 percent of the total BOD load.

Table 4-46(a). Survey of Printing Techniques: By Application Method (74)

Method	Extent of Application
Hand	1.5% (worldwide) Mostly custom work in Far East
Transfer	6% (worldwide) Percentage remaining steady
Flatbed	3% (United States) Used in United States for mainly custom work
Roller	17% (worldwide) Decrease from 63% in 1970
Rotary screen	75% (United States) Increasing annually

Table 4-46(b). Survey of Printing Techniques: By Dye Class (74)

Dye Class	Extent of Application
Pigment	66% (United States) Recently declining
Reactive	6% (United States)
Vat	10% (United States)
Disperse	Not reported
Naphthol	3% (worldwide)
Acid	6% (United States)

Table 4-47. Pollutants Associated With Textile Printing and Their Sources (11, 17, 22, 23, 75, 76)

Pollutant	Typical Source(s)
Suspended solids	Discarded print paste and clear (pigment printing)
Urea (nutrient)	Print paste (wet printing)
Air emissions	Drying/curing oven emissions (solvents, acetic acid)
Solvents	Nonaqueous oil/water thickeners Machine cleaning Screen cleaning
Aquatic toxicity	Surfactants Solvents
Color	Discarded print paste Color kitchen operations Implement cleaning
Metals	Discarded print paste Photo operations Reducing agents in discharge printing Screen making Engraving operations
Water (and heat)	Washing of printed cloth Desizing operation
BOD	Preparation, if on site
Foam	Back-coating operations Carpet printing

Table 4-48. Water and BOD Generated by Process (Percentage of Total Waste) (76)

Process	Water (%)	BOD (%)
Desizing	5	22
Scouring	1	54
Bleaching	46	5
Mercerizing	2	0
Dyeing	8	5
Printing	7	6
Washing off	30	1
Finishing	1	7
Total	100	100

Figure 4-18 categorizes pollutants according to the scheme developed in Section 2.1. A description of each category and applicable pollution prevention strategies are presented below:

- Hard-to-treat wastes include color residues, metals, phosphate-containing chemicals, nitrogen-containing chemicals, and nonbiodegradable organic materials (such as some surfactants and solvents). These wastes resist effluent treatment and can pass through conventional activated sludge treatment systems. For the textile printer, alkyl phenol ethoxylate (APEO) based surfactants, "white spirit" solvents, and print pastes containing urea are the most difficult wastes to manage. APEO and white spirit solvents can be replaced with more biodegradable products. Print pastes are of concern because urea, which is used in the pastes, contains ammonia-nitrogen nutrient characteristics. Several options are available for reducing or eliminating urea in print pastes. These options are discussed in Section 4.11.3.

- Highly dispersable wastes include effluent from print thickener systems, which produce high TSS/COD/BOD levels in the effluent, and air emissions. Currently, the most effective way to eliminate or reduce thickener systems is through automated color kitchens and careful monitoring of textile printing machine requirements, which can reduce the amount of print paste that is prepared and used. Systems to recover or recycle thickeners from effluent are being tested in sizing applications but have not yet been used by textile printers.

- Offensive or hazardous wastes include metals and other pollutants from degraded dye, and immediate oxygen demand (IOD) from reducing agents used in discharge printing (75, 76). Organic solvents used for screen cleaning also are included in this category (75).

- High volume wastes include water from fabric preparation and print washing off. Although washing produces large volumes of wastewater, it does not produce a heavy BOD load. The major BOD source is preparation, particularly desizing and scouring.

Other targets for pollution prevention include chemicals containing ammonia nitrogen (notably urea), phosphates, APEO surfactants, and Stoddard solvent (76).

4.11.3 Specific Pollution Prevention Strategies

4.11.3.1 Oils/Hydrocarbons

Perhaps the greatest pollution problem of the past in textile printing has been the discharge of oil/water emulsions, which form the basis of printing paste. These emulsions have the desirable thixotropic rheology that printing demands (i.e., high viscosity under normal conditions with high flow under the application of shearing forces). Yet, these emulsions also produce substantial amounts of fats, oils, and grease (FOG) in wastewater and cause the atmospheric release of hydrocarbons from drying and curing ovens. Emulsions have now been largely replaced by synthetic polymers, similar to those used for warp sizes. A relatively small percentage of synthetic polymer (perhaps 2 percent) is required for thickening printing pastes to produce the correct rheology for printing, compared with 70 percent deodorized kerosene in the old method (22, 23). Table 4-49 compares typical recipes for oil- and synthetic-based print pastes.

In applications where oil emulsions are still used, biodegradable vegetable oils often are used instead of mineral

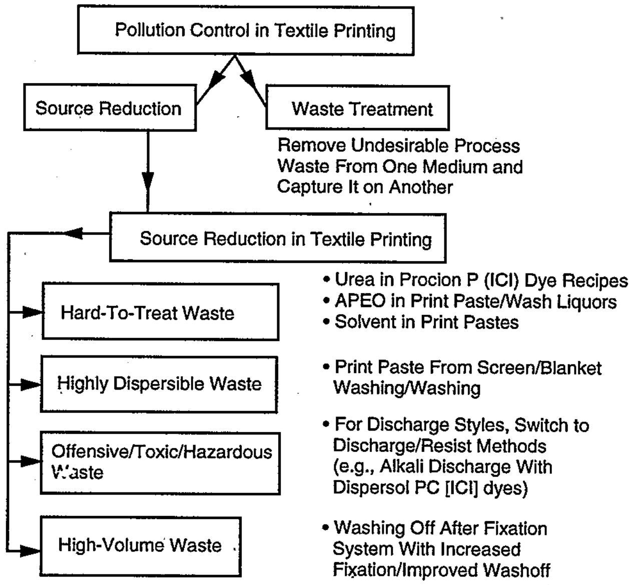


Figure 4-18. Source reduction of chemicals in textile printing (76).

oils because vegetable oils are easier to treat in wastewater (23, 23).

4.11.3.2 Discharge Printing: Reducing Agents

Reducing agents required in discharge printing contribute IOD to the wastewater as well as metals, if the reducing agent is metal based. Until recently, the common discharge (reducing) printing process for polyester involved the following steps:

1. Anthraquinone dyes (applied overall in a standard dyeing) were used to create a "ground" shade. Dyes selected for this step were resistant to the discharge process.
2. An easily discharged (reduced) azo dye was selected for overpadding (without fixation).
3. A discharge agent was overprinted according to the desired pattern.
4. The fabric was then steamed or heated. This fixed the overpadded azo dye on the polyester fabric, except where the discharge agent destroyed the overpadded azo dye, allowing the ground shade to show through.

The discharge agents of choice were based on heavy metal salts, including stannous chloride, zinc formaldehyde sulfoxylate, cuprous acetate, or similar heavy metals, which washed off into the wastewater during afterwashing of the printed fabric (17). Modern practice favors the use of nonmetallic discharge agents (e.g., sodium hydrosulfite).

Additional new technology is available that uses ester-based dyes instead of azo dyes (e.g., Dispersol PC from ICI) for overpadding. These new dyes can be discharged with alkali-based discharge agents (17), eliminating the need for reductive discharge agents. The alkali destroys the ester link and no reducing agent is needed, thus eliminating the pollution problems with metals and IOD. These are similar to the alkali-clearable disperse dyes described in Section 4.10, "Dyeing."

Table 4-49. Print Paste Recipes (Parts per 1,000 of Total Print Paste) (22, 23)

Ingredients	Oil-Based	Synthetic Polymer-Based
Water	100	815
Emulsifier	10	0
Binder	150	150
Kerosene	700	0
Thickener	0	15
Pigment (dye)	20	20
Catalyst	20	0
Total mix	1,000	1,000
Pollutants	900	185

4.11.3.3 Transfer Printing

Transfer printing, also known as sublistatic transfer printing, is the newest, fastest growing printing method. This technology exploits the properties of disperse dyes, which sublime when heated (i.e., the solid dye vaporizes and is deposited as a solid upon another surface). With transfer printing, disperse dyes are printed on paper using fast, cheap, and efficient printing methods. The paper then is placed in contact with a synthetic fabric (usually polyester) under high pressure and heat (about 300°F). The solid dyes vaporize and, because they have a greater affinity for the cloth than for the paper, deposit themselves onto the cloth in the exact pattern printed on the paper. Transfer printing can be performed at relatively high speeds because the cloth rapidly absorbs the dyes.

Because most transfer printing is done on polyester (or high-percentage polyester blends), dyes must be insoluble in water. Dyes that are compatible with transfer printing include disperse dyes and solvent dyes (77).

Transfer printing can produce patterns of any design or color. The paper, however, must be compatible with the fabric width. This method of printing is economical for short runs, one of a kind items, and piecework, and for frequent color or pattern changes, because no cleanup is required. For larger runs, rotary screen printing is more economical. Transfer printing also is useful for applying designs on cloth, cut panels, and finished garments and is best suited for manmade fibers such as polyester, nylon, and some acrylics. A major advantage of transfer printing is that quality control can be performed on paper before printing, minimizing fabric waste.

In transfer printing, many pollution prevention problems that would otherwise be the responsibility of the printer (e.g., color mixing, cleanup, effluent treatment) shift to the transfer paper manufacturer. The net benefit for the environment depends on the practices of the transfer paper manufacturer and the printer. From the printer's standpoint, transfer printing offers several advantages. In contrast with conventional printing methods, transfer printing deposits only the dyestuff on the fiber; no other chemicals are involved in the printing process. For this reason, the process requires no afterwashing and, as a result, generates no effluent. Although conventional printing methods require up to 250 kilograms of water per kilogram of textile, transfer printing requires a minimal amount of water, perhaps 2 kilograms per kilogram of textile. Other advantages of transfer printing include:

- Dyestuff consumption is lower.
- Less energy is used.

- No aftertreatment (e.g., steaming, washing, drying) is required, lowering costs.
- Less production space is required.
- Less skilled personnel are required.
- Less pollution is generated.
- Inspection of cloth and paper before printing eliminates costly seconds.

Nonetheless, transfer printing has several disadvantages. First, it is limited to volatile dyes and the fibers for which such dyes show an affinity. Second, this method is most appropriate for synthetic fibers; it does not work with natural fibers. Third, dye penetration is limited because only a small quantity of dyestuff generally is delivered to the paper. Penetration can be a problem particularly for knit goods, which, when stretched, will show the ground color (3).

4.11.3.4 Ink-Jet Printing

Ink-jet printing is a noncontact printing method in which droplets of colorant solution are propelled toward a substrate and directed to a desired spot (78). Ink jet is an emerging technology in the textile industry and has not yet been adopted for widespread commercial use. Ink-jet printing lends itself to computerized control, offering several benefits, including pollution prevention.

The dye types most amenable to ink-jet printing of textiles are fiber reactive, vat, sulfur, and naphthol dyes because one essential component can be put in the droplet while another can be applied to the substrate, as shown in Table 4-50. Other conventional dye types (i.e., acid, basic, and disperse dyes) can be applied and fixed with heat or steam. Those listed in the table, however, produce a reaction upon impact.

Ink-jet printing offers several advantages (60, 79):

- Eliminates the need for photographic screen making, which contributes silver to the effluent stream.
- Eliminates messy color-mix kitchen activities.
- Offers the potential for instantaneous pattern or color changeover without cleanup waste or fabric loss.
- Eliminates the need for thickeners and clears (kerosene, Stoddard solvent, or synthetic polymers).

Table 4-50. Ink-Jet Dye Types (78)

Dye Class	Droplet	Substrate
Fiber reactive	Dye	Alkali
Naphthol	Diazo salt	Naphthol coupler
Sulfur	Reduced dye	Oxidizer
Vat	Reduced dye	Oxidizer

- Eliminates screen, squeegee, and machine cleaning wastes.
- Offers the potential for direct computer control of printing, which reduces seconds, strikeoffs, and other wastes.

The ink-jet technique is used widely in document printing, and its application to textile printing is relatively straightforward. Recipes for suitable colorant solutions based on commercially available dyes and chemicals have been published in the textile trade literature (78).

Prototype printers are available from Iris Graphics (New Jersey), Stork (Switzerland), Wilcox (Australia), and others.

4.11.4 Pollution Prevention Practices

Throughout the textile printing industry, printers, machinery manufacturers, chemical suppliers, and marketing agents are developing an awareness of environmental issues (79). The main components of a successful pollution prevention program in printing plants are raw material conservation, product substitution, process and equipment modification, material handling, scheduling, and waste recovery (79). More specific pollution prevention measures also can be implemented to reduce the amounts of pollutants associated with printing, as described in the sections below.

4.11.4.1 Design-Stage Planning

The planning stages of printing processes and products offer opportunities to "design in" pollution prevention. Specifications for screens, tanks, homogenizers, and all other equipment are crucial because of the inherent difficulty in cleaning printing pastes. The design of the fabric and pattern (e.g., dye selection for colors that require no metals) is similarly important and can affect the overall environmental impacts from printing. Other areas to address to minimize machine cleaning include maintenance, cleaning, nonprocess chemical control, and production scheduling. These issues are discussed more fully in other sections of this document.

4.11.4.2 Surfactants

Surfactants, which are used widely in textile printing, should be carefully selected because of their pollution potential. Surfactants provide the correct print paste penetration properties and, in some cases, adjust the rheology of the pastes. They are a primary component of both conventional and foam-type print pastes. Surfactants are also used for afterwashing of printed goods.

The criteria for selecting surfactants in printing are the same as those for preparation, dyeing, and other operations. As in almost every other textile process, a good understanding of surfactants is essential because they are one of the main causes of aquatic toxicity and BOD in textile wastewater. Many types of surfactants are available, and selecting the correct one requires a good understanding of several subtle issues, as discussed in Section 4.4, "Chemical Specialties." The most popular surfactants are the nonionics, and of these, the most degradable are the LAEs. These products combine excellent wetting properties, good biodegradability and reasonable cost and, therefore, are the products of choice at this time. For a full discussion of nonionics, see Section 4.4, "Chemical Specialties."

4.11.4.3 Air Emissions

Air emissions from fixation steamers and ovens can be reduced by using nonvolatile pH buffers such as monosodium phosphate (MSP) in place of more volatile pH buffers such as acetic or formic acid. (The subject of hydrocarbon emissions from solvent thickeners was previously discussed in Section 4.11.3.1.)

4.11.4.4 Chemical Expertise

For the printer, chemical expertise is as important as textile design and knowledge of printing techniques. Most designers and printers are not aware of the environmental consequences of specific colors or paste types that they select for patterns (see Section 3.2, "Design-Stage Planning for Facilities, Processes, and Products").

4.11.4.5 Maintenance

Equipment maintenance procedures are very important in printing. Printing operations are inherently messy, so equipment often falls into disrepair. Print pastes dripping on the floor from printing machines as well as leaking pumps, pipes, and containers are not uncommon in printing plants. Workers can develop poor attitudes about housekeeping as a result. For that reason, training programs to bolster worker attitudes and to optimize chemical handling practices are important.

4.11.4.6 Water Conservation

High-extraction, low-carryover process step separations should be implemented for water conservation in afterwashing of prints. The purpose of high extraction between sequential washing steps in multistage print washing is to prevent impurities from carrying over into downstream wash boxes (i.e., to prevent carryover). To effectively remove unfixed dye and other print paste components by washing, as much water as possible must be removed between washing steps. Water that is not removed will carry over and contribute to washing inefficiency. In continuous print washers, extraction between steps can be done with high-extraction pad rolls or with vacuum extractors. Countercurrent washing is a widely practiced, effective method for reducing water consumption. Equipment to reduce carryover is described under Section 3.19, "New Equipment." For a more complete description of this entire subject, see Section 2.2.7, "Water Conservation."

4.11.4.7 Alternative Technologies

In developing pollution prevention strategies, mills should consider process alternatives such as pigment, wet, discharge, or transfer printing, as well as emerging technologies such as ink jet. In addition, mills should also examine chemical alternatives such as the use of polymers instead of oil/water emulsions.

4.11.4.8 Markets for Waste

Markets for printing wastes exist but are largely untapped. Spent printing pastes could, for example, be mixed with concrete to impart color and toughness (from the polymer content of the pastes). To benefit from reuse opportunities, printers must segregate print pastes from other wastes and capture them in as pure a form as possible. See Section 3.9, "Developing Markets for Waste" for further information.

4.11.4.9 Color Shop Practices and Print Paste Handling

In a print plant, the color kitchen is the main source of solid and liquid waste. Wastes from kitchens include excess and off-color pastes as well as wastes generated from handling and dispensing chemicals and from washing containers and equipment. Print pastes adhere to every implement and container (dippers, mixers, tubs, homogenizers, drums, screens, stirrers, and squeegees), typically creating messy color shop operations. In addition to solid wastes, color kitchens also account for a surprisingly large share of the total effluent color load, even more than washoff operations (79).

Automated print paste makeup apparatus eliminates spills caused by human error (and subsequent cleanups) as well as the amount of leftover paste to be disposed of at the end of a run (76). Numerous vendors supply apparatus for automated print paste makeup, along with modern color dispensing. The advantage of automated print paste makeup is that the printer can reproduce a paste recipe in any amount at any time. For example, with conventional mixing, printers make up 50 gallons of a paste recipe when only 37 gallons are needed in case they run out of that particular recipe at the end of a print run. The result is 13 excess gallons of paste. With automated print paste makeup, however, as little as 5 gallons of a particular recipe can be made up at any one time. If the paste runs out near the end of a run, more of the same recipe can be reproduced quickly and easily.

Reducing the length of pipe runs reduces startup, stopoff, and cleanup print paste waste (79). Modern equipment (pumps and squeegees) are of lower volume configuration, which also reduces the amount of such wastes. See also Sections 4.18, "Support Work Areas," and 3.19, "Pollution Prevention Through New Equipment."

The importance of worker attitudes toward pollution prevention cannot be overemphasized in color shop practices and print paste handling. Companies must instill a pollution prevention ethic in workers, even in the face of disorder. The proper attitude can have tremendous positive impacts.

Another important pollution prevention practice to implement is dry capture and segregation of solid wastes and print pastes at every possible point in the operation. Dry capture involves wiping off equipment such as implements, screens, and mixers, and containing print pastes in their concentrated form before they become diluted. Pastes then can be dried until solid (perhaps 10 percent of the original weight and volume) and incinerated or landfilled. All print operations, including screen washers and drum washers are potential points of control.

Once mixed, the shelf life of fiber reactive print pastes is very short (79). The use of low-reactivity dyes and proper timing of the print paste makeup can help to prevent pastes from expiring on the shelf. Automated mix kitchens are extremely important in this regard because they allow the printer to make up several small, consistent batches of paste over the course of a production run (48). Without automated mix kitchens, the printer must select between one large but consistent mix that ages and many smaller but less consistent mixes, which are made up as the run progresses.

Alginates are the preferred thickeners for fiber reactive dyes because they do not react with the dyes. Pastes thickened with alginates, however, are susceptible to microbial attack and will spoil. Biocide additives can prevent microbial attack (79). Timely mix makeup and automated color kitchens also can prevent the need to dispose of obsolete print pastes (79).

Air emissions from printing operations are associated with fixation (79). The major pollutants result from volatilization of oils, hydrocarbons, and acetic acid. As mentioned previously, synthetic polymer thickeners and MSP are chemicals that can be substituted to reduce or eliminate these problems.

4.11.4.10 Print Paste Reuse

When producing special colors for customers, excess pigment print paste can be held in inventory until a suitable use is identified (80). Pastes have a finite shelf life, however, and must be discarded if kept too long. Proper management of pastes to maximize their reuse potential can have a significant impact on the amount of wasted paste. In one case study, a facility reduced the amount of print paste that was landfilled by 90 percent simply by appointing an experienced color mixer to the position of "master of reuse." This person reviewed all orders for new colors and determined which of the stored excesses could be mixed to produce desired new colors (81).

4.11.4.11 Urea Replacement in Fiber Reactive Printing

Urea is used as an additive in reactive print pastes, especially for rayon, because it has the following properties that aid in the printing process:

- Swells the cellulose fibers before steam fixation of fiber reactive dyes.
- Causes dyes to disaggregate.
- Increases the solubility of dyes.
- Retards the evaporation of water during drying.
- Increases the condensation of water on the print during steaming.

The benefits of using urea include increased solubility of the reactive dye in the print paste, improved color yield, and improved levelness and smoothness of the printed area, especially with viscose fabrics (79).

Although urea offers several technical advantages, the printing industry has targeted it for elimination because it contributes nitrogen to the effluent stream (76). Several experimental methods are being evaluated for eliminating urea, including two-stage printing (flash aging), use of alternate nonnitrogen chemicals, and prewetting before steaming (76, 79):

- Flash aging involves a multistep process: printing with highly reactive dyes, drying, overpadding with alkali/salt bath, then high-temperature steaming (125°C for about 1 minute) (79). This method does not use urea, but it uses more alkali. Although one pollutant is substituted for another, urea is generally thought to be more of a problem than alkali.
- Chemical substitution with nonnitrogen chemicals has been unsuccessful so far. One possible substitute for urea is dicyanamide, which contains nitrogen but is less polluting than urea. Table 4-51 compares urea amounts from prints on cotton using urea alone and urea in combination with 15 grams of a urea-free proprietary printing assistant per kilogram of print paste. The reduced urea amounts range from 5.6 to 59.4 grams of urea per kilogram of paste, depending on dye selection and depth of shade. Combining urea with a proprietary printing assistant can reduce urea use by up to 80 percent.

Table 4-51. Comparison of Relative Color Values From Prints on Cotton With Matexil FN-T-Treated/Reduced Urea Recipe and Near-Optimum Urea Alone (76)

		Urea Alone Recipe		
Procion	Dye Concentration (g/kg)	Concentration (g/kg)	Relative Color	Relative Color Value for 20 g/kg Urea Plus FN-T Recipe
Yellow SP-8G 40 liquid	120	75	21.8	21.8
Yellow P-3R 33 liquid	150	75	32.9	32.3
Orange P-2R 40 liquid	120	75	36.6	36.5
Scarlet P-2R 33 liquid	150	75	41.8	41.2
Red P-4BN 33 liquid	150	75	38.7	40.7
Red P-8B grains	40	75	38.1	34.5
Brown P-4RD 25 liquid	200	75	57.1	50.7
Blue P-3R 40 liquid	120	50	21.7	20.2
Blue P-GN 40 liquid	100	75	27.8	26.2
Blue P-5R 40 liquid	120	50	36.5	26.2
Turquoise H-A 25 liquid	120	100	21.7	11.7
Turquoise P-GR 50 liquid	90	75	16.3	15.3
Navy P-2R 40 liquid	150	75	52.6	52.6
Black P-N 50 liquid	140	75	50.6	57
Black P-2R 40 liquid	150	50	60.8	58.4

- Prewetting involves the use of moisture mist systems to prewet fabric to a wet add-on of 30 percent immediately before steaming. Prewetting attracts moisture to the fabric during steaming, which is one of the main functions that urea performs. These methods, however, are not as effective on rayon as they are on cotton. As shown in Figure 4-19, rayon printing is more complex. With proper attention, however, reduced-urea recipes can be used for rayon as well. Table 4-52 presents typical urea reduction amounts (76).

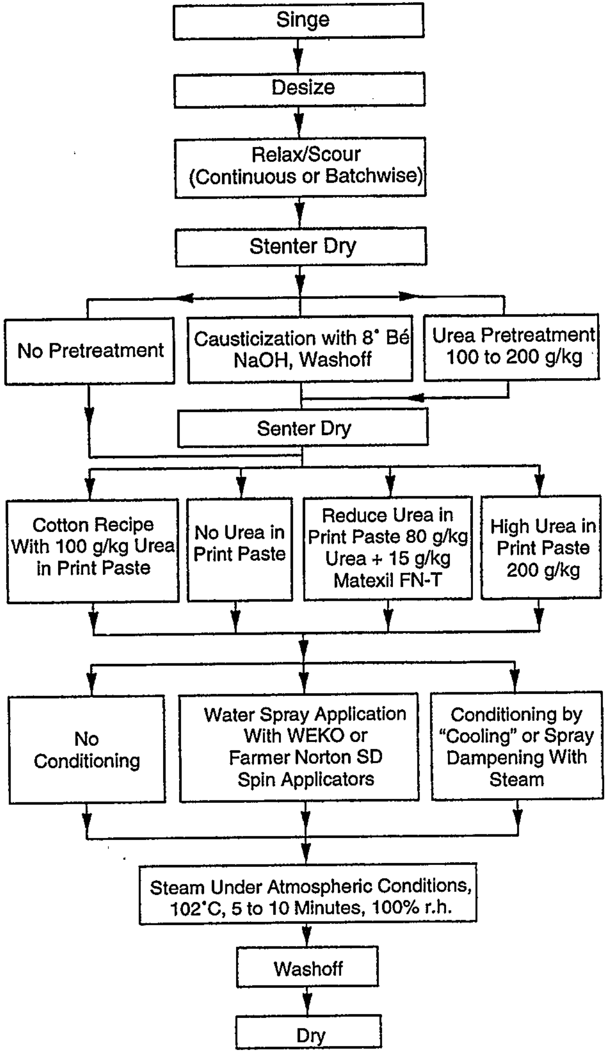


Figure 4-19. Schematic of rayon preparation/printing (76).

4.11.4.12 Silver

Many textile printers use photographic techniques for color separations and screen making. Silver is a highly toxic by-product of these processes. One photographic firm recovers silver from processing solutions by electrolysis, resulting in a 96-percent reuse rate for fixer solutions and an 84-percent recovery rate for developer solutions. The recovered solutions have a value of $1.1 million per year. The recovered silver is worth $800,000 annually (75).

Ink-jet printing (an emerging technology) and computer-driven laser screen making equipment (a new but proven technology) directly digitize patterns and eliminate the need for photographic processes that produce toxic silver in effluent (78).

4.11.4.13 Synthetic Polymer Thickeners for Oil/Water Systems

The rheology requirements for screen printing pastes are quite specific. The pastes must be thixotropic, moving easily through a screen when exposed to shearing force but remaining immobile (e.g., stationary on the fabric during steaming) when not under shearing force. Thixotropy traditionally is achieved by using water emulsified in oil, about 30 parts water to 70 parts oil, along with an emulsifier/surfactant. Recently, synthetic and natural polymer solutions with the same properties as oil/water emulsions have been developed for use as thickeners.

Table 4-52. Comparison of High-Urea Print Recipe Versus Reduced-Urea Recipe on Causticized Viscose (Relative Color Values) (76)

Procion	Control Recipe 200 g/kg Urea	Reduced-Urea Recipe 80 g/kg Urea + 15 g/kg Matexil FN-T
Yellow SP-8G 40 liquid	17.2	18
Yellow P-3R 33 liquid	26	31.3
Red P-4BN 33 liquid	36.7	39
Violet P-3R grains	36.9	32.8
Blue P-3R 40 liquid	14	13.8
Blue P-5R 40 liquid	31.4	30.1
Turquoise P-GR 50 liquid	8.9	6.2
Navy P-2R 40 liquid	23.4	18.5
Brown P-4RD 25 liquid	47.1	40.1
Black P-N 50 liquid	43.6	47.2
Black P-2R 40 liquid	46.7	46.6

In addition to synthetic and natural polymers, pigment binders also can be used as thickeners, but a cross-linker (e.g., melamine) must be used to provide durability (75). Other additives to the print paste contribute to BOD and COD, much like warp size additives (75).

Natural polymers are easily degradable and do not produce hazardous or difficult-to-treat effluent (75). Emulsions contain hydrocarbon oils, which can be hard to degrade and can produce hydrocarbon air emissions. Emulsions also exhibit aquatic toxicity (75). Synthetic polymer thickeners are less degradable than emulsions and are analogous to synthetic warp sizes. In fact, most of the polymers used as thickeners are the same as those used as warp sizes (75).

Water-soluble thickeners used in printing are similar to warp size materials. Therefore, similar pollution prevention considerations apply (27).

4.11.4.14 Washing

In washing off, high-efficiency counterflow washers can conserve up to 30 percent of the water and energy used by conventional washers (79). Less-polluting synthetic thickeners are generally used in place of oil thickeners. Surfactant selection is important in washing. As with dyeing, print fixation conditions should be adjusted to reduce washoff.

4.11.4.15 Emerging Technologies

Several emerging technologies should be considered. These technologies are not yet commercially available but might become important in the future. Printers should stay abreast of:

- Ink-jet printing (78).
- Systems to reclaim and reuse print paste thickener (analogous to size recovery systems) (76).
- Alginate recovery and reuse. These are natural products that can be reused in a fashion similar to size to reuse; however, different technologies are involved (79).

4.12. Finishing

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.12, Finishing		
General	Design fabrics to require minimal chemical finishing; use mechanical alternatives; avoid fabric distortions in handling; use low add-on methods (e.g., foam, spray)	
Fabric scraps and trimmings	Pay better attention to width control to reduce the need for salvage trimming; train workers; establish goals; assign individual responsibility; ensure seams are sewn straight in previous processes; collect salvage trim for resale	
VOCs	Minimize volatile chemical use in finishes	
BOD/COD and suspended solids	Avoid mix discards; use automated chemical feeds; train workers and mix kitchen design	
Packaging	Purchase chemicals in bulk or IBCs	
Formaldehyde vapors	Use nonchemical methods of stabilizing fabrics; design fabrics not to shrink; use optimum catalyst and curing conditions; use chemical alternatives	
Toxics	Use special process alternatives for mothproofing wool and for applying special finishes (e.g., antiodor, mildewproof)	

An endless array of textile products is manufactured from a limited list of perhaps 10 to 20 basic raw fiber types. In many cases, the fiber itself (or the structure of the fabric) cannot provide all the properties that an end-product requires. To provide these properties, most fabrics undergo one or more finishing processes. Finishing improves or modifies fabrics, enhancing properties such as aesthetics, performance, durability, and resistance to insects/molds/fungi, as well as improving fabric safety to protect the user (e.g., flame retardancy). Through the application of needle lubricants, anticurl, and other agents, finishing can also fine tune the attributes of fabrics to facilitate cut and sew operations.

Finishing involves chemical and mechanical processes. In some cases, the finisher can choose between chemical and mechanical finishing, achieving the same objective in either case. The types of pollutants associated with finishing operations and the pollution prevention approaches available for reducing these pollutants are described below.

4.12.1 Types of Pollutants

Finishing operations generate solid and liquid wastes, as well as atmospheric pollutants. Pollutant categories include:

- *Solid wastes:* Fabric scraps and trimmings from selvages and seams; fiber dust and fragments from napping, shearing, and related operations; paper tubes; and empty chemical drums.
- *Liquids:* Discarded finishing mixes and rinsewater from finishing implements and equipment, as well as facility cleanup.
- *Vapors:* Exhaust gases from drying and curing.

4.12.2 Pollution Prevention for Major Waste Categories

4.12.2.1 Solid Wastes

Finish operations generate solid waste in the form of selvage and seam trimmings, which can be sold as raw materials for braided rugs or for other craft-related activities. For maximum pollution prevention, mills should collect these wastes in an organized fashion to facilitate recycling or reuse. Many mills use traversing windups to form neat rolls of selvage trimmings approximately 20 inches long and 20 inches in diameter. When collected in this manner, selvage trimmings have high resale value. An inferior practice is simply to stuff selvage trimmings in clear plastic bags. The selvage trimmings become tangled in the bags and then must be untangled, making reuse much more labor intensive. The end result is that the selvage trimmings lose much of their resale value.

Seam trimming involves cutting 1 to 5 yards of cloth near the seam, or up to 5 percent of the total fabric piece. Excess yarn and fabric generated from cutout seams should be reduced wherever possible to lower material costs and reduce waste. An audit can determine which operations generate the most waste. For example, the straightness of the seams sewn by the operator is a major factor in the amount of waste generated. Straighter seam sewing can reduce the amount of fabric that must be cut away to remove creases, dye streaks, and clip or pin outs, to ensure a fabric of even width, and to prevent shrinkage.

In the worst case, QC samples may be cut from the end of the fabric piece near a bad seam. Although such samples are not representative of the entire piece, tests based on these samples may cause rejection of the entire piece if the tests indicate a local defect caused by poor sewing. If this occurs, the entire piece must be reworked, generating additional pollution and costs.

The keys to reducing waste caused by bad seams are training and retraining of workers, using good sewing equipment (and maintaining it properly), and auditing seam quality. In a good operation, as little as 0.2 percent of the cloth is cut out as seams, while in the worst-case scenario, a loss of as much as 5 percent can occur. To help monitor seam quality, many mills use different-colored threads in each department. Bad seams then can be traced by the color of the thread to the department where they occurred, and corrective action can be taken. Seam quality also can be improved by requiring workers to place seam cutouts in specially marked waste cans. Segregating cutouts facilitates audits and promotes easier recycling.

Paper tubes often are used to roll up fabric. These tubes can be reused many times before they become damaged. If they are damaged on one end only (as commonly occurs), the damaged end can be trimmed off and the remainder of the tube can still be used. In many mills, tube salvage is contracted out to local sheltered workshops. With knit goods, tubes can be avoided altogether by folding the pieces of the knit goods flat. Some mills have eliminated the use of paper tubes completely and instead use PVC pipe. Although costs are initially higher, the PVC pipe has a long lifetime.

Drums also are a major component of the mill's solid waste stream. The use of drums is covered thoroughly in Section 1.2.3, "Solid Waste," but several considerations in drum use are specific to finishing. Returnable IBCs should be requested wherever possible instead of standard drums because IBCs significantly reduce the amount of solid waste. If standard drums are used, they should be returned whenever possible; the return policy should permit unwashed drums to be returned. Rinsewater from drum cleaning can be a major source of water pollution.

4.12.2.2 Liquid Wastes

Liquid wastes from finishing operations include discarded mixes and rinses from cleanup activities. Both types of waste can be reduced using general pollution prevention techniques. Good pollution prevention practice, for example, calls for accurate calculation and makeup of mix quantities to minimize discards (46); the use of automated mix kitchens to minimize discards was discussed in Sections 4.11, "Printing," and 1.3.2, "Equipment." Automated mix systems can automatically meter, dispense, and mix finish recipes in the necessary quantity. Because the system can prepare small quantities of mix quickly and accurately, the mixer has no reason to prepare excess amounts of finish, which usually are discarded.

Onsite drum washing can add large volumes of contaminated wastewater to the waste stream and should be eliminated. Many mills have removed drum washers from operation for this reason. More importantly, bulk delivery tanker trucks should never be washed out at the plant site. Some truck drivers try to avoid cleaning costs by washing out their trucks at the plant site and pouring washwater into the plant's waste system or (even worse) into parking lot drains.

4.12.2.3 Atmospheric Emissions

As described in Section 2.2.3, "Toxic Air Emissions," many pollutants have been detected in air emissions from textile mills. Sources include:

- Dryers
- Curing ovens
- Steaming operations: knits (calendaring)
- Ventilation from mix kitchens
- Bulk storage tanks: breathing losses and spills
- Chemical warehouses

Table 4-53 lists some observed air pollutants from finishing, along with typical sources. These can be minimized by:

- Avoiding the need for chemical finishes (discussed below).
- Properly controlling air circulation and temperature in dryers (see Section 1.3.2, "Equipment").

Table 4-53. ***Pollutants Detected in Textile Mill Air Emissions (11)***

Pollutant	Possible Source(s)
Acetic acid	Residue from dyeing or printing
Acrylic monomers	Residue from handbuilder
Biphenyl	Residue from dye carrier
Carbon monoxide	Incomplete oxidation of fuel
Dibutyl phthalate	Residue from dye carrier
Ethylene oxide	Breakdown of wetting agent
Formaldehyde	Breakdown of cross-linking resin
Glycol ethers	Softeners
Hexane	Softeners, wax water repellent
Hydrocarbons	Softeners, wax water repellent, spin finish residues, knitting/winding lubricants
Hydrogen chloride	Chloride catalyst, machine cleaner, reduction of chlorinated organic residues from dyeing in recycle air, in reducing atmosphere, in heater flames of drying and curing ovens
Methanol	Cross-linking reaction product, wetter
Methyl ethyl ketone	Machine cleaning solvent
Methyl methacrylate	Handbuilder impurity
Methylene chloride	Machine cleaning solvent
Perchloroethylene	Machine cleaning solvent, dye residue
Toluene	Machine cleaning solvent
Trichloroethane	Machine cleaning solvent, spot remover
Vinyl acetate	Handbuilder impurity
Xylene	Machine cleaning solvent, dye residue

4.12.3 Pollution Prevention for Fabrics Other Than Wool

Finishing of cotton, cellulosic, and synthetic fibers involves a variety of chemical and physical processes, which can generate pollution. The sections below identify general and specific pollution prevention strategies that can be applied to finishing operations.

4.12.3.1 Chemical Finishing Alternatives

Typical finishing recipes for cotton and cotton blends call for a combination of the following:

- Cross-linking resin and its required catalyst.
- Softener.
- Wetting or penetrating agent.
- Sewing lubricant.
- Handbuilder (stiffener).
- Functional additives (e.g., water repellent, flame retardant).

If the fabric does not contain cotton (or other cellulose fibers), a resin and catalyst are not necessary. Many chemical and mechanical alternatives are available for every type of finishing operation. These alternatives are listed in the annual *AATCC Buyer's Guide* (19). Although discussing the pollution prevention advantages and disadvantages of each of these alternatives is impossible, the following paragraphs present some general and specific strategies for selecting appropriate alternatives to maximize pollution prevention.

General Strategies

- *Proper fabric design:* Fabric should be designed to meet end-use requirements with minimal finishing (20, 82), including selecting the correct fiber (e.g., cotton, polyester), yarn count and form (e.g., ring spun, rotor spun, filament), and fabric structure (e.g., knit woven, nonwoven, braided). Most finish properties (e.g., antisoil) can be achieved with proper fabric design (20). Table 4-54 contains some examples of mechanical finishes or design choices that can reduce the need for chemical processing. Textile fabric design is primarily driven by considerations of color, artistic design, and aesthetics. Designs based on engineering and chemical principles can eliminate the need for finishing and reduce waste, but designers rarely incorporate those principles into their designs (20). The environmental impact of product specifications also should be considered. Table 4-55 shows softener alternatives and their environmental impacts. Vertical manufacturing operations (those that include cut and sew operations in the finishing process) enable designers to specify a greater variety of fabric structures and construction than commission finishing operations. Because designers are closer to the customer, they also have an opportunity to work with the customer and convey information about the environmental consequences of design and color alternatives.

Table 4-54. Examples of Mechanical Finishes and Design Alternatives That Avoid Chemical Processing (20)

Desired End-Use Property	Mechanical Finish or Design Alternative (Nonchemical)
Soil release	Use cotton; will not retain oily stains
Shrinkage control	
Cotton knit	Design fabric with proper width and yield; use "compactor" (see Section 1.3.2, "Equipment"); handle only when relaxed
Synthetic	Heatset fabric (no resin required)
Softness	Use bulkier yarns Use looser knit or weave Use enzyme softening of cotton Use mechanical calandar (wovens only) Use napping, shearing, sueding, sanding, etc.
Bulk/stiffness	Use higher twist "hard" yarn Use tight construction

- *Proper fabric handling:* After establishing a design specification, proper fabric handling can reduce the need for further processing. In particular, knit fabrics should be handled with minimum tension to avoid stretching the fabric, which can result in shrinkage or require later stabilization with resin to avoid shrinkage (82).
- *Consideration of mechanical alternatives first:* If fabric design and handling issues have been addressed and further finishing is still required, mechanical alternatives should be considered before selecting chemical finishing. One major purpose of finishes is to stabilize fabrics and reduce shrinkage, but heat-setting (thermosetting) of synthetic fabrics or compacting of cotton fabrics will also suffice for this purpose.
- *Optimization of chemical finishing processes:* After deciding to use chemical finishing, finish application and processing should be optimized to avoid generating more waste than is necessary. Each greige style should be treated with an optimum recipe to produce the desired end properties.

Table 4-55. Types of Softeners Used in Textiles and Their Environmental Considerations (83)

Material	Type	Environmental Consideration(s)
Fatty materials	Anionic	Biodegradable; some methods of production use metal catalyst, thus may result in residual metal impurities
	Cationic (quaternary)	High aquatic toxicity
Petrochemical materials	Hydrocarbon	Produce hydrocarbon emissions from drying and curing ovens
	Alkene oxides	Can contain volatile ethylene oxide impurity, which may vaporize from dryers
	Polyethylene	Nonbiodegradable; can produce hydrocarbon emissions from drying and curing ovens
Silicone	Reactive	Durable
	Nonreactive	Nondurable

Specific Strategies

In addition to these general principles for avoiding or minimizing chemical use, recommendations can be made for reducing or eliminating many specific chemicals used in finishing cotton and blends.

Formaldehyde-containing resins used for permanent press finishing. Cotton, rayon, and other forms of cellulose and blends that contain these fibers usually require finishing with a reactive agent to cross-link adjacent cellulose chains. This step immobilizes the fibers, reducing shrinkage and improving bending properties (i.e., crease recovery). Many types of reactive cross-linkers exist. Currently, the products of choice for cross-linking cellulose are N-methylol compounds, which are produced from reacting urea with formaldehyde and other additives. In application and use, these reactive N-methylol cross-linkers can release formaldehyde.

The issue of formaldehyde emissions from textiles has received considerable publicity. Formaldehyde, which is connected to cancer in animals, is a cross-linker. Other low-molecular-weight cross-linking agents also can be carcinogenic, however. For that reason, an efficient alternative that is not carcinogenic, mutagenic, or teratogenic is unlikely to be found for cross-linking agents. The most widely used cross-linking agent is dimethylol dihydroxy ethylene urea (DMDHEU). This agent usually reacts with cellulose under high temperatures in the presence of a catalyst such as magnesium chloride. When properly used, applied, and cured, formaldehyde releases from fabrics treated with DMDHEU are minimal. Generalizing about personnel exposure to formaldehyde in fabrics is difficult because the amount of airborne formaldehyde that fabrics release varies greatly depending on temperature, humidity, ventilation, and other factors (84).

A few nonformaldehyde cross-linkers are used commercially (usually as a research experiment at the mill level). These cross-linkers are considerably more expensive than DMDHEU and, therefore, have never been used widely in the U.S. textile industry. They include butane tetra carboxylic acid (BTCA) and dimethyl dihydroxy ethylene urea (DMeDHEU). Although neither agent contains formaldehyde, their performance is inferior to that of DMDHEU.

Pollution prevention strategies for formaldehyde reduction are highlighted below:

- Fabric designers should use fibers and construction techniques that require few, if any, cross-linkers.
- Fabrics should be handled properly to avoid shrinkage during processing.
- Handbuilders and dye fixatives, if used, should contain low or no formaldehyde (see below).
- When applying resins, low-formaldehyde versions of DMDHEU should be selected wherever possible. The resins should be applied under optimum conditions, including providing for proper finish penetration before curing. The use of efficient catalysts minimizes resin carryover. Finally, finished fabrics should be cured under proper time/temperature conditions.
- The fabric should be washed after curing to remove the catalyst, reducing the potential for formaldehyde release. (The crosslinking curing reaction is easily reversed in the presence of the catalyst.)
- Once finished, fabrics should be stored in well-ventilated areas away from formaldehyde sources.

Softeners. A wide variety of softeners exist, including natural and synthetic compounds (24). The main types of softeners are fat, petrochemical, and silicon based (25). The environmental considerations of each type are listed in Table 4-55. Finish recipes, which include softeners, often are made up the same way they were many years ago, without regard for environmental considerations (22, 23).

The performance and environmental impacts of each type of softener vary, and each type has advantages and disadvantages (24, 25). Fatty acid softeners are very biodegradable (24), while both paraffin and polyethylene softeners are nonbiodegradable (24). Quaternary types have high aquatic toxicity (24). Mineral oil and paraffin wax softeners are still used, although these types of softeners smoke when heated, producing air emissions from dryers (22, 23). Polyethylene glycol (PEG) and polyethylene oxide (PO), on the other hand, are nonsmoking alternatives. Reactive silicone softeners are well fixed and do not wash off of the fiber, whereas most other types wash off during home laundering of the textile products (24).

In some cases, cellulase enzymes can remove surface roughness in yarns and fabrics, creating smoothness and lubricity without the use of chemical additives (24). Certain types of yarn (i.e., ring spun yarns) are inherently softer, while rotor spun yarns are "scratchy" and require more softeners to provide comfort for apparel end-uses. For maximum pollution prevention, opportunities for using nonchemical alternatives should be further investigated.

Builders. One class of functional materials applied to fabrics is builders or handbuilders. For many applications (e.g., men's suits), a fabric must have "body" or stiffness. In lightweight fabrics, this body or stiffness can be provided by using builders or handbuilders. These agents increase the bulk of the fabric and, sometimes, the bending or rigidity of the fabric. Generally, builders or handbuilders are film-forming agents that might or might not react with the fabric. Builders include (25):

- N-methylol film-forming materials (reactive):
  - Trimethylol melamine
  - Urea formaldehyde
- Natural polymers (nonreactive):
  - Starches
  - Modified starches
  - Alginates, gums, etc.
- Synthetic polymers (nonreactive):
  - Polyvinyl alcohol
  - Poly acrylates (acrylic, vinyl)

Acrylic handbuilders and stiffeners can replace formaldehyde-based N-methylol handbuilders (22, 23). Acrylics are good substitutes in many applications, but the use of acrylate monomers, and especially their manufacture, is linked to other pollution problems.[9] The alginates, starches, and modified starches are the least harmful environmentally, but they also have high BOD. The reactive types give a distinctive "bounce" or lively feel to the cloth, whereas the nonreactive types often feel "dead" or "cakey."

Functional materials. The above sections cover the most commonly used finishing agents. In addition, a wide variety of other functional finishes is also used. The environmental impacts of these finishes vary greatly, however, and substitution possibilities are explored in more detail elsewhere (e.g., Lewin and Sello [85]). The extent to which individual functional finishes contribute to pollution in textile operations is described further in sections covering generation of particular pollutants. For example, antiodor finishes based on metals are discussed in Section 2.2.5, "Metals."

Finishing equipment. Finishing equipment should be designed, selected, and maintained to minimize pollution. Major considerations include design and maintenance of dryer air systems and finishing ranges, use of low add-on finishing recipes, proper control of curing conditions, and general system maintenance (see also Section 1.3.2, "Equipment").

Air distribution systems in dryers should be clean with no leaks or distorted exit/pickup orifices to reduce flows (54). Makeup air needs to be well balanced, both in terms of intake and exhaust flows as well as end-to-end, side-to-side, and top-to-bottom within the dryer. Hot air ports should be located or moved as close to the fabric drying line as possible to reduce energy requirements and to lower air emissions.

Low add-on finishing results in less air volume discharge and lower energy use and, consequently, reduced boiler emissions (54). Low add-on finishing is discussed in more detail below and in Sections 3.6, "High-Extraction, Low-Carryover Process Step Separations," and 3.19, "Pollution Prevention Through New Equipment."

Proper humidity and temperature control in drying and curing ovens can ensure maximum reaction and minimum emissions from drying, curing, or later processing. Automatic humidity sensors often are used along with real-time air flow and damper controls to maintain nearly ideal drying and curing conditions at all times. For example, in drying, about 50 to 60 percent relative humidity is optimum for many fabrics. Optimum curing conditions depend on the fiber, reactant, and catalyst involved and should be investigated as part of the pollution prevention strategy.

Other considerations for preventing pollution in finishing include:

- Performing regular maintenance of finishing equipment to ensure that optimum finishing conditions prevail at all times.
- Designing plumbing runs from the mix kitchen to the finishing ranges to be as short as practical to minimize the amount of mixes dumped from the finish distribution lines at the end of a run.
- Auditing pad troughs and chemical feed lines for leaks. Inspection and maintenance routines should be established to minimize the amount of time required to respond to leaks.

4.12.3.2 Mechanical Finishing as an Alternative to Chemicals

Mechanical finishing can impart a wide variety of end-use properties. Table 4-54 contains an abbreviated list; a complete analysis would be beyond the scope of this document because dozens of mechanical finishing processes currently exist. Mechanical finishing generates less pollution than chemical finishing because it involves no:

- Mix discards
- Pads to dump
- Chemically contaminated machines to clean
- Chemical residues to release in storage and use
- Obsolete chemicals to dispose of
- Drums to wash and recycle
- Finish components vaporizing in dryers
- Breathing or spill losses from bulk tanks

Mechanical finishing has several advantages, most importantly that it does not use chemicals (although fiber lubricants may at times be required for certain processes, such as napping). By avoiding the use of reactive chemistry, dyed shades are not changed during the finishing process (i.e., no shade breaks). In addition, because mechanical finishing does not subject dyes to reactive chemicals or to the conditions of pH and heat that are necessary for chemical finishing, the result is less off-shade work and associated redyes.

Some of the most popular fabrics today are cotton and cotton blend knits, and these fabrics often require chemical resin stabilization for shrinkage control and sewability (82). Stabilization of these knits is possible without the use of chemical additives, however. The two keys to accomplishing this are to (82):

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[9] Acrylate is synthesized from materials such as methyl methacrylate monomer. These materials are polymerized with a free radical mechanism that results in leftover monomer. All of the monomers are toxic and carcinogenic and, therefore, undesirable.

- Ensure that the equilibrium relaxed configuration of the knit fabric is exactly equal to the customer specification in terms of width, yield (weight), and shrinkage.

- Design a process that allows for complete relaxation of the fabric.

Commercially available computer-assisted design programs allow the finisher to select the correct yarn, tension, stitch length, machine cut, and diameter for making knit goods with the proper width, yield, and shrinkage (82). A key to computer-assisted design is to keep the processing step as tensionless and consistent as possible. Commercial knit finishing equipment (e.g., compactors, dryers) is available that can control the width and length of the fabric during processing, allowing the knit to fully relax. The operation of these machines is documented in the literature (82). Design factors and knitting machine setup requirements also are available (82). Specifications for knit fabric width and yield must be compatible with the relax dimensions of the greige goods (82).

4.12.3.3 Novel Finishing Practices

Low add-on finishing conserves energy and reduces pollution because fewer chemicals are needed for a given level of performance (84). Low add-on finishing also can prevent leaching or transport of chemicals from the interior of fibers to the surface, which can occur with high add-on methods, thus improving fastness, shade change, and softness of finished goods. In addition, these finishes accelerate production (84). The effectiveness of low add-on finishes depends on finish penetration of the fabric during the lowest possible wet pickup (WPU) (84). Table 4-56 describes some low add-on finishing techniques.

Table 4-56. Commercial Low Add-On Finishing Processes (84)

Process	Application
Air-jet pad	Saturation/expression
Curved blade applicator	Controlled application
Fabric-transfer loop	Combination
Gas phase	Controlled application
High extraction pad	Saturation/expression
Kiss roll	Controlled application
Printing	Controlled application
Spray	Controlled application
Stable foam	Controlled application
Unstable foam	Controlled application
Vacuum systems	Saturation/expression
Wicking systems	Controlled application

Because less water is used with low add-on finishes, the chemicals (if properly applied) are more evenly distributed throughout the fabric, resulting in more efficient fabric stabilization. Evaporation and drying occurs only on the surface of the yarn. When moisture add-on is high, however, moisture flows from the inside of the yarn to the surface, transporting chemicals to the surface. Surfacing of the chemicals causes uneven treatment of the yarn, requiring greater chemical add-on to obtain the same performance. The best finish distribution (i.e., the optimum performance obtained with the least amount of chemical add-on) is obtained by lowering the WPU level to a minimum level that will fully wet the fabric (approximately 45 percent for cotton and blends in most cases) and by keeping the temperature low in the dryer.

Smith (84) presented a test methodology that can be used to assess the optimum WPU ratio required to ensure minimum unevenness of finish distribution. Table 4-57 presents laboratory results for various types of cotton fabrics.

4.12.3.4 Foam

Foam technology is used for applying stain release chemicals to carpets. Liquid solutions normally used for treatment often are replaced by foams, which lowers WPU to as little as 8 percent (86). The minimum WPU level for good finish penetration on cotton and cotton blends normally is approximately 45 percent (84). For example, one plant that adopted foam technology reportedly reduced water use by 20 million liters per year. The same plant cut energy use by 10 percent overall (86).

For a surface finish on a synthetic fiber as described in Powell (86), the appropriate WPU is much lower than the 45 percent determined for cotton, which is more

Table 4-57. Optimum Wet Pickup Levels for Various Cotton Fabrics (84)

Fabric (100% Cotton)	Optimum Wet Pickup (%)
5.5 oz/yd^2 printcloth	
Bleached	36
Mercerized	41
5.5 oz/yd^2 printcloth, 60 minutes dwell time before cure	
Bleached	22
Mercerized	20
5.5 oz/yd^2 printcloth, 5 seconds steam before cure	
Bleached	18
Mercerized	18
5.5 oz/yd^2 poplin	
Bleached	31
Mercerized	38
5.5 oz/yd^2 drill	
Bleached	45
Mercerized	46

absorbent than synthetic fibers (84). A further benefit of low add-on techniques is that less water must be evaporated from the fabric, resulting in energy savings.

Foam, however, can be difficult to handle in actual production situations. Foams are quite different from liquid finishes and tend to collapse when pumped through constricted pipes and T-joints, or around sharp bends, corners, and elbows. They are difficult to form and to keep stabilized; foams require some running time to stabilize, so whenever the production line stops, foam must continue to be generated to avoid long startup delays. During stopoff, therefore, foam must be sent to waste, creating floating solids in waste treatment systems, as well as bulking of clarifiers and other operational difficulties. Careful planning and engineering can minimize the problems associated with foams, but cannot eliminate them.

4.12.3.5 Spray

Softeners and other surface finishes can be added by oversprays and other techniques with inherently low add-on. Because of the lower add-on, these methods require no dumping of residual pad liquors at the end of a run. Spray applications should be investigated as part of pollution prevention planning.

4.12.3.6 Mix Kitchens and Mixing Practices

In finishing, more padding liquor often is prepared than needed for the lot being run (60). Preparing more material than is needed, or overmixing, is one of the main sources of pollution in textile manufacturing not only in finishing, but also in printing and continuous dyeing operations.

Overmixing is done for one of two reasons. First, employees mix excessive amounts of material such as finish to avoid having to make up a second mix to finish off a lot. When the lot is completed, the excess finish is dumped. In many cases, however, overmixing occurs because equipment is not designed to mix less than complete batches. Mix tanks, for example, commonly lack volume marking; therefore, the only way to make a mix properly is to make a full tank (normally 200 gallons). A mill might even make up a 200-gallon mix to run a 100-yard sample lot. The sample lot consumes perhaps only 10 to 15 gallons of mix, and the remaining 185 to 190 gallons are dumped into the waste treatment system.

Such flagrant waste can be avoided with new or modified systems or by simply improving mixing procedures. The best pollution prevention practice is to use automatic chemical dispensing in the mix tanks. If mixes are made manually, only the minimum amount required for the lot should be prepared. All mix tanks should be equipped with volume markers that allow the makeup of mixes in any amount. Because most mix tanks hold 200 gallons, the mix operator must be able to see marks on the inside of the tank to measure out any volume other than 200 gallons. In the case of leftover mixes, additions to the leftovers should be made whenever possible to produce new mixes. The calculations are relatively straightforward, as shown in the sample below:

1. Two hundred gallons of 6-percent softener solution is made up using 100 pounds of softener diluted to 200 gallons.
2. The lot uses 145 gallons, and 55 gallons are left over.
3. The next lot calls for 100 gallons of 4-percent softener mix.
4. One option (i.e., the one that is most often chosen) is to dump the leftover 55 gallons of mix containing 27.5 pounds (55 x 8.34 x 0.06) of softener and make up a new mix with 33.4 pounds (100 x 8.34 x 0.04) of softener in 100 gallons of water. (Note: One gallon of water weighs 8.34 pounds.)
5. A better way is to add 5.9 pounds (33.4 - 27.5) of softener to the leftover 55 gallons, and add water to 100 gallons. Adding softener and water to the mix avoids waste, reducing pollution and costs.

Scheduling makeup of similar mixes in sequence is helpful in preparing new mixes from leftover materials. Also, worker training is needed for performing the calculations shown.

Scheduling also is important in minimizing cleanup. Each worker should be familiar with dry capture of spilled chemicals using scoops, squeegees, or vacuums (rather than washing chemicals down the drain with a hose). Proper vacuums or other equipment must be available in the mix area. Implement washing should be minimized whenever possible. The preferred methods of chemical handling are direct chemical dispensing or IBCs. If manual methods and drum storage are used, a separate dipper for each chemical should be available, eliminating the need for continuous washing of dippers and buckets.

4.12.4 Pollution Prevention Practices for Wool Finishing

Pollution is a concern in several areas of wool finishing. A recent study by the International Wool Secretariat (IWS) identified four high priority areas (7):

- Pesticide residues in wastewater from chemicals applied to sheep.
- Discharge of mothproofing agents from wool carpet manufacture.
- Emissions of halo-organics from wool shrinkproofing.
- Chromium releases from chrome dyeing operations.

The following areas are being regulated to reduce aquatic toxicity from wool operations (3, 7, 87-89):

- *Agricultural residues:* The main concern in this area is pentachlorophenol insecticides used on sheep (3). An alternative is to use less-toxic insecticides. Substituting a less toxic insecticide for a more toxic one is an example of a pollution prevention strategy that must transcend production boundaries because the problem originates in upstream operations (i.e., farms) but does not become apparent until the wool is washed at the mill. Sheep ranchers must be educated to understand the problems of using toxic insecticides.
- *Mothproofers:* Resistance to insects, or mothproofing, traditionally has used chemicals that, because of increasing regulation, are no longer acceptable (87, 88). These changes especially affect the carpet industry, where mothproofing of wool fabric is an important finishing step. The usual mothproofing procedure requires permethrin, a chemical that now is strictly controlled in many parts of the world. Although permethrin is reportedly biodegradable and has low mammal toxicity (humans), it has high aquatic toxicity (87). Mothproofing of wool is performed most often by adding chemicals to the dyebath, which then exhaust onto the wool (87, 90). The spent dyebaths, when discarded, can cause aquatic toxicity (87, 90).

Several chemical alternatives for mothproofing have been reported, including:

- *Clorphenylid:* Was used widely but now has been withdrawn because of environmental problems generated during its manufacture.
- *Flucofuron:* Not fully evaluated at this time but is known to be ineffective against certain pests. Evaluations are still underway.
- *Cycloprothrin:* Has good performance with an aquatic toxicity rating that is approximately three orders of magnitude less than that of permethrin (90).
- *Diphenylurea:* Has lower aquatic toxicity than permethrin but is less biodegradable (87).
- *Cyfluthrin:* Effective but has been withdrawn because of reactions by textile mill workers to the chemical (87, 89).
- *Sulcofuron:* Shows low affinity in some application methods and is ineffective against certain pests (89).

European Community directives on aquatic pollution from mothproofing agents are shown in Table 4-58.

Leftover portions of wool processing baths are sometimes discharged, contributing to pollution problems (87). Commercial solutions are typically applied with exhaust and continuous (e.g., spray) processes (87).

Table 4-58. European Community Directives on Aquatic Pollution From Mothproofing Agents Used for Wool (9)

Active Ingredient	Mothproofing Agents	EQS Nonograms/Liter of Active Ingredient
Chlorphenylid	Eulan WA New	50
Cyfluthrin	Eulan SP	1
Sulcofuron	Mitin FF h.c.	25,000
Flucofuron	Mitin N	1,000
Permithrin	Eulan SPN Eulan WP Mitin BC Perigen SMA-V	10

The discharges of mothproofing agents from finishing operations can be reduced, but they can never be completely eliminated as long as mothproofing agents are used (87). Treatment of spent (or leftover) wool finishing baths with alkali hydrölyzes toxic chemical contents. The amount of mothproofing agent used should be controlled carefully to produce the desired result with the least amount of application. Another alternative that currently is under investigation is nitromethylene. Studies on mixtures of nitromethylene and permethrin show promise and are continuing (87). Because of regulations prohibiting certain mothproofing agents and other limitations cited above, the only other alternative is a pyrthroid-based insecticide (7).

Other possibilities for reducing pollution from mothproofing operations include:

- New application methods involving microemulsion spray/centrifuge techniques along with recycling of pesticide solutions (see Figure 4-20 and Table 4-59) (7, 87).

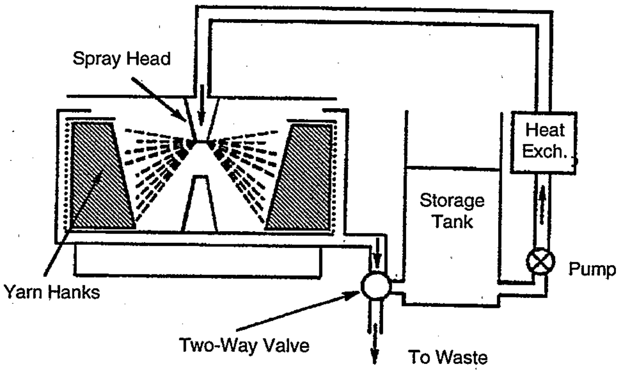

Figure 4-20. Modifications to a centrifuge (hydroextractor) for application of mothproofing agent solution (7).

Table 4-59. Use of Spray/Centrifuge Techniques To Reduce Discharges of Permethrin (7)

Method	Effective Liquor Ratio	Permethrin Concentration (mg/L) in Spent Treatment Bath	Permethrin Load (g/tonne of wool treated)
Hank dyebath	50:1	0.16	8
Conventional tape scour	0.75:1	40	30
Minibowl tape scour	0.1:1	40	4
Modified centrifuge	0.05:1	34	1.7

- New pesticides with low aquatic toxicity.
- Nonpesticide mothproofing methods.

The use of microemulsion spray/centrifuge techniques can reduce discharges of permethrin to as low as 1.7 grams of permethrin per tonne of wool treated, compared with 8.0 grams of permethrin for conventional hank treatments in dyebaths (7). The length of treatment controls the add-on level in the centrifuge technique (88). The evenness of treatment is commercially acceptable, provided that the emulsion is prepared properly and the temperature is controlled (88). The emulsion, which drains from the extractor, is reused. Water use is reduced from 0.75 liters per kilogram (90 gallons per 1,000 pounds) of wool to 0.06 liters per kilogram (7.2 gallons per 1,000 pounds) (88). The best pollution prevention strategy is site-specific based on the properties of the agents involved.

One mill developed the following strategy for reducing wastewater toxicity based on presently available mothproofing agents (89):

- Use sulcofuron as much as possible (but this agent has performance limitations).
- Use flucofuron to the extent permitted by the wastewater regulations.
- Use permethrin (or cyfluthrin if still permitted) for the balance of production.

The results of such a strategy are shown in Figure 4-21.

A second mill used similar logic but arrived at a different strategy because of different processing practices (89). In this mill, the strategy was to:

- Discontinue mothproofing as part of the scouring process.
- Use permethrin to the extent permitted (because of marketing demands).
- Use flucofuron to its limit after reaching the permethrin limit.
- Use sulcofuron for the remaining production.

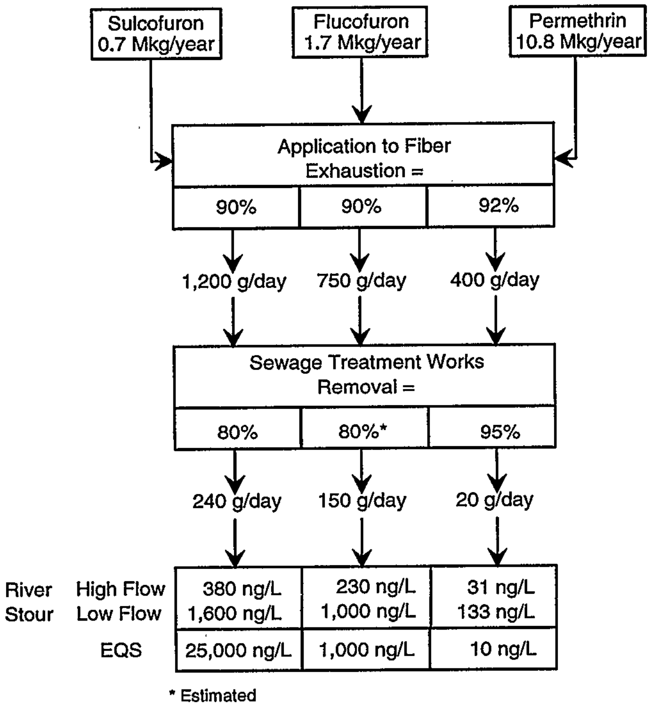

Figure 4-21. Implementation of "best" mothproofing strategy by carpet industry in Kidderminster, United Kingdom (89).

These reduction strategies suggest the need for new nonpolluting mothproofing systems based on zero-pollution discharge application methods for existing chemicals, chemical agents that are safe, or nonchemical mothproofing agents. Zero-pollution discharge application methods include the use of low liquor ratios, microemulsions, accurate metering to ensure the minimum necessary amount of agent is used, and better process controls (89). Research continues on these alternatives, and promising developments are underway (89).

Wastewater from wool shrinkproofing contains halogenated organics. These chemicals appear in drinking water supplies as absorbable organic halogens (AOX) (7). Figure 4-22 presents AOX loads from steps in the wool shrinkproofing process in grams of AOX per tonne processed, as well as in ppm in the effluent (7). Aggregate discharge of chlorine in shrinkproofing is 39 ppm, which is far above the proposed regulatory limit of 1 ppm. Research is underway to develop nonchlorine shrinkproofing methods, but no successes have been reported (7).

4.13 Cutting, Sewing, and Product Fabrication

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Numerous factors affect the amount of waste generated in cutting, sewing, and product fabrication operations, including pattern layout efficiency and the level of expertise of cutting and sewing operators. The level of waste is also a function of design and planning decisions, information flow, and communication. This section discusses the essential elements of a plan to minimize waste from cutting and sewing operations, as well as ways to reuse and obtain value from waste.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.13, Cutting, Sewing, and Product Fabrication		
Fabric scraps	Pattern marker optimization Reuse of cutting room fibers Postconsumer recycling	

4.13.1 Amounts of Waste Generated

Although no published data on cutting room waste are available, typical levels based on inquiries to cutters in various types of textile operations are presented in Table 4-60. The amount of waste varies according to the type of goods produced. Open width knits (48 to 62 in. double knit/warp fabrics) usually represent 13 to 16 percent of "shape" or cutting waste (fabric remnants). In some mills, however, this represents the highest amount of cut waste generation. At some facilities, "tubular" knit fabric, which varies in cylinder sizes (15 to 28 in.), offers the least waste when used in tubular form to produce tubular garments with no sideseam. Typically, pattern design provides for shape or cutting waste levels of approximately 8 percent. This represents an average covering all basic product types (e.g., sweatshirts, t-shirts).

These cutting room efficiency factors can translate into substantial amounts of waste. In the United States each year, about 800 million yards of denim are produced, at an average weight of perhaps 12 ounces per linear yard, or a total weight of well over one-half billion pounds of denim. The efficiency for cutting denim is typically 84 percent or less. (In general, fabric utilization efficiency in cutting and sewing ranges from about 72 percent to 94 percent). Cutting waste therefore represents about 16 percent of denim production, or roughly 100 million pounds annually in the United States for denim alone. Similar analyses can be done for each of the other fabrics presented in Table 4-60.

4.13.2 Pollution Prevention To Reduce Waste Levels

Pattern marker efficiency is essential to reducing the amount of cutting room waste but depends strongly on garment design factors such as shape and seam location, size assortment as required by retail sales, fabric width, and other technical considerations. Cutting practices that minimize waste 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. Commercially viable systems probably could not be developed that would surpass current efforts at minimization of cutting waste. Improvements could almost certainly be made through design modifications or better planning (i.e., coordination between fabric supplier and retailer) and through process improvements such as use of consistent yarn and fabric weights.

Mills can make advances in the reuse of cutting room fibers, which could potentially prevent a substantial amount of pollution. At present, denim cutting waste is

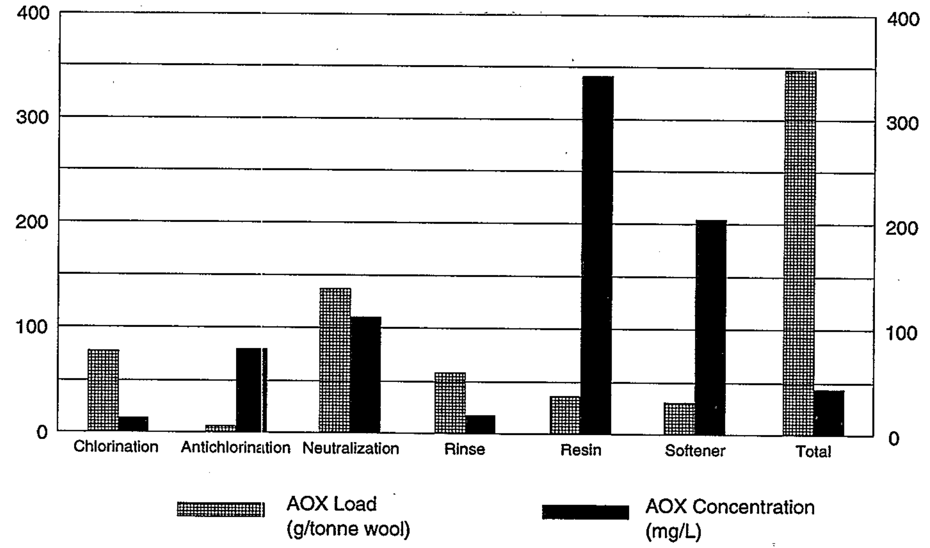

Figure 4-22. AOX loads and concentrations from each of the six bowls of a continuous chlorine/Hercosett plant (7).

Table 4-60. Typical Levels of Cutting Room Wastes

Type of Good	Typical Waste Percentage	Lowest Waste Percentage
Denim	16%-24%	6%
Knits: open width	13%-16%	11%
Knits: tubular	25%-27%	22%
Woven: other than denim	No consensus	No consensus

recycled into end-uses such as paper making. The value of this fiber in such uses, however, is below its value in denim manufacturing. If manufacturing procedures were developed to reclaim fiber from denim cutting waste and reuse it, the cost of the raw fiber would be reduced, and dyeing requirements (and associated pollution) would be reduced because the indigo denim color would already exist in the reclaimed fiber.

In addition to cutting room waste, postconsumer recycling of discarded blue jeans or other denim products could be combined to use the same technology. One attractive feature of this opportunity is that it presents minimal political or business barriers.

4.14 Installation

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.14, Installation		
General	Vendor/customer information exchange; design of textile and also of composite products; purchasing specifications; better general expertise; storage conditions	

The manner in which textile materials such as carpeting, wall coverings, and upholstery are installed can have a considerable impact on their performance. Poor installation techniques can negatively affect the lifetime of the product, requirements for aftermarket treatments, and the quality of indoor air. For example, if inappropriate adhesives are used to bond textile coverings (e.g., to ceilings, walls, floors), retention of solvent odors can produce long-term indoor air pollution. Consumer actions, such as aftermarket textile treatment and care, can also affect textile performance (see Section 4.17, "Consumer Issues and Consumer Care").

Smith and Bristow (83) report that industry working groups have identified the following as important indoor air pollution issues to consider when selecting and installing textile components for indoor use:

- Ageing of products.
- Identification and selection of low emitting products.
- Quantifying indoor air emissions.
- Proper product storage by the installer.
- Effects of adhesives containing VOCs.
- Proper adhesives, eliminating inappropriate adhesives.
- Panels and partitions designed to minimize sorption/reemission.
- Heating, ventilating, and air-conditioning (HVAC) system design, air flow in the room, placement in relation to emitters.

In many cases, textile material is part of a larger textile-containing product. Therefore, all components of the product must be compatible. For example, storage of textile materials with solvents or other VOC-emitting materials can produce contamination that requires time to desorb. Therefore, a key to preventing pollution is to provide better information on the textile product, potential incompatible chemical and mechanical installation procedures, incompatible or inappropriate combinations with other materials, and proper storage conditions. Unfortunately, most textile sales organizations are not sufficiently well informed about such technical issues and are thus unable to understand and communicate the required information. This is an area that shows a specific need for pollution prevention training (see Section 5.3, "Training Programs"). Training programs designed to educate sales personnel about these issues should be developed and implemented.

4.15 Aftermarket Treatments

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.15, Aftermarket Treatment		
General	Vendor/customer information exchange; design of textile and also of composite products; purchasing specifications; better general expertise; storage conditions	

Aftermarket treatment issues are similar to the installation information discussed in the previous section (Section 4.14, "Installation"). The distributor or retailer may add many topical finishes to textiles. Common examples include:

- Soil release
- Antisoil

- Stain blocker
- Antistatic
- Softeners
- Flame retardants
- Water repellent
- Biocides

Often, these finishes are applied with minimal knowledge of the potential impacts on indoor air quality. An example is stain-release fluorocarbon finishes for upholstery, which can perform poorly if not applied properly. The poor performance results in excessive cleaning requirements, solvent use, and indoor air pollution. In general, greater attention needs to be given to the selection and use of topical finishes.

4.16 Consumer Issues and Consumer Care

The following table introduces the pollutants and waste streams discussed in this section, as well as suggested pollution prevention activities for each.

Pollutant or Waste Stream	Pollution Prevention Actions Described in This Section	Comments
4.16, Customer Care		
General	Vendor/customer information exchange; design of textile and also of composite products; purchasing specifications; better general expertise; storage conditions	

Most textile products require regular consumer care and maintenance. Consumers use a variety of aftermarket cleaning products, which they must select and use properly because improper use can lead to problems such as indoor air pollution. For example, inappropriate or improperly applied cleaning materials can produce long-term indoor air pollution. The same can be said for other consumer activities, such as dry cleaning of garments and spot removal from carpets and upholstery.

Smith and Bristow (83) report that industry working groups have identified several important consumer issues regarding indoor air pollution. These relate to textile products and materials that interact with textile products:

- Consumer attitudes and information
- Cleaning product selection and use
- Cosmetics, toiletries, and personal products
- Deodorizers, room fresheners, and perfumes
- Consumer use patterns and practices
- Interaction with hobby materials
- Use of pesticides
- Solvent uses

Currently, no protocol exists for providing consumers with information regarding air pollution issues. With the recent emphasis on indoor air quality, however, industry programs are likely to be developed.

4.17 Globalization of Pollution Prevention

The most difficult aspect of pollution prevention, and the aspect that can perhaps pay the highest dividends, is globalization of pollution prevention concepts. Most textile manufacturers have approached pollution prevention on a process-by-process basis, but few have globalized these concepts. Each part of the process—beginning with design, purchasing, and training, and continuing all the way through the unit manufacturing processes, and finally ending with distribution, merchandising, and cut and sew—affects all other parts. A successful pollution prevention program must be comprehensive and include every aspect of textile manufacturing from R&D to marketing (91). This is a great challenge because of the textile industry's extremely fragmented nature.

The basic premise of pollution prevention is globalization. Treatment systems often create chains of waste or move waste from one medium to another, so to be effective, pollution prevention must focus on treatment systems as a whole rather than fragments of these systems. Fava and Page (92) present pollution prevention as a global multimedia approach, which is preferable to medium-by-medium attacks on pollution (92). The pollution prevention approach can be globalized beyond unit processes to evaluate the entire life cycle analysis of pollution associated with products (92). These concepts must have a broad focus and embrace all parts of the operation (65).

Berglund and Snyder (93) give a graphic depiction of globalization of pollution prevention concepts, integrating ideas such as source reduction and recycling and also present the relationship of process development from conception through laboratory, pilot plant, and commercialization (see Figure 3-2). The further along in process development, the more difficult and costly pollution prevention efforts become to implement; therefore, considering pollution prevention at the design stage is the easiest, most economical approach (see also Section 3.2, "Design-Stage Planning"). Interdisciplinary team reviews are useful to integrate the perspectives of customers, regulators, and raw material suppliers in order to identify alternatives, select raw material suppliers, and evaluate options based on future regulatory factors (93).

4.17.1 Scope of Globalization

A truly global approach to pollution prevention coordinates all manufacturing segments to produce minimum overall waste, including:

- Dye and chemical suppliers.
- Designers of fabrics.
- Merchandisers.
- R&D.
- Customers.
- Support functions.
- Production scheduling.
- Maintenance.
- Personnel training.
- Purchasing.
- The entire manufacturing pipeline, including spinning, weaving/knitting, dyeing/finishing, and cut and sew.
- Regulators.

Individual process tweaking can accomplish significant changes, but a process-by-process examination of pollution prevention does not accomplish as much as a globalized pollution prevention program (91, 94).

4.17.2 Barriers to Globalization

Pollution prevention faces significant barriers, involving mainly the lack of global attitudes (95). Primary disincentives include risk of change, inadequate recognition of benefits because of nonglobal costing procedures, and lack of information and communications. A successful pollution prevention program eliminates these disincentives through improved information, employee understanding, quality evaluations, and effective cost systems (95). Above all, a global perspective and better understanding of pollution prevention need to be fostered among employees (95). Wagner (14) provides a sketch of the role of supplier, finisher, and regulator in a globalized pollution prevention scheme (see Figure 4-23). To move forward with pollution prevention, the industry must change its way of thinking; and a united and integrated effort must be undertaken by the vendor, processor, and customer (60). For example, suppliers should provide product information to wet processors and accept responsibility for reuse of packaging and shipping materials (66).

4.17.3 Examples of Globalization

Every business is different, just as every mill is different, so specifying how to globalize pollution prevention programs in all settings is impossible. The following examples are typical, however, and could be implemented in most operations:

- Preparation versus upstream/downstream compatibility.
- Designer/finisher/customer communications to reduce chemical finishing.
- Enhanced information exchange.

4.17.3.1 Preparation

In textile manufacturing, chemicals are often added in the processing stages. These chemicals must later be removed by energy and chemically intensive scouring procedures. Minimization of upstream chemical residues is important in the reduction of toxic pollutants from effluents for cotton and synthetic dyeing (96). Examples of these chemical residues include:

- Lubricants
- Spin finishes
- Agricultural chemicals
- Size materials
- Knitting oils
- Winding lubricants
- Tints

An overall global pollution prevention scheme should consider the downstream impact of all processing residues. Mills should set up dyeing and finishing processes that minimize chemical residues from spin finishes, agricultural chemicals, sizes, oils, tints, and winding emulsions. Finishers and dyers often attempt this unsuccessfully because of a lack of information about upstream processes (92). One solution is to overcome the proprietary nature of chemical specialties and move toward global selection of compatible processing assistants. The barriers to this approach are great, but the potential rewards are immense.

Additives should be selected, wherever possible, that will not interfere with downstream processes. For yarn manufacturing, low BOD winding emulsions and waxes are commercially available that do not generate wastewater pollutants when removed from the yarn fibers. In addition, they help reduce the normally high oxygen demand loads in wastewater produced during fiber preparation. In this way, globalization across unit process boundaries can prevent pollution.

4.17.3.2 Designer/Vendor/Supplier/Finisher/Customer Globalization

Many knit fabrics normally require chemical resin stabilization for shrinkage control and sewability (82). Often, however, mills can stabilize these fabrics without using chemicals, provided the equilibrium relaxed configuration

Dye/Chemical Manufacturer	**Textile Processor**	**Authorities**
Product Development • High Exhaustion • Low: Toxicity COD Metal Content	Optimize: • Product Selection • Formulations • Processes • Housekeeping	Cooperate With Industry To Develop Rational Solutions
Process Development • Reproducible/Robust • Low Liquor Amounts • Less Chemicals • Shorter Dyeing Time • Lower Temperatures • Dyebath Reuseable	Recycle Wherever Possible Implement Effective Waste Treatment Communicate Efforts and Successes	Do Not Force Export of Environmental Problems Educate Population Amount Risk/Benefit of Required Technologies

Figure 4-23. An integrated approach to environmental problems in the textile industry (14).

of the fabric is exactly equal to the customer specification in terms of width, yield, and shrinkage and provided that complete relaxation is attained (82). The pollution that results from chemical fabric stabilizers, stiffeners, and softeners can be reduced by better knit designs, which inherently require less chemical stabilization. Proper fabric design and handling can eliminate much of the need for chemicals.

Commercially available computer-assisted fabric design programs aid in yarn selection, tensions, stitch length, machine cut and diameter, and other parameters for making a customer-specified construction at the proper width, yield, and shrinkage (82). The concept of design as a shrinkage control tool is a good example of globalization. If the customer can be integrated into the process to correlate the finished goods specifications with the design parameters, then the finisher's job is mostly a matter of tensionless handling. Few if any chemicals are needed. (See Section 4.12, "Finishing," for more information). In fact, if the need to prepare cloth in order to remove upstream impurities and to overcome technical design deficiencies were eliminated, then dyeing and printing would be the main task of wet processing and the need for finishing would be reduced.

An example of globalization is in the area of color matching (see also Section 4.3.4). In most markets, essentially all shades are matched to customer- or designer-specified standards. In some cases (e.g., bright green, royal blue, deep violet), metal-bearing dyes are required to match the specified shade. Often, a slight modification of hue, value (depth), or chroma (brightness) could result in the reduction or elimination of the metal-bearing dye from the recipe. This would reduce metals in the textile mill wastewater effluent or waste treatment sludges.

Few if any companies take the time to inform designers of these alternatives, and thus the designer never becomes aware of the environmental implications of the color selection. Designers should be free to select colors they need to meet aesthetic design criteria, but they should be made aware of the consequences and alternatives.

Another example is vendor/customer relationships. For a pollution prevention program to be complete, vendors must become involved. The result of such cooperation is that customers and vendors ultimately agree on standard QC tests, purchasing specifications for contents, impurities, packaging, and other issues. In the textile industry, this requires continual effort on the part of the mill. A good incoming QC check system, and constant review of methods and test results, even when no problems are evident, builds the necessary customer/vendor relationships. The result can be lower pollution and better quality.

4.17.3.3 The Role of Information Exchange in Globalization

As mentioned above, a global perspective requires accurate information (92) and a system for exchanging the information. Incentives to establish such a system are also necessary, and these can be difficult to establish in a fragmented manufacturing complex such as textiles.

Globalization includes not only design, additives' effects on downstream processing, and the need for later removal by scouring but also development of an overall view of manufacturing equipment to eliminate solvent loss, dragout, and impurity buildup. These concepts can be extended to the consumer level, aftermarket treatments, cleaning solvents, use conditions, installation, maintenance, and ultimately product recycling.

In the dyestuff and textile chemical business, the proprietary nature of products and processes often hampers pollution prevention opportunities (91). The methods, difficulties, and rewards of this information exchange are discussed in other sections of this document:

- Section 3.12, "Raw Material Prescreening."
- Section 3.13, "Disinformation About Environmental Issues."
- Section 4.3, "Dyes."
- Section 4.4, "Chemical Specialties."
- Section 6.5, "Risk Assessment."

Information exchange has been useful in designing and upgrading cost systems. Glover and Hill (65) and Moore[10] present methods for equating the cost of several complex types of pollution in the same terms as other cost factors now in cost systems, thus allowing more incisive risk/benefit analysis. Computer models are widely used to equate the effects of factors such as off-quality, delivery, and pollution.

4.17.4 Priorities and Commitments

A company's business priorities and commitments control, to a large extent, its ability to globalize its pollution prevention program. Technical pollution prevention activities are usually site-specific and process-related, but globalization of pollution prevention must be based on a high level of technical understanding that transcends production unit boundaries. This is a difficult criterion to fulfill because those with broad-ranging resources and responsibilities rarely have the required level of technical expertise. This is a crucial point, especially because most pollution prevention activities involve complex technical tradeoffs. Establishing the required communications is difficult enough, but information exchange is not an end in itself; instead, it is a way for each unit to understand another's predicament. Some companies have already successfully explored ways to develop special global business relationships between suppliers, manufacturing sites, support groups, and customers.

4.18 Support Work Areas

Textile processing operations comprise several different types of chemical mixing areas, including print color shops, dye drug rooms, slasher kitchens, and size mix kitchens. Because the majority of chemicals in the mill are handled and dispensed from these areas, they have the potential to produce more pollution than all other parts of the mill combined. Therefore, they deserve special attention. Some of the important pollution prevention aspects of chemical mixing areas are:

- Design features
- Employee attitudes and work practices
- Implements
- Mix tanks
- Cleanup practices
- Automated chemical dispensing systems

These will be discussed in further detail in this section.

4.18.1 Design Features

Design features of chemical mixing areas are an important consideration when developing a pollution prevention program. The following issues should be considered:

- Chemical mixing areas should be well lit and well ventilated and should provide ample work space so that they remain neat and orderly even when in full use. This is important in creating a careful work attitude among employees.
- The ventilation system should feature temperature and humidity control. Sorption of moisture from the atmosphere may result in a 4-percent to 20-percent error in dye weight (97).
- The area should be located as close to the production machines as possible (and practical), but not out in the open production area itself. A mezzanine location is ideal, if properly cooled and ventilated.
- The floor should be smooth, well sealed, and have good drainage, which facilitates cleanup. A vacuum should be available to capture powder spills. Under no circumstances should spills be washed down the drain with water from a hose.
- Drums and bags of chemicals should not be stored in standing water or over floor drains. Spill containment pallets are useful in preventing small-scale spills. All drums should be tested when opened (see Section 4.4, "Chemical Specialties") and marked with the opening date. This allows quick determination of the age of chemicals and verifies that they were tested when received.
- Leaks and drips should be repaired immediately, and all hoses should have automatic shutoff valves so they cannot keep running when laid down.

Additional information about design features is presented in Section 3.2.3, "Design-Stage Planning for Facilities."

4.18.2 Employee Work Practices

Constant training and retraining of employees is necessary to maintain the proper attitude and work practices. Mills need to keep employees up-to-date on pollution prevention techniques and make them aware of the long-term benefits of pollution prevention.

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[10] Moore, S., and B. Smith, 1994. Personal communication between Samuel Moore, Burlington Research, Burlington, NC, and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

Chemical mixing areas are one place where employees should focus on pollution prevention. An average worker in a drug room or color kitchen makes 300 weighings per day (97). Often, these weighings involve several hundred pounds of chemicals or dyes. A typical large mill that dyes 100,000 pounds of cloth per day might weigh approximately 1 ton of dye per day. Increasing dyebath exhaustion as an effective method of pollution prevention for color in wastewater is discussed in Sections 4.3, "Dyes," and 4.10, "Dyeing," but it is no more important than avoiding small spills and implement cleaning in the drug room.

As an example, if 2,000 pounds of dye were put into dyeing machines and the exhaustion were 95 percent, then 100 pounds would be discharged. If, on the other hand, 4 ounces of dye per weighing were spilled, washed off of implements, or drained from pasteup buckets for 300 weighings per day, that would be 75 pounds of dye ([300 * 4]/16). In such a case, over 40 percent of the total color discharge is from weighing. Information pertinent to this topic is also discussed in Section 3.11, "Optimized Chemical Handling Practices."

4.18.3 Implements

The use of proper implements and equipment in chemical mixing areas can greatly reduce chemical waste through misweighings, spills, and washoffs. Some of these issues are discussed in the following paragraphs.

Careful weighing of chemicals is essential to right-first-time production, so scales are the most important piece of equipment in the drug room. The inaccurate weighing of chemicals by the dipperfull or with inappropriate scales can lead to weight discrepancies. Although chemical weighing does not require the same precision as dyestuff weighing, produce scales are not accurate and precise enough for chemical weighing. In addition to having the proper scales, employees must maintain and calibrate the scales frequently.

Manual handling of dyes and chemicals generally is done by dipping the chemical out of the drum, weighing it into a bucket, then putting the weighed amount into a mix tank with water and other mix components. The usual procedure is then to wash the dipper and the bucket. If a different dipper is used for each chemical, it does not require washing because it will always be used to measure the same chemical. The use of automatic dispensing to the mix tanks is preferable to manual handling because it avoids all containerized handling and saves time and potential errors associated with manual weighing. These issues will be discussed below.

4.18.4 Mix Tanks

Mix tanks should be made with volume marks on the inside so that any desired amount of mix can be formulated. One useful method is to etch a volume scale on a stainless steel vertical rod welded inside of the tank. Volume marks in 5- or 10-gallon increments are normally used.

4.18.5 Cleanup Practices

Efficient and proper cleanup practices in chemical mixing areas are important aspects of pollution prevention. Cleanup practices include:

- Workers should never wash drums in the mix kitchen or dispose of obsolete dyes and chemicals down the drain. When a drum of chemicals is empty and a new one is opened, the old drum should be emptied or drained thoroughly into the new. (Of course, returnable IBCs are preferred.)
- In pigment printing operations, assess screen and squeegee cleaning, which is a major source of color, as well as suspended solids, in the wastewater.
- Implement (buckets, dippers, other containers) cleanup is important, as discussed above.
- Automated chemical systems are by far the most preferable because they require infrequent cleaning.

4.18.6 Automated Chemical Dispensing Systems

An important innovation in chemical handling is the automated drug room (10). Drug rooms improve right-first-time dyeings, improve quality, reduce reworks, decrease handling, and prevent waste (10). They can also correct for off-specification dyes, for example, by automatically adjusting formulas to compensate for drum-to-drum dye strength variations. In addition, automated drug rooms reduce mismade mixes and the amount of waste that results from mismade mixes.

Dry dispensing systems for powder dyes are available that are fast and accurate (97). These are shown in Figures 4-24 and 4-25. The systems feature storage compartments, valves, weighing devices, and mechanical parts that are extremely resistant to corrosion and are easy to clean (97). Precision of 0.01 gram on a 10-kilogram delivery is available, and the accuracy is within 1 percent. The system also includes hard automated container transport to and from the dispensing area (97). Similar systems are available for liquid dispensing. These interface directly to IBCs, eliminating any manual handling at all.

These systems improve pollution prevention by improving handling, as well as the accuracy of color and chemical dispensing. If color is inaccurately dispensed, corrective additions must later be made to the dyeing, which not only increases color use but also may decrease color exhaust, require additional time, chemicals, and energy,

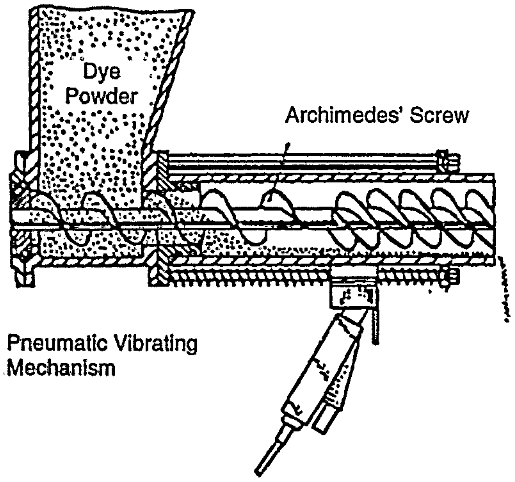

Figure 4-24. Vibrascrew dispense system (97).

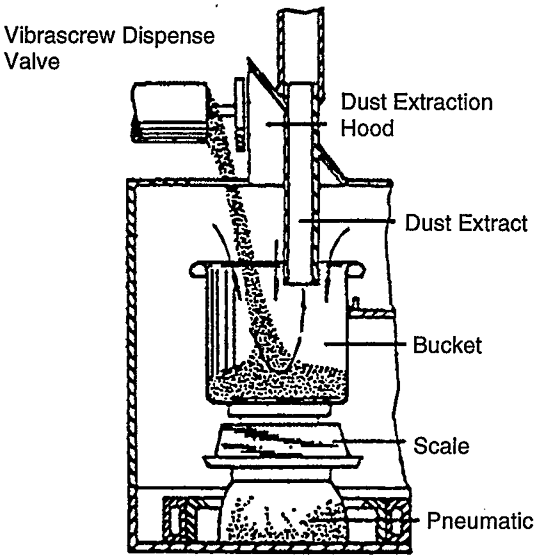

Figure 4-25. Dispense and weigh scale set-up (97).

and in some cases require stripping and redyeing, the costliest outcome in terms of economics and pollution.

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Chapter 5
Implementation of a Pollution Prevention Program

Environmental concerns and costs associated with waste generation, handling, disposal, and liability have raised awareness about the importance of waste management and prevention practices. Incorporating pollution prevention into a company's overall business strategy is the most effective way to address these concerns and capitalize on the numerous benefits resulting from prevention efforts. Many companies have found it advantageous to model their pollution prevention programs on, and integrate them into, existing total quality management (TQM) programs (1).[1]

This chapter describes the steps needed to integrate pollution prevention into the business environment and develop and implement a successful, sustainable pollution prevention program.

5.1 Steps in Implementation

Implementing a pollution prevention program involves several steps:

- Designating a pollution prevention coordinator.
- Establishing management commitment and support.
- Organizing a team to lead the pollution prevention effort.
- Developing a pollution prevention plan.
- Developing a process flow diagram.
- Setting goals and priorities for the pollution prevention program.
- Developing an action plan.
- Implementing the action plan.
- Expanding the plan to meet future goals and priorities.

The following subsections outline these basic steps for implementing a successful pollution prevention program.

5.1.1 Establishing Management Commitment and Support

No pollution prevention program succeeds without genuine management commitment to the prevention philosophy. Employees look to management for guidance on how to carry out their daily tasks. Thus, if management places strong emphasis on pollution prevention, employees will as well. On the other hand, if management sees pollution prevention as an easy way to pass the buck to workers, the pollution prevention program will fail. In short, if management makes a serious commitment to pollution prevention, that commitment will filter down through all levels of the textile operation.

Many companies demonstrate their commitment to pollution prevention by establishing and endorsing a written pollution prevention policy. Once endorsed by management, the policy should be distributed to all employees to raise their awareness about pollution prevention. A sample corporate policy statement on pollution prevention is shown in Figure 5-1 (2).

Management also needs to provide leadership in educating employees about pollution prevention, its relationship to the company's business strategy, its potential to benefit the company, and its impact on how employees do their jobs. One way for management to introduce employees to pollution prevention concepts is to prepare a short oral or written presentation. Suggested topics could include (3):

- Cost savings through reduced raw material use, as well as reduced waste handling, transportation, and storage costs.
- Increased productivity.
- Improved product quality.
- Regulatory compliance.
- Worker health and safety.
- Reduction of potential long-term liability.
- Examples of other companies' achievements.
- Improved public image for the company.

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[1] When companies apply TQM-type tools and principles to environmental issues, they often refer to it as total quality environmental management (TQEM). TQEM is the environmental management method endorsed by the Global Environmental Management Initiative (GEMI), an organization with a membership of approximately 30 leading industrial corporations. For further information, see Wells et al. (2).

We, [company name], are committed to excellence and leadership in protecting the environment. In keeping with this policy, our objective is to reduce waste generation and emissions. We strive to minimize adverse impact on the air, water, and land through excellence in pollution prevention. By successfully preventing pollution at its source, we can achieve cost savings, increase operational efficiencies, improve the quality of our products and services, and maintain a safe and healthy workplace for our employees.

[Company name]'s environmental guidelines include the following:

- Environmental protection is everyone's responsibility. It is valued and displays commitment to [company name].
- Preventing pollution by reducing and eliminating the generation of waste and emissions at the source is a prime consideration in research, process design, and plant operations. [Company name] is committed to identifying and implementing pollution prevention opportunities through encouragement and involvement of all employees.
- Technologies and techniques which substitute nonhazardous materials and utilize other source reduction approaches will be given top priority in addressing all environmental issues.
- [Company name] seeks to demonstrate its corporate citizenship by adhering to all environmental regulations. We promote cooperation and coordination between industry, government, and the public toward the shared goal of preventing pollution at its source.

Figure 5-1. A management policy statement (4).

- Emphasis that the U.S. Environmental Protection Agency (EPA) and states place on pollution prevention as an environmental protection policy.

Case studies can be very effective in communicating how other companies have approached pollution prevention problems, the actions taken, and the results. Chapter 7 of this document summarizes case studies of pollution prevention in the textile industry. Case studies from industries besides textiles are also worthy of review because solutions identified in one industry can often be successfully transferred and applied in many other industries.

Management should also seek assistance from state environmental agencies and EPA. Staff from these agencies as well as consultants may be able to provide technical assistance in establishing a pollution prevention program. EPA operates a Pollution Prevention Information Clearinghouse that can provide documents, fact sheets, case studies, and other reference material on pollution prevention. EPA's Enviroene bulletin board, also accessible through the Internet, is a repository of information on pollution prevention, technical assistance, and environmental compliance.[2]

5.1.2 Designating a Pollution Prevention Coordinator

A successful pollution prevention program requires not only support from top management but also input and participation from all levels of the organization. To organize the effort, every pollution prevention program needs an effective pollution prevention coordinator.

The pollution prevention coordinator establishes pollution prevention teams and work groups, organizes and conducts meetings, and tracks the progress being made toward reaching pollution prevention goals. Most often, the coordinator comes from middle-management levels. The ideal person is not necessarily the one who knows the most about wastes; an individual with good organizational skills and leadership qualities who can motivate people and communicate needs and results is also a good candidate.

5.1.3 Organizing a Pollution Prevention Team

After establishing management commitment, general goals, and resources, and naming a pollution prevention coordinator, a pollution prevention team should be organized to lead the effort. The team should consist of people with different backgrounds and expertise to bring to the pollution prevention process as well as anyone else who expresses an interest (volunteers should

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[2] The Enviroene bulletin board can be reached at (703) 908-2092. The URL for access via the Internet's World Wide Web is: http://wastenot.inel.gov/enviro-sense.

always be welcome). The team should include both front-line and supervisory personnel.

The list of recommended members for the chemical prescreening committee (see Section 4.4.4.2) is a good start, perhaps with some modifications:

- Industrial hygienist
- Industrial engineer
- Plant engineer/shop foreman
- Laboratory manager/chemist
- Legal representative
- Wage hour worker representative
- Purchasing agent
- Personnel manager

Team-building can begin with an initial meeting to discuss general concepts of pollution prevention, how the company can gain from pollution prevention, and brainstorming on how to develop a pollution prevention plan, the first formal step in the process.

5.1.4 Developing a Pollution Prevention Plan

The pollution prevention plan should be the first task of the pollution prevention team. Some facilities may already have a pollution prevention plan because some states require them. The plan envisioned here is not a list of projects to be undertaken; rather, it is a formal guide to how the team will conduct its business. The plan should cover or include:

- A statement of support from management.
- The structure, philosophy, guidelines, and purpose of the pollution prevention team.
- Concrete plans for encouraging participation from all employees in the facility.
- The structure of any incentive or reward programs to be introduced.
- Procedures for conducting process evaluations and identifying pollution prevention opportunities.
- Procedures, criteria, and schedules for implementing pollution prevention projects.
- Provisions for employee training, where necessary.
- Resources needed to conduct program activities.

Developing a viable pollution prevention program requires that the company adopts the pollution prevention plan as part of its overall operating procedures and that everyone understands and accepts the principles and ideas the plan contains. To help in this regard, the plan should be presented to top management so that management knows what the pollution prevention team is doing, how the team will conduct its assessments, and what types of resource commitment are necessary.

5.1.5 Developing a Process Flow Diagram

One of the most important tasks of the pollution prevention team is to develop a process flow diagram, or process map (5). Process mapping breaks down the operations of the facility into functional unit operations, each of which can be portrayed in terms of material inputs, outputs, and losses. Developing the process map helps the pollution prevention team form a consensus about how the production process is organized and provides a focal point for identifying and prioritizing pollution prevention opportunities, as shown below. It is also a powerful communication tool that can be used to convey information to workers and management about trouble spots and to pinpoint process areas that require attention. Useful information for constructing the process map may be obtained from sources such as those shown in Table 5-1 (6).

The process map should cover the main operations of the facility and any ancillary operations (e.g., shipping and receiving, chemical mixing areas, maintenance

Table 5-1. Sources of Facility Information (6)

Type of Information	Sources of Information
Regulatory information	Waste shipment manifests Emission inventories Biennial hazardous waste reports Waste, wastewater, and air emission analyses Environmental audit reports Permits and/or permit applications Form R for SARA[a] Title III, Sec. 313 (Toxics Release Inventory)
Process information	Process flow diagrams Design and actual material and heat balances
Raw material/ production information	Product composition and batch sheets Material application diagrams MSDSs[b] Product and raw material inventory records Operator data logs Operating procedures Production schedules
Accounting information	Waste handling, treatment, and disposal costs Water and sewer costs, including surcharges Costs for disposal of nonhazardous waste, such as trash and scrap metal Product, energy, and raw material costs

[a] SARA = Superfund Amendments and Reauthorization Act.
[b] MSDS = material safety data sheet.

operations). Another extremely useful addition to the diagram is a depiction of upstream and downstream operations because in textiles, pollution and waste issues often cross facility boundaries (e.g., chemicals added at the spinning mill are removed and become a waste at the weaving or finishing mill). An understanding of where pollution originates and where it ultimately ends up is thus very important for global pollution prevention.

As simple as this diagram may appear, the effort needed to complete such a diagram is often surprising, as is the amount of debate that can develop over exactly how the facility operates. Figures 5-2 and 5-3 provide examples of life-cycle process maps for production of a knit cotton golf shirt and a polyester woven dress. Note that in both cases, the maps begin with the production of the raw material (seed cotton for the golf shirt and polyester filament for the dress) and end with delivery of the finished product to the retail distributor, even though the facility (e.g., a finishing operation) may occupy only a portion of the process map. As emphasized throughout this manual, pollution prevention in textiles often requires a global view of operations and an understanding of what happens to the materials or product beyond the facility boundaries.

Once the basic unit operations are identified and the sequence of operations is laid down in a working diagram, the pollution prevention team should walk through the facility to verify and validate the diagram, as described in Section 5.2, "Waste Audit." Modifications to the diagram can be made as observations and discussions with process operators or supervisors sharpen the team's understanding of unit operations.

During the walkthrough, the team should attempt to complete a materials accounting for each process, identifying all inputs and outputs for each unit operation. The team should focus on identifying points in the process where wastes are generated. Wastes should be classified according to the environmental media to which they are released (i.e., air, water, or land [solid and hazardous waste]). Wherever possible, the amounts of waste generated or lost from the process should also be quantified (e.g., in pounds per week, gallons per hour). Especially important is the identification not only of wastes intentionally generated (e.g., dumped batches of size or finishing chemicals) but also of losses attributable to leaks and spills, losses associated with equipment cleanup and maintenance (e.g., during color changes), and losses resulting from off-specification production runs. Some types of losses may not be readily observable during a facility walkthrough and may only be identified through discussions with operators or floor supervisors.

Another important step is to observe operations and talk to operators during all shifts at the facility because losses associated with certain operations (e.g., cleaning and maintenance) may be observable only during certain shifts. To help identify and quantify wastes, the team may need to examine purchasing and accounting records, inventories, standard operating procedures, production records, and waste disposal manifests (7).

5.1.6 Setting Goals and Priorities

After preparing the process map and conducting the in-plant survey or audit, the team should prepare a document based on the information collected. The document should contain 1) a list of all waste streams, 2) any general observations about the waste streams, and 3) an assessment of pollution prevention procedures already in place. The information should be compiled by reviewing facility operations at several different levels to identify issues such as:

- Individual unit process issues
- Facilitywide issues
- Global/corporate issues
- Supplier/customer issues

The document should be used to develop specific lists of goals and priorities for manufacturing processes as well as support activities, such as maintenance, material handling, training, and purchasing. Some goals may be specific to particular wastes (e.g., eliminating the use of solvent cleaners for a particular printing machine), while others may apply to an entire department or the whole facility. In addition to specific goals, the document should also include general goals such as improving worker health and safety or improving the company's public image. The document should describe the current practices and the pollution prevention team's objective regarding future practices, thus serving as the baseline for future progress assessments.

5.1.7 Developing an Action Plan

Once goals and priorities have been set and have been endorsed by those involved (e.g., management, production, suppliers, customers), the team should develop an action plan, keeping in mind the general categories of pollution prevention techniques described in Chapter 3:

- Design-stage planning for processes and products.
- Developing enhanced expertise and competence.
- Equipment maintenance and operations audit.
- A global, integrated view of manufacturing.
- Chemical alternatives.
- High-extraction, low-carryover process step separations.
- Incoming raw material quality control (QC).

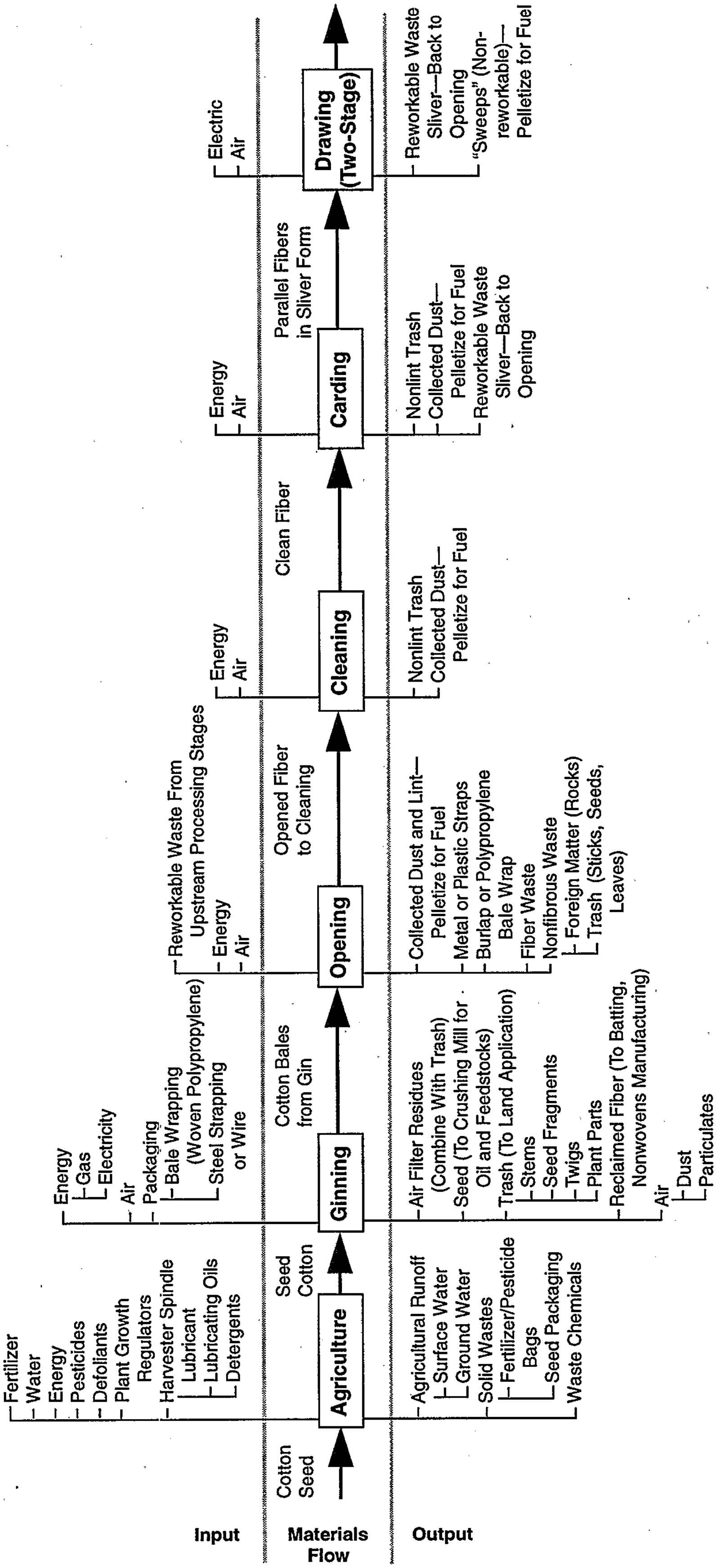

Figure 5-2. Materials flow for cotton knit golf shirt.

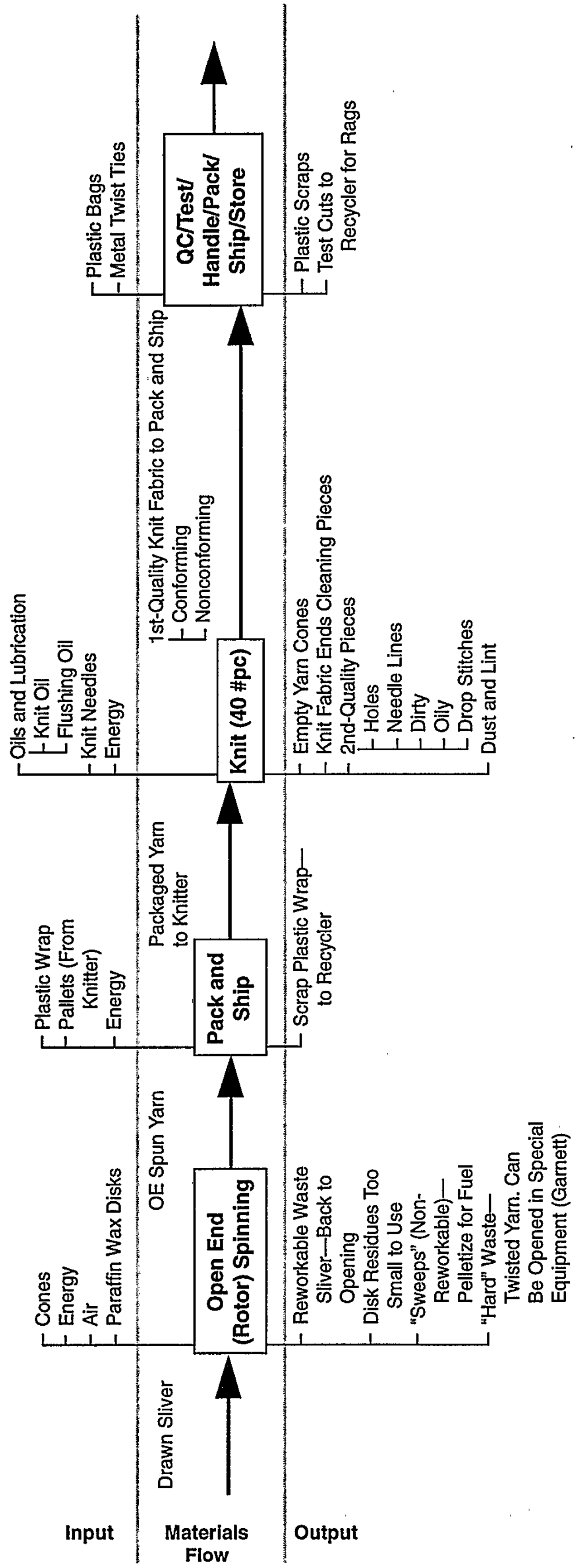

Figure 5-2. Materials flow for cotton knit golf shirt (continued).

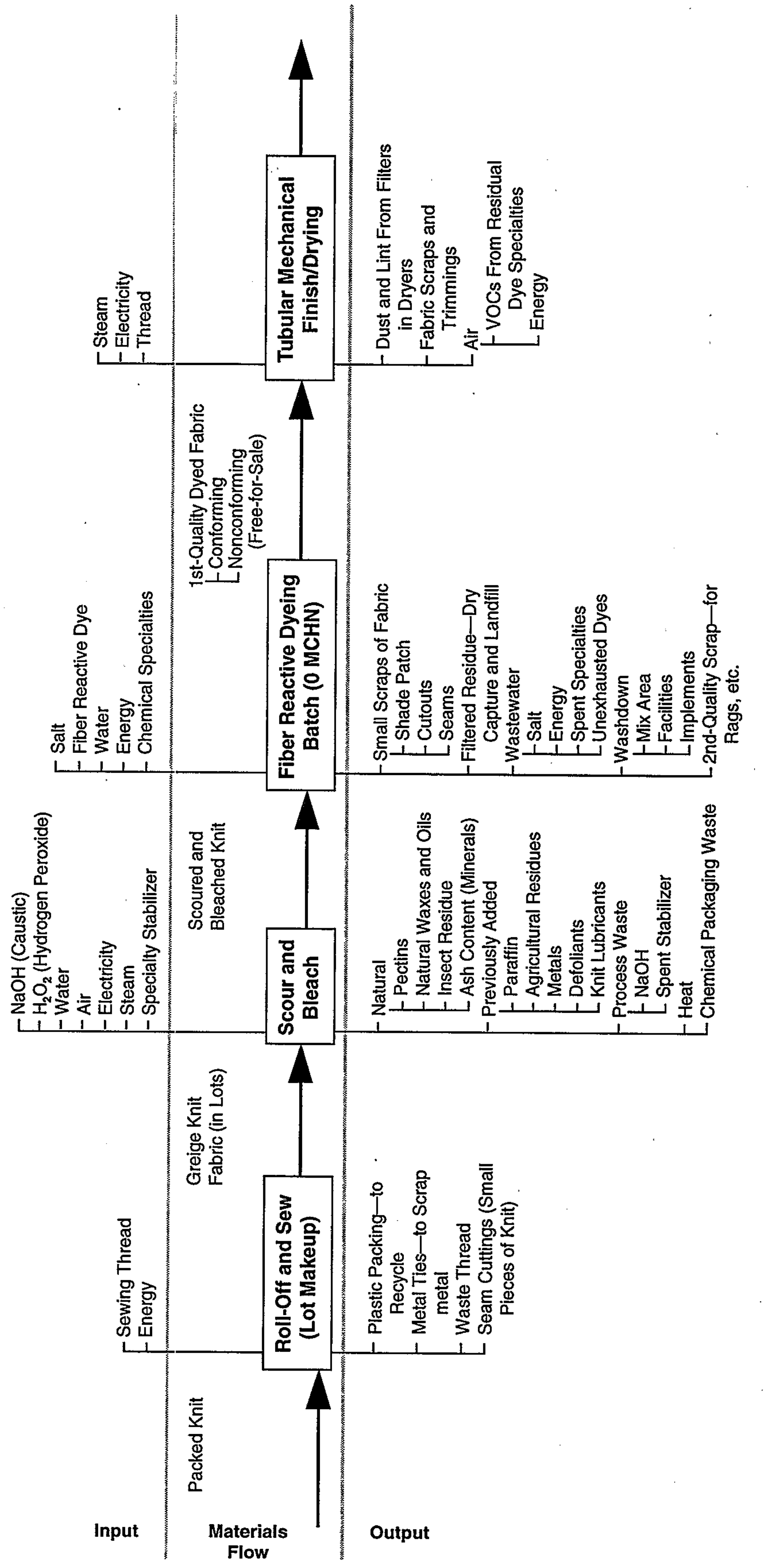

Figure 5-2. Materials flow for cotton knit golf shirt (continued).

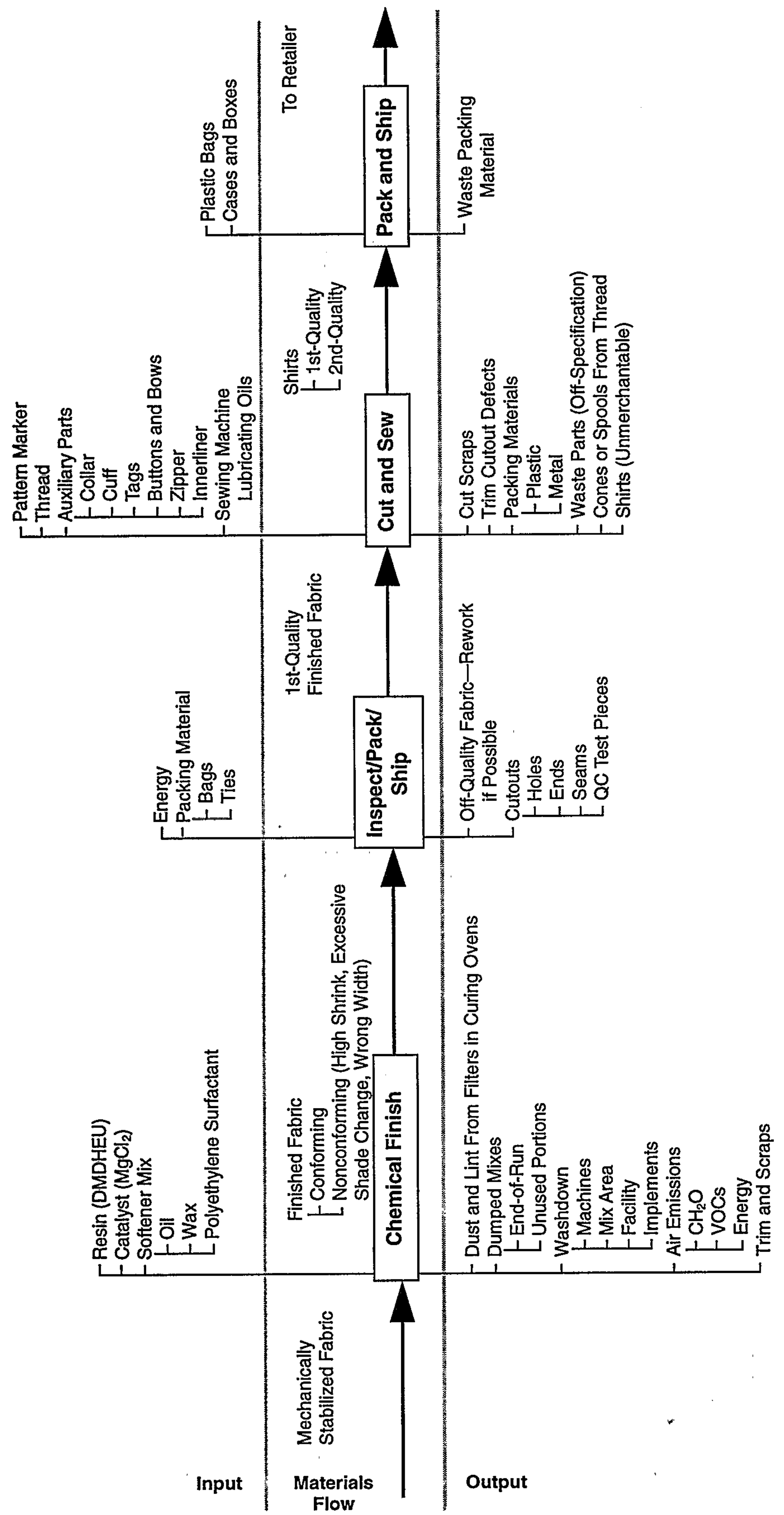

Figure 5-2. Materials flow for cotton knit golf shirt (continued).

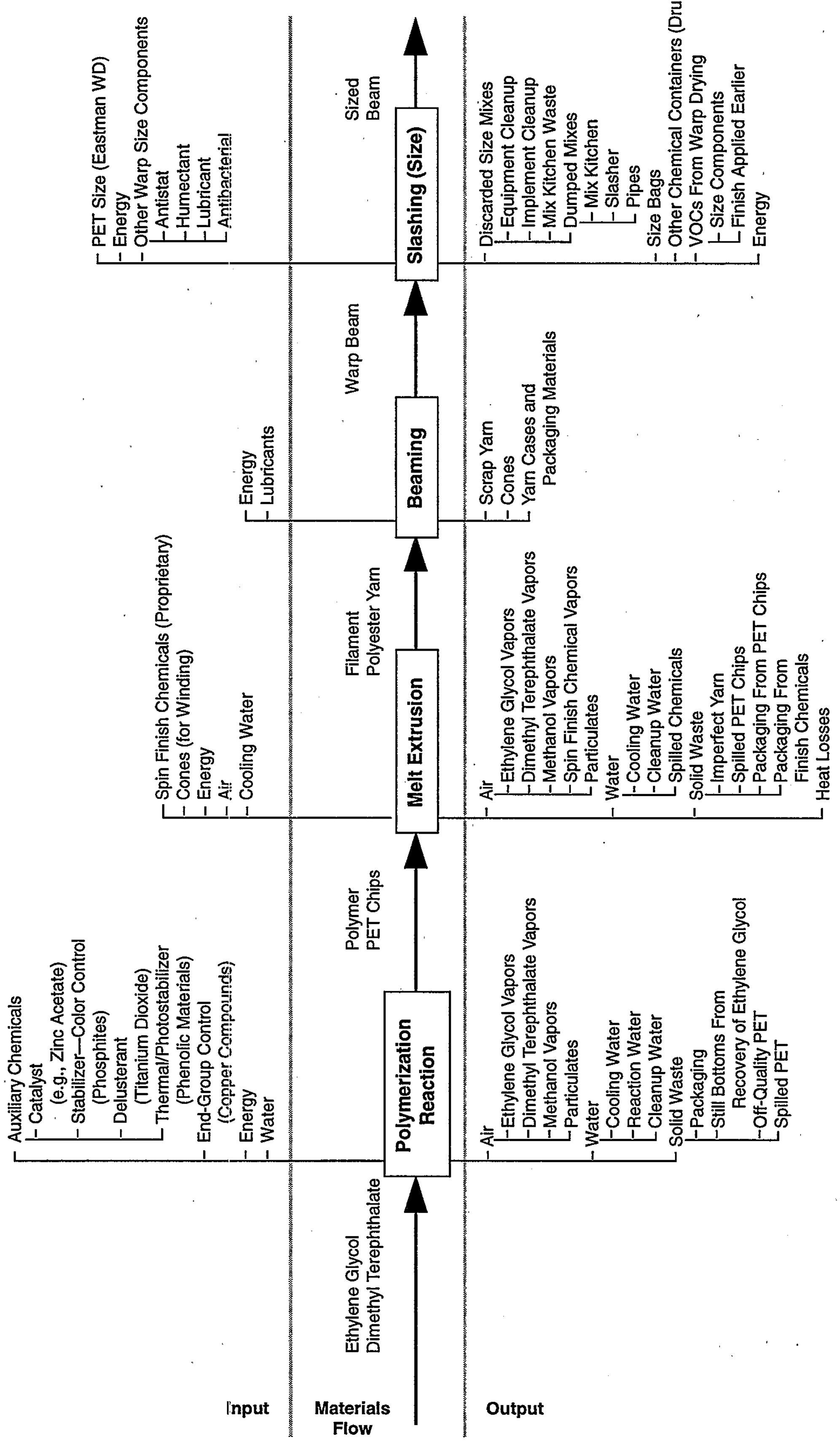

Figure 5-3. Materials flow for polyester woven dress.

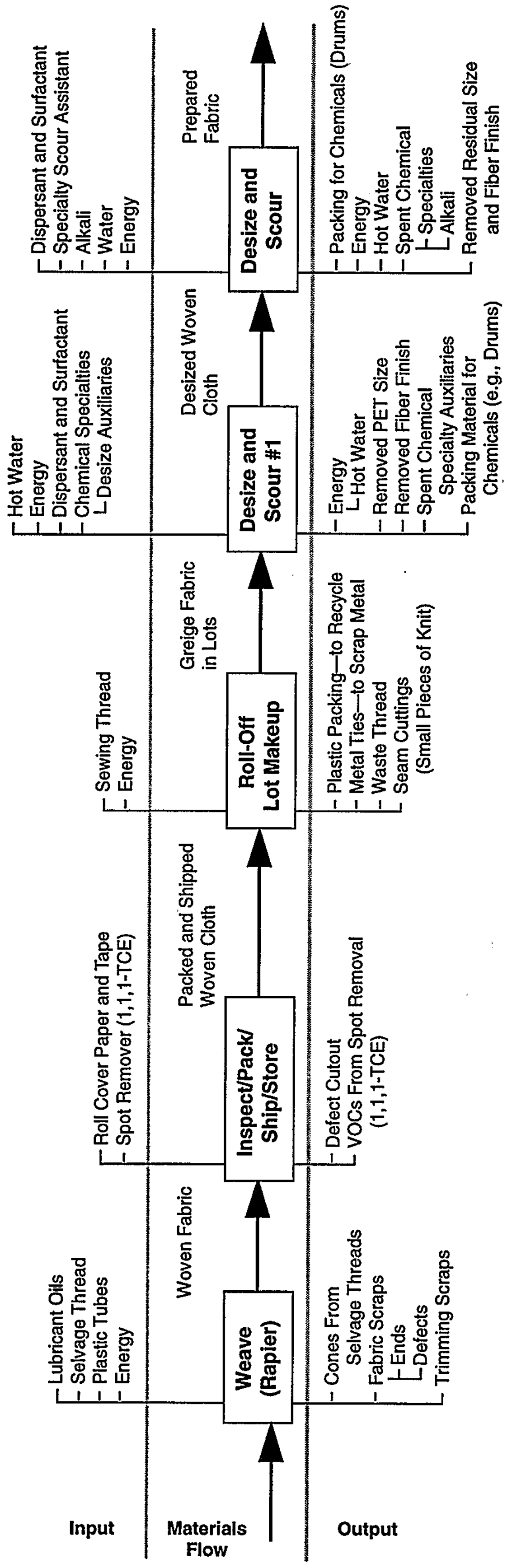

Figure 5-3. Materials flow for polyester woven dress (continued).

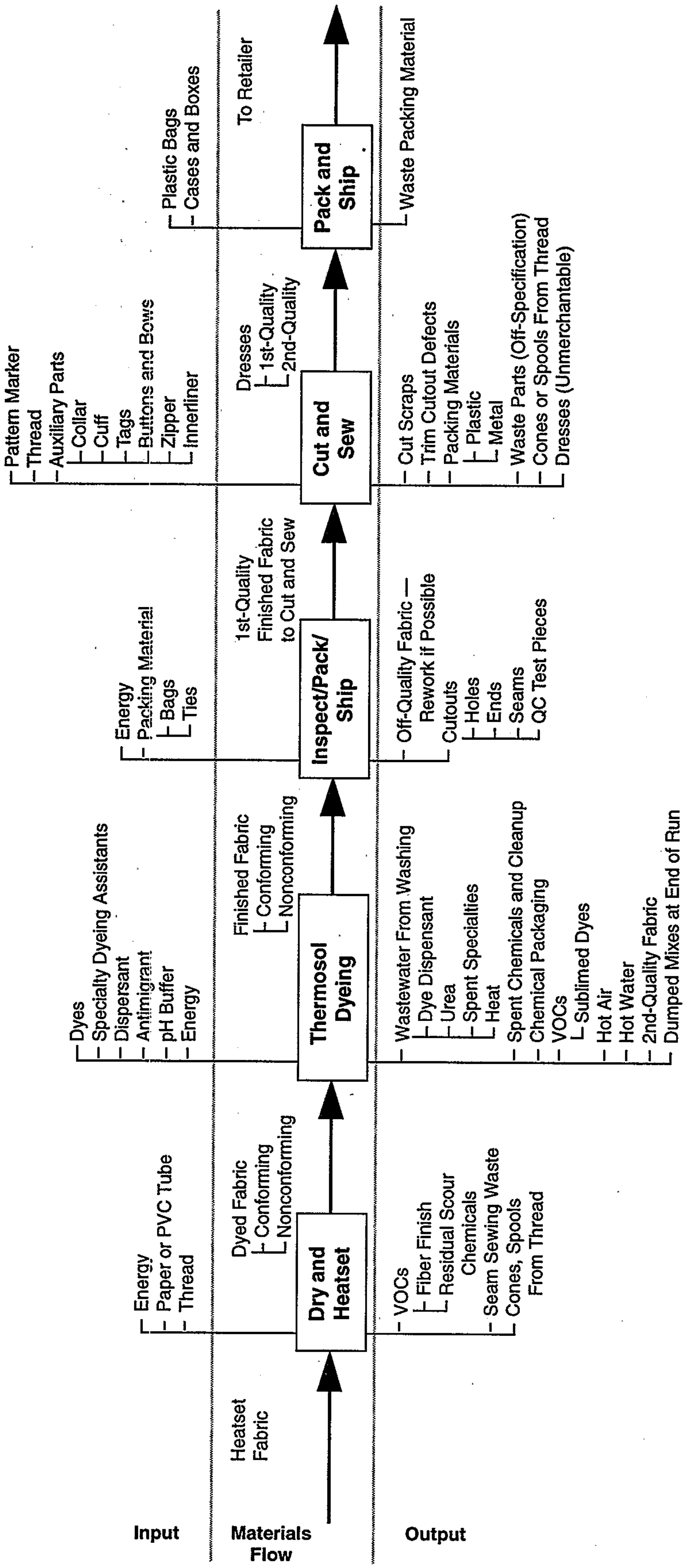

Figure 5-3. Materials flow for polyester woven dress (continued).

- Maintenance, cleaning, and nonprocess chemical control.
- Developing markets for wastes.
- Process alternatives.
- Optimized chemical handling practices.
- Raw material prescreening (before use).
- Reducing disinformation and politics.
- Scheduling dyeing operations to minimize machine cleaning.
- Standard tests, methods, and definitions.
- Consumer, installer, and end-user information.
- Technology transfer of pollution prevention successes.
- Training programs and worker attitudes.
- Segregation, reuse, onsite recovery, and offsite reuse.
- Inventory management.
- Improved process control.

The action plan is based on ideas generated by pollution prevention team members and, more importantly, by those most familiar with the processes (e.g., supervisors, front-line workers). The team should develop a multifaceted approach to soliciting ideas for pollution prevention. Pollution prevention team members can meet individually with small groups of employees familiar with particular unit operations to brainstorm about waste and pollution issues and to develop ideas. A pollution prevention suggestion box can be used to encourage people to contribute ideas outside of these sessions or anonymously. All ideas should be taken seriously, and none should be rejected automatically for reasons such as "That's already been tried," "That'll never work," or "That's too expensive." Pollution prevention is about finding new and sometimes unconventional ways of doing things, and many of the best pollution prevention ideas probably sounded outlandish when first proposed.

Every pollution prevention idea should be reviewed to determine if it can help the mill achieve its pollution prevention goals. Ideas should be developed for each waste stream and each process in all high-priority areas. The techniques should be both general and process-specific and should include design changes, new equipment acquisition, and potentially major business changes. Each technique should be carefully evaluated on a technical and an economic basis. From these, the optimum outcome should be selected and an action plan drafted. The selection of the optimum outcome is subjective and site-specific. In addition to having the proper pollution prevention techniques, a pollution prevention program must have flexibility to accommodate new processes, styles of cloth, and unforeseen market events.

Employee involvement and commitment to the pollution prevention effort is crucial. While numerous checklists are available that provide ideas for pollution prevention projects, the best source of suggestions and innovations is employees involved in daily mill operations. Getting employees involved requires ensuring that they have a solid understanding of pollution prevention and of the company's pollution prevention goals. Training and incentive programs are very useful in encouraging employee involvement. For example, one manufacturer posted all waste types and amounts from each machine on a sign mounted on the machine. Whenever an employee found a way to reduce or eliminate waste, the employee's name was added to the sign along with the type and amount of waste reduction. Other companies have put a "bounty" on waste and organized people against waste (PAW) groups. Employee contributions should be acknowledged in newsletters or other communications about the pollution prevention program.

5.1.8 Implementing the Action Plan

The next step is actual implementation of the plan. This consists of carrying out the selected techniques on the production floor, monitoring the results, and providing feedback. In many cases, in-house resources are adequate for pollution prevention implementation. In other cases, however, outside assistance may be needed. Implementation must be viewed as an ongoing process, not simply a one-time activity. Once the pollution prevention program is in progress, the pollution prevention team should continue assessing, quantifying, and documenting pollution prevention progress, giving feedback to those involved in production areas. Waste streams should be monitored and documented, with follow-up technical and economic evaluations.

5.1.9 Expanding the Action Plan

Once implemented at the unit process level, the pollution prevention plan should be expanded to broader levels (i.e., facilitywide as well as corporate and supplier/customer levels) and should be combined with the company's future goals. These goals may include:

- Long-term planning
- Research and development (R&D)
- Product and process design
- Purchasing specifications (including packaging)
- Customer relations
- TQM programs

In expanding the plan to a broader level, the company will benefit by making the community, customers, and suppliers aware of pollution prevention successes and by considering their concerns in future planning. Participating in technology transfer of pollution prevention successes is also advantageous, as is supporting the pollution prevention efforts of other textile companies, suppliers, customers, trade associations, and local businesses. In fact, many companies have used pollution prevention ideas originated at their own facilities as the starting point for new business areas.

5.1.10 Renewal

Similar to TQM programs, pollution prevention programs should incorporate a feedback loop. Finally, priorities should be reassessed and new, higher, and more global goals should be set.

5.2 Waste Audit[3]

Like manufacturers in most industries, textile manufacturers produce and ultimately discard four types of waste: wastewater, toxic air emissions, solid waste, and hazardous waste. Although manufacturers use different methods for handling each waste, the basic approach to each should be identification, elimination, and reduction. The first step in successful waste management begins with identification of waste types and amounts, and the tool most commonly used is a waste audit (9).

A waste audit is a facility assessment designed to collect technical and economic information in order to assess appropriate waste reduction techniques. The audit is probably the most important single item in the implementation of a pollution prevention program. It allows the identification and quantification of individual waste streams and allows the identification of practices, procedures, and processes that lead to waste generation. The information collected in the waste audit can be used to select and evaluate appropriate waste reduction and management techniques (9).

Mills can approach a waste audit in many different ways. This section discusses the steps that have been most widely recommended (8-13). While these steps can serve as a checklist to begin planning for the waste audit, the most important rule for any pollution prevention program is to think. Do not rely entirely on lists and forms. No pollution prevention checklist has ever been written, or ever will be written, that can rival a thinking employee.

The following suggested protocol for an audit is an expansion of the method suggested by North Carolina Office of Waste Reduction, which identifies the following as important steps in a successful waste audit (14):

- Identify all normal discharges.
- Identify potential abnormal discharges: bulk, obsolete, discards.
- Characterize all emissions and discharges by type, quantity, and content through sampling and testing.
- Evaluate treatment/disposal methods currently in use.
- Assess compliance status.
- Assess current waste costs.
- Formulate an action plan for an aggressive attack on waste.
- Establish an attitude throughout the facility that:
  - Raw materials are a valuable limited resource.
  - Waste of raw materials, energy, water, and chemical processing assistants is unacceptable.

Either one person or a team of people can perform the audit. The team approach is preferable because a team brings a wider range of knowledge and experience to the audit. An in-house team should include personnel from:

- Management
- Plant engineering
- Environmental engineering
- Safety and health
- Purchasing
- Finance
- QC

For the waste audit to succeed, the team also needs a leader who has both authority and technical expertise.

Involving a financial or accounting specialist in the waste audit is also important. Often, the costs of waste treatment and disposal are seen as a fixed overhead item (the price of doing business) and are not well known. Cost accounting systems that do not assign the costs of waste treatment and disposal to individual product lines or operating departments make encouraging waste reduction in those areas difficult (14). EPA has sponsored several projects to improve awareness of this problem in industry and is developing tools to assist in evaluating pollution prevention projects.

5.2.1 Steps for Performing a Waste Audit

The process of conducting a waste audit should include the collection of information on types, quantities, compositions, and sources of all air, solid, hazardous, and wastewater waste streams. In many cases, this information can be obtained through background data and supplemented with observed data from the plant survey.

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[3] Unless otherwise noted, the information contained in this section is from Hunt (8).

5.2.1.1 Background Information

The first step in a successful waste audit is to collect all available background information, including information on production processes, facility layout, waste stream generation, and waste management costs. This information can be used to develop a general flow diagram or material diagram for each process associated with the facility. The diagram should identify the source, type, quantity, and concentration of each identified waste stream. The background information can further be used to develop and organize the plant survey and to help identify data gaps, sampling points, problem areas, and data conflicts.

Background data collected before site inspection should include the following:

- A determination of whether the facility uses any chemicals subject to reporting requirements under Title III, Section 313, of the Superfund Amendments and Reauthorization Act (SARA) (11).
- Production-oriented information:
  - Process flow diagrams
  - Plant layout
  - Purchasing records
  - Material safety data sheets (MSDSs)
  - Operating manuals
- Water-use data:
  - Plant operating schedule
  - Production volumes
- Waste stream information:
  - Waste manifests.
  - Waste reports, as well as Toxic Release Inventory (TRI) and Resource Conservation and Recovery Act (RCRA) information.
  - Permits: air, National Pollutant Discharge Elimination System (NPDES), publicly owned treatment works (POTW) pretreatment, water, solid, hazardous.
  - Self-monitoring reports.
  - Violations information and history.
  - Waste collection and storage points.
  - Layout of waste treatment systems (e.g., air, water).
  - Operating guides/manuals for waste treatment systems.
  - Chemical prescreening procedures (9).
  - Incoming raw material QC procedures.
- Economic information:
  - Waste and sewer bills
  - Solid waste disposal costs
  - Waste treatment system operating costs
  - Contracts and consultants
- General:
  - Current pollution prevention plan, if any
  - Previous audits
  - Vendor information

At the conclusion of the preliminary data collection phase, the waste audit team should identify areas in which data are missing and, to the extent possible, develop a material balance. The data should be tabulated in a standardized format.

5.2.1.2 Plant Survey

After collecting background information, the next step in a waste audit is to conduct a plant survey. The plant survey should be used to 1) verify and fill gaps in background data, 2) identify additional waste streams, and 3) observe and collect data on actual operation and management practices. Each step of the manufacturing process, from material delivery to final product, should be investigated (see Tables 5-2 and 5-3).

If complete and detailed data on waste stream quantity and composition are not available, then the survey process should include development of a sampling program. Before conducting the survey, sampling points should be identified based on the waste flow diagram. These sampling points are subject to change as the survey identifies new waste streams.

5.2.2 Sampling

A program to sample and test waste streams of concern should be designed to collect information regarding routine and nonroutine (exceptional) waste streams. The information should include types, amount, composition, and sources of all waste streams (i.e., air, water, solid, hazardous) (8, 11). Some sampling guidelines to follow include:

- Identify type of waste and point of origin (9, 11).
- Determine fate (e.g., waste treatment, storm sewer, atmosphere).
- Determine rate produced or emissions factors (amount produced per hour, per production unit) (8, 13).
- Determine variability (potential shock loading).

In most cases, only qualitative data are needed for a waste audit; however, in cases where quantitative data are needed, sampling should be done over a sufficient period to account for 1) variations in production scheduling and 2) seasonality or irregularity of production schedules.

Table 5-2. Potential Sources of Waste (4)

Plant Category	Area	Possible Waste Material
Material receiving	Loading docks, incoming pipelines, receiving areas	Packaging materials, off-specification materials, damaged containers, spill residue, transfer-line leaking/dumping
Raw material storage/final product storage	Racks, silos, warehouses, drum storage yards, storerooms	Tank bottoms; off-specification and excess materials; spill residues; leaking pumps, valves, and pipes; damaged containers; empty containers
Production	Melting, curing, baking, distilling, washing, coating machinery, formulating	Washwater, solvents; still bottoms; off-specification product; catalysts; empty containers; sweepings; duct cleanout; additives; oil; process solution dumps; rinsewater; excess materials; filters; leaking process tanks; spill residue; pumps, pipes, valves, and hoses
Support services	Laboratories	Reagents, off-specification chemicals, samples, sample containers
	Maintenance shops	Solvents, cleaning agents, degreasing sludges, sandblasting waste, lubes, oils, greases, scrap metal, caustics
	Garages	Oils, filters, solvents, acids, caustics, cleaning bath sludges, batteries
	Powerhouse/ boilers	Fly ash, slag, tube cleanout material, chemical additives, oil, empty containers
	Cooling towers	Chemical additives, empty containers, cooling tower bottom sediment

5.2.3 Plant Survey Methods and Procedures

The specific information collected during the audit is shown in Table 5-4 (8, 10, 14).

To identify missing or inaccurate information, a preliminary review of the data should be done during, or immediately following, the survey. In addition, survey results should be converted into a pollution release inventory using direct measurements, mass balance, and engineering calculations (11). Sources of information that may be useful in completing the waste audit include 1) purchasing records, 2) MSDSs, and 3) physical inventories (9).

At the end of the background information stage of the waste audit and the plant survey, the waste audit team should have the following information about each waste stream:

Table 5-3. Examples of Information Obtained From In-Plant Survey (4)

Area	Information
Material delivery and storage	Material transfer and handling procedures Material storage procedures Evidence of leaks or spills Inventory of materials Condition of pipes, pumps, tanks, valves, and storage/delivery area
Production processes	Exact sources of all process wastes Waste flow/quantity and concentration Operational procedures Source, quantity, and concentration of intermittent waste streams (e.g., cleaning, batch dumps) Condition of all process equipment including tanks, pumps, pipes, and valves Evidence of leaks or spills Maintenance procedures and schedule Potential sources of leaks and spills
Waste Management	Operational procedures for waste treatment units Quantity and concentration of all treated wastes and residues Waste handling procedures Efficiency of waste treatment units Waste stream mixing

- Point of origin
- Subsequent handling/treatment/disposal
- Physical and chemical characteristics
- Quantity
- Rate of generation (i.e., pounds per unit of product)
- Variations in generation rate
- Potential for contamination or upset
- Cost for management and disposal

5.2.4 Evaluation and Selection of Waste Reduction Techniques

Following completion of the waste audit, the next step is to evaluate the information collected and to use that information to select appropriate waste reduction techniques. Procedures used to identify, evaluate, and select applicable waste reduction techniques should:

- List waste streams.
- Identify potential waste reduction techniques for each waste stream.

Table 5-4. Information Collected During an Audit

Area of Facility	Type of Information
General	General facility layout, indicating proper facility design
Receiving areas (loading docks, pipelines)	Waste packaging materials and handling of these materials
	Off-specification or obsolete materials
	Spill residues on floor or ground
	Proper spill containment equipment (e.g., shop vacuum)
	Proper spill containment supplies (e.g., absorbent powder)
	Unprotected parking lot drains near loading dock
Raw material warehouse	Obsolete materials
	Unnecessary duplication
	Intermediate bulk containers (IBCs) instead of bags and drums
Processing floor	Equipment operations audit protocol
	Segregation and collection of reusable waste (e.g., rags)
	Equipment condition (maintenance)
	Proper equipment operation
	Processes for which less-polluting alternatives exist
	Leaks from machines and spills of processing baths
	Leaks from pumps, pipes, and valves
	Damaged and leaking containers
	Cleaning practices for machines
	Dry capture of spills (versus washing spills down the drain with a hose)
	Discards of excess or off-specification processing solutions
	Proper flow control on washers and cooling water
	Running hoses
	Process controls and sensors: • Condition and maintenance • Obsolescence • Use and effectiveness
	Possible improvements in process step separations (high extraction, low carryover)
Mix kitchens, drug rooms	Chemical for which less-polluting alternatives exist (e.g., metal-bearing reducing agents)
	Leaking pumps, pipes, and valves
	Damaged and leaking containers
Mix kitchens, drug rooms (continued)	Cleaning practices for implements and mix tanks
	Dry capture of spills (versus washing spills down the drain with a hose)
	Discards of excess or off-specification processing solutions
	Optimized chemical handling practices and worker attitudes
In-process goods storage	Collection of reusable waste (e.g., seam, sewing waste)
Shop	Solvents and cleaners in use
	Disposal practices for: • Spent cleaning materials and sludges • Lubricating oils • Batteries • Machine waste and scrap metal
	Equipment maintenance audit protocol
Offices	Segregation and collection of reusable waste (e.g., paper)
Scheduling department	Protocol for process equipment scheduling
Laboratory	Incoming process raw material QC protocol: • Specialty and commodity chemicals • Fiber, yarn, or fabric
	Incoming nonprocess/nonshop chemicals testing protocol
	Sampling practices for incoming material evaluation
	Use of standard tests and reporting
Power plant, boilers, raw water treatment, air handling	Ash disposal methods
	Boiler stack testing previously done
	Boiler tub cleanout materials
	Boiler chemical use and disposal
	Boiler chemical packaging disposal
	Proper disposal of filter backwash
	Air washer additives use, disposal, and packaging
	Air washer tower bottom sediment
Discussion with line supervisors	Is schedule appropriate to minimize machine cleaning?
	Is preventive maintenance adequate?

- Evaluate the technical and economic aspects of each technique.
- Select the most cost-effective waste reduction technique(s) for each waste stream.

In addition to the above procedures designed to address specific waste streams, procedures should also be developed to address facilitywide waste reduction methods (i.e., materials handling, maintenance, and operating procedures).

5.2.4.1 Technical Feasibility

Following identification of waste reduction procedures, the next step is to evaluate the technical feasibility of each technique. This evaluation should consider:

- Applicability
- Waste reduction potential
- Operation and maintenance requirements

- Safety and health
- Ease of implementation
- Reliability
- Special design considerations

5.2.4.2 Risks and Liabilities of Waste Minimization

These feasibility considerations are not all equally important. The team leader must determine which factors should receive special consideration. An important part of the evaluation process is to consider the risks and liabilities associated with managing each waste stream. Therefore, one criterion for judging the relative importance of each factor is the liability associated with that factor. Figure 5-4 provides a hierarchical view of the liabilities associated with each waste minimization category.

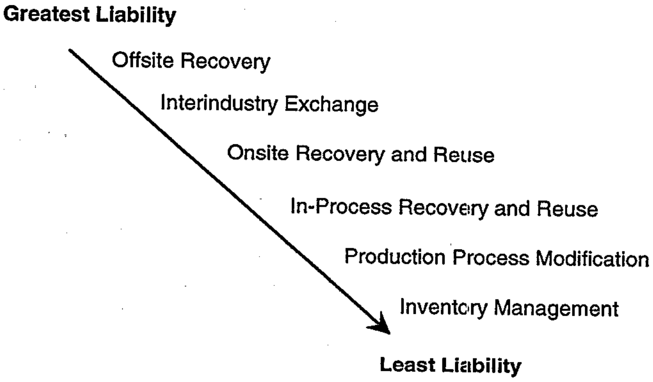

Figure 5-4. **Waste reduction heirarchy (8).**

5.2.4.3 Economic Analysis

In addition to the technical analysis, the team should conduct an economic analysis of each reduction technique. Costs to consider include implementation costs (i.e., capital, installation, operating, and maintenance) and cost savings resulting from lower production and waste management/disposal costs. These costs can be used in a return on investment analysis to calculate the payback period. Current waste management costs are very important to consider. These costs include the cost of shipping waste off site as well as the onsite costs of labor and time required to handle, manage, track, store, treat, and manifest the waste. Other costs to consider include liability insurance premiums, long-term liability and legal costs, worker health and safety, community relations, and regulatory compliance.

In combination, the technical and economic analyses allow selection of the best waste minimization options. After identification of the options, an implementation plan should be developed for each waste stream. The implementation plan should include the implementation schedule, equipment needs, conceptual design, implementation requirements, and cost estimates.

5.2.5 Waste Minimization Program Implementation and Monitoring

The waste minimization program comprises waste stream reduction plans and general facility recommendations. For the program to be successful, procedures must be established for monitoring and evaluating the techniques once they are in place. Also, the program should allow for development and implementation of new waste reduction techniques. Important points about waste minimization programs include:

- Program implementation can be handled in many different ways. Waste streams that present problems or areas where the investment will have a rapid payback period should be addressed first. Simple and low-cost techniques also should be implemented quickly.
- Keeping employees informed during development and implementation stages is essential. They will be helpful in evaluating program performance and determining ways to improve the program.
- Developing a recordkeeping system to track the effectiveness of each segment of the program is also important. This allows a comparison of generation and reduction data over time. Economic data can be used to determine the efficiency of waste stream reduction techniques.
- Corporate commitment is crucial. The program must be an integral part of the firm's corporate policy, and a senior-level person should have the authority and resources to develop, operate, and monitor the program.
- Some firms have adopted incentive programs to encourage the success of their waste reduction programs. These incentives include:
  - A corporate-level waste reduction engineering group to provide technical assistance.
  - Awards and financial incentives for new ideas and innovations.
  - Annual audits.
  - A companywide information exchange (e.g., bulletins, newsletters).
  - Separate capital expenditure review processes for waste minimization projects (results in less paperwork and a quicker review process).

5.2.6 Air Inventory

Although the foregoing waste audit procedures are general in nature, the authors who developed them primarily focused on solid and liquid wastes. Recently, air emissions have received additional attention. This section describes pollution prevention audit information that focuses mainly on air issues (15).

Unlike data on water, solid, and hazardous waste, comprehensive air inventory data are not readily available, and analytical methods and sampling procedures for air toxics are much more difficult than for other types of waste. Also, unlike water testing, air testing generally focuses on specific compounds listed as hazardous air pollutants (HAPs) or toxic air pollutants (TAPs).[4] This complicates the process of auditing air emissions.

The basic concept involved in air testing is similar to that described above: identify sources, then quantify the waste from them (15). The required methodology is quite different, however. Some of the more important methods are:

- Source tests
- Continuous emissions monitors
- Mass balance calculations
- Emissions factors
- Engineering estimates

The audit must include point sources, area sources, and fugitive emissions (15). Fugitive emissions are difficult to estimate because of the difficulties inherent in capturing a representative sample for testing as well as difficulties in determining flow rates. A high percentage of textile emissions comprise fugitive emissions (15).

An accurate inventory requires expertise in air sampling and testing as well as a thorough knowledge of textile operations and textile chemicals (15). Helpful information includes:

- MSDSs.
- Material use rates.
- Specific chemical reactions that occur in the process.
- Fuel use rates.
- Temperatures in ovens, steamers, and other similar equipment.
- Production rates.
- Storage tank information.
- Stack dimensions, air flows, and exit velocities.
- Treatment methods (if any) for air and water.
- Vapor pressures and vapor density of chemicals in use.

A walkthrough audit is extremely useful for air, just as it is for other types of waste (15).

5.2.7 Forms and Lists

Forms and lists have value in that they promote consistent evaluations and organize information in consistent ways, which helps communicate results (12). Several forms have been developed to ensure complete and consistent evaluations. Most pollution situations are site-specific, however. Therefore, an auditor must always think and not rely entirely on lists and forms.

5.3 Training Programs and Worker Attitudes

Training involves instructing a worker about the specifics of machinery, the facility, and pollution in relation to daily tasks; effective training is widely recognized as a crucial ingredient in a good pollution prevention program (8, 9, 12, 13, 16-20). For short-term improvements, the worker is an important focus of an effective pollution prevention program. Short-term successes, in turn, form the foundation for long-term improvements. In short, without good work practices and worker attitudes, a pollution prevention program cannot succeed in a labor-intensive industry such as textiles.

Information concerning general competence of workers is discussed in Section 3.3, "Enhanced Chemical and Pollution Prevention Expertise." This section focuses more on worker-level training as it relates to specific tasks that affect pollution prevention in daily job performance.

5.3.1 Importance of Training Programs

Pollution prevention training should include all employees, from the president to the floor sweeper. Of special importance are employees involved in maintenance, laboratory, scheduling, design, sales, and other support functions (8). The cost of training is low: it usually requires no capital investment, and operating costs are generally minimal (13). Training programs, however, are one of the highest return low-technology and low-risk approaches to pollution prevention.

Training has two purposes. One is to inform employees. The other is to influence employee attitudes with the goal of making employees more aware of and responsive to pollution prevention. Often, training programs can be combined because the same type of attitudes that foster pollution prevention also contribute to improved product quality and employee safety. Training programs, however, contribute only minimally to shaping employee attitudes. Other factors must be conducive to improved attitudes, including:

- Good maintenance of equipment and facilities
- Neat, orderly workplace
- Responsiveness to employee suggestions

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[4] Further information about specific types of chemicals and tests is found in Section 2.2.3, "Toxic Air Pollutants."

Also, as stated in Section 3.3, "Enhanced Chemical and Pollution Prevention Expertise," employee suggestions should be solicited and acted upon (9). Nothing stops employee involvement in a program faster than failure to act on comments and suggestions.

5.3.2 Information To Include in Worker Training

Richardson and others suggest that the information below be included in worker training (9). This information should be presented from the worker's point of view and within the worker's frame of reference. The credibility of the training program sets the tone for the employee pollution prevention effort.

An attitude-oriented training approach should include the following information:

- Company policy.
- Goals.
- Priorities.
- Importance of policies, goals, and priorities.
- The effect waste has on the environment.
- Sources of waste.
- The effect employee actions have on the environment.
- The effect of waste on profits and employee success.
- Importance of right-first-time production.
- Detrimental effects of poor housekeeping and maintenance.
- What is expected of employees.
- What employees can expect from management.
- What employees will gain in return.

An information-oriented training approach should include the following information:

- How the process works chemically and physically
- How and why processes produce waste
- Specific instructions concerning waste reduction

This document provides useful, general information for training programs. Site-specific and job-specific information must be added, however, to complete the necessary information package for a good training program.

5.4 Technology Transfer

The adoption of proven, successful pollution prevention technology is one of the most cost-effective ways to deal with environmental protection. The easiest technology transfer activities involve adoption of methods from similar operations. Adopting methods from different operations within the same industry is slightly more complex and less certain. The least certain, and most energy- and time-consuming, is the adoption of known, proven technologies from other industries. Overall, however, technology transfer is a sure way to obtain positive results with minimal investment of time and resources. This is especially true for smaller and less sophisticated operations.

A company that can pursue a large R&D effort or can make large capital investments can reasonably expect to achieve pollution prevention by investigating new technology and new science or by replacing equipment and developing new processes. That is an appropriate long-term activity. Technology transfer is extremely valuable, however, to smaller mills (and to larger mills as well) in building a framework for a pollution prevention program. The implementation of known technologies such as orderly work practices, optimization of processes, and training is fundamental to any good pollution prevention program, large or small (20).

Helpful sources of information for pollution prevention technologies include:

- State pollution prevention offices
- Compendia of case histories
- Pollution prevention libraries
- Trade associations
- Trade publications

Table 5-5 provides a brief list of the types of information that can be easily found.

Table 5-5. Sources of Case Study Information on Pollution Prevention in Textiles

Source Document/List	Number of Cases	References
Accomplishments of North Carolina Industries	55	NCDEM (1987)[a]
Leaders in Hazardous Waste Reduction	16	NCDEM (1990)
Managing and Recycling Solvents	12	NCSUCOE (1986)[b]
Pollution Prevention Case Studies	34	NCDEM (1993)
Case Studies of Waste Reduction	64	WRRC (1989)[c]
Profits of Pollution Prevention	25	NCDEM (1985)
Handbook for Using a Waste Reduction Approach To Meet Aquatic Toxicity Limits	10	NCDEM (1991)

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[a] NCDEM = North Carolina Division of Environmental Management, 3825 Barrett Drive, Raleigh, NC 27611.

[b] NCSUCOE = North Carolina State University College of Engineering, Raleigh, NC 27695.

[c] WRRC = Waste Reduction Resource Center for the Southeast; 3825 Barrett Drive, Raleigh, NC 27611.

In addition, several states and industry trade groups have established programs to educate textile retirees in the techniques of pollution prevention and then place the retirees in mills to consult on pollution prevention planning and implementation. These programs provide a valuable resource for onsite study and consultation.

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Chapter 6
Pollution Prevention Incentives and Overcoming Barriers to Pollution Prevention

The business realities of the textile industry sometimes cause companies to shift their focus away from pollution prevention. Today, textiles is an extremely fragmented and competitive business, subject to cyclical business trends. When demand is high for textile products, companies tend to focus on production volume above all else. When demand is low, capital-intensive activities such as equipment replacement and modernization are restricted, to the detriment of pollution prevention programs. In addition to the general and specific pollution prevention methods presented in Chapters 3 and 4, therefore, this chapter addresses the business considerations of pollution prevention.

In some cases, these business considerations take the form of barriers between customers and suppliers; in other cases, the considerations create internal barriers. Both types of barriers are discussed below.

6.1 The Need for Integration

One major barrier to pollution prevention in textile operations is the lack of integration in the textile industry. Textiles typically are shipped from one facility to another as they progress from raw material production stages through spinning, weaving, knitting, preparation, finishing, and cut and sew. This segregated industry structure is the source of an enormous diversity of capabilities that exist to satisfy the ever-changing needs of the apparel, furnishings, and textile specialties markets. At each processing stage, however, pollutants that were added at upstream (i.e., previous) operations may be removed, while others, with the potential to cause pollution in downstream facilities, may be added.

Textile facilities often lack the ability to influence production methods used at upstream facilities. Likewise, they have little incentive to change their own operations to reduce pollution at downstream facilities. The lack of integration in the industry means that opportunities to reduce pollution fail to be acted upon. Pollution problems caused at upstream facilities are accepted as a fact of life and textile managers concentrate on meeting orders, satisfying customer requirements, and staying competitive, not minimizing pollution at someone else's facility.

Current trends may benefit pollution prevention efforts, even among facilities that normally do not concern themselves with each other's operations. During the 1980s, the importance of customer-supplier relationships came to the forefront of U.S. manufacturing. Largely because of the emergence of concepts such as total quality management (TQM), just-in-time manufacturing, electronic data interchange, and ISO 9000 standards, customers began talking more frequently with their suppliers about issues of joint concern. Now that these lines of communication are open, these relationships with customers need to be expanded to support pollution prevention. Several current developments appear to provide the incentive for this growth.

6.1.1 ISO 14000 Environmental Standards

The ISO 9000 certification process provides a means for companies to ensure that their suppliers adhere to recognized quality management standards and have in place a sound quality management program. Even companies that have not pursued the rigors of ISO 9000 certification have embraced quality management and implemented TQM programs at their facilities. In the 1990s, many expect a TQM-type movement to develop with respect to companies' environmental management systems. As of this writing, a technical committee of the International Organization for Standardization (ISO) is overseeing the development of the ISO 14000 series of standards, which will be patterned after ISO 9000. ISO 14000 is on a fast-track development schedule and is expected to be released in 1996.

The ISO 14000 standards will focus on environmental management, rather than environmental performance. The standards will define the features of an environmental management system (EMS) that need to be in place to ensure that companies identify and focus on improving areas where they have significant environmental impacts. The idea is that if the correct type of management system is in place, performance will follow. Additional specifications in the 14000-series will cover environmental auditing, environmental labeling, environmental performance evaluation, life-cycle assessment, and product standards (1).

ISO 14000 certification could provide the basis for assessing supplier conformity with recognized standards for environmental management and for demonstrating a company's commitment to being a good "environmental citizen." This certification will provide a basis for comparing suppliers and vendors of products (2). This represents a departure from the previous emphasis on regulatory means for environmental protection (3). The variations in regulations that exist from one country or region to another are a major drawback to the regulatory approach (4). ISO 14000 is expected to provide an equitable, impartial basis for supplier relationships and certification, as well as for international environmental protection (4, 5). The standards of ISO 14000 are expected to consider not only the environmental factors involved but also the way business is conducted, hopefully without creating trade barriers (2, 3). ISO 14000 will also provide advantages in the area of economic returns and liability control.

According to preliminary reports, ISO 14000 will set standards for companies in the following areas (6):

- Developing corporate policy.
- Identifying the environmental consequences of actions and products.
- Setting clear environmental goals for all activities.
- Implementing environmental programs to achieve those goals.
- Assigning responsibility for those activities and goals.
- Informing and training employees, suppliers, and customers.
- Establishing policies and procedures to deal with incidents such as spills.
- Conducting periodic audit and review.
- Ensuring continual improvement of environmental performance.

ISO 14000 will undoubtedly be adopted first by large, multinational firms doing business in environmentally sensitive European markets. The crucial determinant of how effective ISO 14000 will become is not whether it will be adopted by manufacturers, but how effectively it will be adopted by customers as a certification tool for suppliers. If this practice becomes widespread, textile facilities may find themselves being asked about measures they are taking to reduce pollution related both to their own operations as well as to upstream and downstream operations.

6.1.2 Other Initiatives

An organization of European retailers has been formed to foster cleaner production practices among suppliers, as assessed by life-cycle analysis. This effort is called the project for the introduction of ecologically sound assortments in the retail trade (PRIMA) (7). One focus of this effort is to accurately identify the environmental burden associated with various products. This in turn encourages the development of environmentally improved products in the global sense through manufacturing, purchasing, marketing, and consumer demand/consumption of the product. Technically valid and accurate guidelines for product selection and assessment of environmental impact have been developed through close collaboration of manufacturers and retailers. As noted in Sections 4.16 and 4.17 as well as Chapter 6, involvement of retailers and consumers is a powerful pollution prevention factor, especially in view of modern trends toward demand activated manufacturing and the impact of design decisions in pollution prevention. An entity relationship diagram from the retail perspective is shown in Figure 6-1.

The PRIMA system provides a basis for comparing domestic and import suppliers; this comparison system is necessary because very different regulatory standards are often applied to suppliers of similar products. The system is based on evaluation of consumer preferences, establishment of purchasing specifications for environmentally friendly textile products, and identification of specific suppliers with superior environmental practices. The system also specifies the most environmentally benign manufacturing processes for a given retail product. Environmental and economic conse-

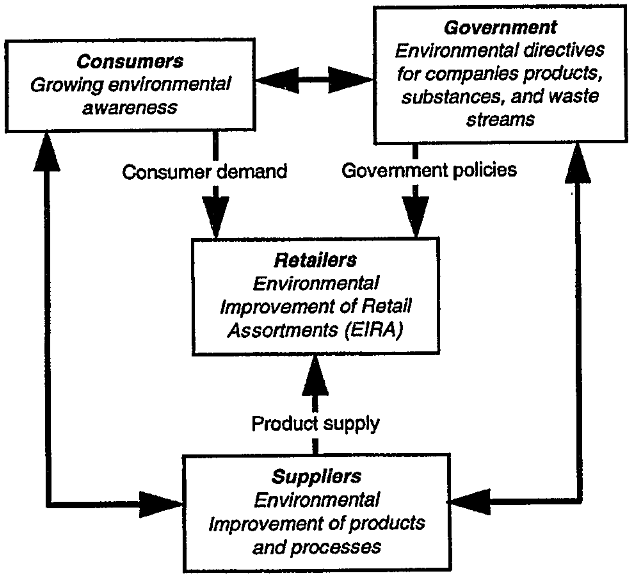

Figure 6-1. An entity relationship diagram from the retail perspective (7).

quences of various retailing policies are analyzed, and comparison of all data allow the retailer and designer to make informed choices about the optimum allocation of resources.

6.2 Business Opportunities and Pollution Prevention Needs

A good pollution prevention program should identify and exploit the market opportunities associated with pollution prevention. These opportunities, if properly pursued, not only offset the costs of pollution prevention but can lead to new business opportunities. Many companies have discovered new business opportunities as a result of their efforts to solve pollution problems. This section discusses only two of the most obvious opportunities relevant to the textile industry: the sale of waste by-products and the promotion of "green" or environmentally friendly products.

6.2.1 Marketing of Waste By-Products

Wastes are an unavoidable by-product of any manufacturing process, and many textile processes produce high volumes of waste. The term waste usually implies something without value, something that cannot be used or reused for any worthwhile purpose and that is typically discarded. Increasingly, though, companies are finding that their wastes do have value and can be reused in manufacturing processes, either within their own operations or by another firm. The sale of waste by-products from a textile operation represents a significant business opportunity that can produce income and also eliminate the costs associated with waste disposal.

Although waste by-product sale or reuse is gaining prominence in the textile industry, certain business and technical barriers restrict market opportunities. First, the value of most waste by-products is almost always less than that of the primary products. The sales incentive is therefore low for these by-products, and companies can easily lose sight of the fact that collecting and selling wastes can be a profitable venture. A further reason that wastes are undervalued is that companies may not fully account for the costs of collection and disposal, as well as the potential liability associated with some wastes. When the costs of managing these wastes are considered, the sale of waste products may become substantially more profitable.

Technical barriers also restrict the sale of waste by-products. For quality and safety reasons, many companies are reluctant to buy waste materials for use as raw materials. With so many disincentives, companies may overlook valuable opportunities, based on generalized, and often uninformed, business views about marketing wastes. Markets for industrial waste by-products are constantly improving, however, and more companies are considering potential waste reuse opportunities. Some research and development work may be necessary, however, to demonstrate the potential viability of new reuse applications.

6.2.2 Consumer Information

In addition to highlighting the potential value of waste by-products, a well-designed pollution prevention program can produce valuable information about the environmental impacts of products or processes. If properly presented, information about the environmental friendliness of products or processes can be used to educate customers, which in turn may influence their product purchases. According to studies summarized by Wagner, 70 percent of customers would choose a product based on environmental considerations if the price were the same, and 30 percent of customers say they would pay up to 20 percent extra (8). As this business tactic becomes more popular, companies increasingly recognize the marketing advantage of environmentally friendly products. Numerous textile companies have already begun promoting environmentally friendly brand names, including Burlington's Green Vista, Dyersburg's Ecosport, CRI's Green Tag, and others (8).

To use (and recycle) products properly, more information on use, installation, proper combinations of products, and inappropriate end-uses should be made available to consumers. The plastics industry is a good example of an industry that provides recycling information to consumers in the form of an easily understood code, to differentiate among different types of plastics. With textiles, product information may be important in certain cases to avoid adverse impacts on indoor air quality and other environmental concerns.

Although the sale of environmental products is gaining prominence, these green claims in advertising need to be kept in perspective. Sales and advertising departments, either deliberately or through lack of knowledge, may make incorrect, misleading, or improper claims for products. This does little to inform the public about textiles and environmental issues, and may hurt the company's image or reputation. Some have cast doubt on the objectivity of environmental claims made in clever advertising and marketing strategies (9). This issue, which depends largely on the communication between those responsible for the technical and marketing areas, is further discussed in Section 3.13, "Disinformation About Environmental Issues."

6.3 Priorities and Commitments

Upper management normally controls the resources needed to develop and operate a pollution prevention program. Commitment from upper management, therefore, is essential for a successful program (10). The first step in any pollution prevention program, and perhaps the most important, is to convince management of the importance of pollution prevention as a better way of doing business. Regulatory consequences, as well as cost and liability of waste, are major business considerations and are often the driving force that causes management to consider pollution prevention as a business strategy. Reducing waste inherently increases raw material utilization and process efficiency, and thus increases profits. In addition, regulation of waste entails enormous complexity and sometimes liability for waste generators, making waste minimization and pollution prevention the preferred business strategy (11).

To clearly establish management commitment, the first step in a pollution prevention program should be to establish pollution prevention as a clear corporate policy. The Textile Finisher's Association (United Kingdom) understood the need for recognition and commitment by upper management and formed a task force under a senior manager. This idea was endorsed, stating that "Commitment by senior management . . . was essential to ensure action" (12). Undoubtedly, many pollution prevention program managers throughout industry would echo this same sentiment.

After establishing corporate commitment, the pollution prevention program can expand to include an implementation schedule, conceptual design, identification of equipment needs, and cost estimates. Some companies have streamlined paperwork and other procedures related to pollution prevention expenditures, thus accelerating the implementation process (13). A good pollution prevention corporate policy should be formalized (written) and easy to understand, and should set achievable goals for management as well as for production workers and supervisors (14).

Most pollution prevention project initiatives show a substantial initial payback and lead to increased profits because ideas that produce the highest payback and cost the least are generally implemented first (13). Management must also accept, however, the fact that as time passes, a rigorous pollution prevention program will mean some fundamental changes in the way the company conducts business. Another important fact to recognize is that even in a modest-sized plant, the effort required to carry out successful pollution prevention programs is significant (10).

Regulatory pollution prevention programs are becoming more common. Hollod and McCartney (11) and other authors, however, have warned that regulatory pollution prevention programs are counterproductive because they may define waste reduction too narrowly and thereby lead to decreased (not increased) industry efforts. Industry has responded well to the pollution prevention challenge and has established a clear commitment without regulatory pollution prevention.

Further information on implementation can be found in Chapter 5, "Implementation of a Pollution Prevention Program."

6.4 Conflicting Goals

In business, conflicting goals often arise that make choosing among competing alternatives difficult. Pollution prevention is no exception. Usually, economic gain and pollution prevention go hand in hand because high processing efficiency and low waste are compatible goals. Also, worker attitudes that promote pollution prevention are compatible with product quality. Occasionally, however, these goals may conflict, resulting in conditions that can hamper pollution prevention efforts unless identified and resolved. Most of these conflicts are caused by policy, not technical, issues, including:

- Water conservation.
- Low biological oxygen demand (BOD) versus pass-through aquatic toxicity.
- Dye stability versus treatability.
- Quality considerations and high-value products.
- Proprietary issues.
- Segregation and capture versus disposal facilities.
- Cost.
- Marketing.

6.4.1 Water Conservation

In most municipalities, industrial sewer users pay a fee for sewer use based on a formula that includes water volume, BOD, total suspended solids (TSS), and other factors. Typical values for textile waste are (15):

- Water = 15 gallons per pound of production
- BOD = 400 parts per million (ppm)
- TSS = 25 ppm

Usually, the BOD fee is expressed as a particular amount (typically $0.25 to $0.50) per pound of BOD over a certain base concentration limit (typically 250 to 300 ppm). When water use decreases, the (constant) number of pounds of BOD is contained in less water, simultaneously raising the BOD concentration. Publicly owned treatment works (POTWs) surcharge formulas are usually written so that the cost savings resulting from water reduction are partially—and sometimes even fully—offset by an increased BOD surcharge. The reason for the increased surcharge is to defray additional operating costs because of the excess cost of treating high BOD wastewater.

Municipalities often use the above reasoning to convince mills to build expensive pretreatment facilities. In most cases, textile wastes are low in TSS but high in BOD, typically 25 ppm TSS and 400 ppm BOD before pretreatment (15). Pretreatment converts some of the BOD into suspended solids (biomass), thereby decreasing BOD but increasing the amount of TSS sent to the POTW. The net result is that the POTW still has to dispose of the same amount of sludge, and operating costs do not decrease. In essence, pretreatment at the textile mill does not accomplish anything. Municipalities should rethink this issue and not penalize mills for water conservation.

Holme (12) reports a significant U.K. study of water conservation by the Textile Finisher's Association, which concluded that water conservation would lead to higher pollutant concentrations in wastewater, and thus a revision of pollutant loading limits would be appropriate (12). Similar examples have been cited elsewhere (16).

6.4.2 Low BOD Versus Pass-Through Aquatic Toxicity

Selecting chemical specialties with the lowest possible BOD values also can reduce BOD. This leads to lower BOD in the effluent and thus reduces the sewer surcharge. As described in Sections 2.2.6, "Aquatic Toxicity," and 4.4, "Chemical Specialties," chemical specialties are the most likely to pass through POTWs and result in aquatic toxicity. The structure of POTW surcharges in many cases encourages mills to make undesirable substitutions of nondegradable/low-BOD surfactants, which pass through treatment systems and increase aquatic toxicity in the treated effluent.

6.4.3 Dye Stability Versus Treatability

Consumers have demanded dye and printed fabrics with more permanent color, so the textile industry has provided them. Dyes are now resistant to all manner of environmental agents (e.g., water, light, solvents, rubbing). In the process of becoming more permanent, however, dyes have also become resistant to treatment and now tend to pass through waste treatment systems, producing aesthetically undesirable color pollution in the receiving waters. Although generally harmless, the color pollution is highly visible and is becoming an increasing focus of regulatory agencies. Treatment systems often degrade resistant dyes, using chlorine and other agents, into colorless, though more harmful, materials.

6.4.4 Quality Considerations and High-Value Products

Pollution prevention tends to be most cost-effective wherever processing efficiency is most directly linked to the firm's bottom line. This includes most high-volume textile products, such as sheeting and denim. For a few special products, however, profitability depends almost exclusively upon product quality or exceptional styling and marketing. In these product markets, the cost of waste and waste management is relatively insignificant, and the economic incentives for reducing waste or pollution are not nearly as significant. Examples include very high-value products, such as coated fabrics for offset printing, blankets, or papermaking felts. These products sell for extremely high prices in relation to the raw material costs, and quality requirements are exceptionally rigid.

The potential loss of value because of off-quality product or seconds that may result when converting to alternate technologies is great, and waste raw materials have essentially no value compared with the product. These conditions make it difficult to convince a manufacturer to focus much attention on substituting raw materials, modifying processes, and changing designs or specifications on an already successful product. Because of the lack of economic incentive, progress on pollution prevention is slower in these market segments.

6.4.5 Proprietary Issues

Many chemical and dye suppliers attempt to keep the chemical nature and composition of materials secret, although the products they offer often are quite similar upon analysis. Nonetheless, this commercial desire for secrecy as a competitive tool creates a significant problem for the textile processor, who needs to know the chemicals being used in the process in order to implement pollution prevention measures.

This problem is increasing as some of the largest, most reputable companies adopt secrecy tactics. In addition, the large dyestuff companies are abandoning the Colour Index, a widely used listing of generic dyestuffs. This will further contribute to the lack of information and will make evaluating chemical and dye substitution possibilities more difficult and more expensive. Lack of information about chemical compositions makes substitution evaluations, especially for air and aquatic toxicity concerns, difficult or impossible. This, combined with the fact that the structure of POTW charges and regulatory administrative measures often punishes technically correct substitutions, often leads to poor decisions by chemical and dye suppliers.

6.4.6 Segregation and Capture Versus Disposal Facilities

Another example of conflicting goals occurs in waste segregation and capture. Some technologies exist that facilitate separation and capture of hazardous constituents in wastewater, thereby keeping them out of the effluent stream. If disposal of these captured hazardous concentrated wastes is illegal (which is often the case), however, then the processor has little incentive to treat the waste. Keeping hazardous waste out of sewers is often desirable but not rewarded.

6.4.7 Cost

Cost accounting practices for textile operations (and manufacturing operations in general) often fail to reward pollution prevention activities. Waste treatment and disposal costs (as well as liability) are usually considered part of overhead and are almost never allocated to the unit processes actually responsible for them.

For example, a reduction in the use of knitting oil at a knitting mill, which reduces BOD in the knit scouring and dyeing operation, will usually not be rewarded because no link is made between waste treatment costs and the use of knitting oil in the knit operations. This is a purely business, not technical, matter. The issue is discussed further in other chapters of this document, and substantial literature exists in the environmental management field that discusses this problem and ways to address it.

6.4.8 Marketing

Environmental protection sometimes increases production costs, which increases consumer costs. In some cases, product lines must be discontinued and are no longer available to the public. In one case, a manufacturer withdrew a flame retardant cotton fabric line from the market because the high cost of production resulted in a market price that was no longer competitive (17).

6.5 Risk Assessment Methods, Data, and Procedures

Many pollution prevention techniques described in this document involve tradeoffs in risk, so when mills evaluate pollution prevention techniques, they must account for the risks associated with those techniques.[1] To make reasonable risk/benefit assessments, three elements are required:

- One must be able to quantify the risk (by quantifying the exposure or concentrations present) and the hazard (i.e., the ability of the waste to damage the environment).
- One must be able to quantify the benefit.
- One must be willing to somehow trade off, replace, equate, substitute, or exchange some amount of risk for some amount of benefit.

If any one of these three is missing, the risk/benefit analysis will be flawed and pollution prevention decisions may be less than optimal.

6.5.1 Tradeoffs in Benefits and Risk

Several categories of waste were cited in Chapter 2, "Waste Categories for Pollution Prevention," including dispersable, hard-to-treat, offensive, and high-volume wastes. Table 6-1 evaluates the risks associated with each type of waste:

Table 6-1. Waste Hazards and Exposure Potentials

Type	Hazard	Exposure Potential
Dispersable	Varies	Very high
Hard-to-treat	Varies	Very high
Offensive	Very high	Varies
High-volume	Varies	Very high

- *Highly dispersable wastes:* Are likely to become widespread in the environment and present greater potential for exposure, albeit at lower concentrations if they become diluted in the process. Because these wastes are at some point well contained within the textile processing operation, the cost of preventing dispersion (and reducing risk) is generally less than the cost of treatment once the waste has been dispersed over a large area. This is especially true for wastes that are hazardous at low concentration or that are persistent or bioaccumulative.
- *Hard-to-treat wastes:* Tend to interfere with or pass through waste systems. The cost of treatment is thus relatively high, while avoidance through pollution prevention techniques is often fairly inexpensive. The main techniques for avoiding these wastes are chemical substitution and process changes.
- *Offensive wastes:* Are hazardous and can do relatively significant damage if released; require great care in storage and handling, spill control, auditing, and treatment. The risk of these materials can be reduced by substituting less-offensive (less-hazardous) materials, which do not pose similar threats.
- *High-volume wastes:* Can be costly to treat and dispose of because of the large amounts of material that require handling. In many cases, the raw materials have relatively low unit costs to treat and/or dispose of, but are present in such large amounts that their total costs are substantial. In addition, the costs of collection, transportation, and disposal, as well as the liabilities associated with these wastes, represent a

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[1] This section requires an understanding of three key terms: risk, hazard, and exposure. Risk is an exposure to a hazard. Hazard is the discharge of a material to the environment in such a way that it can affect a susceptible site (place where it can do harm). Exposure is the level or concentration of the material that is present at the susceptible site.

significant risk to the manufacturer. Pollution prevention, especially reuse and recycling, reduces these costs and liabilities and conserves raw materials that can be saved and reused in textile processing operations.

Controlling these wastes by treatment is usually more expensive than controlling the hazard or exposure using a pollution prevention approach. Each pollution prevention technique described in this document focuses on one of the three elements listed below (see Table 6-2). Each pollution prevention technique is designed to help:

- Quantify hazards or exposures and, therefore, risks
- Quantify benefits
- Evaluate tradeoffs between risks and benefits

Although the information contained in Table 6-2 is basic, it provides a framework for thinking about pollution prevention that can be useful in textile operations, especially when designing, implementing, and evaluating a pollution prevention program.

Table 6-2. Control Points for Pollution Prevention Techniques

Pollution Prevention Technique	Control Point
Design-stage planning	All
More chemical expertise	Evaluation, benefits
Equipment maintenance	Release
Global, integrated view	Evaluation, benefits
Chemical alternatives	Hazard
High extraction	Release
Incoming raw material QC	Hazard
Nonprocess chemical control	Hazard
Process alternatives	Hazard, release, benefits
Material utilization	Release
Optimized chemical handling	Release
Raw material prescreening	Hazard
Reducing disinformation	Evaluation
Risk assessment methods	Evaluation
Scheduling to minimize cleaning	Release
Standards, tests, and definitions	Evaluation
Consumer information	Evaluation
Technology transfer	Evaluation
Training programs	Evaluation, release
Waste audit	Evaluation, benefits
Segregation and reuse	Release
Improved process control	Release

6.5.2 Barriers: Known Versus Unknown

One barrier to effective pollution prevention is ignorance or insufficient understanding of one of the three elements listed above (i.e., risk quantification, benefit quantification, or evaluation of tradeoffs). Training or consultation with experts can overcome these barriers. A more difficult barrier to overcome is a lack of information on hazards, such as aquatic toxicity of a chemical or pollutant, or a lack of information about the chemical constitution of specialty processing assistants (14, 15, 18). If this basic information is missing, hazard evaluation is impossible, making the task of prioritizing pollution prevention actions more difficult.

In addition, many barriers exist because environmental burdens are not tied directly to the unit processes that are actually responsible. For example:

- Warp sizing operations contribute aquatic toxicity and BOD, which end up in the wastewater of the desizing operation. The sizing operation, however, does not participate in the cost of treating this waste.
- End-of-pipeline quality control (QC) fails to allocate the costs of defective production to specific unit process problem areas; rather it serves only as a point to discard or rework nonconforming production. Most rework or discard necessitates additional processing with associated costs, wastes, and waste treatment and disposal.
- Business policies often view each plant in a fragmented industry as a separate profit center, with little consideration of global issues. This view frustrates coordination among sites to further overall pollution prevention goals.
- A lack of standard terminology, tests, and definitions for even the most fundamental environmental properties of chemical materials inhibits communications and proper evaluation.

6.5.3 Overcoming Barriers

To design a good pollution prevention program, barriers must be overcome. Several efforts to do so are underway, and some examples are described below.

Glover and Hill (19) report good results from using computer modelling to evaluate operating costs of global pollution prevention. Their analysis (see Table 6-3) shows the relative cost of pollution in the same terms as other cost factors now in cost systems. This allows more incisive risk/benefit analysis. In addition, the computer model allows the effects of quality, energy, and other factors to be compared on a cost basis. The program also allows easy quantification of benefits, based on changes in operational parameters in a textile manufacturing operation.

Table 6-3. Computer Simulation of Cost Impacts of Pollution Prevention in Dyeing (10)

	Cost Components					
Case	**Dyes**	**Energy**	**Water**	**Chemicals**	**Effluent**	**Total**
Base case[a] Exhaust 10:1	\$43.20 38.4%	\$26.23 23.3%	\$8.23 7.3%	\$26.87 23.9%	\$8.00 7.1%	\$112.52 100.0%
Base case + 1 shading addition	\$47.52 39.9%	\$28.30 23.8%	\$8.23 6.9%	\$26.87 22.6%	\$8.12 6.8%	\$119.04 100.0%
Base case + 2 shading additions	\$51.84 41.3%	\$30.33 24.2%	\$8.23 6.6%	\$26.87 21.4%	\$8.14 6.5%	\$125.41 100.0%
Base case + strip and redye	\$86.40 37.8%	\$36.45 16.0%	\$8.50 3.7%	\$86.00 37.7%	\$10.98 4.8%	\$228.33 100.0%
Continuous: pad-dry-chem-pad-steam (Vat)	\$46.98 44.1%	\$28.03 26.3%	\$6.01 5.6%	\$18.43 17.3%	\$7.02 6.6%	\$106.47 100.0%
Process: pad-dry-bake (reactive dye)	\$29.25 34.0%	\$29.02 33.8%	\$3.65 4.2%	\$17.87 20.8%	\$6.14 7.1%	\$85.93 100.0%
Process: pad-batch (reactive dye)	\$31.32 42.3%	\$19.48 26.3%	\$3.60 4.9%	\$13.44 18.2%	\$6.12 8.3%	\$73.96 100.0%

[a] Base case = woven 100 percent cotton, singe-desize-scour-bleach-mercerize-stenter dry, 500-kg batch, continuous jet, fiber-reactive dye, portionwise addition of salt, washoff three hot rinses, LR 10:1, fixation 70 percent.

Other systems are being developed to assist in the evaluation of tradeoffs, especially when comparing chemical systems, process alternatives, or chemical alternatives (20, 21).[2] In one case, an equation is used to rate all pollutants in terms of their degradability and effect on waste treatment systems and to express the aquatic toxicity of treated effluent as a numerical value.[3] Another system ranks four attributes of each chemical (i.e., toxicity, air emissions, biodegradability, and Resource Conservation and Recovery Act [RCRA] status) (20). Another effort is underway to provide on-line electronic access via the Internet to a chemical database that includes all important pollution characteristics of chemicals, plus their interactions with each other and with substrates and processes (21). None of these systems has reached technical commercial perfection, but each indicates positive progress toward filling the information vacuum.

6.6 Human Resources

Much of this document focuses on technical solutions to pollution prevention. For an effective pollution prevention program, however, employees must have a high level of understanding of the technical processes and an awareness of pollution prevention. Developing human resources is crucial to the success of pollution prevention. In short, a good pollution prevention program goes beyond technical expertise; it requires a high degree of involvement and commitment on the part of all employees. This is a "human" approach to pollution prevention and is quite different from process tweaking, chemical alternatives, and other technical approaches to pollution prevention.

6.6.1 Workers and Supervisors

The value of enthusiastic, concerned employees in a pollution prevention program cannot be overstated. Some companies successfully use a reward system for employees who make significant pollution prevention observations or suggestions (13). By way of example and incentive, a modest water leak costs as much in 1 year as a week of paid vacation for one worker (14). The value of developing worker and supervisory expertise has been described in other chapters of this document, such as Sections 3.2, "Enhanced Chemical and Pollution Prevention Expertise," and 5.3, "Training Programs and Worker Attitudes."

6.6.2 Management and Staff

Morris reports that one company cut its waste almost in half by adding a full-time environmental manager to the staff (17). This is not an unusual case. Many companies now are allocating management and staff positions to pollution prevention, and these positions usually pay for themselves in lower waste collection costs, lower disposal and system operation costs, better production process efficiency, and better quality.

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[2] Moore, S. 1994. Personal communication between Samuel Moore of Burlington Research and Brent Smith, Department of Textile Chemistry, North Carolina State University, Raleigh, NC.

[3] See footnote 2.

Technical understanding is essential for textile managers because cost and liability (civil and criminal) are their responsibility. Pollution prevention concepts should be part of every employee's training and education programs. This applies especially to the staff who lay the groundwork for pollution prevention, such as:

- Purchasing agents
- Process designers
- Fabric designers
- Product salespeople

Pollution prevention is an area that requires interaction of workers, supervisors, engineers, chemists, managers, designers, suppliers, and customers. These human resources are necessary to tackle tough pollution reduction problems identified in this document, such as:

- Salt
- Color
- Aquatic toxicity
- Air toxicity
- Hazardous waste
- Indoor air quality

6.7 Technical Understanding of Processes

Understanding of processes is discussed from a personnel education and training point of view in Section 3.2, "Enhanced Chemical and Pollution Prevention Expertise." Everyone involved with textile manufacturing operations needs an enhanced understanding of processes on a global scale. A global view of operations, encompassing the role of suppliers, designers, unit processes, and customers is required to ensure maximum benefit from a pollution prevention program. This is not part of pollution prevention project initiation but is a long-term process that requires long-term commitment.

Bide describes the need for better technical understanding at the worker and first-line supervisor level (22). The same need exists in other parts of the textile manufacturing process. Watkins describes an emerging pollution prevention philosophy based on examining the current and future challenges related to the textile industry and targeting executives and managers, rather than the typical unit process operators and supervisors (23). The purpose of these efforts is to focus on a synergism of pollution prevention/environmental protection and sound business/profitability by globally integrating pollution prevention with product life cycle analysis (23).

A global view of operations, including suppliers, designers, unit processes, and customers, is best accomplished by approaching the highest levels of management. One purpose of this document is to provide managers with a perspective that fosters a global approach to pollution prevention, embracing designers, suppliers, and customers. This is difficult in a fragmented and competitive industry such as textiles.

6.8 References

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Chapter 7
Selected Case Studies of Pollution Prevention in the Textile Industry

This chapter presents summaries of 21 published case studies on successful implementation of pollution prevention in textile processing. These cases are from actual production settings and reflect commercial use of the concepts and methods presented in Chapters 2, 3, and 4. Hundreds of case studies have been published, and undoubtedly, many thousands of applications remain unpublished. The case studies presented in this chapter are typical, and many others are cited elsewhere in this document.

(For information on the American Textile Manufacturers Institute's program to promote pollution prevention throughout the industry, see ATMI's 1994 report on its E^3 program in Appendix A.)

Pollution Prevention Case Study: Adams-Millis, 1980

Location:	High Point, North Carolina, and Franklinton, North Carolina
General target waste:	Water
Specific target wastes:	All water pollutants, energy
Pollution prevention techniques:	Segregation, direct reuse Scheduling Audit and analysis
Unit processes:	Dyeing (batch) Water conservation
Product:	Nylon pantyhose
Summary of activities:	This mill implemented dyebath reuse for the dyeing of nylon pantyhose in rotary drum dyeing machines. Water use decreased by 35 percent with a cost savings of $0.02 per pound of production. The mill also reduced energy use by 57 percent.
Reference:	Waste Reduction Resource Center for the Southeast. 1994. Textile case studies. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: Americal Corporation, 1993

Location: Henderson, North Carolina

General target waste: Water

Specific target wastes: Biological oxygen demand (BOD), chemical oxygen demand (COD), fats, oil, and grease (FOG), ammonia-nitrogen

Pollution prevention techniques:
Design-stage planning for processes
Chemical alternatives, substitution
Incoming raw material control
Raw material prescreening
Improved process control
Goal-setting, priorities
Audit and analysis
Substitution of physical (time/temperature) factors for chemicals

Unit processes:
Raw materials—fibers
Raw materials—chemical specialties
Dyeing (batch)
Global (vendor involvement through chemical substitutions)

Product: Nylon pantyhose

Summary of activities: This company monitored incoming yarns for oil content. Alternative dyeing auxiliaries and softeners were evaluated to find less-polluting alternatives. Dyeing processes were optimized to the best temperature for maximum dye exhaust without using excessive chemical dyeing assistants. The dye process was extended for 15 additional minutes to obtain better exhaustion. Results showed approximately a 60-percent drop in BOD and COD, a 20-percent drop in FOG, and a 98-percent drop in ammonia-nitrogen. This resulted in a savings of $35,000 annually. Work continues with low-bath-ratio dyeing machines to further improve pollution prevention.

Reference: North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Amital Spinning Corporation, 1992

Location: New Bern, North Carolina

General target wastes: Water, solid

Specific target wastes: Packaging, process fiber waste

Pollution prevention techniques:

- Design-stage planning for facility
- Incoming raw material control
- Marketing wastes
- Process optimization
- Optimized chemical handling
- Segregation, direct reuse
- Incentives
- Goal-setting, priorities
- Audit and analysis
- Training, work practices

Unit processes:

- Raw materials—chemical specialties
- Raw materials—chemical commodities
- Raw materials—dyes
- Dyeing (batch, yarn)
- Global (vendor involvement through packaging swap)
- Support area improvements
- Purchasing specifications—packaging
- Water conservation

Product: Dyed high-bulk acrylic yarn

Summary of activities: Amital combined process water reuse and solid waste control activities to reduce waste and energy consumption. The company now purchases dyes and chemicals in 400-gallon intermediate bulk containers (IBCs) or in bulk. Drum disposal decreased by 69 per week, or about 3,500 annually. Pallet disposal decreased by 40 per week, or 2,000 annually. Pallet reuse and other packaging-oriented activities involve raw material suppliers, so vendors were made a partner in the reduction of packaging materials. Vendors must accept a return pallet for every pallet delivered. For internal use, Amital fabricates custom pallets designed specifically for ease of handling. Noncontact cooling water is recycled to the mix kitchen. This reduces the need to heat water for mix kitchen use. Water use decreased from 19.34 gallons per pound to 2.7, an 86-percent drop. Chemical use was optimized, and process cycle times were reduced. Solid waste recycling activities included cardboard, plastic, and acrylic yarn waste recycling. About 1.1 million pounds of solid waste were produced in 1992. Of that, about 933,000 pounds, or over 90 percent, was recovered/recycled. Total savings was estimated at over $1.5 million annually for all activities combined. Amital received the Governor's Award for Significant Pollution Prevention Achievement for these activities.

Reference: Lynn, E. 1994. Open forum. Amer. Dyestuff Reporter. 83(10):9.

Pollution Prevention Case Study: Bigelow Carpets, 1983

Location: Not disclosed

General target waste: Water

Specific target wastes: All water pollutants, water conservation

Pollution prevention techniques:
Equipment modifications
Process alternatives
Segregation, direct reuse
Scheduling

Unit processes:
Dyeing (batch, carpet)
Water conservation

Product: Carpet

Summary of activities: Dyebaths were reused by equipping pairs of dyeing machines with plumbing and pumps capable of moving a processing bath back and forth from one machine to the other. This allowed immediate reuse of dyebaths for over 20 cycles. Scheduling of lots on the pair was coordinated to ensure efficient reuse. The cost savings was $60,000 per year per pair of machines. Biological oxygen demand, color, and other water pollutants were reduced significantly.

Reference: Berganthal, J. 1984. The case for direct dyebath reuse. Carpet and Rug Industry (October). Cited in: Waste Reduction Resource Center for the Southeast. 1993. Textile case studies. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: Binny Textiles, 1984

Location: Madras, India

General target waste: Water

Specific target wastes: Filter backwash water, washwater

Pollution prevention techniques: Segregation, direct reuse

Unit processes: Support area improvements
Water conservation

Product: General textile operations

Summary of activities: Suspended solids from filter backwashing usually are easy to settle. Filter backwash was collected in a settling pond, held for 12 hours, then decanted for nonprocess uses. The settled solids were periodically collected and landfilled. This saved about 2 million gallons of water annually. In addition, internal reuse of washwater in the preparation and dyeing departments reduced water use by over 100 million gallons annually. Also, about 2.5 million gallons were saved by reusing water in the size department.

Reference: Waste Reduction Resource Center for the Southeast. 1993. Textile case studies. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: Century Textiles and Industries, 1990

Location:	Bombay, India
General target wastes:	Air, water, solid, hazardous
Specific target waste:	Sulfide
Pollution prevention techniques:	Chemical alternatives, substitution Process alternatives
Unit process:	Dyeing (continuous)
Product:	Dyed woven fabric
Summary of activities:	The company was applying sulfur dyes with the traditional sodium sulfide agents and replaced them with an alkaline glucose solution. Initially, a substitution of 61 parts of 80-percent solids glucose solution for 100 parts of 50-percent sodium sulfide was used. Handling difficulties were encountered because of the high viscosity and messy nature of 80-percent glucose solution. Further work with 65 parts of a 50-percent reducing sugar (e.g., corn sugar) waste stream from another industry was successful. Production and fastness properties of the dyed materials were not affected.
Reference:	Sharma, A.M. (no date). Unpublished study cited in: Waste Reduction Resource Center for the Southeast. 1993. Textile case studies. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: American Enka Company, 1985

Location: Enka, North Carolina

General target wastes: Air, water

Specific target wastes: Solvent emissions

Pollution prevention techniques: Segregation, recycle, direct reuse

Unit processes:
Raw materials—fiber manufacture
Yarn formation
Support area improvements

Product: Nylon yarn, polymer films

Summary of activities: American Enka uses isopropyl alcohol (IPA) in the production of polymeric film products. Attempts to use outside recovery of the IPA were not successful because of high losses (15 percent) and contamination from other materials (e.g., benzene, alkyl benzenes, chlorinated hydrocarbons, Dowtherm) that were being recovered in the same distillation operation. This is now being recycled/recovered in-house. The solvent is segregated from other wastes and distilled for production. The recovery rate is 90 percent, and the quality of recovered materials is sufficient for the production use. In addition, the still bottoms are used as an asphalt emulsifier in another product line. The annual cost savings is $90,000. The payback period for the purchase of the $7,500 distillation unit was 1 month. Air and water emissions decreased. Costs and liabilities of transporting IPA raw material and IPA waste were avoided.

Reference: Huisingh, D. 1985. Profits of pollution prevention. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Nordic Water Care Project, 1976 to 1981

Locations:	Denmark, Finland, Norway, Sweden
General target waste:	Water
Specific target waste:	Water conservation
Pollution prevention techniques:	Design-stage planning for processes Design-stage planning for facility Equipment selection Process alternatives Segregation, direct reuse
Unit processes:	All wet processes Preparation Dyeing Printing Finishing Water conservation
Product:	Dyed and finished textile fabrics
Summary of activities:	Between 1976 and 1981, 15 textile operations minimized water use in the Nordic Water Care Project. Some of the more productive and notable activities to reduce water use were as follows: drop/fill replaces overflow washing in jigs, beams, becks, and jets; automatic water flow shutoffs on continuous ranges saved about 25 percent; countercurrent washing. Horizontal washers were shown in this study to be twice as efficient as vertical washers (i.e., one horizontal washer was as efficient as two vertical washers, all having the same water consumption).
Reference:	Asnes, H. 1978. Reduction of water consumption in the textile industry. IFATCC Conference. Cited in: Waste Reduction Resource Center for the Southeast. 1993. Textile case studies. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: Hampshire Hosiery, Ellen Knitting Mills, 1985

Location: Spruce Pine, North Carolina

General target wastes: Water, energy

Specific target waste: Wastewater temperature

Pollution prevention techniques:
Design-stage planning for processes
Design-stage planning for facility
Marketing wastes
Incentives

Unit processes:
Dyeing (batch, yarn)
Global (acquisition and use of wastes from other nearby industries)
Support area improvements (boiler, wastewater handling)

Product: Hosiery

Summary of activities: High-temperature discharges from Hampshire Hosiery dyeing operations were damaging the city sewer system. Segregation of the hot water from dyeing and installation of a heat recovery unit for a cost of $100,000 allowed incoming water to be heated to 105°F from the ambient 80°F. Saved were 52,000 gallons of fuel oil per year. In another activity, the mill installed a hopper, storage silo, conveyer belt, and other handling equipment to burn sawdust from nearby furniture operations. This eliminated the need for 300,000 gallons per year of fuel oil. The sawdust is obtained at a cost of $20 per ton. Overall fuel savings is 66 percent. The boiler conversion to burn sawdust cost $800,000 and the annual savings was $225,000 for reduced fuel costs. Air quality impact was not documented, but the study reported that air pollution decreased.

Reference: Huisingh, D. 1985. Profits of pollution prevention. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Harriet & Henderson Yarns, Inc., 1993

Location:	Henderson, North Carolina; Clarkton, North Carolina; Summerville, Georgia
General target waste:	Solid
Specific target waste:	Cotton cleaning waste
Pollution prevention techniques:	Process optimization Marketing of wastes Recovery for reuse Incentives Goal-setting
Unit processes:	Yarn formation Global (marketing of wastes)
Product:	Spun cotton and cotton blend yarns
Summary of activities:	Harriet & Henderson Yarns was landfilling about 44,000 pounds of cotton cleaning waste per week at a cost of $800 per week. A goal was set to find uses for the by-product, which comprised cellulosic plant parts other than fiber as well as some cotton cellulose hairs. Processes were optimized so that less cellulose fiber was lost during processing (i.e., some of the previously discarded short fibers were recovered as fairly pure cotton lint for resale). This reduced the amount of waste by 16,000 pounds per week and provided a payback because of better raw material use. The sale of the recovered lint brought about $250 per week income and saved about $300 in landfill costs. The nonrecovered cotton trash, stems, and leaves were investigated as animal feed and soil amendment for nutrient value and erosion control. The by-product must be analyzed to ensure suitability for feedstock and to determine nutrient value. Animal feed use pays about $200 per week for 13,600 pounds of this material. The company now has a waiting list of farmers wanting to buy the material.
Reference:	North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: JP Stevens & Company, Inc., 1987

Location: Lincolnton, North Carolina

General target wastes: Water, hazardous, indoor workplace air

Specific target wastes: Aquatic toxicity, odors

Pollution prevention techniques:
Design-stage planning for facility
Equipment selection
Substitution of physical agent for chemical agent
Process alternatives
Improved monitoring and control
Goal-setting, priorities
Audit and analysis

Unit processes:
Yarn formation (carding, roving, spinning, winding)
Support area improvements (air washers)
Water conservation

Product: Yarn

Summary of activities: Ultraviolet (UV) light was substituted for chemical biocides in air washers and cooling towers in a textile mill. During a 6-month test period, extensive data were collected. Results showed improved worker safety, reduced discharge of biocides to the sanitary sewer, reduced chemical inventory and handling, workplace air quality improvements, reduced foaming and pH problems in wastewater, better air washer performance, and more consistent control of workplace air quality. UV disinfection reduced microbial populations in the air washing/cooling units to an averaage of 10^4 colony forming units per milliliter (CFU/mL) over a 6-month test period. The UV system operated with no required maintenance or repairs during the test. An alternative method using reduced UV light plus hydrogen peroxide produced similar results but was more expensive. A supplemental study (to be released later) is evaluating the addition of filters to the system. For the test system, capital costs were $4,560. Startup costs were $1,500. Based on chemical savings, the payback is 11 to 18 months. Extensive test protocol information, data, full analysis, and engineering details are presented in a 30-page report.

Reference: Smith, J.E., and R.B. Whisnant. 1988. Evaluation of a Teflon-based ultraviolet light system on the disinfection of water in a textile air washer. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Neuville Industries, Inc., 1993

Location: Hildebrand, North Carolina

General target waste: Solid

Specific target wastes: Paper, cardboard, polybags

Pollution prevention techniques:
Incoming raw material control (packing)
Segregation, recycle/reuse
Incentives
Goal-setting, priorities
Audit and analysis
Training, attitudes, work practices

Unit processes:
Fabric formation—knitting
Preparation
Dyeing (batch)
Finishing
Global (vendor involvement through packaging)
Purchasing specifications—packaging

Product: Hosiery products

Summary of activities: A recycling committee was established to reduce the solid waste disposal burden. Employee suggestions were an integral part of program initiation. Cardboard, cones, paper, scrap metal, packing materials, knitting oils, polybags, and pallets were targets. Program savings are returned as employee benefits. Waste decreased by about one-third from 266 to 180 cubic yards per week over a 2-year period, or about 4,300 cubic yards annually. The savings was $15,127 per year.

Reference: North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Riddle Fabrics, 1993

Location:	Kings Mountain, North Carolina
General target waste:	Water
Specific target waste:	Biological oxygen demand (BOD)
Pollution prevention techniques:	Chemical alternatives, substitution Process modification Segregation, direct reuse Housekeeping Audit and analysis Water conservation
Unit processes:	Preparation Water conservation
Product:	Cotton label tape
Summary of activities:	Holding tanks were installed for bleach baths, allowing reuse. The bath was reconstituted to correct strength after analysis by titration. BOD decreased over 50 percent from 842 milligrams per liter to 400 milligrams per liter. Water use also decreased. The mill came into compliance with permits and realized economic benefits.
Reference:	North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Russell Mills, 1989

Location:	Undisclosed
General target wastes:	Water, energy
Specific target wastes:	Heat recovery/reuse
Pollution prevention techniques:	Design-stage planning for processes Design-stage planning for facility Equipment maintenance Segregation, direct reuse Improved process control
Unit processes:	Preparation Dyeing Finishing Support area improvements Water conservation
Product:	Dyed and finished textile fabrics
Summary of activities:	The mill installed boiler blowdown and steam condensate recycling. The resulting savings in boiler fuel alone was $1,000 per day.
Reference:	Smith, B. 1989. Amer. Dyestuff Reporter. 78(5).

Pollution Prevention Case Study: Thiele Engdahl, 1988

Location:	Winston-Salem, North Carolina
General target wastes:	Water, air, hazardous
Specific target wastes:	Solvents, isopropyl acetate (IPAc)
Pollution prevention techniques:	Optimized chemical handling Segregation, recovery, direct reuse Nonprocess chemical control
Unit processes:	Printing Support area improvements
Product:	Printed fabric
Summary of activities:	Printing equipment was cleaned with solvents, including IPAc. Solvents were reused twice before onsite redistillation for recovery and reuse. Payback for the distillation system was 2 years. The discharge of solvents to water and air decreased.
Reference:	North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Ti-Caro, 1993

Location: Newton, North Carolina

General target waste: Water

Specific target waste: Biological oxygen demand (BOD)

Pollution prevention techniques:
Chemical alternatives, substitution
Design-stage evaluation—products
Process alternatives
Raw material prescreening
Process optimization
Audit and analysis

Unit processes:
Raw materials—chemical specialties
Fabric formation
Preparation
Dyeing (batch)
Finishing
Global (vendor involvement through prescreening)
Purchasing specifications
Water conservation

Product: Knitted fabric (dyed and finished)

Summary of activities: Ti-Caro required all suppliers to provide environmental impact statements on chemical specialties (e.g., knitting oils, softeners, emulsions, dyes) before production use. Bleaching was done by a pad-batch process, which uses much less water and energy. The bath ratio decreased on all batch processes to 10:1. All processing baths were neutralized (acid/base or redox) before discarding. In some cases, machines were double loaded by piggybacking two lots on the same dyeing machine. Also, scouring and dyeing steps sometimes were combined. Each shade was individually evaluated to determine if it required prebleaching. Water consumption was well below 10 gallons per pound, which is less than half the amount used by other knit dyers. For this reason, the City of Newton granted a modification in BOD permit limits, rewarding the water conservation efforts of the mill.

Reference: North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Ciba-Geigy Corporation, Toms River Plant, 1990

Location:	Toms River, New Jersey
General target waste:	Water
Specific target wastes:	Color, total organic carbon (TOC), laboratory wastewater, landfill leachate, process water
Pollution prevention techniques:	Design-stage planning for processes Design-stage planning for facility Equipment selection Equipment maintenance Process alternatives Optimized chemical handling Scheduling Segregation, direct reuse Improved process control Goal-setting, priorities Audit and analysis Training, work practices
Unit processes:	Raw materials—dyes Support area improvements Water conservation
Product:	Dyestuff and chemical standardization
Summary of activities:	A goal was set to reduce water from approximately 500,000 gallons per day to less than 10,000 gallons per day. Target wastewater streams were cooling water, steam quenching, process water, equipment cleaning, air washer condensate, and stormwater. The goal was achieved by an 18-step procedure over a 5-year period. Activities included recycling point sources, implementing "dry" cleaning methods, scheduling improvements, team building, and facility modification. Ultrafiltration and reverse osmosis were used as part of the study. The capital expenditure was $6 million for chillers, high-pressure cleaning equipment, plumbing and storage, ultrafiltration and reverse osmosis systems, and dust collectors. Engineering diagrams are provided in the study. Process optimization and design improvements were evaluated, especially nonproduction cleaning processes. Extensive data are presented.
Reference:	Kleinbauer, R. (no date). Standardization without effluent at Toms River. Ciba-Geigy Corporation, Toms River, NJ.

Pollution Prevention Case Study: Unidentified Company, 1985

Location: International

General target waste: Water

Specific target waste: Water conservation

Pollution prevention techniques:
Design-stage planning for processes
Design-stage planning for facility
Process alternatives
Segregation, direct reuse
Goal-setting, priorities

Unit processes:
All wet processing operations
Preparation
Dyeing
Printing
Finishing
Support area improvements
Water conservation

Product: Dyed and finished textile fabrics

Summary of activities: Water consumption was reduced by several measures over a 1-month period. Flow on wash boxes was optimized. Countercurrent flow was installed on all soapers, mercerizing range, J-boxes, etc. Washwater was reused in upstream process for less crucial uses (e.g., print blanket washing). All boiler condensate was reused as boiler feed water. Steam condensate from caustic recovery evaporator was reused in mercerizer washer. Overflow/running washes on dye jigs were replaced with static washes. Alternate oxidizer systems, which were easier to wash off, were evaluated for use on continuous vat dyeing ranges. Similar modifications were made in other processes. Water consumption in the mill decreased by 40 percent.

Reference: North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: Unidentified Company, 1982

Location: Undisclosed

General target waste: Water

Specific target waste: Size—polyvinyl alcohol (PVA)

Pollution prevention techniques:
Design-stage planning for products
Design-stage planning for processes
Chemical alternatives, substitution
Process alternatives
Segregation, direct reuse

Unit processes:
Yarn formation
Slashing and sizing
Fabric formation
Preparation
Global (combined effort in several unit processes)
Testing, analysis, monitoring

Product: Woven textile fabrics

Summary of activities: A closed-loop ultrafiltration and recycling system was installed to recover PVA. The PVA was substituted for previously used starch and other nonrecoverable sizes. The project performance was closely monitored for 16 months for pollution and textile quality performance. The capital investment was $600,000, and the operating costs were $61,000 annually. Annual savings were reported to be $420,000 for the value of recovered size, $100,000 for savings in enzymes, and $20,000 for steam savings, or a total of $540,000 annually.

Reference: North Carolina Office of Waste Reduction. 1993. Pollution prevention case studies. North Carolina Office of Waste Reduction, Raleigh, NC.

Pollution Prevention Case Study: United Piece Dye Works, 1989

Location:	Edenton, North Carolina
General target waste:	Water
Specific target wastes:	Phosphates
Pollution prevention techniques:	Design-stage planning for processes Design-stage planning for product Enhanced expertise Chemical alternatives, substitution Process alternatives Raw material prescreening Improving information Goal-setting, priorities Audit and analysis
Unit processes:	Raw materials—chemical specialties Raw materials—chemical commodities Dyeing (batch) Finishing Global (vendor involvement through prescreening) Purchasing specifications—phosphates
Product:	Dyed fabric
Summary of activities:	Sources of phosphate were identified by reviewing vendor information, especially the material safety data sheet (MSDS). Processes, products, and process chemistry were reviewed. Many substitutions of nonphosphate materials for phosphate-containing materials were made. The result was a decrease in phosphate in the effluent from 7.7 milligrams per liter to 1.0 milligram per liter.
Reference:	Schecter, R., and G. Hunt. 1989. Case summaries of waste reduction by industries in the Southeast. Waste Reduction Resource Center for the Southeast, Raleigh, NC.

Pollution Prevention Case Study: West Point Pepperell, 1985

Location: Lumberton, North Carolina

General target wastes: Hazardous and all others

Specific target wastes: Hazardous metals and all others

Pollution prevention techniques:
Chemical alternatives, substitution
Incoming raw material control
Raw material prescreening
Improving information
Audit and analysis

Unit processes:
Raw materials—chemical specialties
Raw materials—chemical commodities
Raw materials—dyes
Fabric formation
Dyeing (batch)
Finishing
Global (vendor involvement through prescreening information)
Purchasing specifications

Product: Dyed knit cotton and cotton blend fabric

Summary of activities: A committee prescreened raw material (dyes and chemicals) to ensure that offensive, toxic, and other objectionable material use were minimized in the production facility. In the event that raw materials with undesirable properties had to be used (i.e., no alternatives exist), difficult raw materials were identified to all workers before use. This process entailed no capital costs. Benefits, such as the ability to dispose of waste treatment sludges (because they do not contain objectional metals or toxics), were realized.

Reference: Huisingh, D. 1985. Profits of pollution prevention. North Carolina Office of Waste Reduction, Raleigh, NC.

Appendix A

ATMI's E^3 Program: Encouraging Environmental Excellence Report 1995

ENCOURAGING ENVIRONMENTAL EXCELLENCE REPORT 1995

Encouraging Environmental Excellence, also known as E3, was created by the American Textile Manufacturers Institute (ATMI) to advance the U.S. textile industry's already strong environmental record. Launched in 1992, E3 is a voluntary initiative that provides ATMI member companies with a forum to share ideas and strategies for dealing with environmental concerns. More important, the program challenges textile companies to further strengthen their corporate commitment to the environment.

And that commitment to preserving the environment is exceptional. Each year, U.S. textile companies invest millions of dollars to try to make sure that their processes for manufacturing textiles are environmentally friendly. In 1993, the most recent year for which data is available, the industry spent approximately $313 million on pollution controls and related equipment.

> "It's one thing for a company to say it believes in protecting the environment, it's another matter to take action and do something about it. And that's what ATMI's E3 program is all about — taking action."
>
> *— Gerald B. Andrews, E3 chairperson and president and CEO, Johnston Industries, Inc.*

"It's one thing for a company to say it believes in protecting the environment, it's another matter to take action and do something about it," notes Gerald B. Andrews, E3 chairperson and president and CEO of Johnston Industries, Inc. "And that's what ATMI's E3 program is all about — taking action. At Johnston Industries, we take the E3 program very seriously, involving everyone from the CEO to individual employees. The program has helped employees understand why environmental preservation is so important to our facilities and to our communities. For us, participating in the E3 program is good business. We wouldn't have it any other way."

HOW THE E3 PROGRAM WORKS

To qualify for E3 membership and annual recertification, an ATMI member company must be in compliance with all federal, state and local environmental laws, something they must do anyway. The E3 program, however, encourages companies to get out in front of regulations and set standards for other industries to follow.

Besides being in compliance with the law, a company must adopt a 10-point plan. The plan's guidelines require that a company develop a corporate environmental policy and set annual goals for reducing waste and conserving water and energy. In addition, a company must develop an outreach program with suppliers and customers to encourage pollution prevention and waste minimization, develop employee education and community awareness programs and audit its facilities.

At the end of each year, a company must submit a detailed report describing its progress in achieving its environmental goals and how those goals were achieved. A company also must develop new goals for the coming year.

Once a company qualifies for E3, membership renewal is not automatic. If an E3 member company violates an environmental statute, it is required to provide ATMI with a written explanation of the violation along with its plan for corrective action. ATMI reserves the right to remove a company from the E3 program if it fails to comply with an environmental statute or the program's guidelines. In 1995, 52 companies were members of the E3 program.

For companies that qualify for membership, ATMI offers its assistance by providing manuals on how to conduct environmental audits. ATMI also supplies case studies and hosts annual education seminars.

To advertise their commitment to environmental excellence, member companies can use the E3 logo and hang tag on their products. They may also contract with their customers to use the hang tag on their products, provided customers specify the cloth, yarn or thread was produced by an American textile manufacturer that promotes environmental preservation.

E3 PROGRAM GUIDELINES

The program's 10 guidelines provide the framework for a company's application to and retention in the program. Each company must meet the following guidelines:

1. Formulate and submit to ATMI a company environmental policy.
2. Describe in detail senior management's commitment toward environmental excellence and how greater environmental awareness is encouraged throughout the company.
3. Submit a copy of its environmental audit form describing how it ensures that officers and employees are in full compliance with existing laws.
4. Describe how it has worked with suppliers as well as customers to address environmental concerns.
5. List its environmental goals and targeted achievement dates.
6. Describe its employee education program.
7. Identify and describe its emergency response plans.
8. Describe how it has relayed its environmental interests and concerns to the surrounding community, residents and policymakers.
9. Describe how it has been able to offer environmental assistance and insights to citizens, interest groups, other companies and local government agencies.
10. Describe its interaction with federal, state and local policymakers.

WHO OVERSEES THE E3 PROGRAM?

The E3 program is managed by a general chairperson, an industry task force and an independent advisory board. The eight-person task force is made up of environmental engineers and public relations professionals from the industry. The group is responsible for managing the program's day-to-day operations, carrying out policy recommendations made by the advisory board and organizing educational seminars and workshops.

The advisory board is made up of nine representatives from state environmental enforcement agencies, businesses, environmental organizations and academia. The board is responsible for reviewing the criteria for the E3 program and the environmental records of member companies. Board members also are required to tour several textile facilities each year.

The success of the E3 program is due in large part to the fact that it is a voluntary initiative. What distinguishes an E3 member company is its willingness to work with government regulators, community groups and employees to address environmental issues quickly and responsibly. In fact, the industry has been recognized as a leader in environmental preservation by the Environmental Protection Agency (EPA).

EPA's WasteWi$e program is a voluntary initiative designed to encourage companies to reduce waste, which is defined as anything that is sent to a landfill. According to Lynda Wynn, manager of the WasteWi$e program, "ATMI and its members in the Encouraging Environmental Excellence program are doing an outstanding job of reducing waste and improving the environment. ATMI is one of the most proactive trade associations on pollution prevention issues, working with its members to demonstrate that conserving natural resources is good for business and for our environment."

> "ATMI is one of the most proactive trade associations on pollution prevention issues, working with its members to demonstrate that conserving natural resources is good for business and for our environment."
>
> — ***Lynda Wynn,*** *manager of EPA's WasteWi$e program*

The U.S. textile industry has also been recognized as a leader in environmental preservation by a number of state and local governments as well as by many local communities.

1995 ENVIRONMENTAL HIGHLIGHTS

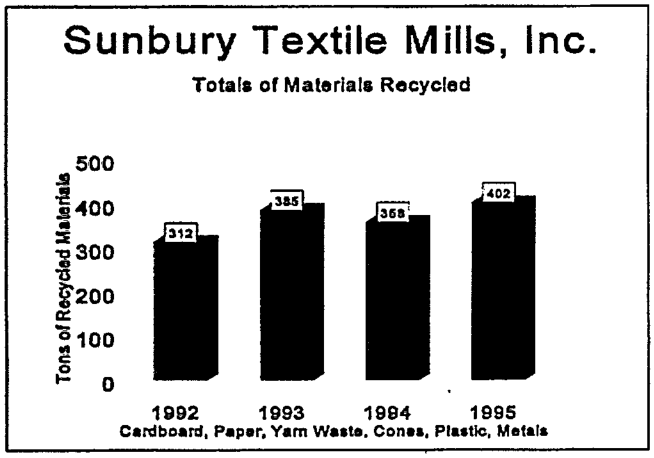
RECYCLING AND WASTE MINIMIZATION

Evidence of E3 member companies' commitment to the environment was especially strong in the recycling area. Companies recycled everything from office paper to dyes and fiber. Some textile companies helped other textile firms recycle their waste. Others recycled products — for example, soda bottles — to make new products, such as denim. Through efforts like these and others, the amount of waste sent to landfills was reduced dramatically.

When a 100-year-old textile mill and warehouse were demolished, Dan River Inc. recycled and resold roughly 4.7 million pounds of materials, including 2 million pounds of bricks and 1.2 million pounds of decking boards made from heart of pine, a wood that is all but extinct today.

Wellington Sears Company, a division of Johnston Industries, Inc., is involved in a project to compost waste fiber generated by the company's Utilization Plant, which itself is a textile recycling facility. The plant takes waste fiber and scraps from other textile and apparel manufacturing facilities and converts them into useable forms, which go into making products such as mops and mattress pads. In the process of recycling, however, additional waste is generated. So the company conducted a study to determine the feasibility of composting the waste material. The study concluded that the waste would make an excellent compost and, as a result, Wellington Sears began operating a full-scale compost facility on site. The company estimates it is keeping more than 5,000 tons of waste out of the landfill each year.

Swift Textiles, Inc. is using recycled soda bottles to make denim. The fabric contains 80 percent cotton and 20 percent polyethylene terephthalate, which comes from recycled soda bottles. The empty soda bottles are sorted by color, washed, dried and melted into pellets. The pellets are then remelted, spun into fiber and combined with cotton yarn, dyed and woven to produce the denim.



Sunbury Textile Mills, Inc. recycles 90 percent or more of its office paper, aluminum cans, drums, cones, spools, cardboard and yarn waste. Through design changes in its yarn manufacturing operation, the company reduced yarn waste in 1995 by 45 tons. The company reduced the overall amount of waste it sent to the local landfill in 1995 by 402 tons. *(See chart at left.)*

The Kent Manufacturing Company, which is in the business of manufacturing wool yarn, does not generate much landfill-bound waste. Even so, the Pickens, S.C., company enlisted the help of the county recycling department in setting up a recycling program. The company has placed a number of recycling containers throughout the organization. Each department has containers for paper, aluminum cans, plastic, fibers, cones and tubes. Before the recycling program began, Kent Manufacturing was sending an average of four dumpsters of waste a week to the county landfill. With the new program in place, the company averages just one dumpster of waste per week.

Southern Mills, Inc.'s biggest challenge was to reduce solid waste sent to local landfills. The company tackled the problem by challenging each manufacturing plant to organize a committee to work with its corporate waste reduction committee to identify what was being transported to the landfills. The result: the company discovered it was sending a lot of drums to the landfill. By working with its suppliers, Southern Mills now only uses drums that can be returned to the original vendor. The company estimates that in 1995 it saved 42,000 pounds of metal and fiber drums from being sent to the landfill.

Carolina Mills, Inc. also works with its vendors as well as its customers to reach the point where every item that comes on company grounds will be recycled. In 1995, the company reduced the amount of waste it sent to the landfill by 65 percent. Meanwhile, Fruit of the Loom reduced the amount of waste it sent to the landfill in 1995 by 2 million pounds a month.

When Fieldcrest Cannon, Inc. treats the wastewater that results from manufacturing sheets and towels, additional waste, known as biological solids, is generated. Rather than disposing of the waste at a landfill or burning it, the company gives it to local farmers, who use it as fertilizer. The waste makes an ideal fertilizer because of its high content of phosphorus and nitrogen.

Alice Manufacturing Co., Inc. no longer sends paper to the landfill since it implemented a recycling program. The company estimates that in 1995 it recycled 476,000 pounds of paper, 256,000 pounds of cardboard and 77,000 pounds of plastic bale wrap.

Unifi, Inc., with the help of Sonoco, expanded a company recycling facility, where fiber, paper, tube waste and corrugated cardboard are baled using highly automated equipment. The company recycles 95 percent or more of its aluminum cans, drums, cones, spools, packaging, plastic dye springs, cardboard, waste oil, wooden pallets and fibers.

Spartan Mills is working with its county recycling department to examine the possibility of recycling dust from fiber reclamation. The company also recycles 90 percent or more of its office paper, aluminum cans, drums, cones, spools, packaging, cardboard, wooden pallets and fibers.

A number of companies are proud of their 100 percent recycling record. Stonecutter Mills Corporation recycles 100 percent of its drums, plastic, packaging, cardboard, fluorescent bulbs, glass and waste oil. Wehadkee Yarn Mills is recycling 100 percent of its dyes, aluminum cans, drums, plastic, cones, spools, packaging, cardboard, wooden pallets and fibers.

American & Efird, Inc. has instituted a recycling program specifically for plastic. American & Efird customers can ship the company's plastic cones, spools and polybags to one of American & Efird's 11 recycling centers located around the country. These products are then consolidated and shipped to a reprocessing center.

Russell Corporation received an award from the Alabama Recycling Coalition for having the top in-house recycling program in the state. The company recycles on site 95 percent or more of its office paper, aluminum cans, drums, plastic, cones, spools, cardboard, wooden pallets, fibers and apparel waste from its cutting and sewing operations. And Artee Industries, Inc. reports that it recycles 95 percent or more of its office paper, aluminum cans, drums, plastic, cones, spools, packaging, cardboard, wooden pallets and fibers.

POLLUTION PREVENTION AND WATER AND ENERGY CONSERVATION

Pollution prevention as well as water and energy conservation were high priorities for many E3 member companies. By recycling wastewater, a number of companies saved thousands of gallons of water a week. Other actions companies took to protect the environment ranged from using chemicals and dyes that are more environmentally friendly to buying equipment that is more energy efficient.

The biggest challenge Mount Vernon Mills, Inc. faced was to help improve the operation of a 30-year-old local wastewater treatment facility. Because Mount Vernon Mills supplies almost all of the wastewater to the facility, the company funded the vast majority of an $11 million project to upgrade the facility. The company is trying to improve the quality of wastewater it sends to the treatment facility by using the most environmentally friendly dyes and chemicals and by working with its vendors to see whether some of those dyes can be recycled. In addition, by recycling packaging materials collected from its customers and reusing solid waste that is generated internally, Mount Vernon Mills has reduced the amount of waste it has sent to the landfill during the last two years by 32 percent.

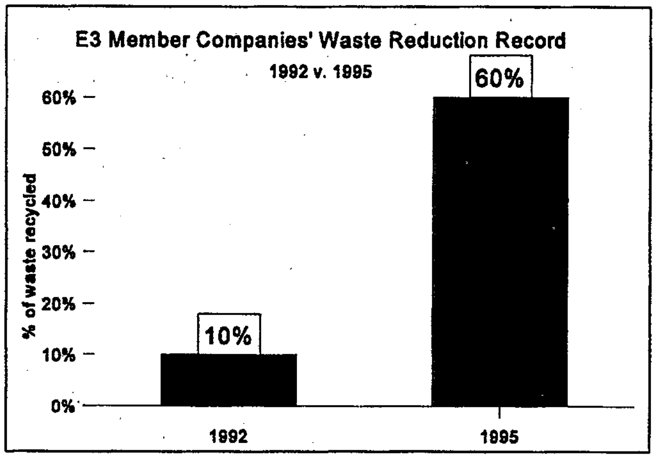
When Dixie Yarns, Inc. purchased a company in North Carolina, it inherited the environmental contamination a previous owner had left behind. Rather than waiting for the EPA to mandate action, Dixie Yarns voluntarily took steps to clean up the site. The company removed 2.3 million pounds of contaminated soil at a cost of $60,000. Dixie Yarns currently is awaiting the appropriate permits from the state so it can begin cleaning up the water, which is also contaminated.

By recycling wastewater, Mayfair Mills, Inc. estimates it saved between 4,000 and 5,000 gallons of water a week in 1995.

At Harriet & Henderson Yarns, every facility has a water tower on site, which helped the company reduce purchased water and wastewater flow by 20 percent. By reusing the water, the company also has reduced the amount of energy and chemicals it uses.

Cone Mills Corporation, which is headquartered in North Carolina, installed a color removal system to remove dye from its wastewater before the water is discharged into a local river. The state is encouraging other area companies to take similar action.

To conserve energy, Shuford Mills, Inc. installed a new dryer at its package dyeing facility. As part of the project, the company also renovated a 20,000-gallon storage tank so that hot water can be recovered during the drying process and reused in the dyeing operation.



At Armtex, Incorporated, each plant has formed an energy conservation team. The team is responsible for conducting plant audits and making recommendations for conserving energy.

Borden Manufacturing Company, in cooperation with the state power and light company, installed a computer system that notifies Borden whenever the utility company's power usage is at peak capacity. When peak capacity is reached, the computer system sounds an alarm and Borden shuts down selected equipment for a specified duration. By voluntarily reducing power consumption during peak periods, Borden has received credits on its monthly power bills. In 1995, those credits translated into a savings of several thousand dollars.

At Coats American, all utilities and production equipment are inspected regularly to spot problems and repair leaks quickly. Production is evaluated periodically against standard usage amounts to spot waste other than leaks. As a result of these inspections, the company estimates that in 1995 it saved approximately $300,000 to $500,000 on its energy bill alone.

Converting to a more energy-efficient lighting system saved Pendleton Woolen Mills 4 million kilowatt-hours in 1995, which translated into a savings of $166 million.

Burlington Industries, Inc. continued its 15-year plan to replace all of its refrigeration machines with ones that contain a more environmentally friendly refrigerant. In 1995, the company replaced 13 machines.

Belding Heminway Co., Inc. improved air quality by eliminating the use of a common ozone-depleting chemical from its manufacturing operations.

Through chemical substitutions, Collins & Aikman Products Co. has reduced SARA 313 releases by 95 percent since 1988. (SARA is the Superfund Amendments and Reauthorization

Act.) The 1986 amendments require companies to report which toxic chemicals they release into the air. The goal is to get industries to reduce the number of chemicals they emit.

By making some modifications at one of its textile finishing operations, WestPoint Stevens Inc. reduced air emissions by nearly 89 percent. As a result, the plant no longer has to apply for a permit under Title V of the Clean Air Act, the federal law that governs air emissions. Not only has the environment benefited, but WestPoint Stevens estimates that being removed from Title V will save $50,000 a year in compliance, record-keeping and personnel costs, and the plant also will be able to avoid the expensive process of applying for a Title V permit.

Because it reduced its air emissions, the New Cherokee Corporation is no longer required to file a permit with the state of Tennessee under the Clean Air Act. The company reduced emissions by eliminating the use of oil as a fuel and by designing a more efficient way to deliver dye to the production process.

ENVIRONMENTAL MANAGEMENT AND AUDITING SYSTEMS

The E3 program requires a strong commitment from senior management to protect the environment, and member companies' environmental management and auditing systems are evidence of that commitment. Environmental management and auditing, however, cannot end there. Employee involvement through education and training is also critical to the success of any company's environmental program.

The environmental manager for Johnston Industries, Inc. reports directly to the corporate vice president of operations. The environmental manager, who is a licensed engineer, is responsible for all aspects of environmental compliance, including air and wastewater permits, pollution prevention, recycling and hazardous and solid waste disposal. Each year, all facilities at Johnston Industries undergo a comprehensive environmental compliance audit. If necessary, corrective actions are scheduled and tracked until they are resolved.

Sara Lee Knit Products, a division of the Sara Lee Corporation, has an environmental awareness program in place at all of its facilities. The company tries to raise awareness about the importance of protecting the environment by periodically running articles in the company newsletter and by participating in events, such as Earth Day. The company's corporate office sponsors annual educational seminars for facility managers and environmental coordinators.

Bloomsburg Mills Inc. trained all employees on how to identify, store, handle and dispose of hazardous materials. Each plant has integrated the environmental program into its monthly safety inspections, with special emphasis on how to handle containers that are not labeled.

Although relatively few chemicals go into the manufacturing of woven fabrics, Arkwright Mills continually audits its facilities, looking for any potential chemical spills as well as possible water contamination. A report is given to the board of directors at each quarterly meeting.

Plant managers at Hamrick Mills are in constant communication with the company president about environmental issues. The company conducts voluntary walk-through inspections every month. To add credibility to the program, the company also hires independent auditors to inspect its facilities every other year.

The environmental program at Inman Mills is headed by a company vice president. The company holds monthly meetings for senior managers and plant personnel on safety and environmental issues.

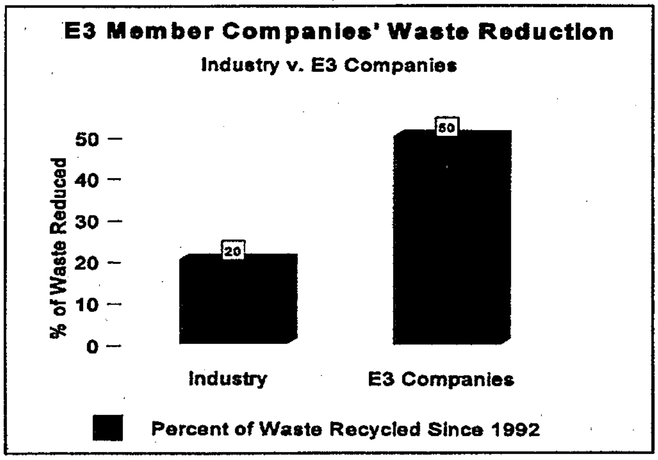
At Dominion Yarn Corporation, plants are required to immediately notify the corporate office about spills or other environmental problems. A report is sent to the director of environmental safety and health at the Dominion Yarn's parent company, Dominion Textiles, Inc. The parent company, in turn, reports this information to the board of directors.

COMMUNITY INVOLVEMENT

With policymakers and the public focusing increasingly on environmental issues, the relationship between textile companies and the communities in which they operate is more important than ever. One of the tenants of the E3 program is for each company to offer its assistance and expertise on environmental issues to others in the community, including citizens, civic organizations and schools. In turn, communities across the country have recognized the many contributions E3 member companies have made to their neighborhoods, cities and states.

Employees at Avondale Mills, Inc. teamed up with representatives from the state power company and various government and regulatory agencies to clean up a local stream so people could swim in it. In addition, a threatened species of water lily continues to thrive in sections of the stream.

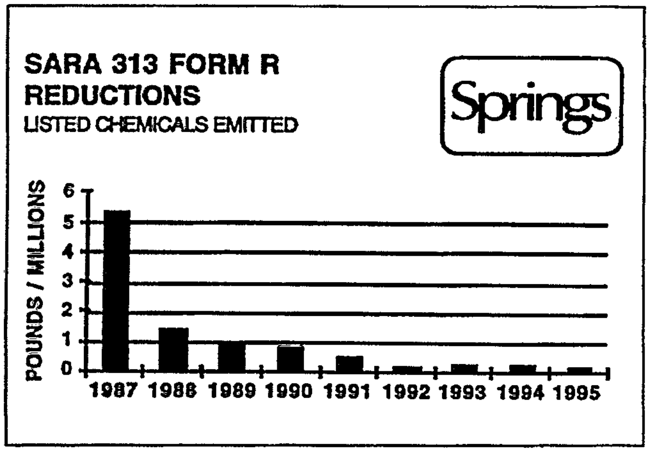
Opp and Micolas Mills, a division of Johnston Industries, Inc., sponsored a poster and coloring contest for local schools, including preschools, to teach young children about the importance of preserving the environment.


E3 Member Companies' Waste Reduction

Industry v. E3 Companies

China Grove Textiles, Inc. chose to teach young children about environmental preservation by inviting 60 fourth graders and their teachers to tour one of its plants. The children received an overview of the manufacturing process. In addition, they were told about the importance of reducing the amount of waste that is going to landfills and how they could help in that effort by recycling items at home.

Dyersburg Fabrics Inc. is active with the Boy Scouts of America, assisting young scouts in obtaining their environmental merit badge. The company also works with the National Bottling Association recycling plastic beverage bottles to make fabric from soda bottles.



Cleyn & Tinker International Inc. is involved in a venture with its local Rotary Club to recycle paper, cardboard boxes, cones and tubes. The company recycled an average of 1,000 pounds of material a month.

Guilford Mills, Inc. won the 1995 North Carolina Governor's Award for Excellence in Waste Reduction. The company won for the large business category and is only one of three companies in the state to have received an award in this category. Guilford was recognized for its significant achievements in reducing air emissions and recycling.

Milliken & Company received first place in the 1995 Keep America Beautiful National Awards in the reduce, reuse, recycle category. Keep America Beautiful is a national, non-profit public education organization that honors individuals and businesses that come up with ways to reduce waste and conserve natural resources and energy. Milliken received the award for a process it developed to clean, retexture and restyle used modular carpets so the carpets can be reused in offices, public buildings and other commercial facilities rather than being disposed of in landfills. In addition, Milliken & Company was recognized by the EPA for its outstanding performance in EPA's 33/50 Program. This voluntary pollution prevention initiative challenged companies to reduce their emissions of 17 toxic chemicals by 33 percent by 1992 and by 50 percent by 1995. Milliken reduced its emissions by 94 percent in 1995.

Renew America, a national environmental organization, recognized Springs Industries, Inc. as a national leader for its chemical reduction program and listed the program in its Environmental Success Index. In 1995, Springs reduced toxic chemicals it used by more than 96 percent. This is the second consecutive year Springs has been honored by the environmental organization. *(See chart above.)*

Thomaston Mills, Inc. and Forstmann & Company, Inc.'s Louisville, Ga., facility both received awards from the Georgia Water & Pollution Control Association (GWPCA) for having outstanding industrial biological wastewater treatment plants. The award is presented to industrial facilities that consistently demonstrate outstanding performance. This is the third time the Louisville facility has received an award from GWPCA.

The E3 Program:
Ensuring a Clean and Competitive Textile Industry

The E3 program has become one of the textile industry's most successful programs. It has changed the way companies look at their business operations by making them more aware of their environmental responsibilities. By becoming an E3 member, companies are saying that environmental preservation is the responsibility of everyone — employees, companies, communities and governments.

Protecting the environment for future generations also requires the U.S. textile industry to think globally. ATMI has been active in working with foreign governments and private organizations to develop stronger, more credible environmental labeling programs.

ATMI has also been active in developing international environmental standards, such as the International Standards Organization (ISO) 14000. The intent of ISO 14000 is to create an environmental standard that applies to all countries and minimizes trade barriers.

An example that typifies how committed companies are to the E3 program is the story of Malden Mills Industries, Inc. In December 1995, a fire destroyed 90 percent of its facility in Lawrence, Mass. In the course of rebuilding, Malden Mills has demonstrated that preserving the environment is of the utmost importance.

> "We want to maintain
> a healthy business
> without compromising
> the environment
> for future generations."
>
> — *Walter Bickford,*
> *director of the environment,*
> *health and safety department,*
> *Malden Mills Industries, Inc.*

The company believes in the philosophy of "sustainable development." Explains Walter Bickford, the company's director of the environment, health and safety department, "In addition to ensuring that our daily production processes don't compromise the environment, we also look at the broader picture and the impact on the local community. We believe in staying in the city and rejuvenating the urban economy rather than fleeing to the country to greener pastures."

As a result, Malden Mills chose to rebuild its turn-of-the-century riverfront factory. The factory, which is in the inner city, is located in a nationally registered historic district. That meant rebuilding to stricter, more expensive standards and actually expanding to rehabilitate evacuated hazardous waste sites adjacent to the property.

As part of the estimated $300 million cost to rebuild, the company is paying particularly close attention to energy conservation and waste reduction. "Being in New England, we're at the end of the energy pipeline," says Bickford. "Our winters are cold, and we use a tremendous amount of energy. Naturally, cost savings is important to us, but saving energy and raw materials are just as important."

With that in mind, the company is buying state-of-the art equipment that is more energy efficient. Also, teams of employees and managers are working together to change machine and process operations, which have reduced the amount of dye the company uses in its manufacturing operations by 30 percent.

Bickford sums up the company's involvement in E3 in this way: "We want to maintain a healthy business without compromising the environment for future generations." ■

E3 MEMBER COMPANIES — 1995

ALABAMA

Russell Corporation
Alexander City, AL

Wellington Sears Company
(as of 1996, a division of Johnston Industries, Inc.)
Valley, AL

GEORGIA

Avondale Mills, Inc.
Monroe, GA

Forstmann & Company, Inc.
Dublin, GA

Johnston Industries, Inc.
Columbus, GA

Southern Mills, Inc.
Union City, GA

Swift Textiles, Inc.
Columbus, GA

Thomaston Mills, Inc.
Thomaston, GA

Wehadkee Yarn Mills
West Point, GA

WestPoint Stevens Inc.
West Point, GA

KENTUCKY

Fruit of the Loom, Inc.
Bowling Green, KY

MASSACHUSETTS

Malden Mills Industries, Inc.
Lawrence, MA

NEW YORK

Belding-Heminway Co., Inc.
New York, NY

Bloomsburg Mills, Inc.
New York, NY

Cleyn & Tinker International Inc.
New York, NY

Frank Ix & Sons, Inc.
New York, NY

NORTH CAROLINA

American & Efird, Inc.
Mount Holly, NC

Armtex, Incorporated
Pilot Mountain, NC

Artee Industries, Inc.
Shelby, NC

Borden Manufacturing Company
Goldsboro, NC

Burlington Industries, Inc.
Greensboro, NC

Carolina Mills, Inc.
Maiden, NC

China Grove Textiles, Inc.
Gastonia, NC

Coats American
Charlotte, NC

Collins & Aikman Products Co.
Charlotte, NC

Cone Mills Corporation
Greensboro, NC

Dominion Yarn Corporation
Landis, NC

Fieldcrest Cannon, Inc.
Kannapolis, NC

Guilford Mills, Inc.
Greensboro, NC

Harriet & Henderson Yarns
Henderson, NC

The New Cherokee Corporation
Spindale, NC

Pharr Yarns, Inc.
McAdenville, NC

Sara Lee Knit Products
Winston-Salem, NC

Shuford Mills, Inc.
Hickory, NC

Stonecutter Mills Corp.
Spindale, NC

Unifi, Inc.
Greensboro, NC

OREGON

Pendleton Woolen Mills
Portland, OR

PENNSYLVANIA

Sunbury Textile Mills, Inc.
Sunbury, PA

SOUTH CAROLINA

Alice Manufacturing Co., Inc.
Easley, SC

Arkwright Mills
Spartanburg, SC

Graniteville Company
Graniteville, SC

Hamrick Mills
Gaffney, SC

Inman Mills
Inman, SC

The Kent Manufacturing Company
Pickens, SC

Mayfair Mills, Inc.
Arcadia, SC

Milliken & Company
Spartanburg, SC

Mount Vernon Mills, Inc.
Greenville, SC

Spartan Mills
Spartanburg, SC

Springs Industries, Inc.
Fort Mill, SC

TENNESSEE

Dixie Yarns, Inc.
Chattanooga, TN

Dyersburg Fabrics Inc.
Dyersburg, TN

VIRGINIA

Dan River Inc.
Danville, VA

1996 NEW E3 MEMBERS

The following ATMI companies became E3 members in 1996:

The Amerbelle Corporation
Vernon, CT

Bradford Dyeing Association
Westerly, RI

Weave Corporation
Hackensack, NJ

Greenwood Mills, Inc.
Greenwood, SC

E3 PROGRAM COMMITTEE MEMBERS — 1995

GENERAL CHAIRPERSON

William J. Armfield, IV
Unifi, Inc.

ADVISORY BOARD

CHAIRPERSON

Charles Tewksbury
Institute of Textile Technology
(retired)

VICE CHAIRPERSON

Patricia Jerman
South Carolina Wildlife Federation

MEMBERS

Robert A. Barnhardt
College of Textiles,
North Carolina State University

Paul Bowers
Georgia Power

Harry Dalton
South Carolina Sierra Club

Patricia Dillon
The Gordon Institute, Tufts University

E. Bruce Harrison, APR
E. Bruce Harrison Company, Inc.

Linda Rimer
North Carolina Department of
Environment, Health and
Natural Resources

Robert Stone
Levi Strauss, Inc. (deceased)

TASK FORCE

CHAIRPERSON

Donald Huffman
Dixie Yarns, Inc.

VICE CHAIRPERSON

R. Nick Odom, Jr.
Springs Industries, Inc.

MEMBERS

Martha Bonsal Day
Joshua L. Baily & Co., Inc.

Bryant Haskins
Burlington Industries, Inc.

John Hightower
Thomaston Mills, Inc.

James Keesler
Arkwright Mills, Inc.

T. Halliburton Wood
Wellington Sears Company

E3 PROGRAM COMMITTEE MEMBERS — 1996

GENERAL CHAIRPERSON

Gerald B. Andrews
Johnston Industries, Inc.

ADVISORY BOARD

CHAIRPERSON

Patricia Jerman
South Carolina Wildlife Federation

VICE CHAIRPERSON

Larry Martin
American Apparel
Manufacturers Association

MEMBERS

Gaylon T. Booker
National Cotton Council of America

Paul Bowers
Georgia Power

Harry Dalton
South Carolina Sierra Club

Patricia Dillon
The Gordon Institute, Tufts University

Gregory Poole
The Gap, Inc.

Linda Rimer
North Carolina Department of
Environment, Health and
Natural Resources

Michael T. Waroblak
Institute of Textile Technology

TASK FORCE

CHAIRPERSON

Donald Huffman
Dixie Yarns, Inc.

VICE CHAIRPERSON

R. Nick Odom, Jr.
Springs Industries, Inc.

MEMBERS

Bailey Barefoot
Swift Textiles, Inc.

Bryant Haskins
Burlington Industries, Inc.

James Keesler
Arkwright Mills, Inc.

Arthur Toompas
Cone Mills Corporation

T. Halliburton Wood
Johnston Industries, Inc.

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References in bold type indicate a general discussion of the entry topic.

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