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Profile of the Textile Industry

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TEXTILE INDUSTRY
(SIC 22)
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II. INTRODUCTION TO THE TEXTILE INDUSTRY

This section provides background information on the history, size, geographic distribution, employment, production, sales, and economic condition of the textile industry. The facilities described within the document are described in terms of their Standard Industrial Classification (SIC) codes.

II.A. History of the Textile Industry

The textile industry is one of the oldest in the world. The oldest known textiles, which date back to about 5000 B.C., are scraps of linen cloth found in Egyptian caves. The industry was primarily a family and domestic one until the early part of the 1500s when the first factory system was established. It wasn't until the Industrial Revolution in England, in the 18th century, that power machines for spinning and weaving were invented. In 1769 when Richard Arkwright's spinning frame with variable speed rollers was patented, water power replaced manual power (Neefus, 1982).

In the early 17th century of colonial America, textiles were primarily manufactured in New England homes. Flax and wool were the major fibers used, however, cotton, grown primarily on southern plantations, became increasingly important (Wilson, 1979). In 1782 Samuel Slater, who had worked as an apprentice to Arkwright's partner, emigrated to America. In Blackstone River, Rhode Island, he started building Arkwright machines and opened the first English-type cotton mill in America (ATMI, 1997a). In the early nineteenth century, in Lowell, Massachusetts, the first mill in America to use power looms began operations. It was the first time that all textile manufacturing operations had been done under the same roof (Wilson, 1979 and ATMI, 1997a).

The twentieth century has seen the development of the first manmade fibers (rayon was first produced in 1910). Although natural fibers (wool, cotton, silk, and linen) are still used extensively today, they are more expensive and are often mixed with manmade fibers such as polyester, the most widely used synthetic fiber. In addition, segments of the textile industry have become highly automated and computerized (ATMI, 1997a).

The textile industry is characterized by product specialization. Most mills only engage in one process or raw material. For example, a mill may be engaged in either broadloom weaving of cotton or broadloom weaving of wool. Similarly, many mills specialize in either spinning or weaving operations, although larger integrated mills may combine the two operations. These large mills normally do not conduct their own dyeing and finishing operations. Weaving, spinning, and knitting mills usually send out their fabrics to one of the approximately 500 dyeing and finishing plants in the United States (EPA, 1996).

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III. INDUSTRIAL PROCESS DESCRIPTION

This section describes the major industrial processes in the textile industry, including the materials and equipment used and the processes employed. The section is designed for those interested in gaining a general understanding of the industry, and for those interested in the interrelationship between the industrial process and the topics described in subsequent sections of this profile -- pollutant outputs, pollution prevention opportunities, and Federal regulations. This section does not attempt to replicate published engineering information that is available for this industry. Refer to Section IX for a list of reference documents that are available. Note also that Section V, Pollution Prevention Opportunities, provides additional information on trade-offs associated with the industrial processes discussed in this section.

This section describes commonly used production processes, associated raw materials, the byproducts produced or released, and the materials either recycled or transferred off-site. This discussion identifies where in each process wastes may be produced. This section concludes with a description of the potential fate (via air, water, and soil pathways) of process-specific waste products.

III.A. Industrial Processes in the Textile Industry

Much of the following section is based upon *"Best Management Practices for Pollution Prevention in the Textile Industry,"* published by the U.S. EPA Office of Research and Development. Additional references are cited in the text.

The textile industry is comprised of a diverse, fragmented group of establishments that produce and/or process textile-related products (fiber, 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. 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 and weaving, or among production of manmade, cotton, and wool fabrics. The primary focus of this section is on weaving and knitting operations, with a brief mention of processes used to make carpets.

In its broadest sense, the textile industry includes the production of yarn, fabric, and finished goods. This section focuses on the following four production stages, with a brief discussion of the fabrication of non-apparel goods:

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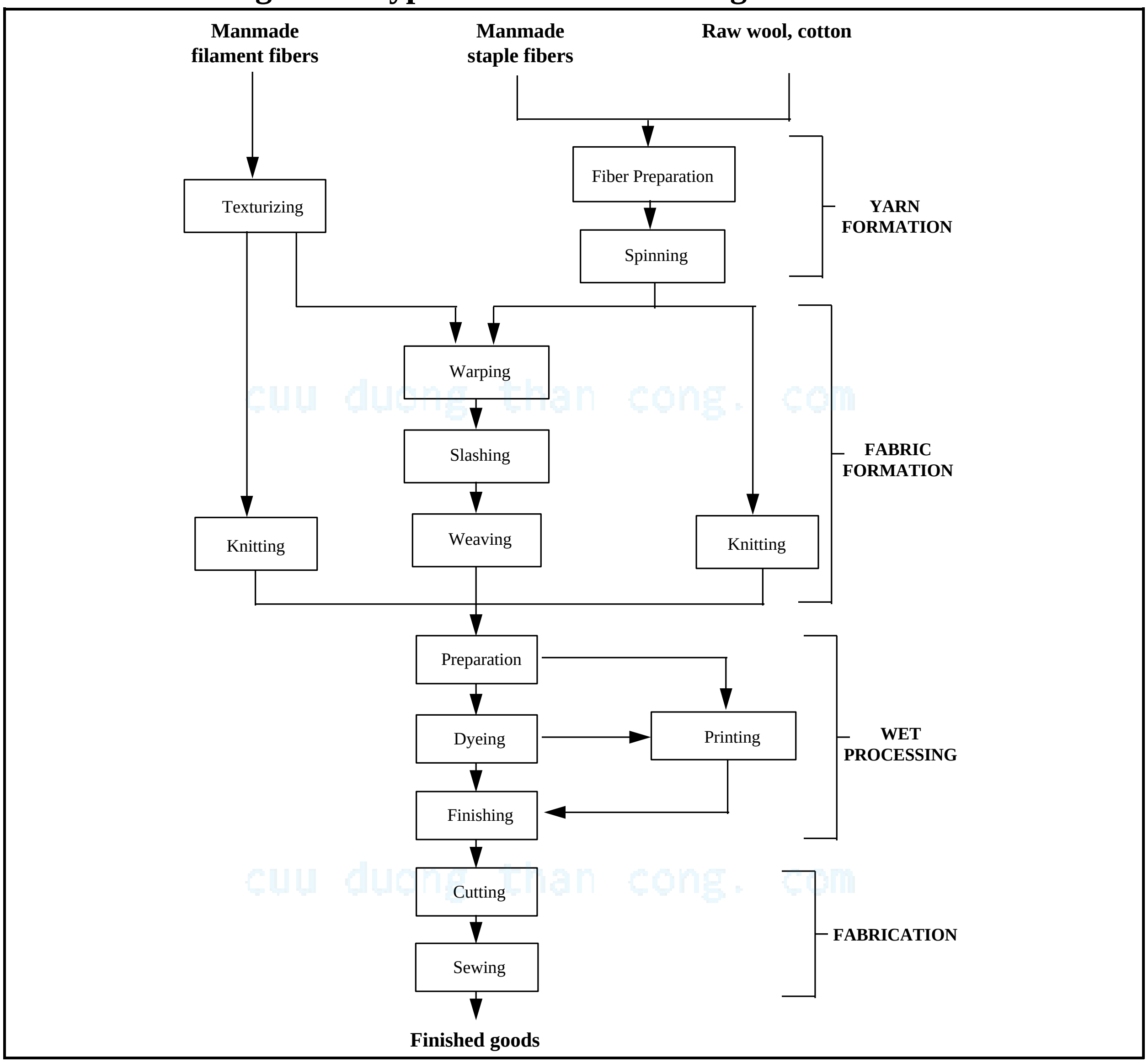
1) yarn formation
2) fabric formation
3) wet processing
4) fabrication

These stages are highlighted in the process flow chart shown in Figure 2 and are discussed in more detail in the following sections.

Figure 2: Typical Textile Processing Flow Chart



Source: ATMI, Comments on draft of this document, 1997b.

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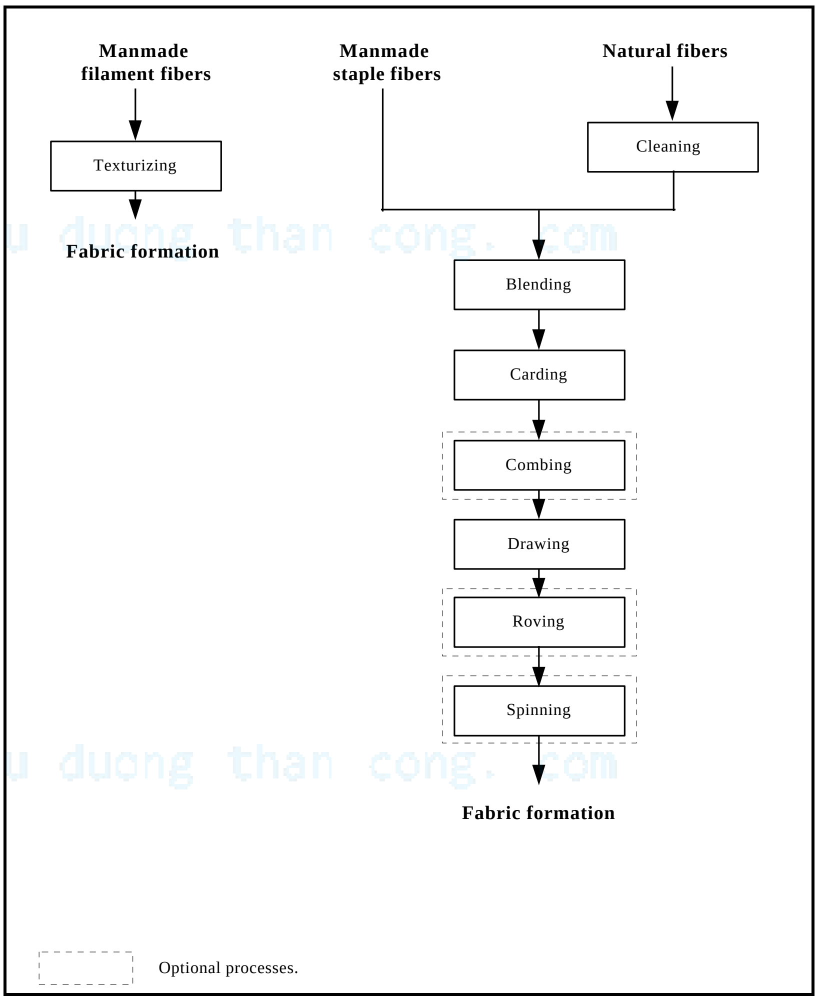
III.A.1. Yarn Formation

Textile fibers are converted into yarn by grouping and twisting operations used to bind them together. Although most textile fibers are processed using spinning operations, the processes leading to spinning vary depending on whether the fibers are natural or manmade. Figure 3 shows the different steps used to form yarn. Note that some of these steps may be optional depending on the type of yarn and spinning equipment used. Natural fibers, known as staple when harvested, include animal and plant fibers, such as cotton and wool. These fibers must go through a series of preparation steps before they can be spun into yarn, including opening, blending, carding, combing, and drafting.

Figure 3: Yarn Formation Processes



Source: ATMI, 1997.

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Manmade fibers may be processed into filament yarn or staple-length fibers (similar in length to natural fibers) so that they can be spun. Filament yarn may be used directly or following further shaping and texturizing. The main steps used for processing natural and manmade fibers into yarn are below.

Natural Fibers

Yarn formation can be performed once textile fibers are uniform and have cohesive surfaces. To achieve this, natural fibers are first cleaned to remove impurities and are then subjected to a series of brushing and drawing steps designed to soften and align the fibers. 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.* Opening of bales sometimes occurs in conjunction with the blending of fibers. 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 are conveyed by air stream to a carding machine, which transports the fibers 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 that 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, whereas 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 yarns are finer (smaller) than yarn that

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has not been combed because of the higher degree of fiber alignment and further removal of short fibers.

- *Drawing.*Several slivers are combined into a continuous, ropelike strand and fed to a machine known as a drawing frame (Wingate, 1979). 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. Once a sliver has been drawn, it is termed a roving.

- *Drafting.* Drafting is a process that uses a frame to stretch the yarn further. This process imparts a slight twist as it removes the yarn and winds it onto a rotating spindle. The yarn, now termed a roving in ring spinning operations, is made up of a loose assemblage of fibers drawn into a single strand and is about eight times the length and one-eighth the diameter of the sliver, or approximately as wide as a pencil (Wingate, 1979). Following drafting, the rovings may be blended with other fibers before being processed into woven, knitted, or nonwoven textiles.

- *Spinning.* The fibers are now spun together into either spun yarns or filament yarns. Filament yarns are made from continuous fine strands of manmade fiber (e.g. not staple length fibers). Spun yarns are composed of overlapping staple length fibers that are bound together by twist. Methods used to produce spun yarns, rather than filament yarns, are discussed in this section. The rovings produced in the drafting step are mounted onto the spinning frame, where they are set for spinning. The yarn is first fed through another set of drawing or delivery rollers, which lengthen and stretch it still further. It is then fed onto a high-speed spindle by a yarn 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. The yarn is collected on a bobbin.

  In ring spinning, the sliver is fed from delivery rollers through a traveler, or wire loop, located on a ring. The rotation of the spindle around the ring adds twist to the yarn. This is illustrated in Figure 4(1). Another method, shown in Figure 4(2), is open-end spinning, which accounts for more than 50 percent of spinning equipment used (ATMI, 1997b). In this method, sliver passes through rollers into a rotating funnel-shaped rotor. The sliver hits the inside of the rotor and rebounds to the left side of the rotor, causing the sliver to twist. Open-end spinning does not use rotating spindles since the yarn is twisted during passage through the rotor.

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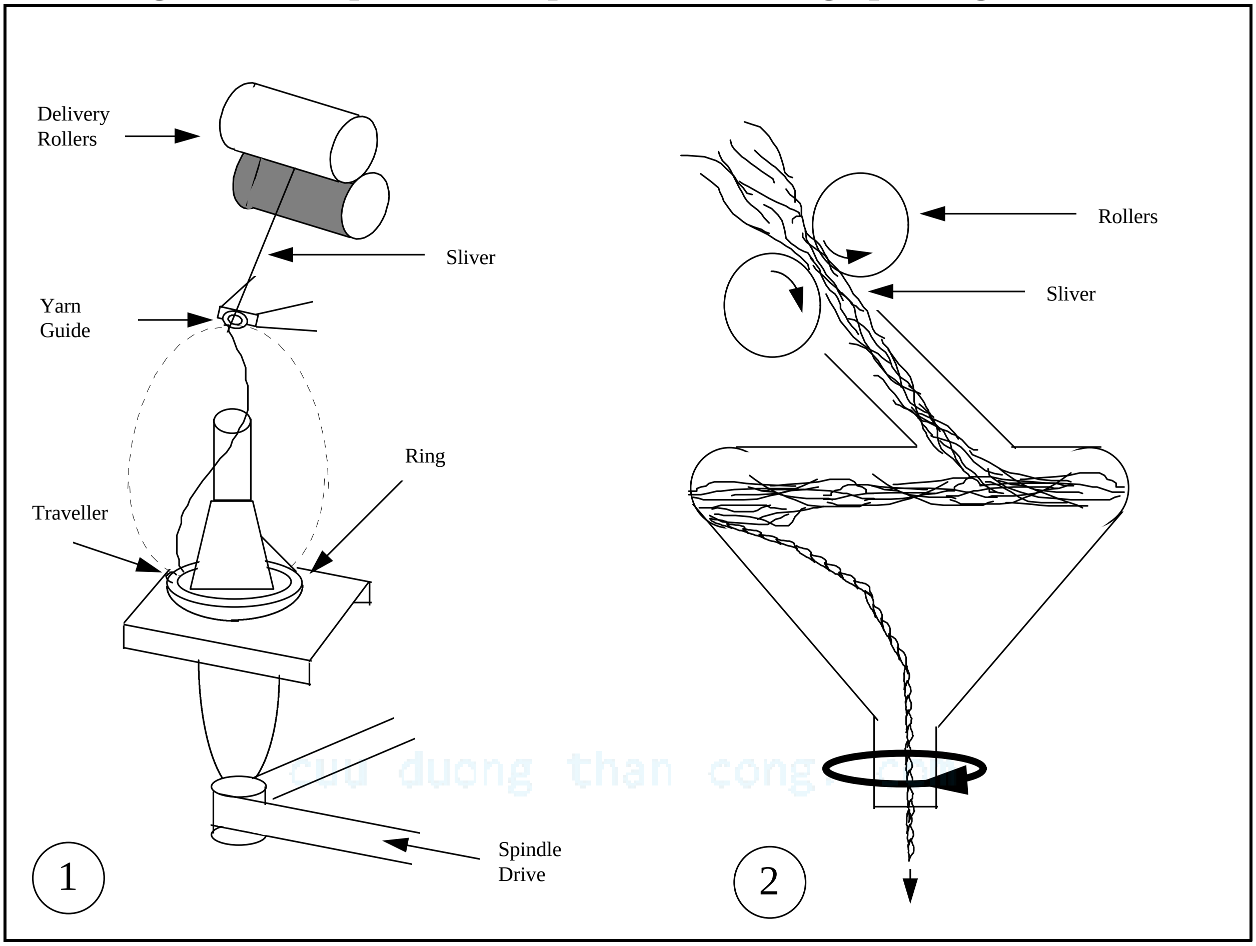
Figure 4: Comparison of Open-End and Ring Spinning Methods



Source: B.P. Corbman, *Textiles: Fiber to Fabric*, McGraw-Hill, Inc., 1975.

Yarn spinning is basically an extension of the preparation steps described above for natural fibers. Additional twisting 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.

Manmade Fibers

Although not classified under SIC 22, manmade fiber production is briefly discussed in the following paragraphs to describe the upstream processing of textiles. Manmade fibers include 1) cellulosic fibers, such as rayon and acetate, which are created by reacting chemicals with wood pulp; and 2) synthetic fibers, such as polyester and nylon, which are synthesized from

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organic chemicals. Since manmade fibers are synthesized from organic chemicals, yarn formation of manmade fibers does not involve the extensive cleaning and combing procedures associated with natural fibers. Manmade fibers, both synthetic and cellulosic, are manufactured using spinning processes that simulate or resemble the manufacture of silk. Spinning, in terms of manmade fiber production, is the process of forming fibers by forcing a liquid through a small opening beyond which the extruded liquid solidifies to form a continuous filament. Following spinning, the manmade fibers are drawn, or stretched, to align the polymer molecules and strengthen the filament. Manmade filaments may then be texturized or otherwise treated to simulate physical characteristics of spun natural fibers. Texturizing is often used to curl or crimp straight rod-like filament fibers to simulate the appearance, structure, and feel of natural fibers. (For more information on the synthesis of manmade fibers, refer to the EPA Industrial Sector Notebook on Plastic Resins and Manmade Fibers.)

Spun yarns are created using manmade fibers that have been cut into staple-length fibers. Staple-length fibers are then used to process fibers on wool or cotton-system machinery. Methods for making spun yarn from manmade fibers are similar to those used for natural fibers. Some fibers are processed as tow, or bundles of staple fibers.

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Fibers can also be produced as filament yarn, which consists of filament strands twisted together slightly. In mills, filament fibers are wound onto bobbins and placed on a twisting machine to make yarn. Filament yarns may be used directly to make fabric or further twisted to the desired consistency. Manmade filaments often require additional drawing and are processed in an integrated drawing/twisting machine. Manmade filaments are typically texturized using mechanical or chemical treatments to impart characteristics similar to those of yarns made from natural fibers.

III.A.2. Fabric Formation

The major methods for fabric manufacture are weaving and knitting. Figure 5 shows fabric formation processes for flat fabrics, such as sheets and apparel. Weaving, or interlacing yarns, is the most common process used to create fabrics. Weaving mills classified as broadwoven mills consume the largest portion of textile fiber and produce the raw textile material from which most textile products are made. Narrow wovens, nonwovens, and rope are also produced primarily for use in industrial applications. Narrow wovens include fabrics less than 12 inches in width, and nonwovens include fabrics bonded by mechanical, chemical, or other means. Knitting is the second most frequently used method of fabric construction. The popularity of knitting has increased in use due to the increased versatility of techniques, the adaptability of manmade fibers, and the growth in consumer demand for wrinkle-resistant, stretchable, snug-fitting fabrics. Manufacturers of knit

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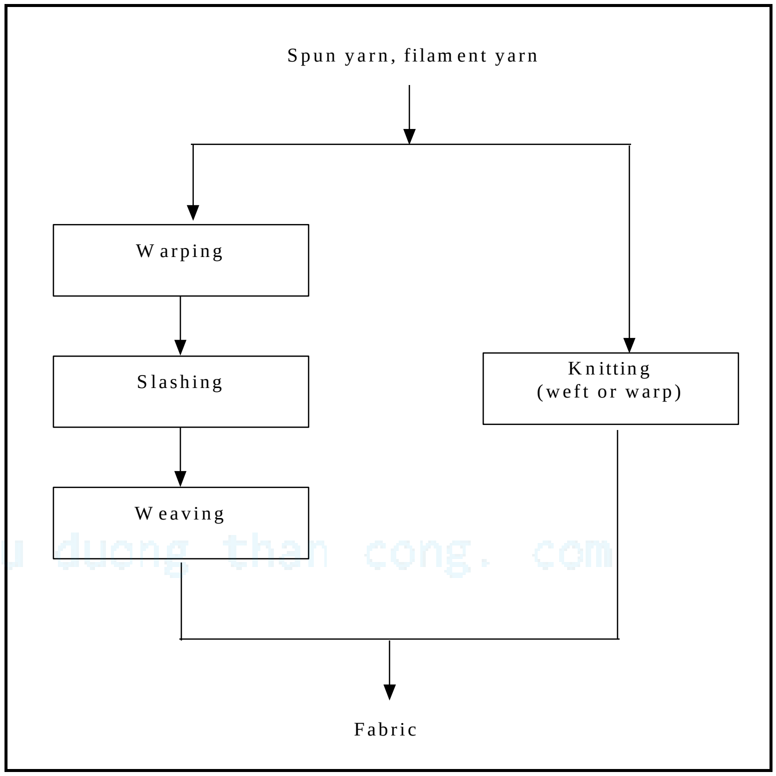
fabrics also consume a sizable amount of textile fibers. Knit fabrics are generally classified as either weft knit (circular-knit goods) or warp knit (flat-knit goods). Tufting is a process used to make most carpets.

Figure 5: General Fabric Formation Processes Used for Producing Flat Fabrics



Source: ATMI, 1997.

Weaving

Weaving is performed on modern looms, which contain similar parts and perform similar operations to simple hand-operated looms. Fabrics are formed from weaving by interlacing one set of yarns with another set oriented crosswise. Figure 6 shows an example of satin weave patterns. Satin, plain, and twill weaves are the most commonly used weave patterns. In the weaving operation, the length-wise yarns that form the basic structure of the fabric are called the warp and the crosswise yarns are called the filling, also referred to as the weft. While the filling yarns undergo little strain in the weaving process, warp yarns undergo much strain during weaving and must be processed to prepare them to withstand the strain (Corbman, 1975).

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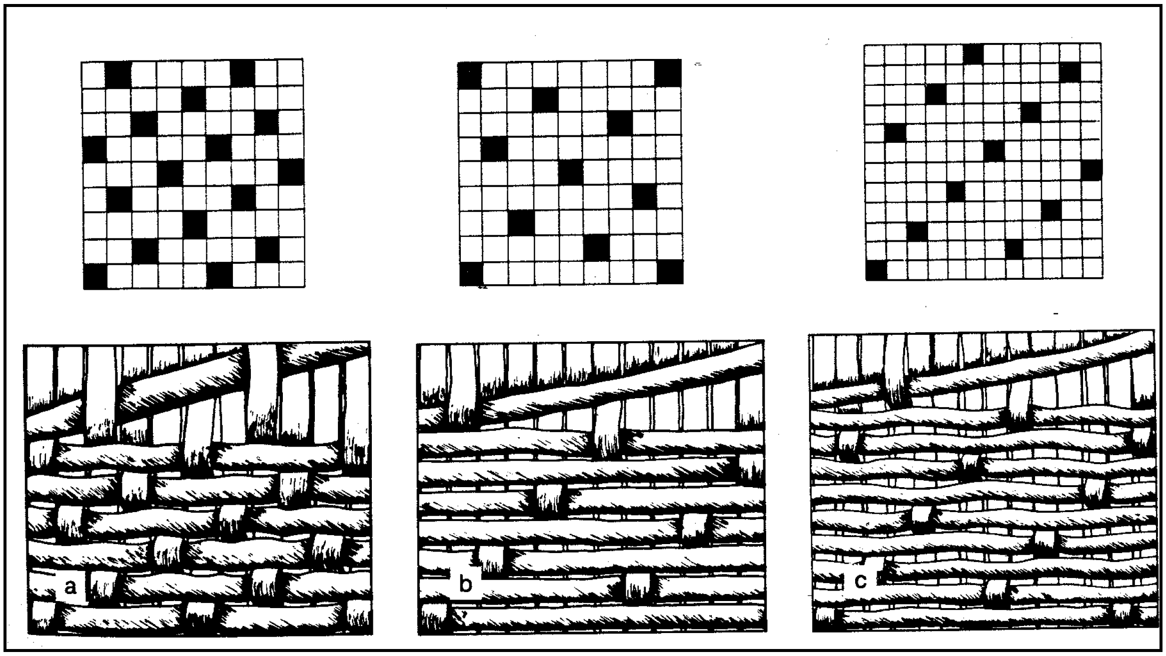
Figure 6: Examples of Satin Weaving Patterns



Source: B.P. Corbman, *Textiles: Fiber to Fabric*, McGraw-Hill, Inc., 1975.

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Before weaving, warp yarns are first wound on large spools, or cones, which are placed on a rack called a creel. The warp yarns are then unwound and passed through a size solution (sizing/slashing) before being wound onto a warp beam in a process known as beaming. The size solution forms a coating that protects the yarn against snagging or abrasion during weaving. Slashing, or applying size to the warp yarn, uses pad/dry techniques in a large range called a slasher. The slasher is made up of the following: a yarn creel with very precise tension controls; a yarn guidance system; and a sizing delivery system, which usually involves tank storage and piping to the size vessels. The yarn sheet is dipped one or more times in size solution and dried on hot cans or in an oven. A devise called a "lease" is then used to separate yarns from a solid sheet back into individual ends for weaving (EPA, 1996).

Starch, the most common primary size component, accounts for roughly two-thirds of all size chemicals used in the U.S. (130 million pounds per year). Starch is used primarily on natural fibers and in a blend with synthetic sizes for coating natural and synthetic yarns. Polyvinyl alcohol (PVA), the leading synthetic size, accounts for much of the remaining size consumed in the U.S. (70 million pounds per year). PVA is increasing in use since it can be recycled, unlike starch. PVA is used with polyester/cotton yarns and pure cotton yarns either in a pure form or in blends with natural and other synthetic sizes. Other synthetic sizes contain acrylic and acrylic copolymer components. Semisynthetic sizes, such as carboxymethyl cellulose (CMC) and modified starches, are also used. Oils, waxes, and other additives are

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often used in conjunction with sizing agents to increase the softness and pliability of the yarns. About 10 to 15 percent of the weight of goods is added as size to cotton warp yarns, compared to about 3 to 5 percent for filament synthetics.

Once size is applied, the wound beam is mounted in a loom. Shuttle looms are rapidly being replaced by shuttleless looms, which have the ability to weave at higher speeds and with less noise. Shuttleless looms are discussed in the next section. The operation of a traditional shuttle loom is discussed in this section to illustrate the weaving process.

The major components of the loom are the warp beam, heddles, harnesses, shuttle, reed, and takeup roll (see Figure 7). In the loom, yarn processing includes shedding, picking, battening, and taking up operations. These steps are discussed below.

- *Shedding.* Shedding is the raising of the warp yarns to form a shed through which the filling yarn, carried by the shuttle, can be inserted. The shed is the vertical space between the raised and unraised warp yarns. On the modern loom, simple and intricate shedding operations are performed automatically by the heddle frame, also known as a harness. This is a rectangular frame to which a series of wires, called heddles, are attached. The yarns are passed through the eye holes of 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 (Corbman, 1975).

- *Picking.* As the harnesses raise the heddles, which raise the warp yarns, the shed is created. The filling yarn in inserted through the shed by a small carrier device called a shuttle. The shuttle is normally pointed at each end to allow passage through the shed. In a traditional shuttle loom, the filling yarn is wound onto a quill, which in turn is mounted in the shuttle. The filling yarn emerges through a hole in the shuttle as it moves across the loom. A single crossing of the shuttle from one side of the loom to the other is known as a pick. As the shuttle moves back and forth across the shed, it weaves an edge, or selvage, on each side of the fabric to prevent the fabric from raveling.

- *Battening.* As the shuttle moves across the loom laying down the fill yarn, it also passes through openings in another frame called a reed (which resembles a comb). With each picking operation, the reed presses or battens each filling yarn against the portion of the fabric that has already been formed. Conventional shuttle looms can operate at speeds of about 150 to 160 picks per minute.

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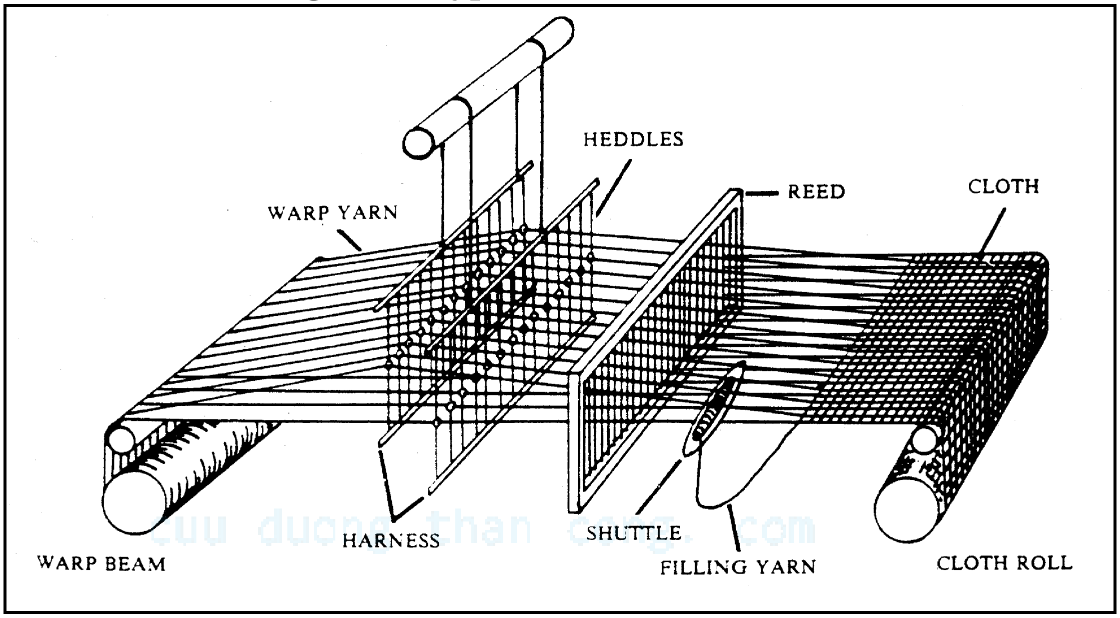
- *Taking up and letting off.* With each weaving operation, the newly constructed fabric must be wound on a cloth beam. This process is called taking up. At the same time, the warp yarns must be let off or released from the warp beams (Corbman, 1975).

Figure 7: Typical Shuttle Loom



Source: I.B. Wingate, *Fairchild's Dictionary of Textiles,* Fairchild Publications, Inc., 1979.

Shuttleless Looms

Because the shuttle can cause yarns to splinter and catch, several types of shuttleless looms have been developed. These operate at higher speeds and reduced noise levels. By the end of 1989, shuttleless looms represented 54 percent of all looms installed, up from 15 percent in 1980. Shuttleless looms use different techniques to transport cut pieces of fill yarn across the shed, as opposed to the continuous yarn used in shuttle looms.

Some of the common shuttleless looms include water-jet looms, air-jet looms, rapier looms, and projectile 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 use a blast of air to move the fill yarn and can operate at speeds of 800 to 1000 picks per minute. 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 to make cotton and woolen/worsted fabrics. In a double rapier loom, two rods

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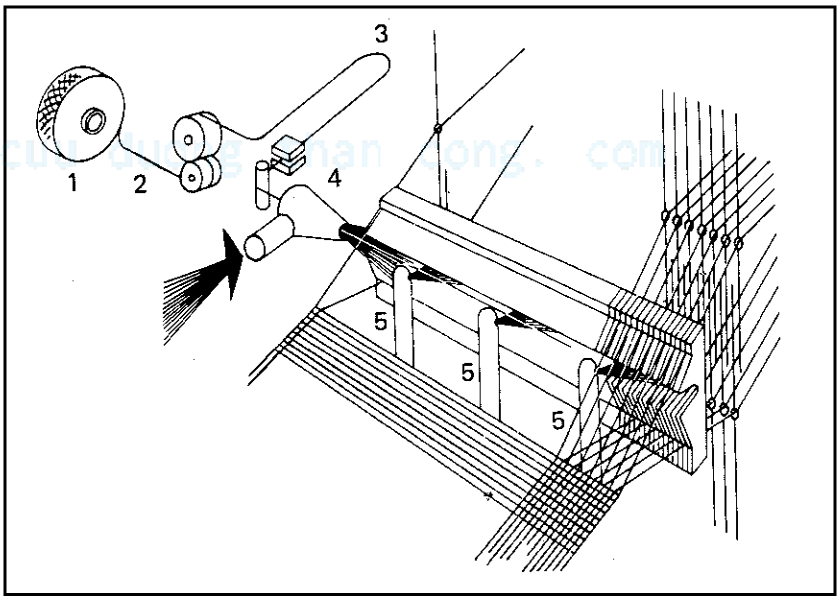
move from each side and meet in the middle. The fill yarn is carried from the rod on the fill side and handed off to the rod on the finish side of the loom. Projectile looms use a projectile to carry the fill yarn across the weave.

Shuttleless looms have been replacing the traditional fly-shuttle loom in recent years. Air looms, although limited in the types of filling yarns they can handle, are increasing in commercial use. The operation of an air jet loom is shown in Figure 8. As shown in the figure, yarn is drawn from the yarn package (1) by the measuring wheel and drive roller arrangement (2). Between the yarn package and the measuring wheel is a tube through which an air current flows in opposite direction to the yarn. This maintains a straight even feed of yarn. The yarn then forms a loop (3) which shortens as the pick penetrates further into the shed. The main jet (4) is the major projecting force for the yarn, although supplementary jets (5) are activated to prevent the pick from buckling.

Figure 8: Typical Air Jet Loom



Source: A. Ormerod, *Modern Preparation and Weaving Machinery,* Butterworths, 1983.

Knitting

Knitted fabrics may be constructed by using hooked needles to interlock one or more sets of yarns through a set of loops. The loops may be either loosely or closely constructed, depending on the purpose of the fabric. Knitted fabrics can be used for hosiery, underwear, sweaters, slacks, suits, coats, rugs, and other home furnishings. Knitting is performed using either weft or warp processes, depicted in Figure 9. In weft (or filling) knitting, one yarn is carried back and forth and under needles to form a fabric. Yarns run

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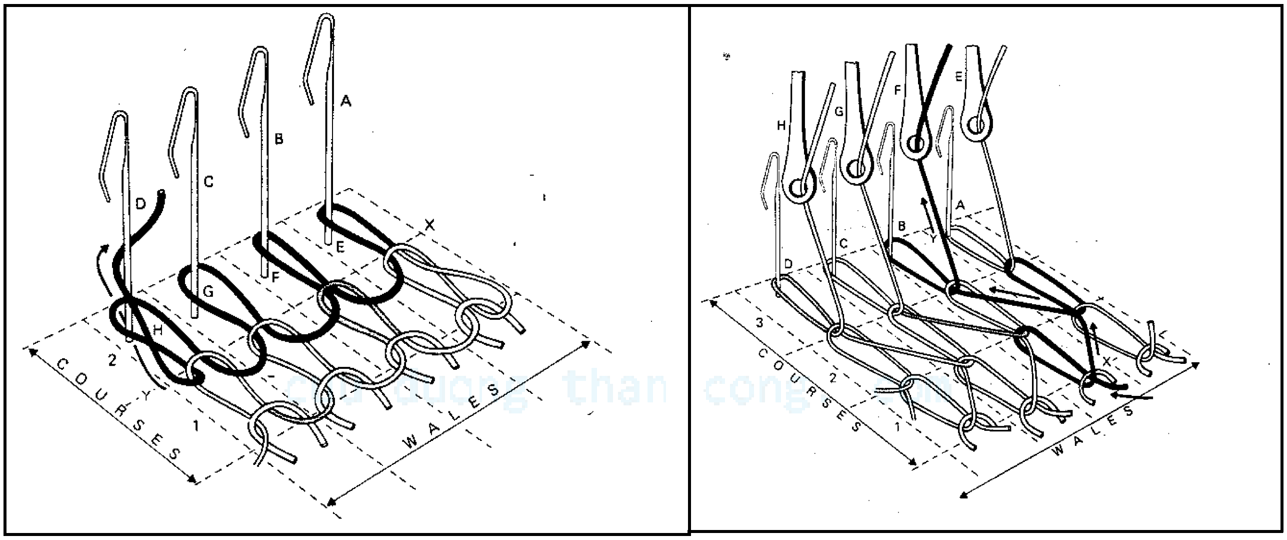
horizontally in the fabric, and connections between loops are horizontal. In warp knitting, a warp beam is set into the knitting machine. Yarns are interlocked to form the fabric, and the yarns run vertically while the connections are on the diagonal. Several different types of machinery are used in both weft and warp knitting.

Figure 9: Comparison Between Warp and Weft Knitting Methods

(a) Weft **(b) Warp**



Source: D.J. Spencer, *Knitting Technology,* Pergamon Press, 1989.

- *Weft knitting.* Weft knitting uses one continuous yarn to form courses, or rows of loops, across a fabric. There are three fundamental stitches in weft knitting: plain-knit, purl, and rib. On a machine, the individual yarn is fed to one or more needles at a time. 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. Warp knitting differs from weft knitting in that each needle loops its own thread. The needles produce parallel rows of loops simultaneously that are interlocked in a zigzag pattern. Fabric is produced in sheet or flat form using one or more sets of warp yarns. The

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yarns are fed from warp beams to a row of needles extending across the width of the machine (Figure 9b). Two common types of warp knitting machines are the Tricot and Raschel machines. Raschel machines are useful because they can process all yarn types in all forms (filament, staple, combed, carded, etc.). Warp knitting can also be used to make pile fabrics often used for upholstery.

Tufting

Tufting is a process used to create carpets, blankets, and upholstery. Tufting is done by inserting additional yarns into a ground fabric of desired weight and yarn content 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. 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.

III.A.3. Wet Processing

Woven and knit fabrics cannot be processed into apparel and other finished goods until the fabrics have passed through several water-intensive wet processing stages. Wet processing enhances the appearance, durability, and serviceability of fabrics by converting undyed and unfinished goods, known as gray or greige (*pronounced* grā[zh]) goods, into finished consumers' goods. Also collectively known as finishing, wet processing has been broken down into four stages in this section for simplification: fabric preparation, dyeing, printing, and finishing. These stages, shown in Figure 10, involve treating gray goods with chemical baths and often require additional washing, rinsing, and drying steps. Note that some of these steps may be optional depending on the style of fabric being manufactured.

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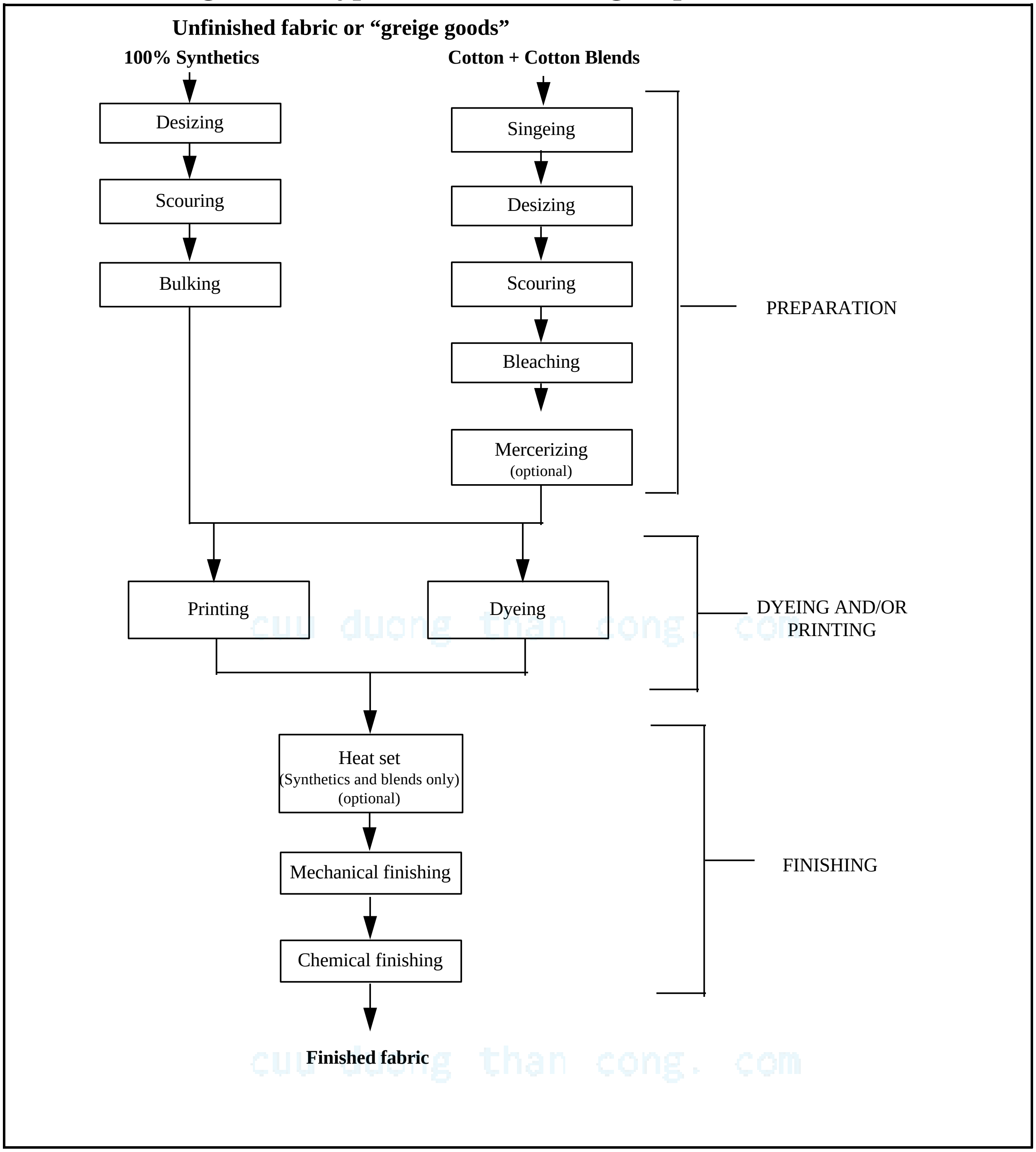
Figure 10: Typical Wet Processing Steps for Fabrics



Source: ATMI, 1997.

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In terms of waste generation and environmental impacts, wet processing is the most significant textile operation. Methods used vary greatly depending on end-products and applications, site-specific manufacturing practices, and fiber type. Natural fibers typically require more processing steps than manmade fibers. For most wool products and some manmade and cotton products, the yarn is dyed before weaving; thus, the pattern is woven into the fabric. Processing methods may also differ based on the final properties desired, such as tensile strength, flexibility, uniformity, and luster (Snowden-Swan, 1995).

Most manufactured textiles are shipped from textile mills to commission dyeing and finishing shops for wet processing, although some firms have integrated wet processing into their operations. A wide range of equipment is used for textile dyeing and finishing (EPA, 1996). Much of the waste generated from the industry is produced during the wet processing stages. Relatively large volumes of wastewater are generated, containing a wide range of contaminants that must be treated prior to disposal. Significant quantities of energy are spent heating and cooling chemical baths and drying fabrics and yarns (Snowden-Swan, 1995).

Fabric Preparation

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Most fabric that is dyed, printed, or finished must first be prepared, with the exception of denim and certain knit styles. Preparation, also known as pretreatment, consists of a series of various treatment and rinsing steps critical to obtaining good results in subsequent textile finishing processes. . In preparation, the mill removes natural impurities or processing chemicals that interfere with dyeing, printing, and finishing. Typical preparation treatments include desizing, scouring, and bleaching. Preparation steps can also include processes, such as singeing and mercerizing, designed to chemically or physically alter the fabric. For instance, the mercerizing stage chemically treats the fabric to increase fiber strength and dye affinity, or ability to pick up dyes. This, in turn, increases the longevity of fabric finishes applied during finishing. Many of the pollutants from preparation result from the removal of previously applied processing chemicals and agricultural residues. These chemical residues can be passed on to subsequent stages with improper preparation.

Most mills can use the same preparation equipment for the entire range of products they produce. In most cases, facilities favor continuous rather than batch preparation processes for economic and pollution control reasons. A number of mills, however, prepare goods, particularly knits, batchwise on dyeing machines to simplify scheduling and handling. Sometimes, facilities operate batchwise to reduce high capital costs required for high productivity and the complexity of storing and tracking goods through continuous wet processing operations.

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Because preparation is relatively uniform across most of a mill's production, preparation is usually the highest-volume process in a mill and hence an important area for pollution prevention. If fabrics contained no contamination upon arrival for wet processing, preparation processes would be unnecessary, eliminating about half the pollution outputs from wet processing and a significant amount of wastewater. The primary pollutants from preparation is wastewater containing alkalinity, BOD, COD, and relatively small amounts of other contaminants such as metals and surfactants. There are many preparation techniques, some of which are described below.

- *Singeing*. If a fabric is to have a smooth finish, singeing is essential. 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. Pollutant outputs associated with singeing include relatively small amounts of exhaust gases from the burners.

- *Desizing*. Desizing is an important preparation step used to remove size materials applied prior to weaving. Manmade fibers are generally sized with water-soluble sizes that are easily removed by a hot-water wash or in the scouring process. Natural fibers such as cotton are most often sized with water-insoluble starches or mixtures of starch and other 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 in scouring.

- *Scouring*. Scouring is a cleaning process that removes impurities from fibers, yarns, or cloth through washing. Alkaline solutions are typically used for scouring; however, in some cases solvent solutions may also be used. Scouring uses alkali, typically sodium hydroxide, to break down natural oils and surfactants and to emulsify and suspend remaining impurities in the scouring bath. The specific scouring procedures, chemicals, temperature, and time vary with the type of fiber, yarn, and cloth construction. Impurities may include lubricants, dirt and other natural materials, water-soluble sizes, antistatic agents, and residual tints used for yarn identification. Typically, scouring wastes contribute a large portion of biological oxygen demand (BOD) loads from preparation processes (NC DEHNR, 1986). Desizing and scouring operations are often combined (ATMI, 1997).

- *Bleaching*. Bleaching is a chemical process that eliminates unwanted colored matter from fibers, yarns, or cloth. Bleaching decolorizes colored

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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 bleach used in textile operations, and is typically used with caustic solutions. Bleaching contributes less than 5 percent of the total textile mill BOD load (NC DEHNR, 1986).

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; and 3) the cloth is thoroughly washed and dried. Peroxide bleaching can be responsible for wastewater with high pH levels. Because peroxide bleaching typically produces wastewater with few contaminants, water conservation and chemical handling issues are the primary pollution concerns.

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- *Mercerizing*. Mercerization is a continuous chemical process used for cotton and cotton/polyester goods to increase dyeability, luster, and appearance. This process, which is carried out at room temperature, causes the flat, twisted ribbon-like cotton fiber to swell into a round shape and to contract in length. This causes the fiber to become more lustrous than the original fiber, increase in strength by as much as 20 percent, and increase its affinity for dyes. Mercerizing typically follows singeing and may either precede or follow bleaching (Corbman, 1975).

  During mercerizing, the fabric is passed through a cold 15 to 20 percent solution of caustic soda and then stretched out on a tenter frame where hot-water sprays remove most of the caustic solution (Corbman, 1975). After treatment, the caustic is removed by several washes under tension. Remaining caustic may be neutralized with a cold acid treatment followed by several more rinses to remove the acid. Wastewater from mercerizing can contain substantial amounts of high pH alkali, accounting for about 20 percent of the weight of goods.

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Dyeing

Dyeing operations are used at various stages of production to add color and intricacy to textiles and increase product value. Most dyeing is performed either by the finishing division of vertically integrated textile companies, or by specialty dyehouses. Specialty dyehouses operate either on a commission

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basis or purchase greige goods and finish them before selling them to apparel and other product manufacturers. Textiles are dyed using a wide range of dyestuffs, techniques, and equipment. Dyes used by the textile industry are largely synthetic, typically derived from coal tar and petroleum-based intermediates. Dyes are sold as powders, granules, pastes, and liquid dispersions, with concentrations of active ingredients ranging typically from 20 to 80 percent.

Methods of Dyeing

Dyeing can be performed using continuous or batch 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, depending on the type of dye and fabric used. 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. Common methods of batch, or exhaust, dyeing include beam, beck, jet, and jig processing. Pad dyeing can be performed by either batch or continuous processes.

In continuous dyeing processes, textiles are fed continuously into a dye range at speeds usually between 50 and 250 meters per minute. Continuous dyeing accounts for about 60 percent of total yardage of product dyed in the industry (Snowden-Swan, 1995). 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 is a measure of the amount of the percentage of dye in a bath that will fix to the fibers of the textile material. Dye fixation on the fiber occurs much more rapidly in continuous dying than in batch dyeing.

Each dyeing process requires different amounts of dye per unit of fabric to be dyed. This is significant since color and salts in wastewater from spent dyes are often a pollution concern for textile facilities. In addition, less dye used results in energy conservation and chemical savings. The amounts of dye used depends on the dye is exhausted from the dyebaths which determines the required dyebath ratio. The dyebath ratio is the ratio of the units of dye required per unit of fabric and typically ranges from 5 to 50 depending on the type of dye, dyeing system, and affinity of the dyes for the fibers.

Dyeing processes may take place at any of several stages of the manufacturing process (fibers, yarn, piece-dyeing). Stock dyeing is used to dye fibers.

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Top dyeing is used to dye combed wool sliver. Yarn dyeing and piece dyeing, done after the yarn has been constructed into fabric, are discussed in more detail below.

- *Yarn Dyeing.* Yarn dyeing is used to create interesting checks, stripes, and plaids with different-colored yarns in the weaving process. In yarn dyeing, dyestuff penetrates the fibers in the core of the yarn.

  Some methods of yarn dyeing are stock, package, and skein dyeing. Stock dyeing dyes fiber using perforated tubes. In package dyeing (Figure 11), spools of yarn are stacked on perforated rods in a rack and immersed in a tank where dye is then forced outward from the rods under pressure. The dye is then pressured back through the packages toward the center to fully penetrate the entire yarn. Most carded and combed cotton used for knitted outerwear is package-dyed. In skein dyeing, yarn is loosely coiled on a reel and then dyed. The coils, or skeins, are hung over a rung and immersed in a dyebath (Corbman, 1975). Skein-dyed yarn is used for bulky acrylic and wool yarns. Typical capacity for package dyeing equipment is 1,210 pounds (550 kg) and for skein dyeing equipment is 220 pounds (100 kg).

- *Piece Dyeing.* Most dyed fabric is piece-dyed since this method gives the manufacturer maximum inventory flexibility to meet color demands as fashion changes. In terms of overall volume, the largest amount of dyeing is performed using beck and jig equipment (Figure 11). Beck dyeing is a versatile, continuous process used to dye long yards of fabric. About 1,980 pounds (900 kg) of fabric can be dyed on beck equipment at a time. The fabric is passed in rope form through the dyebath. The rope moves over a rail onto a reel which immerses it into the dye and then draws the fabric up and forward to the front of the machine. This process is repeated as long as necessary to dye the material uniformly to the desired color intensity. Jig dyeing uses the same procedure of beck dyeing, however, the fabric is held on rollers at full width rather than in rope form as it is passed through the dyebath (Corbman, 1975). This reduces fabric tendency to crack or crease. Jig dyeing equipment can handle 550 pounds (250 kg) of fabric.

  Other piece dyeing methods include jet dyeing and pad dyeing. Fabric can be jet-dyed (at up to 1,100 pounds (500 kg)) by placing it in a heated tube or column where jets of dye solution are forced through it at high pressures. The dye is continually recirculated as the fabric is moved along the tube. Pad dyeing, like jig dyeing, dyes the fabric at full width. The fabric is passed through a trough containing dye and then between two heavy rollers which force the dye into the cloth and squeeze out the excess (Corbman, 1975). Figure 11 illustrates the beck, jig, and jet methods for dyeing.

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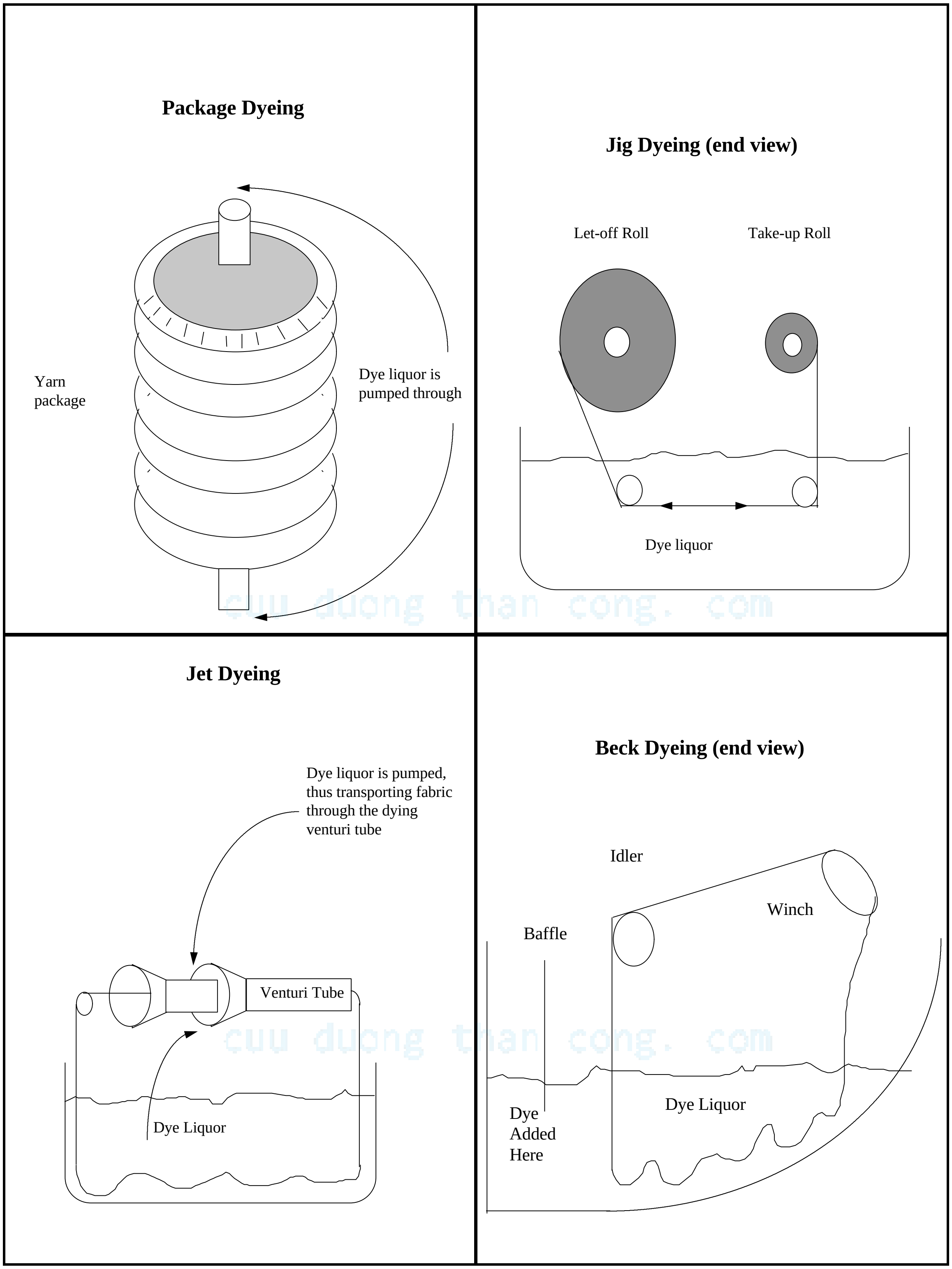

Figure 11: Common Dyeing Methods

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Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995.

Types of Dyes

Dyes 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. Table 6 lists the major dye classes, fixation rates, and the types of fibers for which they have an affinity. Factors that companies consider when selecting a dye include the type of fibers being dyed, desired shade, dyeing uniformity, and fastness (desired stability or resistance of stock or colorants to influences such as light, alkali, etc) (FFTA, 1991).

Most commonly in use today are the reactive and direct types for cotton dyeing, and disperse types for polyester dyeing. Reactive dyes react with fiber molecules to form chemical bonds. Direct dyes can color fabric directly with one operation and without the aid of an affixing agent. Direct dyes are the simplest dyes to apply and the cheapest in their initial and application costs although there are tradeoffs in the dyes' shade range and wetfastness (Corbman, 1975). Direct and reactive dyes have a fixation rate of 90 to 95 percent and 60 to 90 percent, respectively. A variety of auxiliary chemicals may be used during dyeing to assist in dye absorption and fixation into the fibers. Disperse dyes, with fixation rates of 80 to 90 percent, require additional factors, such as dye carriers, pressure, and heat, to penetrate synthetic fibers (Snowden-Swan, 1995; ATMI, 1997). Disperse dyes are dispersed in water where the dyes are dissolved into fibers. Vat dyes, such as indigo, are also commonly used for cotton and other cellulosic fibers.

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Table 6: Typical Characteristics of Dyes Used in Textile Dyeing Operations

Dye Class	Description	Method	Fibers Typically Applied to	Typical Fixation (%)	Typical Pollutants Associated with Various Dyes
Acid	water-soluble anionic compounds	Exhaust/ Beck/ Continuous (carpet)	wool nylon	80-93	color; organic acids; unfixed dyes
Basic	water-soluble, applied in weakly acidic dyebaths; very bright dyes	Exhaust/ Beck	acrylic some polyesters	97-98	N/A
Direct	water-soluble, anionic compounds; can be applied directly to cellulosics without mordants (or metals like chromium and copper)	Exhaust/ Beck/ Continuous	cotton rayon other cellulosics	70-95	color; salt; unfixed dye; cationic fixing agents; surfactant; defoamer; leveling and retarding agents; finish; diluents
Disperse	not water-soluble	High temperature exhaust Continuous	polyester acetate other synthetics	80-92	color; organic acids; carriers; leveling agents; phosphates; defoamers; lubricants; dispersants; delustrants; diluents
Reactive	water-soluble, anionic compounds; largest dye class	Exhaust/ Beck Cold pad batch/ Continuous	cotton other cellulosics wool	60-90	color; salt; alkali; unfixed dye; surfactants; defoamer; diluents; finish
Sulfur	organic compounds containing sulfur or sodium sulfide	Continuous	cotton other cellulosics	60-70	color; alkali; oxidizing agent; reducing agent; unfixed dye
Vat	oldest dyes; more chemically complex; water-insoluble	Exhaust/ Package/ Continuous	cotton other cellulosics	80-95	color; alkali; oxidizing agents; reducing agents

Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995; Snowden-Swan, L.J. "Pollution Prevention in the Textile Industries," in *Industrial Pollution Prevention Handbook*, Freeman, H.M. (Ed.), McGraw-Hill, Inc., New York, 1995.

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Printing

Fabrics are often printed with color and patterns using a variety of techniques and machine types. Of the numerous printing techniques, the most common is rotary screen. However, other methods, such as direct, discharge, resist, flat screen (semicontinuous), and roller printing are often used commercially. Pigments are used for about 75 to 85 percent of all printing operations, do not require washing steps, and generate little waste (Snowden-Swan, 1995). Compared to dyes, pigments are typically insoluble and have no affinity for the fibers. Resin binders are typically used to attach pigments to substrates. Solvents are used as vehicles for transporting the pigment and resin mixture to the substrate. The solvents then evaporate leaving a hard opaque coating. The major types of printing are described below.

- *Rotary screen printing.* Rotary screen printing uses seamless cylindrical screens made of metal foil. The machine uses a rotary screen for each color. As the fabric is fed under uniform tension into the printer section of the machine, its back is usually coated with an adhesive which causes it to adhere to a conveyor printing blanket. Some machines use other methods for gripping the fabric. The fabric passes under the rotating screen through which the printing paste is automatically pumped from pressure tanks. A squeegee in each rotary screen forces the paste through the screen onto the fabric as it moves along (Corbman, 1975). The fabric then passes to a drying oven.

- *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.

- *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 different colored discharge areas (EPA, 1996).

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- *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.

- *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. Ink jet is an emerging technology in the textile industry and has not yet been adopted for widespread commercial use. The dye types most amenable to ink-jet printing of textiles are fiber reactive, vat, sulfur, and naphthol dyes.

- *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.

Finishing

Finishing encompasses chemical or mechanical treatments performed on fiber, yarn, or fabric to improve appearance, texture, or performance. Mechanical finishes can involve brushing, ironing or other physical treatments used to increase the luster and feel of textiles. Application of chemical finishes to textiles can impart a variety of properties ranging from decreasing static cling to increasing flame resistance. The most common chemical finishes are those that ease fabric care, such as the permanent-press, soil-release, and stain-resistant finishes. Chemical finishes are usually followed by drying, curing, and cooling steps. Application of chemical finishes are often done in conjunction with mechanical finishing steps (Snowden-Swan, 1995). Selected mechanical and chemical finishing techniques are described below.

Mechanical Treatments

- *Heatsetting.* Heatsetting is a dry process used to stabilize and impart textural properties to synthetic fabrics and fabrics containing high concentrations of synthetics. When manmade fibers are heatset, the cloth maintains its shape and size in subsequent finishing operations and is - stabilized in the form in which it is held during heatsetting (e.g., smooth, creased, uneven). Textural properties may include interesting and durable surface effects such as pleating, creasing, puckering, and embossing. Heatsetting can also give cloth resistance to wrinkling during wear and ease-of-care properties attributed to improvements in resiliency and in elasticity. Pollution outputs may include volatile components of spin finishes if heatsetting is performed before scouring and bleaching processes. These components are introduced to the fabrics during the

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manufacture of synthetic fibers, when proprietary spin finishes are applied to provide lubrication and impart special properties, such as antistatic, to the fiber.

- *Brushing and napping.* Brushing and napping decrease the luster of fabrics by roughening or raising the fiber surface and change the feel or texture of the fabric (ATMI, 1997b). These processes involve the use of wires or brushes that pull individual fibers.

- *Softening.* Calendering, or ironing, can be used to reduce surface friction between individual fibers, thereby softening the fabric structure and increasing its sheen. In calendering, the fabric passes through two or more rolls. Typically, one roll is made of chilled steel, while the other is made of a softer material like cotton fibers. The steel roll may also be heated using gas or steam. Once goods pass through the machine they are wound up at the back of the machine.

- *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 can be further increased if the rolls are scribed with closely spaced lines.

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- *Shearing.* Shearing is a process that removes surface fibers by passing the fabric over a cutting blade.

- *Compacting.* Compacting, which includes the Sanforizing process, compresses the fabric structure to reduce stresses in the fabric. The Sanforizing process reduces residual shrinkage of fabrics after repeated laundering (Wingate, 1979). 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. Compacting reduces the potential for excessive shrinkage during laundering.

Chemical Treatments

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- *Optical finishes.* Optical finishes added to either brighten or deluster the textile.

- *Absorbent and soil release finishes.* These finishes that alter surface tension and other properties to increase water absorbency or improve soil release.

- *Softeners and abrasion-resistant finishes.* Softeners and abrasion-resistant finishes are added to improve feel or to increase the ability of the textile to resist abrasion and tearing.

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- *Physical stabilization and crease-resistant finishes.* These finishes, which may include formaldehyde-based resin finishes, stabilize cellulosic fibers to laundering and shrinkage, imparting permanent press properties to fabrics (ATMI, 1997b).

III.A.4. Fabrication

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. Apparel and more complex housewares are usually fabricated by the cutting trades. Before cutting, fabrics must be carefully laid out. Accuracy in cutting the lay fabric is important since any defects created at this point may be carried through other operations and end up in the final product. For simple household and industrial products, sewing is relatively straightforward. The product may then be pressed to flatten the fabric and create crisp edges.

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III.B. Raw Material Inputs and Pollution Outputs in the Production Line

Much of the following section is based upon *"Best Management Practices for Pollution Prevention in the Textile Industry,"* by the U.S. EPA Office of Research and Development. Additional references are cited in the text.

Wastewater

Wastewater is, by far, the largest wastestream for the textile industry. Large volume wastes include washwater from preparation and continuous dyeing, alkaline waste from preparation, and batch dye waste containing large amounts of salt, acid, or alkali. Primary sources of biological oxygen demand (BOD) include waste chemicals or batch dumps, starch sizing agents, knitting oils, and degradable surfactants. Wet processing operations, including preparation, dyeing, and finishing, generate the majority of textile wastewater.

Types of wastewater include cleaning water, process water, noncontact cooling water, and stormwater. 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 regarding water use. Because of the wide variety of process steps, textile wastewater typically contains a complex mixture of chemicals.

Desizing, or the process of removing size chemicals from textiles, is one of the industry's largest sources of wastewater pollutants. In this process, large quantities of size used in weaving processes are typically discarded. More than 90 percent of the size used by the U.S. textile industry, or 90,000 tons, is disposed of in the effluent stream. The remaining 10 percent is recycled (EPA, 1996). Desizing processes often contribute up to 50 percent of the BOD load in wastewater from wet processing (Snowden-Swan, 1995). Table 7 shows typical BOD loads from preparation processes.

Dyeing operations generate a large portion of the industry's total wastewater. The primary source of wastewater in dyeing operations is spent dyebath and washwater. Such wastewater typically contains by-products, residual dye, and auxiliary chemicals. Additional pollutants include cleaning solvents, such as oxalic acid.

Of the 700,000 tons of dyes produced annually worldwide, about 10 to 15 percent of the dye is disposed of in effluent from dyeing operations (Snowden-Swan, 1995). However, dyes in wastewater may be chemically bound to fabric fibers (ATMI, 1997b). The average wastewater generation from a dyeing facility is estimated at between one and two million gallons per day. Dyeing and rinsing processes for disperse dyeing generate about 12 to 17 gallons of wastewater per pound of product. Similar processes for reactive

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and direct dyeing generate even more wastewater, about 15 to 20 gallons per pound of product (Snowden-Swan, 1995).

Table 7: Typical BOD Loads from Preparation Processes

Process	Pounds of BOD per 1,000 Pounds of Production
Singeing	0
Desizing	
starch	67
starch, mixed size	20
PVA or CMC	0
Scouring	40-50
Bleaching	
peroxide	3-4
hypochlorite	8
Mercerizing	15
Heatsetting	0

Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995.
PVA = polyvinyl alcohol; CMC = carboxymethyl cellulose

Finishing processes typically generate wastewater containing natural and synthetic polymers and a range of other potentially toxic substances (Snowden-Swan, 1995). Pollution from peroxide bleaching 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. The major pollution issues in the bleaching process are chemical handling, water conservation, and high pH.

Hazardous waste generated by textile manufacturers results primarily from the use of solvents in cleaning knit goods (ATMI, 1997b). Solvents may be used in some scouring or equipment cleaning operations, however, more often scouring processes are aqueous-based and cleaning materials involve mineral spirits or other chemicals (ATMI, 1997b). Spent solvents may include tetrachloroethylene and trichloroethylene (NC DEHNR, P2 Pays, 1985). A few of the more common textile industry water pollutants and their sources are discussed below. In addition, Table 8 summarizes the typical pollutant releases associated with various textile manufacturing processes.

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Color

Dyes and pigments from printing and dyeing operations are the principal sources of color in textile effluent (EPA, 1996). 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. In typical dyeing and printing processes, 50 to 100 percent of the color is fixed on the fiber, as shown in Table 6. The remainder is discarded in the form of spent dyebaths or in wastewater from subsequent textile-washing operations (EPA, 1996).

*Salt*s

Several authors have identified salts in textile-dyeing wastewater as a potential problem area (US EPA, 1996). Many types of salt are either used as raw materials or produced as by-products of neutralization or other reactions in textile wet processes. Salt is used mostly to assist the exhaustion of ionic dyes, particularly anionic dyes, such as direct and fiber reactive dyes on cotton. 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. According to one study, a moderate-sized mill that dyed about 400,000 pounds per week of cotton knit fabrics produced well over 50,000 pounds of salts and a pH of over 10 (US EPA, 1996). The wastewater from this facility contained neutralization salts from six acids and alkalis of 60 ppm. Common salt (sodium chloride) and Glaubers salt (sodium sulfate) constitute the majority of total salt use. Other salts used as raw materials or formed in textile processes include Epsom salt (magnesium chloride), potassium chloride, and others in low concentrations.

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Table 8: Summary of Potential Releases Emitted During Textiles Manufacturing

Process	Air Emissions	Wastewater	Residual Wastes
Fiber preparation	little or no air emissions generated	little or no wastewater generated	fiber waste; packaging waste and hard waste
Yarn spinning	little or no air emissions generated	little or no wastewater generated	packaging wastes; sized yarn; fiber waste; cleaning and processing waste
Slashing/sizing	VOCs	BOD; COD; metals; cleaning waste, size	fiber lint; yarn waste; packaging waste; unused starch-based sizes;
Weaving	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric; used oil
Knitting	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric
Tufting	little or no air emissions generated	little or no wastewater generated	packaging waste; yarn and fabric scraps; off-spec fabric
Desizing	VOCs from glycol ethers	BOD from water-soluble sizes; synthetic size; lubricants; biocides; anti-static compounds	packaging waste; fiber lint; yarn waste; cleaning materials, such as wipes, rags, and filters; cleaning and maintenance wastes containing solvents
Scouring	VOCs from glycol ethers and scouring solvents	disinfectants and insecticide residues; NaOH; detergents, fats; oils; pectin; wax; knitting lubricants; spin finishes; spent solvents	little or no residual waste generated
Bleaching	little or no air emissions generated	hydrogen peroxide, sodium silicate or organic stabilizer; high pH	little or no residual waste generated
Singeing	small amounts of exhaust gases from the burners	little or no wastewater generated	little or no residual waste generated
Mercerizing	little or no air emissions generated	high pH; NaOH	little or no residual waste generated
Heatsetting	volatilization of spin finish agents applied during synthetic fiber manufacture	little or no wastewater generated	little or no residual waste generated

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Table 8: Summary of Potential Releases Emitted During Textiles Manufacturing			
Process	**Air Emissions**	**Wastewater**	**Residual Wastes**
Dyeing (see Table 6 for pollutants associated with particular dye classes)	VOCs	metals; salt; surfactants; toxics; organic processing assistants; cationic materials; color; BOD; COD; sulfide; acidity/ alkalinity; spent solvents	little or no residual waste generated
Printing	solvents, acetic acid from drying and curing oven emissions; combustion gases; particulate matter	suspended solids; urea; solvents; color; metals; heat; BOD; foam	little or no residual waste generated
Finishing	VOCs; contaminants in purchased chemicals; formaldehyde vapors; combustion gases; particulate matter	BOD; COD; suspended solids; toxics; spent solvents	fabric scraps and trimmings; packaging waste
Product Fabrication	little or no air emissions generated	little or no wastewater generated	fabric scraps
Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995; ATMI, Comments on draft document, 1997b.			

Regulatory limits imposed on textile facilities and on publicly owned treatment facilities (POTWs) that receive textile wastewater start at 250 ppm. Although the mammalian and aquatic toxicities of these salts are very low, their massive use in certain textile-dyeing processes can produce wastewater with salt levels well above the regulatory limits.

Metals

Many textile mills have few or no metals in their effluent, but whenever metals are present, they may include metals such as copper, cadmium, chromium, nickel, and zinc. Sources of metals found in textile mill effluents may include fiber, incoming water, dyes, plumbing, and chemical impurities. Dyes may contain metals such as zinc, nickel, chromium, and cobalt (ATMI, 1997b). In some dyes, these metals are functional (i.e., they form an integral part of the dye molecule); however, in most dyes, metals are simply impurities generated during dye manufacture. For example, mercury or other metals may be used as catalysts in the manufacture of certain dyes and may be present as by-products. Metals may be difficult to remove from wastewater (EPA, 1996).

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Aquatic Toxicity

The aquatic toxicity of textile industry wastewater varies considerably among production facilities. Data are available that show that the wastewater of some facilities has fairly high aquatic toxicity, while others show little or no toxicity. The sources of aquatic toxicity can include salt, surfactants, ionic metals and their complexed metals therein, toxic organic chemicals, biocides, and toxic anions (EPA, 1996; ATMI, 1997b). Most textile dyes have low aquatic toxicity. On the other hand, surfactants and related compounds, such as detergents, emulsifiers, dispersants, are used in almost every textile process and can be an important contributor to effluent aquatic toxicity, BOD, and foaming (EPA, 1996).

Air Emissions

Although the textile industry is a relatively minor source of air pollutants compared with many other industries, the industry emits a wide variety of air pollutants, making sampling, analysis, treatment, and prevention more complex. Textile operations involve numerous sources of air emissions. Operations that represent the greatest concern are coating, finishing, and dyeing operations. Textile mills usually generate nitrogen and sulfur oxides from boilers and are often classified as “major sources” under the Clean Air Act (EPA, 1996).

Other significant sources of air emissions in textile operations include resin finishing and drying operations, printing, dyeing, fabric preparation, and wastewater treatment plants (ATMI, 1997b). Hydrocarbons are emitted from drying ovens and, in particular, from mineral oil from high-temperature (200°C) drying/curing. These processes can emit formaldehyde, acids, softeners, and other volatile compounds. Residues from fiber preparation sometimes emit pollutants during heatsetting processes.

Carriers and solvents may be emitted during dyeing operations depending on the types of dyeing processes used and from wastewater treatment plant operations. Carriers used in batch dyeing of disperse dyes may lead to volatilization of aqueous chemical emulsions during heatsetting, drying, or curing stages. Acetic acid and formaldehyde are two major emissions of concern in textiles. Other potential pollutants can include solvent vapors containing toxic compounds such as acetaldehyde, chlorofluorocarbons, p-dichlorobenzene, ethyl acetate, and others. Some process chemicals, such as methyl naphthalene or chlorotoluene, may exhaust into the fibers and are later emitted from dryers as VOCs (EPA, 1996). Formaldehyde might be emitted from bulk resin storage tanks, finished fabric warehouses, driers, and curing ovens located at facilities that apply formaldehyde-containing resins to cotton and polyester/cotton blends (ATMI, 1997b). ATMI estimates that

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the majority of resin finishing plants emit less than one ton per year of formaldehyde from storage tanks, fabric, off-gassing.

Textile manufacturing can produce oil and acid fumes, plasticizers, and other volatile chemicals. Acetic acid emissions may arise from storage tanks, especially from vents during filling. Carbonizing processes, used in wool yarn manufacture, may emit sulfuric acid fumes and decating, a finishing process applied to wool fabrics to set the nap and develop luster, produces formic acid fumes. In addition, cleaning and scouring chemicals were estimated at 10,500 metric tons in 1988 (EPA, 1996).

Other Wastes

The primary residual wastes generated from the textile industry are nonhazardous. These include fabric and yarn scrap, off-spec yarn and fabric, and packaging waste. Cutting room waste generates a high volume of fabric scrap that can be reduced by increasing fabric utilization efficiency in cutting and sewing. Typical efficiency for using fabric averages from 72 to 94 percent. As a result, fabrication waste from carpets amounts to about 2 percent of an annual 900 million square yards of production (a value of $100 million). Denim cutting waste accounts for approximately 16 percent of denim production, or 100 million pounds annually.

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Although a large portion of cutting waste goes to landfill, some innovative programs being implemented to recycle this material. Some facilities collect cotton lint for resale. Cotton trash, leaves, and stems collected during the yarn formation have been sold to farmers as animal feed.

A materials flow sheet is shown in Figure 12 and summarizes raw materials input and waste output generated during the manufacture of a cotton knit golf shirt.

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V. POLLUTION PREVENTION OPPORTUNITIES

The best way to reduce pollution is to prevent it in the first place. Some companies have creatively implemented pollution prevention techniques that improve efficiency and increase profits while at the same time minimizing environmental impacts. This can be done in many ways such as reducing material inputs, re-engineering processes to reuse by-products, improving management practices, and employing substitution of toxic chemicals. Some smaller facilities are able to actually get below regulatory thresholds just by reducing pollutant releases through aggressive pollution prevention policies.

The Pollution Prevention Act of 1990 established a national policy of managing waste through source reduction, which means preventing the generation of waste. The Pollution Prevention Act also established as national policy a hierarchy of waste management options for situations in which source reduction cannot be implemented feasibly. In the waste management hierarchy, if source reduction is not feasible the next alternative is recycling of wastes, followed by energy recovery, and waste treatment as a last alternative.

In order to encourage these approaches, this section provides both general and company-specific descriptions of some pollution prevention advances that have been implemented within the metal casting industry. While the list is not exhaustive, it does provide core information that can be used as the starting point for facilities interested in beginning their own pollution prevention projects. This section provides summary information from activities that may be, or are being implemented by this sector. When possible, information is provided that gives the context in which the technique can be used effectively. Please note that the activities described in this section do not necessarily apply to all facilities that fall within this sector. Facility-specific conditions must be carefully considered when pollution prevention options are evaluated, and the full impacts of the change must examine how each option affects air, land and water pollutant releases.

Most of the pollution prevention activities in the textile industry have focused on reducing chemical use, reusing process water, and reducing all solid waste forms - pallets, cardboard, etc (ATMI, 1997b). This section describes some of the pollution prevention opportunities for textile facilities. Much of the following section is based upon *"Best Management Practices for Pollution Prevention in the Textile Industry,"* by the U.S. EPA Office of Research and Development. Most case studies, unless noted, were taken from this document. Additional references are cited in the text.

V.A. Quality Control for Raw Materials

Raw material quality control programs can be implemented by establishing specific and appropriate purchasing, packaging, and inventory control policies to prevent the ordering and use of untested materials. Textile

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companies can reduce waste by working with suppliers to come up with less-polluting raw materials and by developing purchasing codes that commit companies to using less-polluting raw materials.

Benefits of such programs can include decreased production of off-quality goods, less rework, and increased product consistency. Companies can also control raw materials quality by prescreening and testing shipments as they are received. Prescreening provides facilities with opportunities to determine chemical and mechanical alternatives, proper chemical use and training, and proper disposal and treatment methods.

✔ ***Adopt environmentally responsible purchasing policies and work with suppliers to obtain less-polluting raw materials.***
Facilities can adopt purchasing policies that restrict the use of hazardous chemicals as a way to reduce waste. Facilities can also work with vendors to set acceptable guidelines for the purity and content of chemicals, like chemical specialties, which are typically of unknown composition to the textile mill.

- Mills in the United Kingdom adopted purchasing policies as a way to reduce pollution. Researchers determined that 70 percent of woolen mills in the United Kingdom emitted pentachlorophenol (PCP), a harmful agricultural residue in wool, from their finishing plants. A study determined that it originated in the incoming greige goods. By specifying in company purchasing policies that they would not accept PCP-containing greige goods, the presence of PCP in wastewater decreased by 50 percent. This was a good method of reducing this waste since there are no acceptable PCP treatment technologies (EPA, 1996).

- At its Monroe, North Carolina facility, *Bloomsburg Mills* scours, dyes, and finishes about 22 million yards of fabric per year. The facility uses dye carrier chemicals, such as tetrachloroethylene, biphenyl, and trichlorobenzene, to promote level dyeing. In an effort to reduce SARA III, Section 313 regulatory burdens (TRI reporting), *Bloomsburg Mills* discussed with vendors the elimination of these chemicals. The company substituted a dye carrier containing methyl naphthalene with non-photochemically reactive solvents. This dye carrier subsequently reduced the release of hazardous air pollutants by 91 percent from 64,713 pounds in 1988 to 5,932 pounds in 1993 (NC DEHNR, 1995).

✔ ***Perform tests on raw materials shortly after receipt.***
Prescreening raw materials can be used to determine interactions with processes, substrates, and other chemicals. This method can also be used to determine environmental effects, proper handling, and emergency procedures for chemicals. This can enable the early detection of mislabeled drums and changes in the formulation of a chemical specialty, and reduce the occurrence of costly production mistakes stemming from untested chemicals being processed (NC DEHNR, 1986). Protocol for incoming chemical quality

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control may consist of the following steps: marking the date the container was opened; checking pH, viscosity, density, conductivity, and color; comparing data with previous history and vendor's standard values; entering data on a control chart for display; maintaining records; and reviewing data with the vendor. Environmental data that should be checked include whether the chemicals are listed as priority pollutants under the Clean Water Act, hazardous air pollutants under the Clean Air Act, and as 33/50 chemicals, the indoor air pollution hazard potential, and the potential for release to the environment.

- An example where raw material testing would have been useful involves a mill that used a solvent scouring chemical specialty. The manufacturer produced the chemical specialty, which consisted of emulsifier and xylene as a solvent. Without notifying its customers, the manufacturer changed the solvent composition to chlorotoluene to cut costs and minimize labeling requirements when the vendor's insurance company began to require special labeling and handling of xylene. This had a profound effect on the mill's air emissions, water toxicity, and other aspects of production. If the mill had prescreened chemical specialties, it could have detected these changes and reduced waste (NC DEHNR, 1986).

- A committee at a facility in Lumberton, North Carolina prescreened raw material (dyes and chemicals) to ensure that offensive-smelling, 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 due to lack of alternatives, these 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 since they did not contain toxics or metals, were realized (NC DEHNR, 1986).

✔ ***Purchase raw materials in returnable containers.***

Facilities can work with vendors to ensure that packages can be returned without being cleaned on site. Offsite cleaning transfers chemical wastes back to the production facility, which may be better able to handle wastes. Chemical specialties should be purchased in returnable, reusable containers. Purchase of chemicals in bulk containers and intermediate bulk containers eliminates waste packing materials, and reduces spillage, handling costs, and worker exposure to chemicals. Bagged chemicals and drums tend to be more susceptible to damage and spills than bulk containers (EPA, 1996).

- At its Monroe, North Carolina facility, *Bloomsburg Mills* eliminated the disposal of 50 drums to the landfill each week by receiving and storing process chemicals in reusable totes and plastic drums (NC DEHNR, 1995).

- *Amital* began purchasing dyes and chemicals in 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. By

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making these changes, vendors were partners in the reduction of packaging waste.

V.B. Chemical Substitution

Since textile manufacturing is a chemically intensive process, a primary focus for pollution prevention should be on substituting less-polluting chemicals for textile process chemicals. Chemical substitution can eliminate chemical waste and the need for costly pollution control equipment. Opportunities for chemical substitution vary substantially among mills because of differences in environmental conditions, process conditions, product, and raw materials.

✔ ***Replace chemicals with less-polluting ones.***

By replacing solvents, facilities can reduce waste, reduce costs associated with treatment systems, and increase worker safety. This is one of the best methods to prevent pollution. Some textile chemicals that can be substituted include desizing agents, dyes, and auxiliaries. For instance, replacing enzymes with hydrogen peroxide to desize starch can be cost-effective (ATMI, 1997b). This method produces carbon dioxide and water as wastes instead of hydrolyzed starch, which increases BOD load. Copper-free dyes can be used to reduce metal loading of wastewater although this may sacrifice the range of color shades that can be achieved. Improved fixation reactives can be used to reduce unreacted and degraded dye in spent bath and improve the reuse potential of washwater. High-temperature reactives can also be used in dyeing for simultaneous application of disperse and reactive dyes. This reduces energy use and eliminates the caustic bath required after disperse dyeing. Finally, auxiliaries, such as phosphates, can be substituted with acetic acid and EDTA to reduce phosphorus load in wastewater. New washing agents can also be used to increase wash efficiency, decrease water consumption, and improve fastness of reactives (Snowden-Swan, 1995).

- *Bloomsburg Mills* substituted a solvent containing isopropanol and heptane as a suitable spot-washing alternative for 1,1,1 trichloroethane, a hazardous air pollutant. No loss of quality was noted with the substitution (NC DEHNR, 1995).
- *Guilford Mills'* has integrated plants in both North Carolina and Pennsylvania. At these plants, the company substituted a solvent-based chemical system used in the heatsetting process with a water-based chemical system. An emissions survey conducted by the company identified that heatsetting accounted for the majority of volatile organic compound emissions. The new system uses an acrylic latex emulsion to dissolve gum which stabilizes fabric edges and prevents curling. This change accounted for most of the plants' reductions in VOC emissions, from 246.8 tons per year in 1993 to an estimated 93.7 tons per year in 1995 (NC DEHNR, 1995).

- *Cleveland Mills Company* reduced formaldehyde emission to the air by 84 percent by switching to low-shade change resins in the production process.

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Formaldehyde emissions at the mill dropped from 3,500 to 580 pounds per year (NC DEHNR, 1995).

- *One textile facility* investigated substitutes for sodium sulfide, which is used to convert water-insoluble dyes to the soluble form for application of sulfur dyes to textiles. The facility found that they could replace 100 parts sodium sulfide with 65 parts alkaline solution containing 50 percent reducing sugars plus 25 parts caustic soda. As a result, sulfide levels dropped substantially to below 2 ppm (Snowden-Swan, 1995).

✔ ***Replace chemical treatment with other treatment.***

Waste can be reduced by replacing chemicals in some processes with mechanical or other nonchemical treatment. Instead, some textile mills add chemicals to counteract harmful side effects of other chemicals. In many cases, offending chemicals should be adjusted, substituted, or removed from a process, rather than adding chemicals to offset undesired side effects of other chemicals.

- *JP Stevens and Company, Inc.* substituted chemical biocides, used in disinfecting air washers and cooling towers, with the use of ultraviolet light. Although this may not be viable for all facilities, during a 6-month test period, results showed improved worker safety, reduced discharge of biocides to the sanitary sewer, reduced chemical inventory and handling, improved workplace air quality, and reduced pH and foaming problems in wastewater. The facility also showed enhanced air washer performance and more consistent control of workplace air quality. The UV system operated with no required maintenance or repairs during the test. Based on chemical savings, the payback is expected to be 11 to 18 months.

V.C. Process Modification

Process changes that optimize reactions and raw materials use can be used to prevent pollution. Modifications may include improved process control systems or changes in chemical application methods.

✔ ***Use low-liquor ratio dyeing machines.***

Mills have been moving towards reduced bath ratio dyeing. Bath ratio is defined as the weight of goods (or fabric) divided by the weight of the bath. Some chemicals, such as salt and lubricants, act on the dyebath, whereas others, such as dyes and softeners, act on the fabric. In each case, these chemicals are factored into either the weight of the bath or the weight of the fabric.

Low bath ratio dyeing can save energy and reduce chemical use, because energy and chemical use depend on bath volume. Jet dyeing and package dyeing are commonly used for low bath ratio dyeing. Typical bath ratios for exhaust dyeing methods are as follows: beck (17:1), jet (12:1), jig (5:1), and

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package (10:1). Pad batch methods have a 1:1 bath ratio. Ultra-low liquor bath ratios can also reduce cycle times due to quick machine drains and fills and rapid heating and cooling.

- At its Lumberton, North Carolina facility, *Alamac Knits* upgraded jet dyeing machinery to low-liquor-ratio machines with shorter cycles. This modification resulted in a decrease of between 60 and 70 percent of consumption of dye chemicals.

✔ ***Use pad batch dyeing methods.***

Use of pad batch (cold) dyeing for cotton, rayon, and blends conserves energy, water, dyes and chemicals, labor, and floor space. Pad batch dyeing methods do not require salt or chemical specialties, so this method can be a good way for facilities to reduce waste and save money. While pad batch dyeing is a cost-effective way for facilities to apply reactive dyes to cotton and rayon, this method may not achieve the desired final fabric properties for all cottons. Pad batch dyeing is also not appropriate for dyeing synthetic fabrics (ATMI, 1997b). Salt consumption can be reduced from as much as 100 percent of weight of goods to zero. Water consumption for pad batch dyeing with beam wash-off is only 10 percent of the amount used to dye fabrics using beck methods, or two gallons per pound of dyed fabric. Energy consumption can be reduced from about 9,000 BTUs per pound of dyed fabric for beck methods to under 2,000 BTUs per pound for pad batch methods with beam washing. In addition, labor costs and chemical use can be reduced up to 80 percent as compared to atmospheric beck methods (NC DEHNR, 1988).

In pad batch dyeing, prepared fabric is impregnated with liquor (water and process chemicals) containing premixed fiber reactive dyestuff and alkali. Excess liquid is squeezed out on a device known as a mangle. The fabric is then batched onto rolls or into boxes and covered with plastic film to prevent absorption of CO_2 from air or evaporation of water. The fabric is then stored for two to twelve hours. The goods can be washed with becks, beams, or other available machines. Production of between 75 and 150 yards a minute, depending on the construction and weight of goods involved, is typical. Pad batch dyeing is more flexible than continuous dyeing methods. Either wovens or knits can be dyed, and shades can be changed frequently because reactive dyes remain water soluble. The flexibility of pad batch equipment and the use of water soluble dyes minimizes cleaning operations.

- *Ti-Caro* switched to a pad-batch process for bleaching which reduced water and energy use. The bath ratio decreased on all batch processes to 10:1.

✔ ***Use countercurrent washing to reduce water use.***

Countercurrent washing decreases wastewater from preparation processes. Countercurrent washing is simple, easy to implement, and relatively

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inexpensive. Countercurrent washing is a technique to reuse the least contaminated water from the final wash for the next-to-last wash and so on until the water reaches the first wash stage. Washwater from the first stage is discharged (NC DEHNR, 1988). Table 16 shows typical water savings based on the number of times the water is reused. Countercurrent washing equipment can be retrofitted to any multistage continuous washing operation, whether it is installed for different fabrics or for dyeing, printing, or preparation operations. Flow optimization is usually a good pollution prevention activity to run in conjunction with countercurrent washing.

Table 16: Typical Water Savings Using Countercurrent Washing

Number of Washing Steps	Water Savings (percent)
2	50
3	67
4	75
5	80

Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995.

- *Bloomsburg Mills* uses countercurrent washing to conserve water during the scouring process. The cleaner wash water enters the exit wash unit and counterflows back toward the dirtier units. This provides a more efficient cleaner wash and requires less water (NC DEHNR, 1995).

- *An international company* reduced water consumption by enacting several measures over a one-month period. Countercurrent flow was installed on all soapers, mercerizing range, and J-boxes. J-boxes are large J-shaped containers used to hold fabrics at high temperatures during bleaching. Washwater was reused in upstream processes for less critical uses, such as print blanket washing.

✔ ***Optimize process conditions.***

Mills can reduce waste and increase production efficiency by optimizing process conditions, such as temperature and time. Mills can also modify the processes themselves to increase efficiency.

- *Americal Corporation* improved dyeing exhaustion by extending the length of time fabrics were dyed by 15 minutes. Results showed about a 60 percent drop in BOD and chemical oxygen demand (COD), a 20 percent drop in fats, oils, and grease, and a 98 percent drop in ammonia-nitrogen. This resulted in a savings of $35,000 annually.

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✔ ***Combine processes.***
Mills can reduce waste and increase production efficiency by combining operations. For instance, combined scouring and bleaching can save energy and water. Cold pad-batch methods can be used at room temperature for long desizing, scouring, and bleaching cycles. The single-step, cold-batch method of desizing minimizes energy and water use and maximizes productivity. Note that these methods may not help facilities achieve the desired product result in all cases (ATMI, 1997b).

V.D. Process Water Reuse and Recycle

Although they do not constitute pollution prevention as defined by the Pollution Prevention Act of 1990, recovery, recycling, and reuse can be effective tools for minimizing pollutant releases to the environment. By recovering solvents and raw materials, textile mills can reduce raw materials costs and can reduce pollution with little modification of existing processes. Water is widely used in the industry for processes ranging from dyeing to preparation and finishing. Raw materials, such as unexhausted dyestuff and additives, can also be recycled. Reuse and recycling are excellent ways for facilities to save money, reduce waste, and save energy.

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✔ ***Reuse dyebaths.***
Dyebath reuse is the process of analyzing, replenishing, and reusing exhausted hot dyebaths to dye further batches of material. Although not applicable to all processes, in some processes, dyebath reuse can reduce pollution concentrations and effluent volume and generally requires a smaller capital outlay than pretreatment plant construction. It also saves on the costs of dyes, chemicals, and energy. Dyebath reuse principles can also be applied to bleach baths. Table 17 lists example costs and savings for dyebath reuse for a dye machine. Depending on the machine, types of fabrics, and range of shades, after a couple of years, dyebath reuse could save companies about $21,000 per year for each machine.

Dye bath reuse is comprised of four basic steps. The first step is to save the exhausted dyebath. This can occur by pumping the dyebath to a holding tank, rinsing the product in the same machine in which it was dyed, and then removing the product and returning the dyebath to the dye machine. The product can also be removed from the exhausted dyebath and placed in another machine for rinsing. The dyebath can then be analyzed for residual chemicals. Unexhausted dyestuffs must be analyzed to determine the exact quantities remaining in the dyebath to ensure the proper shade in the next dyeing cycle. This analysis can be performed using a spectrophotometer and guidelines based on specific production experience. Equipment for this is available for under $10,000. After the dyebath has been analyzed, it must be

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reconstituted by adding water, auxiliary chemicals, and dyestuffs. If properly controlled, dyebaths can be reused for 15 or more cycles, with an average of 5 to 25 times.

Table 17: Example Costs and Savings for Dyebath Reuse

Description of Cost/Savings	Value
Total Costs	
Lab and support equipment	$9,000
Machine modifications, tanks, pumps, pipes	$15,000-$25,000
Annual Operating Costs	$1,000-$2,000
Total Savings (Annual)	
Dyes and chemicals	$15,000
Water	$750
Sewer	$750
Energy	$4,500

Source: *Best Management Practices for Pollution Prevention in the Textile Industry*, EPA, Office of Research and Development, 1995.

- *Adams-Millis Company* implemented dyebath reuse at its High Point, North Carolina and Franklinton, North Carolina mills. The mills reused dyebath for dyeing 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.

- *Bigelow Carpets* reused dyebaths 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.

- *Amital* saved a large amount of money by reusing dyebaths and noncontact cooling water. The facility reduced its water consumption from 320,000 gallons per day to 102,000 gallons per day and simultaneously increased production from 12 to 20 batches per day. Additionally, energy consumption for heating dyebath decreased substantially. The investment saved the company about

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$13,000 a month and paid for itself 30 days after implementation (Snowden-Swan, 1995).

✔ ***Reuse rinse baths.***

Wet processing consumes a large amount of water from rinsing of textiles. Preparation and finishing water can also be reused.

- *A yarn finishing company* drastically reduced wastewater pollution, soda (Na_2CO_3), and caustic consumption by implementing recycling. The new process involved reusing the rinse bath three times following mercerizing rather than dumping the bath water after each use. The spent rinsewater was then processed in an evaporator and concentrated caustic was reused in mercerizing. The facility reduced suspended solids by 80 percent, COD by 55 percent, and neutralizing soda in the wastewater by 70 percent. Corresponding reductions in hydrochloric acid used to neutralize the effluent were also made. The investment in new equipment resulted in an annual savings of $189,000, with a payback of under one year (Snowden-Swan, 1995).

- *A Kings Mountain, North Carolina facility* installed holding tanks for bleach bath 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 also came into compliance with permits and realized economic benefits.

V.E. Equipment Modification

An additional method to reduce waste is to modify, retrofit, or replace equipment. Some facilities are switching to computer-controlled dyeing systems, which analyze the process continuously and respond more quickly and accurately than manually controlled systems. In many cases, modifying equipment can provide source reduction by reducing the ratio of water and chemicals to textile goods.

✔ ***Install automated dosing systems and dye machine controllers.***

The use of automated process control equipment has had a significant effect on the textile industry. Chemical dosing systems can be optimized to deliver the right amount of the right chemical at just the right time. These systems improve the efficiency and reliability of chemical reactions in the dyebath, ensuring more consistent and reproducible results. In addition, these systems reduce the tendency to overuse environmentally harmful chemicals, which may pass through treatment systems unreacted or may react to produce undesirable by-products. Dosing systems can also reduce handling losses and equipment cleanup. Automated dosing systems are commercially available and are being adopted throughout the textile industry.

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In addition to automated dosing equipment, dye machine controllers are a good way to increase control over processes. Sales of dye machine controllers are now overtaking sales of dye machines. These devices can be retrofitted for many of the machines in mills. They contain microprocessor controllers that allow feedback control of properties such as pH, color, and temperature. Note that this method only works for acrylic because cationic dyes have high exhaust rates associated with them. This may not work for other fibers or dye classes (ATMI, 1997b).

- *Amital*, which produces acrylic yarn, implemented computer technology to automate dyebath flow and temperature in a new facility. This enabled the facility to precisely control the addition of auxiliary chemicals, such as retarders and leveling agents. As a result, *Amital* produces a clean exhausted dyebath, eliminating the need for postrinsing and reducing water and chemical consumption (Snowden-Swan, 1995).

- *Bloomsburg Mills* upgraded instrumentation and process controls for the dyeing process from manual to computer control. The controlled time of the wash after dyeing has reduced water usage by 28 percent and fuel heat consumption per yard produced by 15.9 percent (NC DEHNR, 1995).

- *Cleveland Mills Company* replaced coal-fired boilers with cleaner natural gas-fired boilers and eliminated the generation of 220,000 pounds of fly ash each year (NC DEHNR, 1995).

✔ ***Use continuous horizontal washers.***
Continuous horizontal washers can conserve energy and water. Horizontal washers work for woven fabrics in a narrow weight range (ATMI, 1997b). These washers operate by spraying clean washwater on the top (final) pass of fabric as it makes a series of horizontal traverses upward in the machine. The unprocessed fabric enters at the 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. Note that vertical, double-laced washers with serpentine counterflow may be more versatile and achieve better results than continuous horizontal washers (ATMI, 1997b).

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✔ ***Use continuous knit bleaching ranges.***
Many textile companies use continuous knit bleaching ranges to reduce water consumption. These ranges consume less water, energy, and chemicals than batch preparation knitting equipment. Recent models have shown improved flexibility in terms of production capacity. Lower capacity machines are available for smaller operations. The new machines feature inherent countercurrent water use and improvements over old rope bleaching units, including better fabric transport, better chemical metering systems, and better filtering of the baths.

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V.F. Good Operating Practices

Companies can improve production efficiency and maintain low operating costs by incorporating pollution prevention codes into their management procedures. These codes can include a written commitment by senior management to ongoing waste reduction at each of the company's facilities and to include pollution prevention objectives in research and new facility design. Establishing training and incentive programs and improving recordkeeping are other ways that companies can prevent pollution without changing industrial processes. These factors, along with better housekeeping practices, can help minimize wastes from maintenance and off-spec materials. Water use can be significantly reduced through minimizing leaks and spills, proper maintenance of production equipment, and identification of unnecessary washing of both fabric and equipment (NC DEHNR, 1985).

✔ ***Schedule 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 of machines and facilities. Scheduling dyeing operations to minimize machine cleanings can have a considerable effect on pollution prevention. Changes required by scheduling activities generate significant amounts of waste for the textile mill. Machine cleaning is a significant contributor to waste load for textile facilities, particularly for changes in polyester color sequence and oligomer build-up (ATMI, 1997b). A well-planned dyeing schedule may reduce the number of machine cleanings required and the pollution that results from startups, stopoffs, and color changes. Minimizing machine cleaning may not be possible in some cases because of the need for flexible schedules to meet changing market demands (ATMI, 1997b).

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 way is to group colors within families (red, yellow, blue), and then run the dyes within one color family from lighter to darker values and from brighter to duller chromas.

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✔ ***Optimize cleaning practices.***
Modifying equipment cleaning practices may reduce wastewater discharges and reduce solvent use. Substituting cleaning solvents with less toxic solvents can reduce hazardous waste generation and can simplify treatment of wastewater (EPA, 1996).

✔ ***Optimize housekeeping practices.***
Good inventory management can reduce waste by using all materials efficiently and reducing the likelihood of accidental releases of stored material. Although it may seem simplistic, housekeeping and work habits of chemical mixers can account for 10 to 50 percent of a mill's total effluent load in BOD, COD, metals, and organic solvents. Improvements in housekeeping generally cost little or nothing and improve employee morale, workplace safety, and product quality (NC DEHNR, 1988). Designating a materials storage area, limiting traffic through the area, and giving one person the responsibility to maintain and distribute materials can also reduce materials use and contamination and dispersal of materials.

✔ ***Adopt worker training programs.***
Companies should establish safety procedures for receiving, storing, and mixing chemicals, and implement worker training programs. These programs should inform workers of the environmental impacts of chemicals and identify those most harmful to the environment. Workers should be trained in proper procedures for handling these chemicals. Training should also include the correct procedures for pasting, dissolving, and emulsifying of chemicals. These procedures should be subject to auditing and recordkeeping. In addition, policies regarding receipt, storage, and mixing should be established.

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