All finished textile products, whether clothing, carpeting, or tire cord, have their origin in wool, cotton, synthetic fibers, or combinations of these. These fibers are processed to make them suitable for their end uses. These processes include: removal of natural impurities from wool and cotton (dirt, grit, grease); removal of process impurities (sizing, metallic contaminants); and finishing, to impart particular qualities of appearance, feel, and durability.

COTTON

The three basic steps in processing cotton (Figure 33.1) are spinning, weaving, and finishing. Cotton spinning and weaving are dry processes. Foreign matter is removed from the raw cotton by opening and cleaning, picking, carding, and combing. The individual fibers are joined, straightened, spun into thread, and wound on spools.

To improve strength and stiffness of lengthwise (warp) yarn, it is passed through a sizing solution that controls abrasion and reduces friction. Starch, polyvinyl acetate (PVA), and carboxymethyl cellulose (CMC) are the sizing agents. This yarn is woven into cloth known as greige goods, which is sent to the finishing mill to process into salable products.

The finishing process, mostly wet, begins with the removal of sizing, natural wax, pectins, alcohols, dirt, oil, and grease to prepare the cloth for the following steps:

Singeing: The cloth passes between heated plates or rollers, or across an open gas flame to burn off loose fibers. Sparks are extinguished as the cloth passes through a water box.

Desizing: Starch is solubilized by enzymes or acid by a 3 to 12 h soaking. Excess liquor is removed. The cloth is then freshwater rinsed and processed through a caustic or penetrant bath.

Caustic scouring: Greige goods are cooked to remove cotton wax, dirt, and grease. The cotton cloth is saturated with liquor consisting of caustic soda, soda ash, pine oil soap, and surfactants and scoured in a steam bath for 1 h. Finally, the cloth is rinsed to remove the scour liquor. This develops a yellow, absorbent pure cellulose fiber.

Bleaching: Peroxide, hypochlorite, or chlorine in combination with sodium silicate and caustic soda are applied as bleach liquor, and the cloth passes into
a steam chamber (J-Box) for approximately 1 h. The bleached cloth is rinsed in water and stored for further processing.

**Mercerization:** Bleached cloth may be mercerized to swell the fiber, thus improving luster, dye affinity, and strength. In mercerization, the cloth is carried through a caustic soda solution (20 to 25% NaOH) while under tension, then through a water rinse, acid dip, and final water wash.

**Dyeing:** Many different chemicals are used for dyeing:

a. Direct dyes are applied directly to the cloth.
b. Vat dyes and sulfur dyes are applied to cloth in a reduced state and then oxidized.

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FIG. 33.1 Cotton processing flow sheet. Usually the greige mill that produces cloth is separate from the finishing mill. The finishing mill uses large volumes of water, often as much as 10 mgd, and requires a complex waste treatment system (Figure 33.5). The finishing mill usually has a large boiler house because of its need for steam for process equipment, and often cogenerates power for its machinery requirements.
c. Developed dyes and naphthol dyes are applied to cloth and developed with a secondary chemical.

d. Aniline black dye is oxidized on the cloth by air or steam.

Printing: This process imparts a colored pattern or design to the cloth by a roller or screen print machine. The colors are fixed by steaming or other treatment.

Final finishing: This process involves sizing (starch or resin), waterproofing, fireproofing, or preshrinking.

WOOL

Raw wool, a protein (keratin), contains glandular secretions (suint and wool grease) and feces from the sheep, plus dirt, straw, and vegetable matter. Residues of treatments applied for disease control or for identification of the animal may also be present. Wool is normally insoluble in water, but above 250°F (121°C) some fractions dissolve. Wool fiber expands upon wetting, but contracts to its original size when dried. Being amphoteric, wool is damaged by caustic or acid solutions, so special care must be taken when subjecting it to such treatments in processing.

Wool Processing

Sorting and blending: Raw fibers are sorted into lots according to fineness and length. Fibers from different lots are blended to maintain uniformity.

Scouring and desuinting: Foreign matter is removed by washing with soaps, alkalies, or other chemicals, or by solvent extraction. Scouring the fleece reduces weight by 35 to 65%. The extracted material is processed to recover lanolin.

Washing: The scour is followed by a clean water rinse.

Carding: The wool fibers are disengaged and rearranged into a web.

Oiling: An antistatic agent is applied to the fibers.

Backwashing: Removing oil that has been put into worsted stock in the blending, oiling, and mixing operations.

Gilling: A special procedure for carding which separates the long, choice fibers of the same length from the shorter fibers.

Top dyeing: The application of a tint to the choice, long fibers (called “wool top”) used for production of worsted, a tightly spun yarn. The tinting is for identification only.

Roving: Narrow strips of web are gently meshed together and wound onto spools for the spinning frames.

Spinning: The rovings are drawn through small rollers which further extend the web by pulling the fibers apart lengthwise.

Winding: The spun rovings are twisted and wound onto bobbins as finished yarn.

Figure 33.2 outlines the wool-processing flow diagram.
Scouring (or slashing) prepares the wool for weaving. In detergent scouring, the predominant method, the wool is treated in successive bowls with capacities of 1000 to 3000 gal (3.8 to 10 m³) each. The first bowl is used for steeping (desunting); the next two contain soap alkali for grease removal; and the final bowls are for rinsing.

Batch or continuous solvent scouring produces less water pollution than detergent scouring. Grease laden solvent is distilled to recover the solvent. A final detergent washing removes residual solvent and grease.

Dyeing is performed in open or pressure-type machines. The pollution loading is related to the dye used.

Fulling is a process of shrinking the woven fabric by subjecting it to moisture, heat, and friction to produce a feltlike texture. Soap is the felting agent and water
is evaporated during the process. Following fulling the wool cloth contains considerable process chemical and must be washed. The cloth passes through a "first soap," is squeezed between rollers, washed in a "second soap," and finally rinsed in a water bath.

In the carbonizing process for removing residual impurities, the wool fabric is impregnated with 4 to 6% sulfuric acid and oven dried at 212 to 220°F (100 to 105°C). The evaporation of the water concentrates the acid, charring organic contaminants. Rollers crush the charred matter, which is then removed by a mechanical dusting machine. The cloth is rinsed, neutralized by soda ash solution, washed again, and dried. Sulfur dioxide or hydrogen peroxide bleaches the natural yellow tint of the wool to white.

SYNTHETICS

The most common synthetic fibers are cellulose base (acetate/rayon) and polymer base (acrylic, nylon, polyester, and orlon). Spun yarn is processed like natural fibers requiring size to impart strength and to provide a protective coating for weaving. Continuous filament yarn requires less sizing.

Static charges build up on synthetic yarn during most processing steps so anti-static oils and lubricants are applied to the fiber before weaving. These include polyvinyl alcohol, styrene-based resins, polyalkylene glycols, gelatin, and polyvinyl acetate.

Synthetic fabric finishing processes are similar to those used with cotton, and include scouring (removal of process chemicals from weaving), initial rinsing, bleaching, second rinsing, dyeing, and final finishing (waterproofing, shrink proofing, etc.).

WATER USES IN THE TEXTILE INDUSTRY

Clean air, free from debris, and controlled at precise temperature and humidity levels is vital to textile processing. The industry is one of the largest users of air-washing equipment to clean and temper air in the processing areas. Tempering requires heating in the winter and cooling in the summer.

Air washers are used throughout cotton mills producing woven fabric; in blending plants where cotton is blended with synthetic staple into yarn and then woven; and in synthetic fiber plants. Air washers also find extensive use in knitting plants, including hosiery and carpet mills. The material removed from the air is transferred to the water, so there are many problems requiring water treatment technology.

The cooling capacity for a typical textile refrigeration unit is 300 to 1200 tons, depending on the size of the plant. Total plant capacity may be from 300 tons in a very small mill up to 18,000 tons. In large plants, the total tonnage may be supplied by a single cooling tower circuit and a single chilled-water system. However, in most cases there are several smaller systems. The tonnage and number of air-conditioning systems operating in a plant depend on the combination of textile processes.

New textile plants are designed to consolidate chilled-water systems into as few independent units as possible to maximize efficiency and reduce maintenance.

Chilled water is piped around the average textile plant for use in air washers,
process-heat exchangers, and small office air-conditioning units. By far, the largest user of chilled water is the air washer. The average plant with 1200 to 2400 tons of air-conditioning capacity may have six to eight air washers.

When refrigeration units are operating during warm weather (Figure 33.3), air washer units are supplied with chilled water, 40 to 50°F (5 to 10°C). Most textile chilled-water systems have high-level float switches on the chilled-water sumps. During summer operation, when the chilled water is dehumidifying plant air, the volume of water in the chilled-water system increases as water condenses from the makeup air. When this occurs, the level in the sump rises until it hits a limit switch which diverts excess chilled water (which is essentially condensate) to the cooling tower as makeup. This procedure conserves treatment chemicals, water, and energy, avoiding wasting excess chilled water and increasing the efficiency of the condenser unit.

Chilled-water sumps contain filters for suspended solids removal. Many potential fouling problems in the air-washer systems can be avoided by removing suspended solids in the chilled-water sump in this manner.

In plants where refrigeration is not required during winter months (Figure 33.4), washers operate independently, continually recirculating water from the sump through the spray nozzles. During these months, there is usually evaporation in the air-washer system, eliminating overflow and requiring makeup.

In a typical textile mill air washer, air entering from the plant first passes through a fine mesh screen or drum roll filter to remove lint, dust, oil, and other

FIG. 33.3 Typical textile air-washer system—summer operation.
debris. Some units have moving paper media while others have stationary synthetic media which are replaced two or three times per year. Some large rotating drum filters have vacuum attachments to continually remove contaminants from the filter medium. A knitting plant or a package dyeing plant with winding operations has oil in the air. However, lint is the major problem in cotton mills.

Most textile air-washer systems automatically blend outside air with in-plant air. The temperature and humidity needs may vary from one department to another in the same plant, requiring separate chilled-water systems.

The mixture of air enters the washing section where several vertical headers with spray nozzles are spaced evenly across the area of air flow. The nozzles spray water against each other so that the incoming air must pass through a barrier of water droplets 2 or 3 ft thick.

The spray nozzle headers are connected to a recirculating pump that has a capacity of 250 to 1200 gal/min (1 to 5 m³/min). The main pump located at the chilled-water sump continually supplies each individual air-washer sump. Overflow and gravity return the water to the main refrigeration unit and chilled-water sump. Capacities of air-washer sump pans range from 600 to 2500 gal (2 to 10 m³).

After the spray section of the washer unit, the air passes through mist eliminator blades to remove moisture. Some washers are designed with steam reheat coils to temper the cooled air to suit a particular textile process. Bypass ductwork is sometimes designed into a unit to allow for simple heating of the air without washing. Large fans or blowers take the air from the end of the washer unit and distribute it through the plant ductwork.
Most textile mills use compressed air to control water atomizers and for other purposes. Cooling water must be supplied to the air-compressor heads, oil coolers, and aftercoolers. The cooling water may come from the main cooling tower system in large plants where there are several air conditioning units, or there may be a separate small tower provided for these units.

The few plants set up for once-through cooling water on air-compressor systems conserve this by sending the spent water into one of the cooling towers during summer operations as makeup.

Some air washer units, particularly in synthetics plants, do not use chilled water for the washing process. The eliminator sections of these washers are followed by steam reheat coils, and chilled water coils to adequately control temperature and humidity.

Rotospray systems, similar in principle to the packaged air washer units, are housed in a cylindrical casing slightly larger than the supply ductwork, and are generally located on the roof of the mill. They have stationary spray nozzles and rotating eliminator blades that look like the compressor stages in a gas turbine. There is very little water in these units, and they are somewhat difficult to treat because the dirt is concentrated in a small amount of water.

**AIR WASHER MAINTENANCE**

Air washers are periodically shut down and washed out to control the severe fouling and deposition problems that occur. The frequency of shutdown and washout depends on the type of textile process being run, and the severity of the problem. It may be weekly in some plants, while in others 5- to 6-week intervals between washouts may be acceptable.

The high degree of recirculation in air washers leads to a variety of water problems including slime formation, deposits, corrosion, and odors. The major part of most deposits is microbial (slime masses). Microbial activity produces a sticky slime that combines with dirt, corrosion products, and crystalline matter to form hard encrusted deposits above the water level and thick slimy masses below the water on metal surfaces inside the washer. Controlling microbial growth in a chilled-water or air-washer system is the key to an effective treatment program. Microbe growth also causes odors, carryover, encrustation, and corrosion under deposits. Oil and other organic matter picked up from the plant air provide food for these microbes. Even though some removal of oil may be accomplished with air filters, residual oil will be present in the washer.

Carryover caused by foaming or biological growth on eliminator blades disrupts air flow and allows solids to pass into plant ductwork. This can cause a variety of problems in the plant from spotting of the product to disrupting the temperature and humidity controls. Severe damage can be done to the plant ductwork. Most textile plant ductwork contains a mat of lint and fiber. When this becomes wet, it becomes encrusted with the dirt present in the washer water and severe corrosion can result.

Corrosion is most severe in textile air-washer and chilled-water systems during summer operations when the water in the systems deconcentrates. Chiller tube sheets and heads are the most vulnerable areas. Dirt, fiber, oil, and microbiological deposits combine in some cases to totally slime over areas of the tube sheet. Severe pitting occurs under deposits of this nature. Corrosion inside the air washer units themselves may occur on any mild steel structures.
TABLE 33.1 Representative Mill Average Raw Waste Characteristics for Various Textile Operations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Wool and animal hair scouring</th>
<th>Wool dyeing and finishing</th>
<th>Cotton and synthetic woven fabric finishing</th>
<th>Cotton and synthetic knit fabric finishing</th>
<th>Dyeing and printing of carpet (cotton, wool, syn.)</th>
<th>Cotton and syn. raw stock and yarn dyeing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use (gal/lb)</td>
<td>4.3</td>
<td>40</td>
<td>13.5</td>
<td>18</td>
<td>8.3</td>
<td>18</td>
</tr>
<tr>
<td>Production (med. size)</td>
<td>80</td>
<td>2-20</td>
<td>6-180</td>
<td>8-40</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>1000 lb/day</td>
<td>4740-6220</td>
<td>150-700</td>
<td>250-850</td>
<td>100-650</td>
<td>144-630</td>
<td>75-340</td>
</tr>
<tr>
<td>BOD₅, range median</td>
<td>5480</td>
<td>300</td>
<td>550</td>
<td>250</td>
<td>340</td>
<td>200</td>
</tr>
<tr>
<td>TSS, range median</td>
<td>5000-24,500</td>
<td>45-300</td>
<td>45-475</td>
<td>40-485</td>
<td>75-150</td>
<td>25-75</td>
</tr>
<tr>
<td>COD, range median</td>
<td>7500</td>
<td>130</td>
<td>185</td>
<td>300</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>Oil and grease, range median</td>
<td>29,600-31,300</td>
<td>280-5000</td>
<td>425-1440</td>
<td>450-1440</td>
<td>570-1360</td>
<td>220-1010</td>
</tr>
<tr>
<td>Total chromium median</td>
<td>30,500</td>
<td>1041</td>
<td>850</td>
<td>850</td>
<td>925</td>
<td>524</td>
</tr>
<tr>
<td>Oil and grease, range median</td>
<td>5000-5600</td>
<td>5340</td>
<td>0.013</td>
<td>0.013</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>Phenol</td>
<td>0.05</td>
<td>4</td>
<td>0.04</td>
<td>0.05</td>
<td>NI*</td>
<td>0.12</td>
</tr>
<tr>
<td>Sulfide</td>
<td>1.50</td>
<td>0.5</td>
<td>0.04</td>
<td>0.27</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Color (ADMI)</td>
<td>0.20</td>
<td>0.1</td>
<td>2.72</td>
<td>0.2</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>pH (units)</td>
<td>2000</td>
<td>500-1700</td>
<td>325</td>
<td>400</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>6-9</td>
<td>6-11</td>
<td>7-11</td>
<td>6-9</td>
<td>6-9</td>
<td>7-12</td>
</tr>
</tbody>
</table>

* NI: No information available.

Note: All above, except color and pH, are reported in mg/L; ranges and medians are given.

A complete equipment survey and a thorough understanding of equipment operations are needed to design an effective water treatment program for air-washer and chilled-water systems.

The selection of an effective biocide and dispersant is generally the starting point in developing a water treatment program for air washers and chilled-water systems. Corrosion control is closely related to the effectiveness of the biocide and dispersant. There are no easy answers to the selection of a corrosion inhibitor for air-washer and chilled-water systems because of the differences between textile plants. The most important part of controlling corrosion is keeping the system clean.

The static charge on textile fiber as it passes through the various textile processes has a great deal to do with their efficiency. For example, if a carding machine is processing staple that has just been brought in from a cold warehouse,
the fibers will be negatively charged and will stick to the steel rolls of the card machine rather than smoothly rolling into a sliver of yarn. Fibers that develop too great a negative charge on spinning frames are subject to excessive breaks. Quaternary ammonium compounds may be used to control static charges in air, because they have the added benefits of being good biocides and cleaning agents.

Steam generation facilities in a textile plant will normally be quite simple. Condensate is usually not more than 25% of total feed water. The boilers are generally low pressure and the steam is rarely used for power generation except in the largest integrated mills.

Effluent treatment may be quite complicated because of the residues of processing chemicals present in the raw wastewater. In-plant containment and process modifications are increasingly necessary to meet effluent restrictions. Typical wastewater characteristics are listed in Table 33.1.

A treatment scheme for a large finishing plant is shown in Figure 33.5. The large equalization basin is provided to even out changes in composition and temperature, and to reduce the heat load on the aeration basin. In some plants the presence of strong waste (caustic from mercerizing, dyes, sizing agents) requires segregation and separate treatment of these streams. Activated carbon has been used as part of the treatment where dyes are a problem.

SUGGESTED READING
