POLLUTION PREVENTION STUDIES IN THE TEXTILE WET PROCESSING INDUSTRY

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ABSTRACT

The objective of this study was to investigate pollution prevention (P2) opportunities in the textile wet processing industry. This industry uses vast amounts of water, energy and chemicals. P2 audits were conducted at four textile companies. The companies were located in Virginia and included: a denim and soft wash laundry; a fiberglass yarn processing plant; a cotton fabric dyeing and printing plant; and a nylon yarn dyeing and finishing plant.

Each company was visited several times. Information about the operations, consumption of water, energy and chemicals were obtained by interviewing personnel. Information about wastewater characteristics, permit applications, water treatment and disposal records were obtained from the plant's records. Wastewater samples from several operations were analyzed for COD, DOC, color, TSS, pH and temperature. Lead, copper, zinc and chromium concentrations were also determined.

The collected information was used to make recommendations to the management of each plant concerning possible implementations. Reusing non-contact cooling water at the fiberglass processing plant will reduce the water consumption by 76% and results in a savings of $99,400 per year, if an additional chilling unit is not needed. There were several possibilities to reduce the consumption of water, energy and chemicals at the cotton dyeing and printing mill. Implementing counter-current flow between bleach washers will save $ 154,000 per year due to reduced consumption of water and energy. The savings will be $ 336,000 per year if the existing washers are replaced by more efficient washers. Improving the wash schedules and communication with clients at the laundry will reduce the consumption of water and chemicals. Dyebath reuse and counter-current flow of rinse waters were recommended for the nylon yarn dyeing and finishing mill.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

Dyes and auxiliary chemicals used in textile mills are developed to be resistant to environmental influences. As a result, they are hard to remove from wastewater generated during the dyeing processes. The best way to reduce the impact of these dyes and chemicals on the environment is by reducing the amount released for treatment. Furthermore, conventional waste treatment often causes only a transfer of waste from one phase to another. Treatment usually results in the generation of solids, sometimes hazardous, which are buried in a landfill. Disposal of waste in a landfill can result in groundwater contamination, gas formation and problems with odors. In other words, waste treatment is not necessarily a cure. As regulations' become more stringent, companies are forced toward more technologically sophisticated treatment methods. This results in an increased cost for waste management and sometimes forces companies to go out of business. More and more companies realize that reducing the waste at the source is necessary to reduce the cost of treatment.

In 1990, Congress passed the Pollution Prevention Act. This act reaffirms the federal objective of the Emergency Planning and Community Right-To-Know Act (Title III of SARA of 1986).

Pollution prevention (P2) is defined as those measures that eliminate or reduce pollution prior to off-site recycling or treatment. Pollution prevention does not only reduce water pollution, but also minimizes the release of pollutants to land and air. In the Pollution Prevention Act, the Congress defines a multimedia waste management hierarchy. Source reduction stands at the top of the waste management hierarchy and is followed by reuse and on-site recycling. Off-site recycling is not considered a pollution prevention measure. Treatment and safe disposal are listed at the bottom of the hierarchy (Smith, 1989a).

Reducing the volume of waste released through P2 can be accomplished by conservation and more efficient use of resources. Source reduction can be achieved by the following techniques: optimization/conservation of chemicals, chemical substitution, process modification, equipment modification and improved maintenance and housekeeping.

The objective of this research was to investigate pollution prevention opportunities in the textile wet processing industry. This was achieved through an extensive literature review and P2 audits performed at textile companies. In the literature review, the different textile wet processing operations are briefly discussed, and a description of various source reduction techniques is provided. Many articles were found that provide examples of source reduction measures successfully implemented at textile mills. These articles were used to clarify the concepts and benefits associated with P2.

In the second part of the study, P2 audits were conducted at four textile mills. The companies included in this study cover a wide range of plants in the textile wet processing industry. The mills are all located in Virginia and include:

1. A stone and soft washing laundry. This laundry washes denim products, cotton apparel and hats.
2. A large fiberglass processing plant. The mill receives fiberglass yarn, weaves it into a woven fabric, and applies special finishes.
3. A large cotton printing, dyeing and finishing facility. Pure cotton and polyester/cotton blend fabric are received from weaving mills all over the world.
4. A nylon yarn dyeing and finishing facility. The processed yarn is used for the production of industrial carpets.

Each plant was visited several times over the course of the P2 audit. The study was conducted by touring the production facility of the plant, interviewing employees, observing daily operations and reviewing existing information. Wastewater samples of several operations were analyzed to evaluate the possibility of reusing or recycling water.

Most of the mills in this study use large amounts of energy for drying operations and the production of steam and hot water. As a result, large amounts of energy are lost through stacks and wastewater-s. Where possible, heat recovery opportunities were investigated. The information collected at the plants was used to make recommendations to management concerning the possible implementations of P2 measures.

CHAPTER 2: LITERATURE REVIEW

2.1 TEXTILE PROCESSING

The textile industry includes a variety of processes ranging from the manufacture of synthetic fibers and fabric production to retail sales. The first step in the production of a textile product is the manufacture of fibers or, in the case of natural fibers, the manipulation of these fibers into useful fibers. Afterward, the fibers are turned into yarn by spinning or texturing. preparation, dyeing and finishing can be done on yarn or on the textile product obtained through knitting, weaving, and non-woven techniques. The last step is the fabrication of a finished product.

The preparation, dyeing and finishing of textile products consume large amounts of energy, chemicals and water. These wet-processing operations require the use of several chemical baths that, often at elevated temperature, give the desired characteristics to the yam or fabric. This section describes the different wet-processing techniques used in the production of cotton fabric. The same techniques are used when other types of fiber are processed, but differences will occur in the amount of raw materials required. Cotton has been chosen for this literature review because 70% by weight of the fibers processed in the United States are cotton fibers. Furthermore, processing natural fibers requires more processing than manufactured fibers. It is important to know that significant differences exist between mills processing the same fabric using the same techniques. For example, one mill might operate its rinsing baths at a higher temperature than another mill thereby reducing the water consumption.

2.1.1 Cotton

The sequence for cotton wet processing is schematically represented in Figure 2.1 (Snowden-Swan, 1995). These processes are usually done in batch, continuous or semicontinuous systems. In batch systems, the machine is loaded with a fixed amount of fabric, chemical solutions are added, and the process is conducted. After processing, the chemical bath is discharged, and the fabric is washed. Subsequent processing is usually done in the same machine. In continuous systems, the chemical mix is placed in pans, and the fabric runs through the machine continuously.

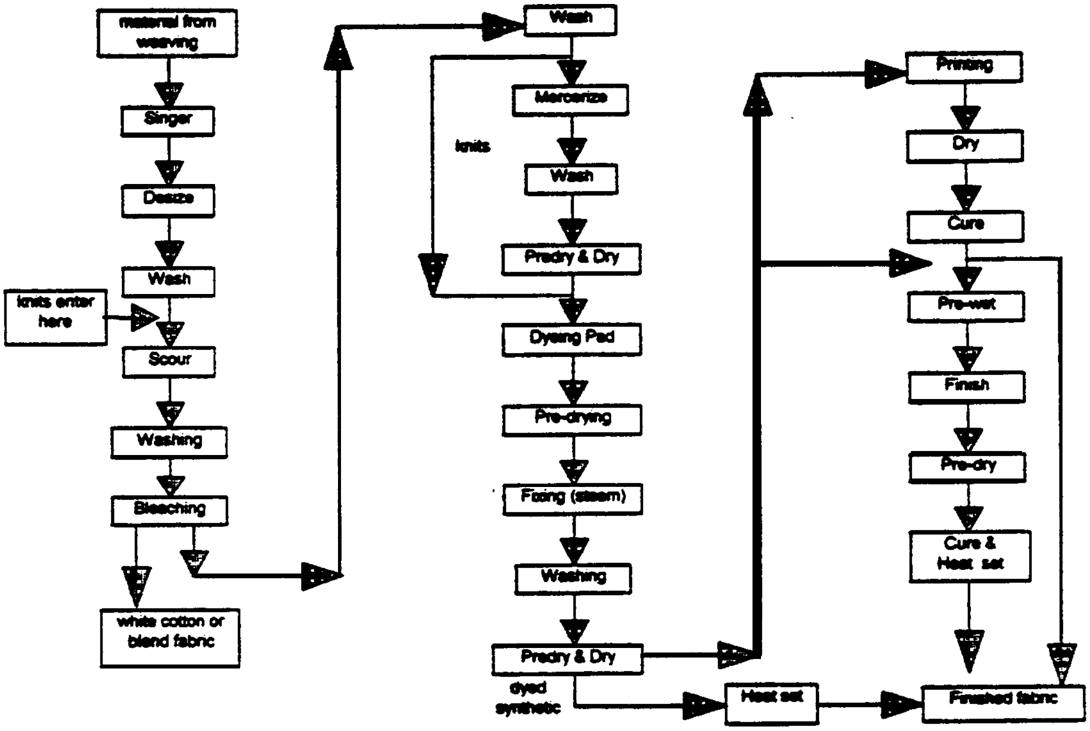


Figure 2.1: Sequence for Textile Wet Processing (Snowden-Swan, 1995).

Cotton wet processing can be divided into three steps. Preparation removes all the natural impurities from the cotton and chemical residuals from previous processing. Natural impurities include waxes, oils, proteins, mineral matter and residuals seeds. The cotton contains a significant amount of contaminants resulting from the widespread use of fertilizers, insecticides and fungicides. Previous knitting or weaving processes leave residuals of knitting oils and sizing chemicals on the surface of the cotton fibers. All these impurities must be removed before dyeing, because they can interfere with the dyeing process. Insufficient preparation can result in an uneven dyeing, can cause spotting or can even damage the fabric permanently.

Sizing

During sizing, chemicals are applied to the yam before the production of a woven fabric. Substances such as starch, polyvinyl alcohol (PVA), polyvinyl acetate, carboxymethyl cellulose (CMC) and gums enhance the tensile strength and smoothness of the warp yarn so it can withstand the mechanical forces during weaving. The commonly used sizing materials for cotton are starch, polyvinyl alcohol (PVA), and carboxymethyl cellulose (CMC). Yams used for the production of knitted fabric are usually treated with waxes or lubricants. (Jones, 1973)

Singeing

Singeing is a processing step that removes surface fibers from woven fabric. These surface fibers form small fiber balls on the cloth after being washed several times. Many different systems are available but usually the goods pass through gas-fired burners at high speed. For woven materials, this is the first processing step. (Dickinson, 1986)

Desizing

After the weaving process, the sizes have to be removed from the fabric because they interfere with subsequent processing steps. Sizes have, in general, a high biological oxygen demand (BOD) and will contribute significantly to the waste load of the mill’s effluent. In 1990, W. B. Achwal reported that waste stream of the desizing operation can contribute up to 50% of the total pollution load of a mill’s wastewater.

Three methods frequently used in textile processing are acid desizing, enzyme desizing, and oxidative desizing. The goal of these different methods is to hydrolyze the starch. Unlike starch, synthetic starches stay intact during desizing, can be recovered and reused. (Correia et al, 1994)

Scouring

Scouring is typically performed in an alkaline solution and high temperature environment. The removal of natural impurities is based upon saponification at high pH. Soaps and detergents added during scouring may precipitate with calcium, magnesium and iron(3+) if present. These metals are therefore removed by the addition of reducing and sequestering agents. The sequesterants will form strong complexes with calcium, magnesium and iron (2+) at high pH. The reducing agents are added to reduce Fe^{3+} to Fe^{2+}. The removal of natural impurities can be done in a single process or can be combined with desizing and/or bleaching. The use of sequestering and reducing agents can be avoided when softened water is used. Scouring is usually the first step in the processing of knitted goods and will remove the knitting oils which were applied to the yarn prior to knitting. (Jones, 1973)

Bleaching

Almost all fabric containing cellulosics are being bleached to remove the natural colored matter. Three chemicals are commonly used: hydrogen peroxide, sodium hypochlorite and sodium chlorite. In sodium hypochlorite bleaching, the washed, and scoured fabric is passed through a dilute sodium hypochlorite bath for impregnation (saturator) and stored in a J-box or a large pit. After bleaching, the goods are washed and treated with antichlor ($NaHSO_3$) to remove any traces of bleach. Bleaching with sodium chlorite is most efficient at pH 4.02. However, chlorine dioxide, a gas with a low threshold limit value for inhalation, is formed at this pH. Sufficient care must be taken to protect operators from chlorine dioxide fumes. Hydrogen peroxide bleaching is carried out under alkaline conditions. As a result, scouring and peroxide bleaching can often be conducted in one step. During peroxide bleaching, stabilizers are added for two reasons.

Stabilizers inactivate metal impurities that may cause catalytic decomposition of hydrogen peroxide. They also act as buffers. A stabilizer frequently used is colloidal sodium silicate. (Dickinson, 1986)

Mercerization

Mercerization is the treatment of pure cotton fabrics or yarn with a strong caustic soda solution to improve strength, dye substantivity, strength and smoothness. Sufficient washing is required after this step to remove any traces of caustic soda. (Correia et al, 1994)

Dyeing

Dyes can be divided into three classes based on their method of application. Fiber reactive dyes **react** with functional groups in the fibers. This class includes acid, basic, reactive, direct and mordant dyes. Reactive dyes are anionic dyes that form covalent bonds with the hydroxyl groups in the cellulose. Acid dyes contain sulfonic groups. These dyes are rarely used in cotton dyeing, but are commonly used on nylon and wool. They attach to organic fibers under acidic conditions. Direct dyes are often used in cotton dyeing. They are applied to the yarn under neutral conditions. Mordant dyes are acid dyes Which are reacted with a metal salt prior to dyeing. The second class of dyes needs chemical reaction before application. Vat dyes are soluble in their reduced form. They are made insoluble by oxidation after they are applied to organic fibers. Sulfur dyes are also made insoluble through oxidation. The third dye class are special dyes such as disperse, solvent, and natural dyes and pigments. Disperse dyes are water insoluble and are used for most synthetic fibers. They contain anthraquinone or azo groups. Solvent dyes have an improved solubility in solvents. Pigments are set to the fabric by an adhesive. Dyes most commonly applied to cotton are reactive and direct dyes. Cotton/polyester goods are dyed using reactive or direct dyes for the cotton portion of the fabric and disperse dyes for the polyester. (Needles, 1986)

Like pretreatment, dyeing can be done in the batch or continuous mode. Continuous dyeing is carried out by passing the fabric through a dyebath of sufficient length. The dye is then fixed onto the fabric by steaming. Subsequently, the fabric is washed to remove excess dye. Batch processes include beam, package, jig, and jet dyeing. Pad-batch dyeing is a specialized technique for the application of reactive dyes to cellulosic fibers. (Marchall, 1986)

Polyester and cotton have different characteristics and thus have different affinities for different dye types. The two materials are therefore considered separately with respect to dyeing operations. Due to the hydrophobic character of polyester, dyeing of this material is enhanced by using water insoluble disperse dyes. These dyes are held in suspension by a dispersant. In a typical batch dyeing sequence, the polyester is dyed at elevated temperature. The machine is then cooled, and the exhausted dyebath is dropped at the highest possible temperature. The machine is refilled with reactive dye solution to dye the cotton portion of the fabric. After completion of the dyeing process the excess dye is removed by dye-extraction and/or washing. (Marshall, 1986)

In printing, the print paste is very thick and viscous to prevent the migration of the dye in the fabric. This makes it possible to create a pattern of colors on the fabric. The paste is transferred onto the fabric using a rotary screen, flat screen or engraved rolls. Other printing techniques use heat to transfer the dye to the fabric. When the different colors are applied to the fabric, it is dried at high temperature to set the colors on the fabric. (Needles, 1986)

Several auxiliary chemicals are added to the bath during the dyeing processes. These chemicals can be divided into two groups: commodity chemicals and specialty chemicals. Specialty chemicals are mixtures which have an unknown composition due to proprietary information. The mixtures are often developed to solve problems specific to the process. Some specialty chemicals are developed to counteract or enhance the effects of other chemicals. In other cases, the specialty chemicals cause side effects that are detrimental to the overall process. For example, wetting agents are often added to preparation and dyeing steps to ensure penetration of chemicals. These wetting agents contain surfactants which can result in excessive foaming. As a result, defoamers are added to the chemical bath. A good example of a commodity chemical is sodium hydroxide which is added to the dyebath when cotton is dyed with reactive dyes. The presence of hydroxide ions opens the structure of the cotton. Salts are added to dyebaths, because they will retard the rate of dyeing. This results in a more even dyeing. Other chemicals commonly added are carriers, water softening chemicals, sequestering agents, wetting agents and reducing agents. Table 2.1 gives a listing of chemicals often used in the different processing steps. (Smith, 1989a)

Finishes

Finishing operations change the properties of the fabric or yarn. They can increase the softness, luster, and durability of textiles. Finishing can also improve the water repelling and flame resistant properties of the fabric. The characteristics of textiles can be altered by physical techniques (dry finishing processes) or by application of chemicals (wet finishing processes). Luster can be added by both physical and chemical methods. Characteristics like flame or water repellency can only be obtained by wet finishing. (Needles, 1986)

2.1.2 Fiberglass

Fibers made from glass are completely inorganic and are used in a wide range of industrial and aerospace applications. Fiberglass fabric is also used in cases where the use of heat and flame resistant material is mandatory.

Glass fibers are essentially undyeable and special techniques **must be** applied if dyeing is required. The fibers or fabric can be sized with a protein that is then insolubilized and dyed with protein dyes. Under acidic conditions, the amino groups on the proteins are present as NH_3^+ groups. These functional groups react with acid,reactive,

Table 2.1: Auxiliary Chemicals Used in Textile Wet Processing (Correia, 1994).

Description	Composition	Function	Processing step
salts	Sodium chloride sodium sulphate	Neutralize zeta potential of the fiber, retarder	**Dyeing**
Acids	Acetic acid Sulfuric acid	pH control	**Preparation, dyeing, finishing**
Bases	Sodium hydroxide sodium carbonate	pH control	**Preparation, dyeing, finishing**
Buffers	Phosphate	pH control	Dyeing
Sequestering agents Chelates	EDTA	Complex hardness Retarder	**Preparation** **Dyeing**
Surface active agents	Anionic, cationic and non ionic	softeners Disperse dyes Regular dye application Wetting agents Emulsifiers	Preparation Dyeing Finishing
Oxidizing agents	Hydrogen peroxide Sodium nitrite	Insolubilize dyes	Dyeing
Reducing agents	Sodium hydrosulphite Sodium sulphide	Solubilize dyes Remove unreacted dyes	Dyeing
Carriers	Phenyl phenols **Chlorinated benzenes**	Enhance absorption	Dyeing

mordant and direct dyes. Another technique used for dyeing fiberglass fabric is coronizing. This involves preheating the goods to temperature above 625^{O}F to remove all organic residues. Afterward, the fabric is dyed using pigments. (Needles, 1986)

2.1.3 Denim Processing

Denim is a woven fabric made from cotton. The warp yam is dyed before the cotton is woven into denim. The fill or weft yarn, which is inserted in-between warp yarn during weaving, is often not dyed. In the 1960's and 1970's some consumers wore their new jeans wet to obtain a great fit. To achieve the aged look, new jeans were bleached in buckets or washed up to 15 times before being worn for the first time. Since the early 1980's, these characteristics are given to the apparel in the factory or industrial laundries. (Kessels and Sulzer, 1989)

The finishing processes give the following characteristics to the jeans (Scott 1990):

1. Remove the size that was applied to the garment during weaving.
2. Give the fabric the worn, abraded and aged look.
3. Stabilize shrinkage.
4. Soften the denim.
5. Remove color to a tone that is currently in fashion.

There are four basic forms of finishing processes in denim manufacturing. All garments are prewashed to strip the sizing agents. This operation involves the use of an enzyme stripper and alkaline detergent, a clear water rinse and one or more softeners. The result is a soft, dark blue jeans that is preshrunk.

Some dark indigo color can be removed by the addition of sodium hypochlorite during washing. The resulting color will range from light blue to almost white depending on the amount of bleach added. After bleaching, the jeans are rinsed and treated with antichlor to remove any traces of bleach. (Kron, 1998)

The use of bleach in denim finishing will remove some indigo but will not give the apparel the worn, abraded look. The addition of stones will highlight the seams and pockets and thus produce the same effect as long-term use. The size of the pumice stones used in this process varies from gram size to stones with a diameter of 2". This process **is** labor intensive, because the pumice stones have to be removed from the pockets of each pair of jeans. A worn look can also be achieved when adding certain enzymes to the wash water. Laundry operators actually prefer to use enzymes. The stones put wear and tear on the washing machines and create problems with TSS in the mill's effluent. However, many denim laundries, are commission laundries and their washing procedures are dictated by the customer. They only use pumice stones when the customer asks for them. (Olson, 1988)

In acid washing, the washers are filled with jeans and bleach soaked pumice stones. This will create light spots when the stones touch the garments. The addition of anticlor will stop the action of the bleach after the stones are removed from the washer. (Greer and Turner, 1983)

Jeans finishing requires large amounts of water, energy and chemicals since the garments are washed in small amounts. Also, each wash is followed by one or more clear rinses. A typical denim finishing sequence is given in Table 2.2. This table also gives a list of chemicals commonly used in the different washes. Other chemicals are often added to improve the procedure. For example, some enzymes work optimally at a slightly acidic pH.

2.2 WASTEWATER CHARACTERISTICS

Provost (1992) agreed with Smith (1989b) to divide waste in four different types: hard-to-treat, highly dispersible, hazardous and toxic, and large volume wastes. Each of these four waste types can be found in the textile industry, and they all have their specific characteristics. Treatment is easiest if each waste is considered separately before being combined.

Difficult-to-treat wastes may include dyes, metals, phenols, toxic compounds and/or phosphates. This type of waste is resistant to conventional biological treatment, can pass through the treatment system and end up in the receiving stream where it sometimes causes toxic effects. It is therefore important to minimize through chemical substitution the use of chemicals which result in difficult-to-treat wastes. If no useful substitute can be found for the problem chemical(s), the chemical(s) should be reused,

Table 2.2: Typical Sequence Used in Denim Laundries.

washing step	Chemicals
Prewash	Enzyme detergent
Rinse	
Bleaching	sodium hypochlorite, detergent
Rinse	
Antichlor wash	Disodium thiosulfate
Rinse	
Stone-washing	Stones and enzymes
Rinse	
Softener	Fabric softener

recycled or segregated from the main waste stream and treated separately.

Examples of highly dispersible wastes are lint, print paste and solvents. Lint and print pastes can clog up pipes and pumps. Lint is easily removed by screens and/or filters. Binders present in the print paste form gels and clog up drains. Normally, print paste does not cause toxicity problems, but it does put a high organic load on the treatment system. Problems associated with print paste can be reduced by making paste in quantity only sufficient for a given job. Excess print paste can be recovered in the concentrated form for recycle or reuse. For example, the water used to clean the rotary print screens can be collected and used as makeup water for a water-based print of the same color. The excess print paste can be treated with the solids removed from the biological treatment system. Other highly dispersible wastes, like solvents, have value and can be recovered through distillation, which reduces the costs of disposal and purchasing new solvent.

Toxic and hazardous wastes are essentially hard-to-treat wastes. Smith separated them from hard-to-treat wastes because of their potential environmental impact. They include metals, chlorinated solvents, and non-biodegradable surfactants. The usage of these chemicals should be avoided if possible and if used, they should be kept out of the wastesteam through segregation. It is easier to treat wastes in their most concentrated form. Metals can often be precipitated through the addition of chemicals. It is more costs effective to treat a small concentrated waste stream than to treat the large combined waste stream.

Large volume wastes can be found in any textile mill. They include wastewater from the preparation of the substrate, rinsing and washing after dyeing operations and waste from batch dyeing operations. These wastes are not heavily contaminated but can put a burden on the hydraulic load of the treatment system. The volume discharged can be reduced through reuse and recycling, process modifications and equipment changes.

2.3 POLLUTION PREVENTION OPPORTUNITIES

Source reduction assessment involves the analysis of the textile wet processing operations to reveal measures that minimize substrate, chemical, water and energy consumption. Substitution of chemicals, process modifications and technology changes can increase the treatability of the wastewater and can also reduce the pollution load. Good housekeeping and raw material control can help to solve certain problems. An overview of pollution prevention techniques is given in Figure 2.2. In the EPA's pollution prevention hierarchy, off-site recycling is considered as treatment and not as pollution prevention technique. This ‘section gives a description of different pollution prevention techniques. Case studies are included to clarify the techniques. Pollution prevention may result in several benefits for the textile processor, including:

1. loss reduction
2. reduction of chemical, water and energy consumption, thereby resulting in savings, sometimes even increased production
3. reduced liability for waste produced
4. improved compliance with regulations

2.3.1 Raw Material Control

Raw materials used in the textile industry include processing water, dyes, process chemicals (auxiliary chemicals) and substrate (yarn, fabric, etc.). These materials can contain several contaminants. Some impurities, like traces of metals in dyes and in auxiliary chemicals, result in undesirable wastes and/or in the use of extra chemicals. The presence of calcium and magnesium in the scouring bath results in insufficient scouring. Sequesterants added to this bath will form strong complexes with calcium, magnesium and iron, and therefore improve scouring. Softening water through ion exchange achieves the same effect and reduces the amount of sequestering and reducing agents used.

Quality control of chemicals under consideration or chemicals used in the plant minimizes hazardous waste generation. Quality control should be done on each shipment of chemicals and can be achieved without a large capital investment. A good practice is to compare each shipment with an established standard. The following set of simple tests, developed by Smith (1987), is performed on a standard, and the results are kept on file. The same tests are then conducted on each shipment of the chemical and the results compared with these of the standard. Any significant variation in quality will be detected.

1. check the pH of the sample with paper or a pH-meter (checking the pH of non-aqueous solution does not give useful results).
2. check the viscosity with Zahn cup.
3. check the density with hydrometer.
4. note the color and clarity visually.
5. note odor .
6. for clear liquids, check the index of refraction with handheld refractometer.

The above set of tests will detect variations in product quality. Some variations

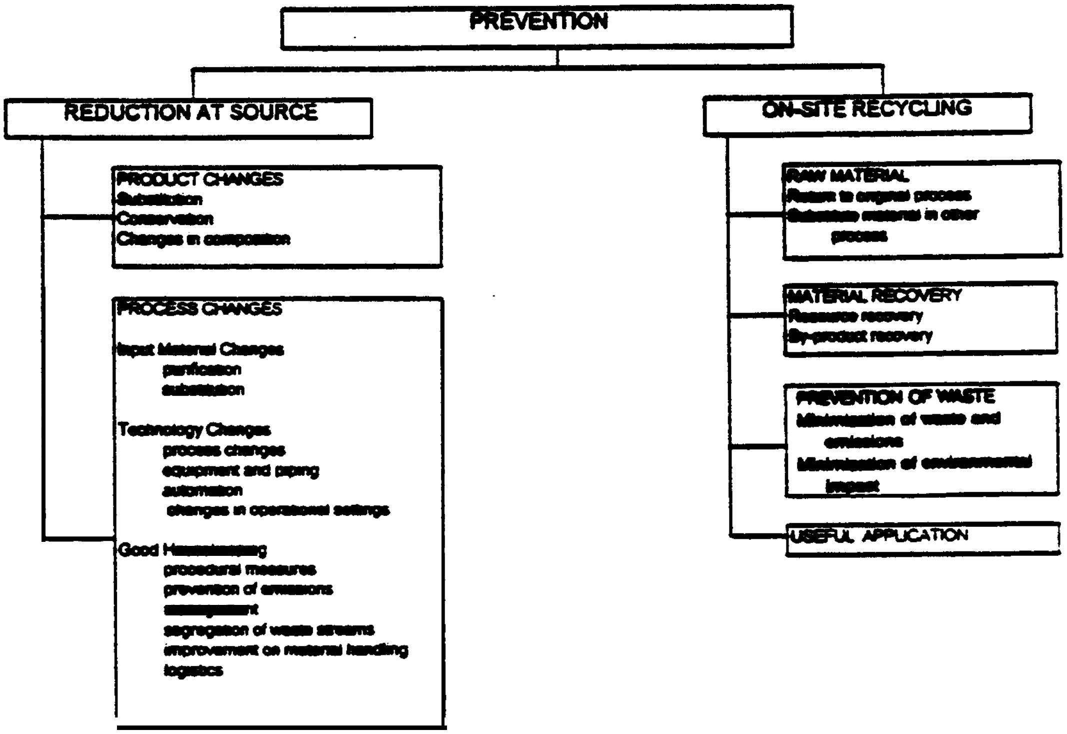


Figure 2.2: Overview of Pollution Prevention Techniques.

are caused by a change in formulation of the product. Smith (1987) reported a chemical manufacturer sold drums of decyl alcohol ethoxylate wetting agents and drums containing a resinous fixative. Drums containing resinous fixative were mislabeled and sold as wetting agent. This resulted in massive dye spots and reworks at the mill that used this chemical in direct dyebaths. The mislabeling would have been detected by raw material control.

Chemical prescreening does not only reduce the production of hazardous waste but reduces the generation of offquality products and improves the consistency between different runs. Defective goods have a lower market value than first quality products. The repair techniques are often expensive and do not guarantee first quality products. Table 2.3 shows typical textile quality levels. The first step in minimizing the production of offquality products is a consistent quality of process chemicals and other raw materials.

Table 2.3: Textile Quality Levels (Smith, 1987 a).

	% Perfect	% Seconds	Unmerchandizable
Bleach	90-92	2-4	upto6%
Dyed	85-87	5-8	up to 8%
Printed	78-82	6-10	Up to 12%

2.3.2 Maintenance and Housekeeping

Substantial waste reduction can be realized through good housekeeping and maintenance. Most improvements in maintenance and housekeeping are simple and inexpensive. Often the difficulty in improving housekeeping practices is motivation of the operating personnel. It is not easy to change habits that have developed over several years. The best way to tackle this problem is to making workers aware of, and periodically reinforce, the consequences of bad habits. For example, making employees realize how much water goes down the drain due to a leaking valve or a running hose can significantly reduce the daily water consumption. (Jones, 1973)

In England, the Water Authorities estimated the water supply losses due to broken valves, leakages, etc. In 1977, Holme reported that losses vary from 6-44% of the total water supply, with an average of 25%.

Spills are often the result of poor housekeeping. Accidental spills, making excess chemical mixes and making up the wrong chemical mix not only cost the company money, but put an unnecessary burden on the wastewater treatment system (EPA, 1978).

Good organization is also important for the improvement of housekeeping practices. Formulations should be mixed near the point of application. This will prevent the use of excessive piping to transport the chemical mix from the mix tanks to the pad pans. The chemicals in the mix tanks, piping and pad pans have to be treated and disposed of at the end of a run. Batch dumps of these strong chemical mixes can contribute significantly to the strength of the waste stream even when the amount discharged is small. It is therefore important to keep good records of the size of each run and the amount of mix dumped after the run. This will help to accurately predict the exact amount of mix needed.

Properly maintained equipment results in good machinery performance and accurately predict , reduces the number of reworks and off-quality products. Leaks and spills due to badly maintained equipment will also be reduced.

2.3.3 Water Conservation

Beckmann and Pflug (1980) reported that the average water consumption in a textile mill was 150 to 200 m^3 per metric ton of finished goods in 1980. In that same year, costs for water supply and wastewater treatment accounted for 4.3% of the total wet processing costs (Beckmann and Pflug, 1980). It is, according to Smith (1989 c), not unusual to find situations where a 10% to 30% reduction in water use can be achieved without major investments. Common situations where water is unnessarily consumed include hoses left running, broken or missing valves, cooling water that is running while machines are not in use, and-defective toilets and water coolers.

Studies have shown that the amount of water used per pound of fabric will vary with the weight of the fabric, process, equipment type and dyestuff. Table 2.4 gives the water usage in cotton wet processing operations. This table shows that the water usage in the dyeing operation depends on the type of dye used.

Preparation

Wastewater can be recycled in continuous preparation processes. The waste

Table 2.4: Water Usage in Different Textile Wet Processing Operations (EPA, 1978).

Process	Volume in gal/1000 lb product
Slashing, sizing yarn[1]	60 - 940
Desizing	300 - 1,100
Kiering	310 - 1,700
Scouring	2,300 - 5,100
Bleaching (range)	300 - 14,900
Mercerizing	27,900 - 36,950
Dyeing	
Aniline Black	15,000 - 23,000
Basic	18,000 - 36,000
Developed colors	8,900 - 25,000
Direct	1,700 - 6,400
Naphtol	2,300 - 16,800
Sulfur	2,900 - 25,600
Vat	1,000 - 20,000

[1] Cloth-weaving-mill waste (composite of all waste connected with each process), EPA 1978.

stream in these processes is continuous and fairly constant in characteristics. The effluent from the desize J-box can be used to makeup the desize mix. Wash water from the caustic washer can be reused in the desize washer. The caustic present in this water will enhance the removal of sizing chemicals. Batch operation processes do not easily allow for water recycling. When trying to reuse wastewater in batch operations, storage facilities for the reusable wastewater must be provided. Other problems associated with the reuse of wastewater from batch bleaching and scouring are the non-continuous character of the waste stream and the higher liquor ratios (Smith, 1986 a).

Supplying only the needed amount of water to a machine and reducing the number of throughputs can result in significant water savings. Evans (1982) investigated possibilities to reduce water and energy consumption in a open width bleach range. This preparation train consists of 3 stages: desizing, scouring and peroxide bleaching. The water consumption in these stages can be reduced by flow reduction and counter current flow. Reducing the water consumption will also reduce the energy consumption since the temperature of the water used varies from 150°F to 190°F. The bleach washers can be operated at a temperature of 150°F - 160°F. The desize and caustic washers must be operated at 180°F-190°F. The viscosity of the materials in these two washers increases quickly with decreasing temperature. The results of Evans' work are shown in Table 2.5.

Table 2.5 Water and Energy Savings Available by Process Changes (Evans, 1982).

Change	**Savings**	
	Water gal./hour	**Energy lb.steam/hour**
Reduce water temperature by 10°F at the bleach stage washers	**0**	**250**
Decrease water flow by 5 gal./min at the caustic washer	**300**	**300**
Counterflow from bleach washers to caustic washers	**3,000**	**2,600**
Fully counterflow wash water	**6,000**	**5,300**
Eliminate one stage	**3,100**	**3,700**
Single stage bleach	**6,200**	**7,000**

In counter current washing, the water flows in the direction opposite to the fabric. As a result, the least contaminated water contacts the cleanest fabric. Table 2.5 shows that the technique can result in significant savings. Many mills use counter current flow in continuous preparation processes. This technique: can also be used for rinsing after dyeing procedures.

Another case study (EPA, 1978) described process changes made in a single stage bleach range processing 65/35 polyester/cotton knit goods in rope form. The unit consisted of a saturator, J-box with wet heel and six box washers. Acetic acid was added to the last two washers to neutralize the fabric. The bleach washers operated at a flow of 30-40 gallons per minute (gpm) between 170 and 19O°F. The fabric leaving the fourth washer had a caustic concentration of 0.025 % at a flowrate of 40 gpm. Reducing the flow to 15 gpm increased the concentration of caustic to 0.033 %. The concentration of caustic in the fabric' was not changed when the temperature of the water was lowered from 205°F to 145°F. As a result of the experiments the water temperature was lowered to 140- 160°F and the flow rate to 20-25 GPM. These measures resulted in significant water and energy savings.

In another mill caustic scoured cotton yarn packages were batch washed by a 10 minute hot running rinse followed by a 10 minute cold running rinse. Full-scale experiments were performed to optimize the process. The experiments revealed that the same fabric quality was obtained by a 3 minute hot running rinse by a 3 minute cold running rinse. (EPA, 1978)

The amount of water used in many fabric pretreatment operations is often preset to treat the most difficult cloth processed. As a result, large amounts of water are wasted when cleaner/easier fabric is treated (Cooper, 1978). Besides this, good preparation is essential to achieve good dyeing. There is a tendency in the textile industry to use more water than necessary when removing chemicals during rinsing. An effective way to discover if the right amount of water is used, is reducing the water flow slowly, for example by 10% increments. The procedure is monitored closely to detect when not enough water is used. At this point, the water level has to be increased by 10%. If this procedure is followed for each type of fabric processed, significant water savings can be achieved.

Surveys conducted in Europe between 1966 and 1975 showed a marked decrease in the water consumption of the textile wet processing. This decrease was the result of increased costs of water supply and effluent treatment. The water consumption was reduced by 50% by improving the efficiency of processes, by minimizing excessive rinsing and by controlling fractures and leaks. (Park, et al., 1984)

Dyeing

Table 2.6 gives the water consumption and typical liquor ratio for different dyeing machines. The liquor ratio is the ratio of the amount of liquor (in pounds) in the exhaust dyebath to the amount of fabric (in pounds). This ratio varies according to the machine type. Low liquor ratio dyeing machines have been developed to save water. However, the largest quantities of water in dyeing operations are not used in the dyebath but in subsequent rinsing. The liquor ratio does not reflect the amount of water used during rinsing. It is therefore not necessary true that a dye machine with a low liquor ratio has a low overall water use (Smith, 1986)

The amount of water used during rinsing depends on the dyeclass, and the type and weight of the fabric. Dürig pointed out in 1981 that the dyeclass, fabric and desired effects determine the dye equipment used and thus the amount of water required for rinsing. It is sometimes possible to achieve the same shades with dyes of two different dye classes. Each of the dye classes requires different dye techniques, chemicals, energy and equipment. All these factors and the pollution load of the procedures must be taken into consideration when comparing different techniques.

The effectiveness of washes increases directly with the volume of water being used but it increases with the power of the number of washes. It is therefore more effective to conduct several washes with a small amount of water than to wash the fabric once with a large volume of water. Removing all the excess water before the next portion of wash water is added to the fabric will prevent excessive contamination of the wash water (EPA, 1978).

Rapid inverse dyeing (RID) is a dye technique that is successfully used in dyeing polyester/cotton blends using disperse and fiber reactive dyes. In the normal dyeing procedure the polyester is dyed with disperse dyes at elevated temperatures. The fabric is then washed to remove all traces of dye and acetic acid. The machine is refilled with reactive dye solution to dye the cotton portion of the fabric. After completion of the dyeing process the excess dye is removed by dye-extraction and rinsing. In RID the cotton is dyed first with reactive dyes. The acidic disperse dyebath is used as a wash for the fiber reactive dyes. This technique reduces the water and energy consumption. The duration of the dye cycle is also reduced. (Smith, 1986)

Table 2.6: Water Usage and Liquor Ratio in Different Dyeing Machines (Smith, 1986).

Dyeing Machine	H_2O consumption (gal/lb)	Typical Liquor Ratio (Liquor/Goods at Time of Dye Application)
Continuous	20	1:1
Beck	28	17:1
Jet	24	12:1
Jig	12	5:1
Beam	20	10:1
Package	22	10:1
Paddle	35	40:1
Stock	20	12:1
Skein	30	17:1

The non-contact cooling water used in finishing and dyeing operations is often discharged to the drain. This water can be use as makeup water for the boiler and as processing water in operations that do not required drinking water quality. (Cooper, 1978)

It is also possible to reuse this water as non-contact cooling water after heat exchange. Cooling water should be segregated from the other waste stream if reuse is not possible since it unnecessarily increases the hydraulic load of the treatment system.

Solvent Processing

Many research projects in the textile industry were conducted during the seventies to investigated the possibility of solvent preparation, dyeing and finishing. Interest in solvent processing remained low due to the lack of suitable dyes, auxiliary and specialty chemicals Holme, 1977). Another influencing factor were the environmental laws that regulate emissions from solvents. Kothe (1973) investigated polyester fiber dyeing by an exhaust method from perchloroethylene. He investigated the use of 1100 dyes. Only one dye gave a color yield greater than 50%.

Use of Reclaimed Water

The required quality of water used in textile wet processing operations is controversial. The industry uses water of drinking water quality although several processes do not require water of this quality. Several articles discussed the use of reclaimed water. McKee and Wolf (1966) reported that high quality water is required for bleaching to prevent staining of the fabric. The water should be colorless with a low concentration of iron, manganese and calcium. Another researcher, Harker (1980), reported the successful use of a sandfiltered, chlorinated activated sludge effluent in a mill in Yorkshire. This company produces high quality blazers and no differences were observed between fabric processed with water of drinking water quality and fabric prepared with reclaimed water.

Inoua and co-workers investigated in 1977 the use of reclaimed water for scouring, bleaching and dyeing of cotton, wool and synthetic fibers. The types of water used in the full-scale experiments were municipal water, water after flocculation, sedimentation and sand filtration of biologically treated wastewater and the same water after activated carbon absorption. Slight differences were observed in the effects of the different water sources on various fibers but these effects were not considered significant.

Tworeck (1984) used municipal supply water and water from the Athlone wastewater treatment plant in his experiments. The treatment plant consisted of an activated sludge reactor followed by sandfilters, prechlorination, activated carbon absorption and chlorine disinfection. He compared the effects of sandfiltered water and final ‘effluent water on the fabric with water of drinking water quality. The water was used in fabric preparation, dyeing and finishing of polyester, nylon, a cotton/nylon blend, wool and other polyester and nylon blends. The reclaimed water had slight effects on the dyeing of the fabric but they were fully acceptable to the mill.

Goodman and Porter (1980) investigated the influence of water conservation and recycling on the water and energy consumption in a typical continuous preparation range. The results of their investigation is shown in Table 2.7. They also discussed the effects

Table 2.7: Influence of Conservation and Recycling on the Water and Energy Consumption in a typical Continuous Preparation Operation (Goodman and Porter, 1980).

Process Modification	water consumption gpd	Average process temperature, °F	**Energy for heating water 10^6 Btu/day**
No conservation	346,000	165	274
Temperature increase and water reduction	194,000	195	202
Multiple use of water	158,000	195	165
water recycled after ultrafiltration	43,000	195	45

of impurities in process water on chemicals and fabric performance. Most wastewater leaving a textile mill needs treatment before reuse is possible. However, there are waste streams that can be reused directly. Table 2.8 gives an overview of the impurities commonly found in textile wastewater and the tolerability of these impurities in reclaimed water. Chemical optimization and substitution of chemicals can result in significant reduction of pollution load and can even make water reclamation possible.

Table 2.8: Impurities Commonly Found in Textile Mill Wastewater (Goodman and Porter, 1980).

Impurity	Effects on reclaimed water
Color	Presence will be critical in most wet processing operations
Oxidizing and reducing agents	Are removed before water is reused during wastewater treatment but can reduce the effect of dyes
pH	Can be controlled easily
Hardness	Can interfere with action of some chemicals
Electrolytes	Can limit use of reclaimed water
Metals	Can limit use of reclaimed water
Total solids	Can interfere with dyes and other chemicals
Surfactants	Can interfere with the dyeing process

2.3.4 Chemical Optimization and Conservation

In many mills, chemical are applied in excessive and unnecessary amounts. The use of chemicals can often be reduced without any significant effects on the quality of the product. Chemicals that are often overused include cleaning agents, surfactants, defoamers, lubricants, carriers and other chemical specialties. Sometimes chemicals arc added to counteract the negative effects of other chemicals. Instead of adding more chemicals to the bath, the offending chemicals should be substituted with a chemical(s) with fewer harmful effects.

Smith wrote in 1989 a series of articles about source reduction. He gave a good example of specialty chemical misuse in the first article of this series. A problem associated with most dyeclasses is the uneven dyeing of the fabric. This can be solved by the addition of leveling agents and retarders. However, the use of these chemicals results in a lower exhaustion of the dyebath and thus in a higher usage of dyes. An even and level exhaustion of the dyebath can be obtained by optimization of the dyebath temperature. As a result of the temperature control, the use of leveling agents, retarders and dyes will be reduced. The color in the effluent will also be lower.

Trying to avoid spillage and preparing precise quantities of chemical mixes will not only conserve water but, more importantly, will reduce the strength of the wastewater. It is very important to adjust the chemical mix to the weight, type and style of the fabric being run. For example, it happens that the quantity of chemicals used in continuous bleach ranges is set to treat the most difficult fabric. Consequently, chemicals are wasted when an easier fabric is processed.

Control equipment will help to optimize the chemical dosage in continuous processes. In these operations, the concentrations of the critical chemicals in the bath are periodically checked. If the concentration of the chemical is either too low or too high, the operator will adjust the feed. Poor results will occur when the concentration of the chemical is too low. As a result, reworks arc often necessary. However, when the concentration of the chemical is too high the fabric can be damaged permanently. There is equipment on the market that maintains the chemical concentration of the bath at predetermined levels. Installation of such automatic chemical feed can result in significant savings due to lower chemical costs, fewer reworks and less damaged fabric. During continuous bleaching, caustic and hydrogen peroxide are added to the saturators of the bleach range by constant feed pumps. The operator takes a sample from the saturator and titrates it to an endpoint thereby finding the correct concentration of hydrogen peroxide and sodium hydroxide. The pumping rate of the pumps is then adjusted to compensate for any deviation from the desired level. An automated chemical feeder constantly determines the bath concentration and adjusts the chemical concentration to the desired level. (EPA, 1978)

Most water used in preparation and dyeing processes is softened. This is often achieved by adding chemicals to the water that form strong complexes with hardness ions. A more environmentally friendly way to soften water is ion exchange. There are also processes that are less efficient when softened water is used. Hall (1982) reports that enzyme desizing and non-chlorine bleaching operations will improve in water with a high hardness.

Cook (1990a) reported that FMC Corp. investigated the use of hydrogen peroxide in denim finishing. According to FMC Corp. hydrogen peroxide can, when used with some auxiliary chemicals, replace the chemicals that are currently used to desize and decolor denim apparel. The new process is supposed to be cost effective, environmentally safe and has additional quality advantages.

2.3.5 Chemical Substitution

The total quantity of chemicals used in textile mills varies from 10% to over 100% of the weight of the cloth. **Many chemicals currently used in the** textile industry influence the aquatic life of the receiving stream. Sometimes these chemicals can be substituted by other chemicals. This is not always easy due to the lack of information about BOD data and aquatic toxicity of the chemicals and due to the proprietary nature of specialty chemicals. A recommendation many mills get is to substitute low BOD chemicals for chemicals with a high BOD. These low BOD chemicals will help to reduce the waste load of the mill's effluent. However, little is known about the long term effects of these products. It is possible that a low 5-day BOD value means that the chemical is resistant to conventional biological treatment and that it might influence aquatic life.

Sizes

The substitution of synthetic sizing materials for starch (50% BOD) in cotton processing will reduce the waste load of the mill (Jones, 1973). Unlike starch, synthetic sizing agents pass the desizing process unchanged and can be recovered and reused. However, when recovery is not practiced, the sizing chemicals end up in the effluent. The biodegradability of Polyvinyl Alcohol (PVA) is currently under discussion. Some researchers, such as Achwal (1990) report problems degrading PVA. Others are able to degrade PVA in a conventional activated sludge system (Porter et al., 1976). Another problem associated with PVA is its solubility in water. PVA is applied to the fabric in a 10% concentration by weight in the feed solution. Large quantities of water are required for PVA desizing due to the low solubility of PVA. As a result, the desize effluent contains less than 1 % PVA by weight. If this PVA is recovered and reused in sizing, it must be concentrated to a solution having a PVA concentration of 10 % by weight. (Cook, 1990)

Currently new sizing chemicals arc under development The technique used in the development is called Interpenetrating Polymer' Network Technology (IPNT). Each polymer consists of a large number of monomers that must react with each other to form the polymer. The new technique allows molecules, that under normal condition do not react, in the same polymer. The result is a hybrid polymer that has the characteristics of both monomers. The ideal size is a polymer that provide high weaving efficiency and dissolves readily in water (Cook, 1990 b).

Desizing

Snowden-Swan (1995) reported substitution enzymes by H_2O_2 for starch desizing. The results in a lower BOD in the effluent since starch is degraded to CO, and water when hydrogen peroxide is used. Starch hydrolyses to anhydroglucose when using amylase enzymes. Another desizing method involves the use of enzymes developed for the home laundry industry. As a result, starch is degrade to ethanol. Ethanol has a lower BOD then anhydroglucose and can be used as fuel.

Dyes

Each dye class produces a waste with specific characteristics. An overview of problems related to specific types of dye is given in Table 2.9. Sometimes, dyes causing specific problems can be replaced by dyes from another class. This is not always a good solution since auxiliary chemicals can also cause problems.

Table 2.9: Overview of Problems Related to Specific Dye Classes.

Dye class	Constituent causing problems	Problem
Pigments	Acrylic binders	High TSS
	Metals	Toxicity
Vat/sulfur dyes	Redox agents (metals)	Toxicity
Fiber reactive dyes	Alkali	High pH
	salt	salt concerns
Direct dyes	Low exhaust of dyebath	High color
Mordant dyes	Metals	Toxicity

4cetic acid

Acetic acid is used in a variety of textile processes. It is, for example, used to lower the pH when dyeing polyester with disperse dyes. The substitution of formic acid for acetic acid can reduce the waste load of the mill significantly. Acetic acid has a BOD equivalent of 0.64 lb/lb whereas the BOD equivalent of formic acid is only 0.12 lb/lb. Eighty-five percent of the BOD load of a dyeing procedure using acetic acid can come from the acid (Jones, 1973). The substitution of formic acid for acetic acid can also result in cost reduction due to the lower weight equivalent of formic acid and its higher purity. Organic acids like acetic acid can also be substituted by mineral acid but they increase the salt content of the waste stream.

Surfactants

Major problems in the textile industry are associated with surfactants, emulsifiers and dispersants. Surfactants are widely used in the industry and can be found in almost every chemical specialty to improve the solubility/dispersibility of the chemical in water. Surfactants are used to ensure even and rapid wetting of the fabric and to improve penetration of chemicals and dyes. Surfactants improve fabric wetting because they reduce the surface tension. It is this characteristic that makes surfactants toxic to aquatic life. The toxicity of the surfactant is strongly influenced by its biodegradability.

Table 2.10: Relative Toxicity of Surfactants in Untreated Wastewater (Moore, 1987)

Surfactant class	Surfactant	Acute 48 hours static LC5O for Daphnia pulex, ppm
nonionic	Nonyl phenol alcohol (AP)	13
	Diethanol cocoamide (DEC)	2
	Linear alcohol ethoxylate (LEA)	5
Anionic	Dodecyl benzene sulfonic acid (DDBSA)	20
	sodium lauryl sulfate (SLS)	28
	Sulfated ethoxylated alcohol (SEA)	20
Cationic	Tallow amine ethoxylate (TAE), 15 mol E-O	6
	Tallow amine ethoxylate (TAB), 150 mol E-O	66
	Alkyl dimethyl benzyl ammonium chloride (ADBAC)	4

Several research groups investigated the biodegradability and toxicity of surfactants (Achwal, 1990, Kravetz, 1983, and Moore, 1987). When evaluating two different surfactants, it is important to consider both the toxicity and biodegradability of the chemicals. A good example of this ‘is the difference between nonyl phenol ethoxylate (AP) and linear alcohol ethoxylate (LEA). Nonyl phenol ethoxylate has highly branched chains. The relative toxicity of these and other surfactants in untreated solutions is represented in Table 2.10. The table shows that there is considerable variation in the relative toxicity of the different surfactants.

The toxicity of AP in the untreated effluent is much lower than the toxicity of LAE. The results are completely different when the toxicity of AP and LAE are measured in treated effluents. These treated effluents showed no sign&ant toxicity due to LEA, but substantial toxicity for AP. The explanation is the difference in the biodegradability of the two chemicals. The more linear a chemical, the greater its biodegradability. Nonyl phenol alcohol was degraded by 25% whereas LEA was completely degraded under the same conditions. Even when the toxicity of LEA before treatment was much higher then the toxicity of AP, the biodegradability of LEA resulted in the complete removal of LEA. As a result, the treated effluent showed no toxicity for LEA and a significant toxicity for AP. The toxicity problem related to AP can thus be solved by substituting LEA. This substitution has a few drawbacks, however. The greater biodegradability of LEA results in an increase in BOD_5. This is something many mills, and especially mills discharging to a POTW, want to avoid. Alkyl phenol ethoxylates, like AP, are often used by the industry because they foam less than fatty alcohol ethoxylates (FAE). Fatty alcohol ethoxylates, like LEA, have lower wetting power, detergency, alkali stability and result in a more stable foam. (Kravetz, 1983). Achwal, reported in 1990 that new surfactants were developed with the same efficiency as AP or better. An extra benefit of these products is that they are completely biodegradable.

Case Study

The city of Mount Airy in Surry County, NC uses a trickling filter to treat the municipal waste. The effluent of the treatment plant failed toxicity tests. Analysis of the treatment plant effluent showed high concentrations of metals (copper and zinc) and alkyl phenol ethoxylates. Each of the textile mills discharging to the town’s sewer was asked to review the chemicals they used and to minimize the use of chemicals that were harmful to aquatic life. Within two months, the effluent from the POTW passed toxicity tests. (Smith, 1989b).

Urea

Urea is frequently used in printing with reactive dyes. This chemical brings several benefits to reactive dye printing. It increases the solubility of the reactive dye in the print paste, improves the color yield, and the levelness and smoothness of the printed area. On the other side, urea drastically increases the nitrogen content of the wastewater ‘and can cause problems in the treatment system. Provost (1992) investigated three alternatives:

1. flash age printing
2. substitution of urea for an alternate chemical
3. mechanical application of moisture prior to steaming

In flash age printing, the print paste does not contain alkali or urea After the cloth is printed and dried, it is overpadded with high concentrations of caustic and electrolytes or with caustic soda and sodium silicate. Complete chemical substitution of urea is not yet possible, but ICI Colors investigated the substitution of urea in print pastes. Currently, in printing 100% cotton fabric with reactive dyes 100 g/kg urea is used in the print paste. ICI Colors investigations showed that this urea dose does not always give the best color yields. Several trials showed that for most ICI reactive dye print recipes, the optimum dose was 50-75 g/kg. If dicyandiamide was added to the recipe in a dose of 15 g/kg, the urea dosage could be reduced to 0-40 g/kg. The color yield for the two recipes mentioned above were similar. The amount of dicyandiamide could even be reduced to 10 g/kg without effects on the color yield. The third possibility for urea substitution currently investigated is mechanical moisture application systems. This investigation is in an early stage and the results are not yet known. (Provost, 1992)

Phosphates

Phosphates are used in buffers, builders for scouring, water conditioners, surfactants and flame retarders. In all these cases, except flame retarding finishes, substitutes can be found for the phosphate containing chemicals. If the use of phosphates is required, batch dumps of the chemical bath should be avoided.

Solvents

Solvents can cause significant problems in wastewater treatment. Although solvent processing has lost its at&action since the 1970’s, there still are many uses for solvents in the textile industry. Some examples of solvent emulsions include scouring agents and dye carriers for polyester. In these cases, the solvents are auxiliary chemicals that will evaporate as VOC’s when the fabric is dried. They can end up in the wastewater stream during batch dumps, leaks and spills.

Non-aqueous solvents are used for machinery cleaning, degreasers and laboratory experiments. Disposal of these solvents with the wastewater should be avoided because of the toxicity of many solvents. Small equipment parts can be cleaned in a special container so that the contaminated solvent can be collected in a solvent recovery bottle for collection and proper disposal. (Smith, 1986)

Different types of solvents should be collected in separate bottles. ‘This will reduce the disposal costs and will simplify recovery of the solvent. Solvent processing and cleaning can reduce the pollution load of the wastewater. The pollutants in the solvent are collected as a slurry at the solvent recovery unit. (Cooper, 1978)

Metals

Metals found in a mill’s effluent come from many sources. They are used in several textile processes and sometimes metals are brought into the mill’s operations by the fabric itself or as impurities from chemical specialties and metal parts of equipment. Metals are used as (Smith, 1989b):

a. oxidizing and reducing agents
b. copper after treatment for direct dyes
c. organometallic finishes
d. essential ingredient in dyes

Metal concentrations of over 75 ppm are found in raw cotton fibers. The metal levels found in cotton yarn or fabric entering the mill can be even higher due to metal contamination from sizing agents, water and processing equipment. Metals found in raw materials, and in the mill’s source water will frequently cause undesirable effects and can even damage the fabric. Besides these effects, metals will contaminate the wastewater and can inhibit biological treatment. There are certain dyes in which metals are an integral part of the dye molecule. A list of some dyes containing metals is shown in Table 2.11. This table shows that many of these dyes are either blue or green. The use of these dyes should be limited and, where possible, dyes not containing metals should be substituted for metal containing dyes. For example, copper-free vat dyes can be used for dyeing 100% cotton fabrics materials without any loss of quality. If it is not possible to use dyes that do not contain metals, maximal dye exhaustion should be provided by optimizing the dyebath temperature, pH and concentration of auxiliary chemicals (Smith, 1989 b).

Table 2.11: Examples of Frequently used Metal Containing Dyes (Smith, 1989 b).

Dye	Metal	Dye	Metal
Vat Blue 29	cobalt	Pigment Blue 15	Copper
Ingrain Blue 14	Nickel	Ingrain Blue 5	Cobalt
Ingrain Blue 13	Copper	Direct Blue 86	Copper
Direct Blue 87	Copper	Pigment Blue 17	Copper
Acid Blue 249	Copper	Ingrain Blue 1	Copper
Pigment Blue 15	Copper	Pigment Green 37	Copper
Pigment Green 7	copper	Ingrain Green 3	Copper
Solvent Blue 25	copper	Solvent Blue 24	Copper
Solvent Blue 55	Copper	Reactive Blue 7	Copper

Dichromate has been used for the oxidation of vat dyes until the 1960’s. The chrome levels in some mills was therefore very high. Chromium had to be removed before biological treatment of the waste was possible. Currently, peroxide oxidizers or periodate are used.

2.3.6 Process Modifications

Preparation

Continuous preparation processes give many opportunities for wastewater reuse since the waste stream is continuous and fairly constant in characteristics. Evans (1982) gives an example of wastewater reuse during continuous preparation of 100% cotton fabric. The reuse/recycle possibilities in this range are:

a. recycle the J-box drain to the saturator.
b. reuse the wash water from the bleach washer in the caustic washer.
c. reuse the wash water from the caustic washer in the desize washer. The presence of caustic in the desize washer will help to remove the desize chemicals and some of the natural impurities of the cotton.
d. use counter current washing.

AGA Gas Inc. investigates the use of oxygen in peroxide bleaching. According to the company, the system results in the same whiteness with a substantial lower concentration of hydrogen peroxide and sodium hydroxide (Cook, 1990 a). The oxygen works synergetically with the hydrogen peroxide.

One-step Bleaching

Juby developed in 1985 a single stage process for the preparation of cotton and polyester/cotton blends. The new system include a singer, open-width saturator, J-box and three Tensitrol washers. The new one-step bleach system has several advantages. The reaction time in the J-box is reduced by one third, from 75 min to 45 min at 210°F. The tensile strength losses are significantly decreased. The conventional three-stage bleaching system results in a tensile strength loss of 11-14% when 88-inch wide 50/50 polyester/cotton muslin sheeting is bleached. The tensile strength loss is reduced to 4%

in the open width one stage bleaching process. The wastewater production is reduced by 90 gal/min. The three Tensitrol washers have a total water use of 95 gal/min at 190°F. The reduced consumption of hot water will also cut the energy requirements. Currently, more efficient washers are available with a total water use of approximately *40* gal/min. The chemical costs increased and chemical feeders need to be redesigned.

Dyeing

As previously mentioned, a dyebath contains many other chemicals besides dyes. During dyeing, some of these chemicals will exhaust onto the fabric whereas others remain in the dyebath. Recovery of these chemicals will reduce chemical usage, and thus, the strength of the wastewater. Commercial dispersed dyestuffs contain dispersants as naphtaline sulfonic acid. During dyeing the dye exhausts onto the fabric but the dispersant stays in the dyebath (Smith., 1986a). Dispersants and other auxiliary chemicals can be recovered by dyebath reuse, a technique that will be explained in more detail later on in this chapter (Pickford, 1981).

The auxiliary chemicals are major contributors to the BOD of the waste since large amounts of these products stay in the dyebath and because some of these products can exert a high BOD. It is therefore very important to minimize the use of these chemicals and/or to find chemicals with a lower BOD. However, care must be taken not to substitute surfactants with a high BOD with chemicals which have a lower BOD but a higher aquatic toxicity.

Pad Batch Dyeing

In pad batch dyeing, the prepared, dry fabric is impregnated with a cold solution of reactive dye and alkali. The excess liquor is squeezed from the fabric as it leaves through the padding trough. The wet fabric is stored on rolls at ambient temperature for fixation during a period of 2 to 48 hours. To prevent evaporation of the dye solution, the rolls are covered with a polyethylene film. The dyed goods are dried after washing off unfixed dye. (Fox and Sumner, 1986)

The general rule is that the amount of salt and other auxiliary chemicals added to the bath is less than in conventional batch dyeing. Often, the addition of these chemicals can be omitted completely. The addition of alkali is necessary to promote sufficient exhaustion of the dyebath and to promote reaction between the dye and cotton. It is no surprise that cold pad batch dyeing results in chemical, water and energy savings. Snowden-Swan (1995)said that the chemical use can be reduced up to 80% compared to atmospheric becks. Becks are vessels used for dyeing fabric in rope form. They can be operated at atmospheric pressure or at elevated pressure. The water consumption of cold-pad-batch dyeing with beam afterwashing is less than 2 gal/lb. The water use for atmospheric becks using the same reactive dyes is 20 gallons per pound of dyed fabric. The energy consumption was reduced from 9000 BTU/lb to 2000 BTU/lb.

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

2.4 RECYCLE, REUSE AND RECOVERY

When the reduction of chemicals is not possible, it might be possible to recover some chemicals. For example, an exhausted dyebath still contains a large amount of auxiliary chemicals. In other cases, sodium hydroxide, synthetic sizes or heat can be recovered.

2.4.1 Recovery of Acetate and Acetone

A manufacturer of lace uses acetate yarn to stabilize the lace during processing. Afterward, the acetate yarn is dissolved in acetone. The acetone/acetate solution is sold to an acetate producer who separates the acetone and acetate. The acetate is reused to make acetate fibers and the acetone is purified. The manufacturer gets the acetate fibers and the purified acetone, but pays only for the separation process (Smith, 1986a).

2.4.2 Heat Recovery

There is great potential in the textile industry for heat recovery. Many textile processes require hot water but the heat in the waste stream of these operations is not recovered. A heat exchanger can be used to transfer the heat of the wastewater to the incoming feed water.

A carpet company installed a heat reclamation system before 1957. The unit raises the incoming water from 55°F to lOO°F. The initial investment was approximately $10,000. The total savings for the company are $4.6 million over 30 years. Operating this 48,000 gallons per hour (gph) system for 80 hours/week, 50 weeks/year saved the company $ 750,000 in 1989 at a fuel cost of $0.95/gallon (Smith, 1989c).

Russell Corp. reduced excess hot water from its bleachery. The hot water was generated by a system that required condensate and flash steam to be cooled by circulating it in a tube heat exchanger. Therefore, the excess hot water had to be dumped. The company installed pressure regulating valves that control the return of the condensate at 15 psi. This system reduced the amount of condensate that flashes into steam and allows the condensate to be returned at a higher temperature. The result was an annual water savings of 140,000 gallons. Each increase of 10°F of boiler feed water resulted in 1% fuel savings. The savings are reported to be $1,000 per day (Huffman, 1986).

Evans (1982) described energy and water saving opportunities in bleaching. A reduction in water temperature of lO°F from 180°F to 170°F in the bleach washers can result in energy savings of 250 lb steam/hr. The temperature of the water in bleach washers in many mills is about 150-160°F.

Burch et al (1982) developed a system for the recovery of energy and water from waste streams. Most recovery systems involve a heat recovery system but the wastewater

is still discharged. The wastewater is vaporized at low pressure. The result is essentially pure steam which is condensed. The refrigerant used in the heat pump operates at high temperatures (202-225°F). Significant cuts in water consumption and energy were reported. The system has a payback period of less than two years when only the costs of supply water and energy are taken into consideration.

2.4.3 Size Recovery

Sizing chemicals are used in large amounts in mills processing woven fabric. In fact, they represent the largest group of chemicals used in the textile industry. The recovery of these chemicals has great pollution prevention opportunities. Some materials, like starch, are degraded which makes their recovery impossible. This is why some mills change to synthetic sizing agents like polyvinyl alcohol and carboxymethyl cellulose. Synthetic sizes pass the desiring process unchanged and can be recovered by ultrafiltration (UF) systems. The recovery of size is mostly only practiced in vertically integrated mills. Mills that buy woven fabric do not invest in size recovery equipment since they do not have the benefit of the recovered material. On the other side, synthetic sizes are more expensive than starch-like chemicals. Mills that weave the yarn but do not desize it after the weaving process, do not buy the more expensive synthetic sizes. This is one example of a situation where an arrangement between two mills resulted in benefits for both parties. (Snowden-Swan, 1995 and Cook, 1990).

Gaston County installed an ultrafiltration system for the recovery of PVA. The net recovery that takes loomshedding, washer and UF efficiency into consideration is 80-85%. The equipment costs, including installation, were $1,275,000. The payback period is 9 months when 2.5 million lb PVA is used each year and the cost of virgin PVA is $1 per lb (Grizzle, 1982).

Polyvinyl alcohol can also be reclaimed by vacuum extraction. Currently, vacuum extraction is widely used to remove water from fabric before drying. Perkins (1987) reported that drying requirements can be lowered by more than 50% on some fabrics by extraction of unbound water before drying. He also investigated the recovery of PVA by vacuum extraction. This was done by either saturating the fabric with water in a desize saturator or by spraying the fabric. Afterwards, the cloth passed through a vacuum extractor. The recoverability of the PVA depended on its viscosity and water solubility. The temperature of the water was also an important factor. He reported a recovery of 53% of the size from 50/50 polyester/cotton at a vacuum of 15 inches of mercury.

2.4.4 Caustic Recovery

Mercerizing is a preparation step of cotton and cotton blends which uses a concentrated solution of sodium hydroxide (more than 20%). The recovery of caustic **in this** step is very practical since mercerizing is a continuous operation which makes the characteristics of its waste stream are fairly constant. A good recovery system can recover up to 98% of the caustic (Snowden-Swan). In another type of mercerizing, the fabric is treated with liquid ammonia. The ammonia is captured as gas, recovered and reused (Smith, 1986). The benefits of caustic recovery are a reduced alkalinity of the wastewater and reduced chemical consumption.

2.4.5 Dyebath Reuse

Dyebath reconstitution and reuse is an at&active process due to cost reduction, energy savings and pollution reduction. Dyebath reuse has been used for many dyes and materials. This section will discuss the procedure and will give examples where the technique has been used successfully.

Batch dyeing is inefficient in the ‘use of chemicals, energy and water. The amount of auxiliary chemicals used varies from a few percent to over 100% on the weight of the fabric. Most of these chemicals do not absorb into the fabric and increase the waste load of the mill’s effluent. Dye quantities are often only a few percent of the weight of the fabric. By reconstituting and reusing dyebaths, the efficiency of batch dyeing can be increased, and the use of chemicals, water and energy can be reduced significantly. No articles discussing dyebath reuse in continuous dyeing have been found. This could be feasible if the dyebath can be stored until the same material is dyed with the same dye formula or if it can be reused to dye the same material to a different shade.

Method

Bergenthal et al, (1985) suggested the following procedure for dyebath reconstitution:

1. Store the exhausted dyebath. The exhausted dyebath can be pumped into a holding tank where it is analyzed and reconstituted. In the meantime the fabric is rinsed in the dye machine. The same can be achieved with two identical dye machines. One machine is preparing the yam or fabric for dyeing while the other machine is dyeing the material. After dyeing, the dye solution of the second machine is pumped to the first machine for analysis and reconstitution. The second machine will be after-rinsing the fabric while machine 1 is in its dye cycle. Another alternative is to remove the fabric from the dye machine after dyeing and leave the exhausted dyebath in the dye machine for analysis and reconstitution. This eliminates the need for holding tanks.

2. Analysis of the dyebath for residential chemicals. Dyestuff that is not exhausted from the dyebath can be measured by a spectrophotometer. If the dyebath is cloudy, extraction methods should be used. Most auxiliary chemicals will not be removed from the dyebath. The makeup quantity can be estimated or can be determined analytically. According to Smith (1985), estimation of the losses is, in most cases, sufficient. Tincher et al. (1981) have developed a computer program that can help to determine the amount of auxiliary chemicals and dyes needed to reconstitute the dyebath.

3. Reconstituting the dyebath. In this step the necessary quantities of dyestuff, auxiliary and specialty chemicals are added to the exhausted dyebath. Water is also added to the bath to make-up for evaporation and the volume carried off by the fabric.

4. Reuse the dyebath. After the addition of the necessary chemicals and water, the temperature of the dyebath is raised to the desired temperature. Considerable time and energy are saved since the temperature of the reconstituted dyebath is higher than the temperature of the mill's source water.

Potential for Dyebath Reuse

The dyes applied to and the dyeing procedure used, depend largely on fiber characteristics. Also, auxiliary chemicals and specialty chemicals added to the dyebath vary with the fiber. It is therefore no surprise that the results of dyebath reuse vary. Cook (1983) showed that batch dyeing systems can be adapted for dyebath reuse. He came to this conclusion through several case studies. All case studies were successful and resulted in significant annual savings. Table 2.12 summarizes the different case studies. The table shows that dyebath reconstitution can be practiced for many fabrics, dye classes and dye machines. Some case studies conducted included dyeings in which the shades achieved were different from the previous one. Some of the case studies listed in Table 2.12 will be discussed in more detail later on in this chapter.

Tincher et al. (1982) developed a system to decolorize and reuse dyebaths with ozone and/or singlet oxygen. They concluded that acid and basic dyes can be destroyed with ozone treatment. The destruction of disperse dyes requires a much higher quantity of ozone. The auxiliary chemicals present in the dyebath are more resistant to ozone treatment. The lab dyeings showed that polyester carpet can be dyed with ozone decolorized dyebaths. In this case, it is necessary to treat the dyebath with a reductant before reuse. The carpets were of acceptable quality. Nylon carpets dyed in ozone treated dyebaths are also of acceptable quality.

Table 2.12: Successful Dyebath Reuse Case Studies (Cook, F.L., 1983).

Type of Material	Fiber	Dye Class	Machine
Knit Fabric	Polyester	Disperse	Jet
	Cotton	Reactive or Direct	Beck
	Polyester/Cotton	Disperse/Reactive or Disperse/Direct	Beck Beck
Yarn Package	Polyester	Disperse	Package
	Polyester/Cotton	Disperse/Reactive or Disperse/Direct	Package
Socks	Nylon/Spandex	Acid	Paddle
Pantyhose	Nylon/Spandex	Disperse/Acid	Rotary Drum
Carpet	Nylon	Disperse/Acid	Beck
	Polyester	Disperse	Beck
Woven Fabric	Aramid	Basic	Jet
Skein	Acrylic	Basic	Skein

Case Studies

A company is reported to use dyebath reuse when dyeing nylon pantyhose with rotary paddle dye machines. The company currently practiced the technique on 95% of its rotary paddle machines at two of its plants. Another pollution prevention technique used at the plant was the reuse of the final softener as prescour for the next batch of pantyhoses. (Cook, 1983)

Another mill instituted dyebath reuse when dyeing nylon carpets with disperse dyes in becks. The company experienced problems with the build up of surfactants in succeeding reuse cycles. The result was a slightly lower dye exhaustion of the baths. The problem was solved by slightly increasing the dye concentration in subsequent baths. The projected annual savings were $115,000. (Cook, 1983)

Bigelow-Sanford, Inc. performs batch dyeing operations on nylon carpet. The pilot study included two grades of nylon and six shades for each grade. Two multi-shade dyeings were performed and consisted of six and ten dyeings. All shades were first quality. A one week full-scale study conducted with the same nylon grades and same dyes resulted in savings of $0.025/ carpet. The projected annual savings were $30,000 per dye machine modified for dyebath reuse (Bergenthal, et al., 1985).

In 1981, Tincher et al. reported the reuse of dyebaths when Nomex non-woven fabric was dyed in jet dyeing machines. Nomex requires large quantities of expensive* auxiliary chemicals. As a result, large volumes of a high strength wastewater are produced. The results showed that dyebath reuse saved 25 cents/lb of fabric processed when the dyebath was reused ten times. Demonstration dyeings were conducted at a plant that performed on average 875 dyecycles/yr on jet dyeing machines. The annual savings were expected to be over $110,000. The capital cost for analysis equipment, pumps and piping was only $15,000. As a result of the dyebath reuse, the quantity of spent dye liquor discharged per year dropped from 500,000 gallons to 140,000 gallons.

Pilot scale studies of atmospheric disperse dyeing of nylon carpet, nylon pantyhoses and pressure dyeing of polyester yam packages were reported in 1978 by Cook and Tincher. All reconstitutions resulted in first quality products. The dyebaths were used for five to ten dyeings, but had to be dropped when using a light shade after a dark shade. The savings in water, chemicals and energy were significant.

Limitations

The success of dyebath reuse depends upon the type of dye and fabric. The easiest dyes to be reused for a limited number of dyecycles due to the buildup of impurities. Chemicals used in pretreatment steps and impurities from the fabric can accumulate in the dyebath. ‘Impurities can also be present in auxiliary chemicals added to the dyebath. Some of these impurities can retard the dyeing process or can cause spotting. Cook and Tincher reported in 1978 that, when dyeing pantyhoses with disperse dyes, a dulling of the shade occurred in the tenth dyecycle. According to these researchers, the number of dyecycles can be increased by passing part of the exhausted dyebath through a ultrafiltration unit. This will lower the buildup of impurities.

Aftertreatment of the fabric with chemicals is required when dyeing with reactive, vat and sulphur dyes. As a result, storage equipment is required to hold the exhausted dyebath when the dyed fabric is aftertreated. This increases the equipment cost and the quantity of water required for cleaning. (Beckmann et al., 1983). Dyebath analysis is difficult when using reactive dyes because spectrophotometry can not differentiate between hydrolyzed and intact dyes (Snowden-Swan, 1995).

2.5 DENIM LAUNDRY WASTEWATER TREATMENT

Denim laundry wastewater can be extremely variable in its characteristics. The TSS can be high due to the use of pumice stones in the washing processes. The organic loading of the wastewater comes in large part from the first wash cycle. This wash cycle removes sizes and other chemicals used in previous processing. The BOD, : COD ratio of the wastewater is typically in the range 1:4 - 1:2 (Ward 1993). The high quantities of chemicals used in the different processing steps will contribute to the TDS of the wastewater. Heavy metal levels can be toxic to micro organisms. However, denim laundry wastewater is not considered toxic by the EPA and most of the laundries in the United States do not have a pretreatment system. Many will be forced to treat their wastewater to some extent in the near future because local POTW's can not handle the high loading of the wastewater.

Ellis Corp. conducted pilot scale studies at a blue jeans manufacturing plant that included a prewashing facility. The company had problems with BOD, TSS and manganese. The pilot-scale study included a vibrating strainer, inclined plate clarifier, dissolved air flotation (DAF) unit and sand filter. Organic polymers and lime added to the wastewater before the DAF improved the removal of solids and manganese. Some small pumice stones collected at the bottom of the DAF unit and were removed by a scraper. The DAF unit was able to remove 60% of the BOD and COD, and most of the solids. Manganese levels were reduced to acceptable levels. Waste collected in the different treatment steps was dewatered with a rotary drum, vacuum filter. The volume of the sludge was reduced 3.5 times. The second phase of the study concerned the potential reuse of the treated effluent. It was estimated that 50% of the water could be reused without further treatment. Use of ultrafiltration and reversed osmosis membranes would make it possible to reuse an additional 25% . (Davis, 1991)

Ward reported in 1993 that membrane filtration of denim laundry wastewater produced water that can be recycled. Recycling 60-70% of a laundry's effluent was possible. The membrane concentrate needs further treatment before it is discharged to the sewer. He recommended the use of a screen to remove lint and large stones. Pumice stones escaping the screen had a low density due to their porosity and could be remove in a DAF unit. The BOD loading of the wastewater was reduced through biological treatment. Removal of color was achieved through absorption of dyes on the microorganisms. Further color reduction was possible by DAF, coagulation and sedimentation, chemical oxidation, membrane filtration and carbon adsorption. Membrane filtration and carbon adsorption of the complete stream is costly and should only be used as a polishing step after biological treatment.

A major jeans manufacturer installed a two-step wastewater treatment system. Settleable solids were removed in a sedimentation clarifier after equal&ion of the waste. A DAF unit removed floatable solids, oils and greases. Chemicals added to the water before the DAF unit improved removal of solids. The second phase of the wastewater treatment system included the use of reverse osmosis membrane systems. The treated wastewater was of drinking water quality and could be reused as process water. (Davis, 1990). According to Davis, recycling wastewater becomes economically attractive if water and sewer charges are over $5 per 1000 gallons.

2.6 CASE STUDIES

In the previous sections of this chapter the different parts of pollution prevention were discussed. Each section also contained a number of case studies that applied to that technique. This section discusses two pollution prevention audits conducted at textile mills. (EPA, 1991).

2.6.1 Burke Mills, Inc. Valdese, North Carolina.

This company processes texturized polyesters and produces high twist filament yarn for sewing thread and neckwear emblems. The mill includes a dyehouse for spun yam, filament yarn and stretch nylon.

The company uses l,l,l-trichloroethane to clean the yarn pretreatment machinery. Proper disposal of the solvent costs $650 per 55 gallon drum. In 1985, the company decided to purchase the 1,l,1-TCE in 3,000 gallon shipments instead of 55 gallon drums. A distillation unit was purchased for $ 6,500. The unit was able to reclaim more then 90% of the solvent. As a result, the amount of solvent that had to be disposed of dropped from 5,400 to 55 gallon a year. The total annual savings were reported as $99,964 with a payback period of less than one month. The bulk purchase of 1,l,1-TCE saves the company $11,330 per year. Housekeeping was improved through central distribution of the solvent that resulted in safer conditions and improved control over the chemical.

The solid waste produced at Burke Mills, Inc. was significantly reduced through recycling plastic cylindrical tubes, dirty and excess yam and cardboard. The excess and dirty yarn is sold to a company that chops the yam and uses it as stuffing material. Approximately 100 tons of yarn are sold for recycling every year. The non-reusable plastic yarn tubes are sold to the supplier. There the tubes were melted and reformed into new yam tubes.

2.6.2 Amital Spinning Corporation, New Bern, North Carolina.

Amital Spinning Corp. produces acrylic yam for the sweater industry. Ninety percent of the yam is dyed at the company. Batch dyeing of yarn results in the largest waste stream: 320,000 gallons per day for the processing of 12 batches of yarn. In 1988, the company's monthly water supply and disposal bill is $26,000.

The management decided to reuse non-contact cooling water and process water. The non-contact cooling water is reused for the preparation of the dyebath if its temperature is 140°F or more. The non-contact cooling water with a temperature below 140°F is pumped into a tank and reused as non-contact cooling water. An altimeter is installed in the tank to control the pump and keep the water level in the tank at 17 to 21 feet. The cooling system runs on recycled water when available and switches to city water when the water level in the tank is too low.

Through dyebath reuse, the mill manages to reuse the contact water and chemicals. The exhausted dyebath is pumped back into preparation tanks. Here, the chemicals are replenished. Water is added to replace the water lost through evaporation and absorption onto the fabric. The water source for this is the non-contact cooling water with a temperature of 140°F or above.

The reuse of non-contact cooling water and process water has resulted in a 60% reduction of water use and wastewater generation, but has not affected the quality. The water use dropped to 102,000 gpd for processing 20 batches. The average water supply and disposal bill was $13,000/month, a 50% decrease. The payback period was less then 30 days due to reduced water costs and increased production.

CHAPTER 3: METHODS AND MATERIALS

3.1 APPROACH

This research was conducted by working closely with four different textile wet processing plants located in Virginia. The plants included:

- Plant 1: A denim stone washing and bleaching facility. This laundry washes cotton shirts, socks and hats, in addition to denim.
- Plant 2: A glass fiber processing plant. The mill receives fiberglass yam and converts it to a woven fabric to which special finishes are applied.
- Plant 3: A cotton and polyester/cotton dyeing and printing mill. Pure cotton and polyester/cotton blend fabric are received from weaving mills all over the world.
- Plant 4: Nylon yarn dyeing and finishing facility. The processed yarn is used for the production of industrial carpets.

Each plant was visited several times over the course of this project (7/15/94 - 3/3l/95. During the first visit, the production facility of the plant was toured, and a set of forms was given to the person responsible for environmental issues. A copy of these forms can be found in Appendix A. The forms were developed to provide information about the pollution prevention and waste minimization techniques currently practiced at the plant. The basic format for these worksheets was taken from the EPA publication, “Facility Pollution Prevention Guide” (1992).

During the next visits, employees operating machinery and management personnel were interviewed to identify points in the manufacturing process where pollution prevention (P2) techniques might be successful. The operations were observed for 2 to 4 hours in Plant 2, and 3, and 24 hours in Plants 1, and 4. The number of visits depended on the situation at the mill. Some facilities had a significant collection of wastewater quality data, computerized inventory and purchase files, flow measurements and/or flow estimates of the different wastewater sources. These facilities required fewer visits.

Wastewater samples of each of the mill's operations were taken and analyzed for chemical oxygen demand (COD), dissolved organic carbon (DOC), color, total suspended solids (TSS), pH and temperature. Lead, copper, zinc, nickel, and chromium levels were also determined. All the analyses were performed according to Standard Methods for *the Examination of Water und Wastewater* (1991). The information collected was then used to set up a material balance for each unit operation. Other information collected included water and air permit applications, wastewater analyses, water and sewage bills, etc. A list of all the information obtained at each plant is given in Table 3.1. The physico-chemical treatability wastewater from Plants 1 and 4 was tested using the jar test method. A short term biological treatability study was performed for Plant 4.

This information was used with the material balances to make recommendations to the mill's management concerning possible implementation of P2 options. The technical feasibility of the ideas was discussed with management personnel of each mill. An economic analysis of proposed changes was developed as the last step for some options.

3.2 BATCH BIOLOGICAL STUDY

A short term biological study was conducted using wastewater from the nylon yarn dyeing and printing facility (Plant 4). Both aerobic and anaerobic reactors were used in this experiment. Mixed liquor (17 1) of the POTW's activated sludge system was aerated constantly in a batch activated sludge reactor and feed was added two times per day. The reactor operated at an hydraulic retention time (HRT) of three days and a mixed liquor volatile suspended solids concentration of 3,000 mg/l. A 2.4 liter bottle was filled with mixed liquor from the POTW's anaerobic digester. The MLVSS of the anaerobic reactor was 10,000 mg/l. The bottle was closed with a rubber stopper, and purged with N_2 gas. Twice a day, feed solution was added to the anaerobic digester. The HRT of the reactor was 3 days. During the acclimation period the concentration of the textile waste in both the anaerobic and aerobic reactor feeds was increased by 10% per day. The sludge was allowed to acclimate to the textile wastewater over a period of 10 days.

Table 3.1: Information Collected at Participating Mills (Harries, 1994)

Design Information	Process Mow Diagrams
	Process Description
	Material Balance
Environmental Information	Wastewater Analysis Data
	Water Permit Application
	Air Permit Application
	Disposal Records
Raw Material Data	Material Safety and Data Shuts
	Raw Material Inventory records
	Chemical Usage
	Gas and/or Coal Bill
	Required Water Quality
Other Information	Treatment and Disposal Costs
	Water and Sewer Charges

The biological treatability experiment was performed by filling 300 ml BOD bottles with a mixture of anaerobic or aerobic sludge, municipal waste and textile waste. The experiment was set up so that there were four sets of bottles. Each set contained a different amount of textile and municipal waste, approximately 3,000 mg/l MLVSS and 250 ml wastewater. The anaerobic bottles were closed with rubber stoppers, and the aerobic bottles were aerated by means of porous air stones. After 2,4,6,10 and 14 days, biodegradation was checked by measuring the COD, TSS, MLVSS, and color content of the batch reactors. An overview of the study is given in Table 3.2.

Table 3.2: Batch Biological Study.

Type of Reactor	Mixture	Assumed MLVSS	Nutrients Added (mg/l)
Aerobic	75% Municipal, 25% Textile Waste	3,000 mg/l	113
	50% Municipal, 50% Textile Waste		226
	25% Municipal, 75% Textile Waste		340
	100% Textile Waste		459
Anaerobic	75% Municipal, 25% Textile Waste	3,000 mg/l	113
	50% Municipal, 50% Textile Waste		226
	25% Municipal, 75% Textile Waste		340
	100% Textile Waste		459

Nitrogen and phosphorus were added to the reactors according to the percentage of textile waste in each reactor. It was assumed that the textile wastewater did not contain any phosphorus and nitrogen. Ammonium mono basic phosphate ($NH_4H_2PO_4$) was added to satisfy the nitrogen and phosphorus demand of the sludge. The amount added to each bottle is given in Table 3.2.

3.3 COAGULATION EXPERIMENTS

The coagulation experiments were performed in a jar test. A measured amount of coagulant was added to 500 ml sample and mixed at 100 rpm for 1 min. The mixing speed was then lowered to 30 rpm, and mixing was continued for 29 min. The samples were then allowed to settle 1 for 30 min. A sample of the supernatant was analyzed for total suspended solids and color. The coagulants used for the different plants are given in Table 3.3.

Table 3.3: Coagulants Used in the Jar Tests.

Denim laundry	Inorganic chemicals	$Al_2(SO_4)_3$, $FeCl_3$
	Cationic polymers	Selfloc 1438 Al220 577C
Nylon dyeing and processing plant	inorganic chemicals	$Al_2(SO_4)_3$, $FeCl_3$
	Cationic polymer	Selfloc 1438 Al220 577C
	Anionic polymer	A130

3.4 ANALYTICAL PROCEDURES

The color in American Dye Manufacturers Institute (ADMI) units was measured using a Bausch and Lomb, Spectronic 20 spectrophotometer (1.0 cm pathlength) for samples from Plants 1 and 2. The color in water samples from the other plants was measured using a Beckman DU Series 600 spectrophotometer (1 .0 cm pathlength). After filtration of the sample with a 1.2µm glass microfiber filter and adjustment of the pH of the samples to 7.6, the percent transmittance was measured at 590 nm, 540 nm and 438 nm. Distilled water blanks were used for 100% transmittance.

The DOC was analyzed using a Dohrmann, DC-80, total organic carbon analyzer. The samples were aerated to remove inorganic CO_2 after filtration with a 1.2 µm glass microfiber filter and acidification ($pH < 2$). Depending on the expected organic carbon concentration, a 40 µl (400 - 2000 mg C/l), a 200 µl (10 - 400 mg C/l) or a 1 ml (0 - 10 mg C/l) syringe was used to inject the samples into the DOC analyzer.

Total suspended solids (TSS) were measured according to Section C of Standard

Methods for the Examination of Water and Wastewater (1991). A measured amount of sample was pipetted onto a glass microfiber filter with a pore size 1.5 µm and dried at 103° C for 1 hour. Before weighing, the samples were placed in a desiccator and allowed to cool for 10 min.

The pH was measured using a Fisher, Accumet pH meter, model 610A. The pH meter was calibrated with pH 7 and pH 4 buffers before the pH of samples was measured.

For the measurement of the metals, a Perking Elder, atomic absorption spectrophotometer, model 5l00PC, was used. Each sample was filtered using a glass microfiber filter with 12 µm pores and acidified with HNO_3 to pH below 2.

The COD of the samples was determined after making proper dilutions. The closed reflux, titrimetric method was used. The digestion period was two hours. A description of the method *can be* found *in Standard Methods for the Examination of Water and Wastewater* (199 1).

CHAPTER 4. DENIM LAUNDRY

4.1 PROCESS DESCRIPTION

The different washes performed at this laundry include Super Soft Wash, Sand Wash, Stone Wash and Simulated Stone Wash. Each wash consists of a number of wash cycles. Among the different wash cycles are: desize, stone wash, sand wash, enzyme wash, bleaching, antichlor, softener, and dye fixation. Each wash cycle is always followed by a clear rinse to remove chemicals. The number of possible combinations and the variation in sequence of the wash cycles results in over 300 different wash procedures. The variability in the production process is further increased because the laundry does commission work for several textile mills. Each mill has its own style and shades which is reflected in the use of different chemicals, duration of washes, etc. Figure 4.1 gives an overview of the wash procedures. Rinses are not included in the schematic diagram, but an understanding of when garmentsare rinsed can be gleaned from the text below and Table 4.4.

A Super Soft Wash consists of three wash cycles. The first cycle removes the size and unfixed dye. This cycle is followed by a clear rinse and a wash cycle containing softener. Sometimes, a second rinse and another softener cycle are part of the wash formulation. Most other wash procedures involve the removal of size in the first cycle. The next cycle is usually a bleach cycle to remove some of the unfixed dye. Bleach can be used separately or together with sand or pumice stones. Bleaching is a very delicate process since the strength of the bleach can change. The washer operator has a sample of the bleached garment. (S)he will wet this sample and visually match the color of the sample with the color of the clothes in the washer. The use of sand, stones and/or enzymes gives the garment a worn and aged look. In a Simulated Stone Wash, the aged and worn look is obtained by the action of enzymes. A sodium bisulfite cycle follows the enzyme wash cycle to neutralize the action of the enzymes. A Simulated Stone

Wash can also include a bleach cycle.

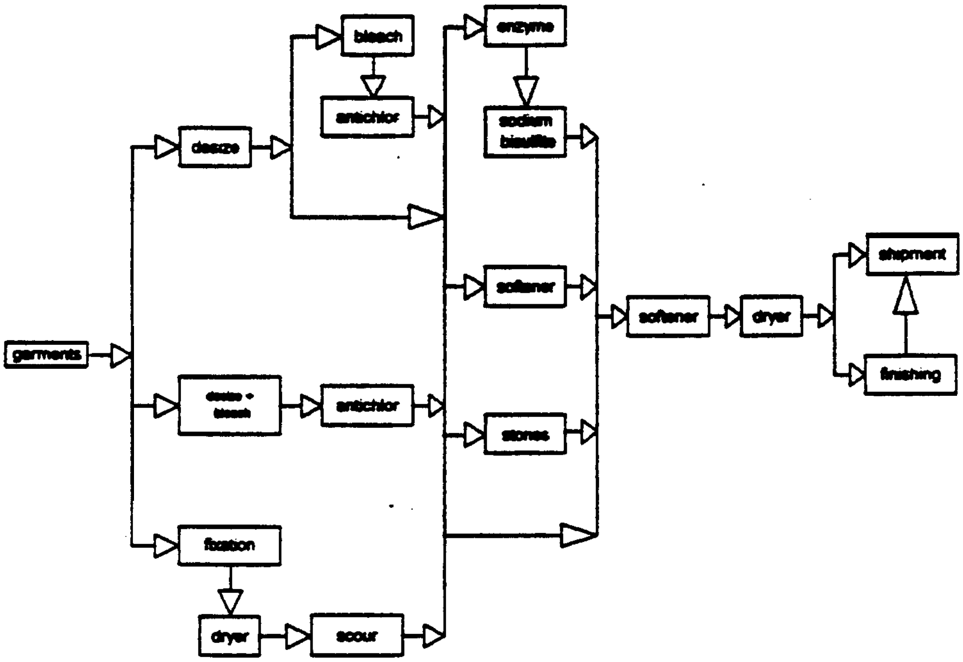


Figure 4.1: Process Flow Diagram of the Super Soft and Stone Washing Laundry.

Sometimes, the dyes are not fixed onto the fabric when the apparel arrives at the laundry. The first step in this wash (dye fixation) is the addition of a fixative to the wash water. The clothes are dried after the wash procedure and extraction of excess liquor. This ensures proper fixation of the dyes. The garments are then loaded back into the washer to remove the chemicals and for further processing.

After the wash procedure, the clothes are dried and sorted according to size. The clothes are then shipped to the manufacture in large cardboard boxes or are finished after being dried in one of the two dryers. Finishing includes inspection, ironing, and tagging. These clothes are shipped to stores in small boxes.

The facility has several washers. Three have a capacity of 450 lbs, one of 250 lbs and a sample washer with a maximum capacity of 35 lbs. The manufacturer of the washers recommends that the washers be loaded to 50% of their maximum capacity. Each washer is computer programmed and will stop operation when the addition of chemicals is required. They can operate at three different water levels. Estimates of water use by the washers were available at the plant It was not known if the measurements were performed when the washers were loaded with clothes or not. Water use in one of the big washers was therefore estimated when the washer was loaded with clothes. The results are given in Table 4.1. The quantity of water in the washer was determined by closing off a pit under the washer. The water depth in the pit was then measured when the washer dumped the water. The volume of water was calculated using the dimensions of the pit. The obtained values were close to the estimates available at the plant. The plant estimates were considered more accurate since closing off the pit was difficult and some water leaked from the pit during the measurements. The low water level could not be measured because the company never uses this level.

Table 4.1: Estimated Water Use by the Washers.

Water level	Measured, 450 lb washer, gal.	Plant records, 450 lb washer,gal.	Plant records, 250 lb washer, gal.
High	210	230	190
Medium	170	180	140
Low	-	60	-

The clothes arrive at the laundry in small loads. It is common that a load of clothes arrive at the laundry early in the morning and that a second load of the same garments arrive later that day or the next morning. However, the clothes are not consolidated and are washed and returned to clients as soon as possible. Table 4.2 shows the number of wash formulae, the total weight of clothes washed and the number of loads of a specific wash formulation in a single day at the plant.

Table 43: Reduction Schedule at the Denim Laundry.

Wash cycle	Total load, lb	Number of loads washed
Soft Wash # 1	845	6
Soft Wash # 2	660	5
Soft Wash # 3	516	3
Soft Wash # 4	702	4
Soft Wash # 5	672	5
Soft Wash # 6	353	2
Soft Wash # 7	511	3
Soft Wash # 8	447	3
Soft Wash # 9	575	4
Soft Wash # 10	632	4
Simulated Stone Wash	336	2

The facility has two dryers. Hot air for the two dryers is provided through heat exchange. One heat exchanger heats up the air circulating the dryers by steam produced in the boiler. Condensate water is returned to the boiler. The source waters are hard, and large quantities of water softening chemicals are added to the boiler.

4.2 WATER SOURCE

The facility has two different fresh water sources, groundwater from on site well and municipal water. The well pump is designed to deliver 18,000 gallons in 13 hours. The remaining water demand is supplied by a 2-inch water line from the town. The well water flows into three interconnecting fresh water tanks. If the water level in these tanks

Table 4.4: Characteristics of the Spent Washwater of a Simulated Stone Wash.

Wash cycle	**DOC** mg/l	COD mg/l	Color ADMI	Conductivity mmho	pH	Temperature °C	TSS mg/l	TDS mg/l
Desize	2,773	3,580	1,902	1.78	8.8	62	468	6,932
Rinse	479	1,225	438	0.44	8.1	59	122	988
Enzyme	922	4,930	1,202	0.44	6.0	51	197	1,503
Rinse	186	445	358	1.28	9.8	58	151	1,205
Bleach	322	288	153	5.70	8.5	67	130	4,758
Rinse	96	294	199	1.15	7.1	52	105	963
Antichlor	49	243	131	1.61	5.9	67	78	1,374
Rinse	17	68	70	0.43	6.3	66	72	372
Softener	55	225	200	0.71	8.8	72	86	696
Rinse	24	79	99	0.23	8.1	55	63	277
softener	25	85	29	0.20	8.0	53	105	161

Table 4.5: Characteristics of Spent Washwater of a Super Soft Wash.

Wash cycle	**DOC** mg/l	COD mg/l	Color	Conductivity mmho	pH	Temperature °C	TSS mg/l	TDS mg/l
Desize	247.2	957	64	0.41	9.18	61.1	18	526
softener	156.5	464	125	0.20	7.62	63.0	11	219

This water contains chemicals from the previous wash. It should therefore be possible to reuse this water as wash water in the next batch, using the same technique as in dyebath reuse. In other words, the clear rinse following the enzyme wash contains enzymes and auxiliary chemicals used in the enzyme wash. It is, in theory, possible to transfer this water into a holding tank, add the required chemicals and reuse it in the enzyme wash of the next batch. However, Table 4.4 shows that the clear rinse water following the enzyme wash also contained a significant amount of color. If colored water is used as process water it is likely to stain the white pockets of the jeans. It is not known at what level color is acceptable. It is recommended that the company investigate which color level is acceptable. This will make it possible to determine which spent washwaters can be reused directly and which waters need pretreatment.

4.4 WASH SCHEDULES

During some visits, the washers were cleaned when washing light colored apparel after darker colors by filling the washers with hot water. Some detergent was added to the washer. The washer was then operated for 10 to 20 minutes. Sometimes this procedure was repeated. The decision to clean the washers and the number of times the washer was cleaned depended completely on the judgement of the washer operator. One day, the same dark clothes were washed during the first and the second shift. The first shift operator decided to clean the washers two times. The second shift operator cleaned the washer only once. Therefore, each large washer was cleaned three times since these clothes were washed in all three large washers. The total water consumption for the cleaning operations was approximately 3,000 gallons. The problem was that part of the wash load arrived early that day, and the second part in the afternoon. If all the clothes were washed in the second shift, the water consumption for cleaning would have been 900 gallons.

On another day, the washers were cleaned several times and there was no consistency in the cleaning of the washers. For example, one washer was cleaned when white clothes were washed after beige clothes. The exact same sequence of wash procedures in another washer did not result in cleaning. Washing navy blue clothes after red colored garments also required cleaning whereas washing beige clothes after navy blue clothes did not. The total number of washer cleanings performed that day was 11. Better organization of the washes could have reduced the number of washer cleanings to three if the dark clothes were washed in all three large washers. The dark colored garments could have been washed in one washer due to the small load of each color. This would have reduced the number of cleanings from eleven to one. The water savings were sufficient to do three to five batches of a Super Soft Wash.

Efforts should be made to determine when cleaning the washers is required and the number of cleanings. According to the management, holding the clothes to better organize the washings is not possible because the customers want their clothes returned quickly. Better communication with clients will perhaps allow for better organ&ion of wash schedules, savings of water, chemicals, energy, and reduce the potential for errors. The company should consider offering a reduction in cost to clients who can be more flexible in when clothes must be returned. It is likely that being able to better schedule the washing of dark and light clothes and similar types of clothes will result in a savings of wash water and clean-up waters.

4.5. BLEACH QUALITY

The supplier of the bleach delivers bleach with a specific gravity (S.G.) of 1.2. The bleach has a concentration of 15% by weight. The washer operators noticed that they needed longer bleach cycles to match the shade of the sample when the bleach storage tank was almost empty. This led them to believe that the strength of the bleach decreased over time. Also,’ the strength of the bleach varied with each delivery. Scott (1990) reported the same problem. The management of the laundry has made efforts to find a practical method to check the strength of the bleach. However, they have not found a usable method.

A company in England checked the strength of their bleach by testing the specific gravity using a hydrometer (Scott, 1990). The strength of the of bleach was determined with a graph that gave the bleach strength as a function of the specific gravity. The same method can be used at this plant to detect variations in the bleach strength. This will allow to adjust the volume of bleach needed.

4.6 PRETREATMENT

As mentioned before, the results of the spent wastewater analysis (Table 4.4 and 4.5) show that some water can probably be reused without pretreatment. Other wastewater will need some treatment before reuse is possible. Some coagulation/flocculation/sedimentation experiments were therefore performed on this wastewater. The wastewater used for these experiments was collected as a grab sample of combined wastewater. The sample was taken before the 200 mesh screen After flowing through the screen, the wastewater is chlorinated, stored and then discharged to the sewer.

4.6.1 FILTRATION

A known amount of wastewater was filtered using filters of different pore sizes. The method used to determine the amount of solids retained on the filters was the same as used for the determination of TSS. The color of the filtrate was determined after adjusting the pH of the filtrate to pH 7.6. The transmittance of light through the samples was determined at 438 nm, 540 nm, and 590 nm. A value for the color was then calculated using the equations used to calculated the color in American Dye Manufacturers Institute (ADMI) units. If the sample was filtered with a 1.2 μm filter, the color of the filtrate could have been expressed in ADMI units.

The experimental results are given in Table 4.6 and in Figure 4.2. The results also show that a significant amount of color is associated with the solids on the filtrate. Interpolation of these results shows that 40% of the solids would be retained by a filter with 1 µm pores.

Table 4.6: Results of Filtration Experiment.

Filter Pore size µm	Filter type	Color ADMI	Cumulative solids removal. mg/l	% Solids retained
25	Whatman 4	1,777	14	0.85
11	Whatman 1	1,727	29	1.77
8	Whatman 2	1,713	68	4.15
1.5	Whatman 934-AH	809	362	22
0.8	Gelman GN-4	589	760	46
0.45	Gelman GN-6	257	1,640	100

The breakdown of solids used in stonewashing produces a wastewater high it solids. The 200 mesh screen is reported to remove 8 to 10 tons of lint, solids and grit in one week when many stonewashing cycles are performed. The number of stonewashing cycles performed during the period of this study was low, and no data to support this removal are available. However, Young (1990) reported that wastewater from stonewashing operations can have a concentration of suspended solids of up to 2,000 mg/l after passing through a 80 mesh stainless steel shaker screen. Davis (1991) recommended the removals of solids by sedimentation *or* flotation after the addition of chemicals. Therefore, jar tests were performed to investigate the removal of color and TSS. The coagulants used included $FeCl_3$, alum, Al220, Selfloc 1438 and 577C. Selfloc 1438 and 577C are cationic polymers. Al220 is a cationic polymer that contains alum polyamine. Only alum and 577C gave promising results and are included in the discussion.

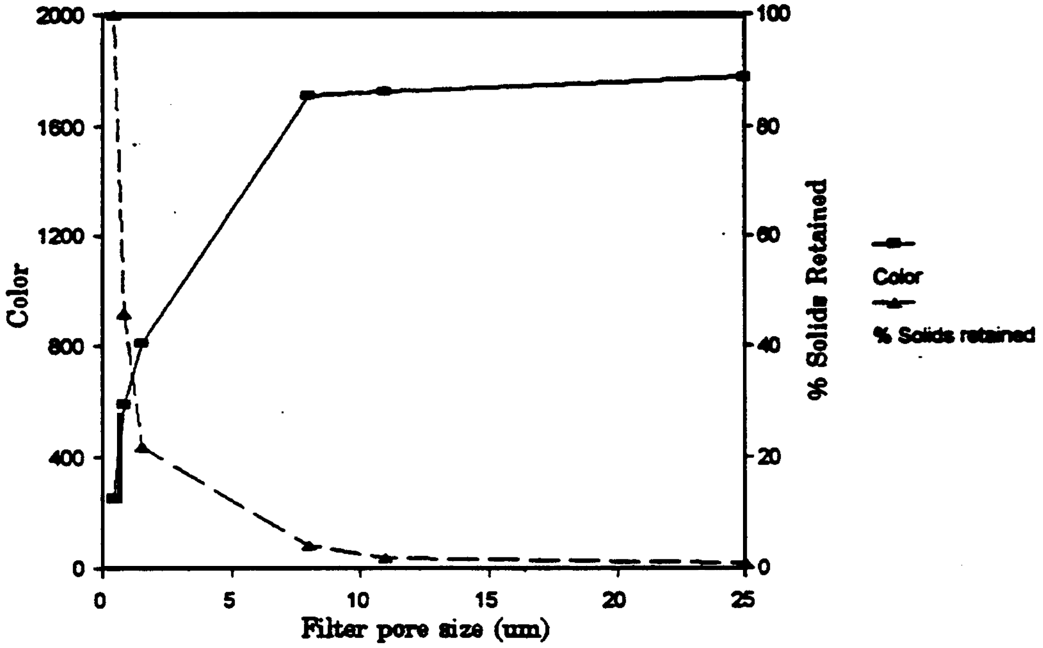


Figure 4.2: Color and Cumulative Suspended Solids Content after Filtration.

4.6.2 **Coagulation with Alum**

The initial TSS and color of the wastewater was 362 mg/l and 807 ADMI, respectively. The formation of flocs was visually observed at a dose of 200 mg/l and higher. Table 4.7 and Figure 4.3 show that 200 mg/l alum is the best concentration of those considered for the removal of solids. The TSS at alum concentrations below 200 mg/l was higher than the TSS of the control. For example, the TSS was 315 and 520 mg/l at 50 and 100 mg/l alum. Poor sedimentation was visually observed in jars with an alum concentration of 200 mg/l or higher.

Table 4.7: Coagulation with Alum at pH = 6.

Alum dose mg/l	True color ADMI	Apparent color	Suspended solids mg/l
raw wastewater	807		362
0	807	1,873	236
20	1,172	1,836	280
50	794	1,828	315
100	600	1,725	520
200	516	1,001	145
400	578	1,193	159

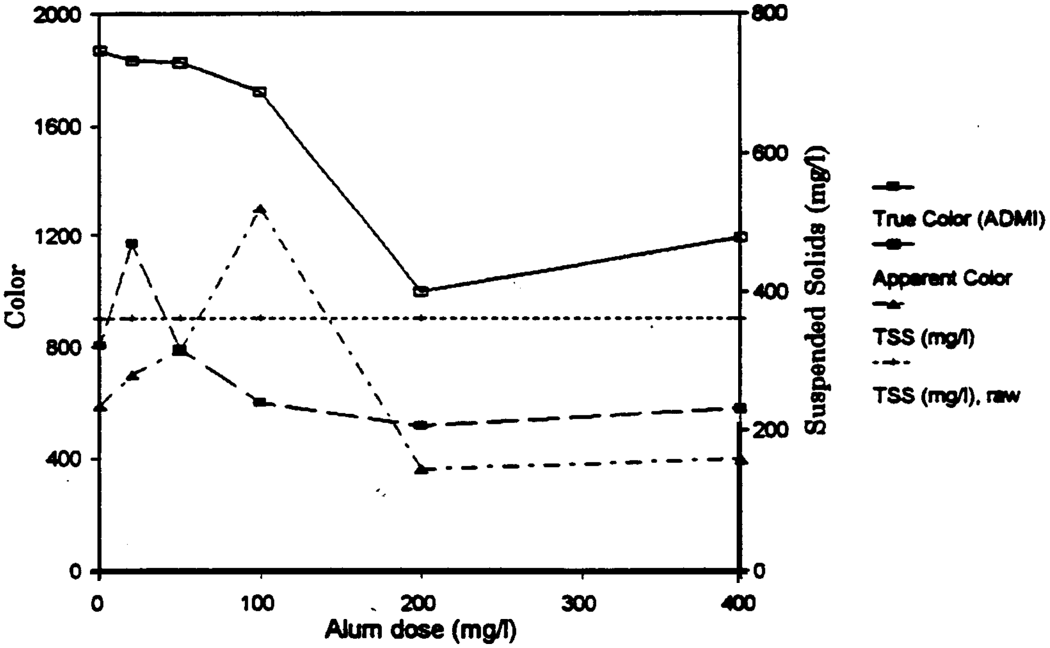


figure 43: Coagulation with Alum at pH = 6.

Once the best alum dose was determined, the influence of the pH on coagulation was investigated. The results are shown in Table..4.8 and Figure 4.4. Comparison of Figures 4.3 and 4.4 show that the solids concentration in the supernatant at pH 6 is very different in both experiments. This can be explained by the collection of unsettled flocs when a sample was taken for the determination of TSS.

Table 4.8: Coagulation with Alum (200 mg/l) at Different pH levels.

pH	True color ADMI	Apparent color	suspended solids mg/l
6.2	807		362
3	397	1,804	350
4	405	695	190
5	271	842	267
6	385	1,430	358
7	431	1,077	293
8	534	1.384	343

4.6.3 Coagulation with a Cationic polymer, 577C

The results of this jar test are shown in Table 4.9 and Figure 4.5. Only a few very large, unsettleable flocs were formed at all concentrations. These flocs were so large that they were not disturbed when collecting supernatant for TSS determination.

4.7 RECOMMENDATIONS

Efforts should be made to determine when cleaning the washers is necessary. Large quantities of water are currently wasted **by** leaving this decision to the washer operator. The number of washer cleanings can probably also be reduced by improved communication with the clients and by giving a cost break to clients who can allow more time for the return of their materials. This would allow the company to better schedule the order of washes from light to dark clothes, thereby reducing the amount of clean-up

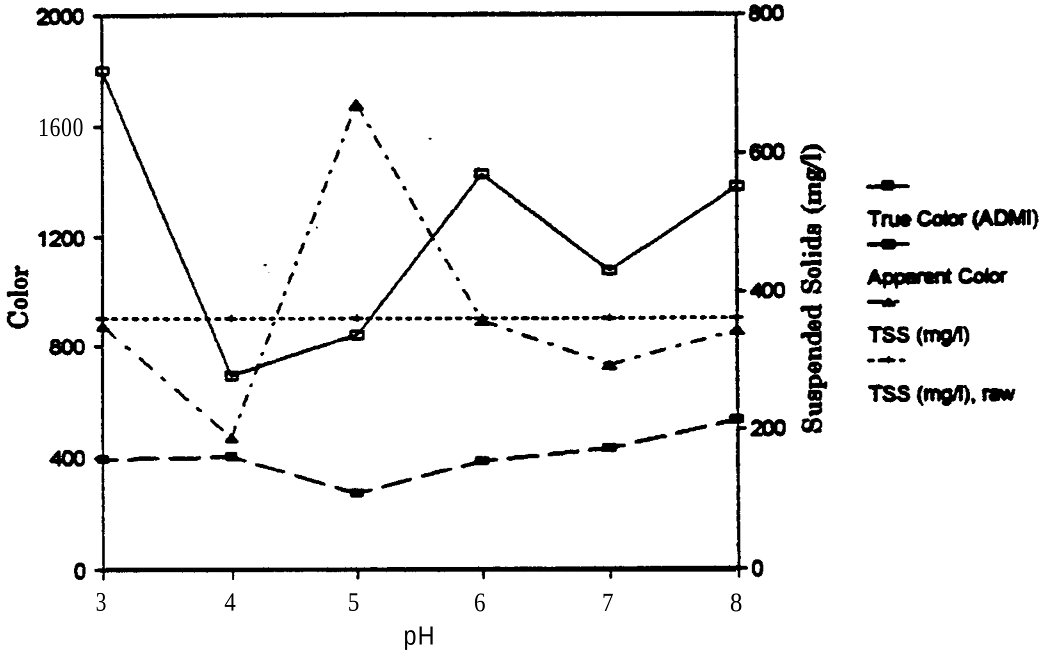


Figure 4.4: Coagulation with Alum (200 mg/l) at Different pH Levels.

Table 4.9: Coagulation with Cationic Polymer 577C, pH = 7.

Polymer dose mg/l	True color ADMI	Apparent color	Suspended solids mg/l
raw wastewater	807	-	362
0	755	2,051	173
2	775	1,885	127
4	708	1,846	118
10	613	1,723	167
20	552	1,854	200
50	321	2,146	250

time and rinse waters required to manage a miscellaneous assortment of light and dark garments. The chemical feed boxes of the washers overflow when too much chemicals

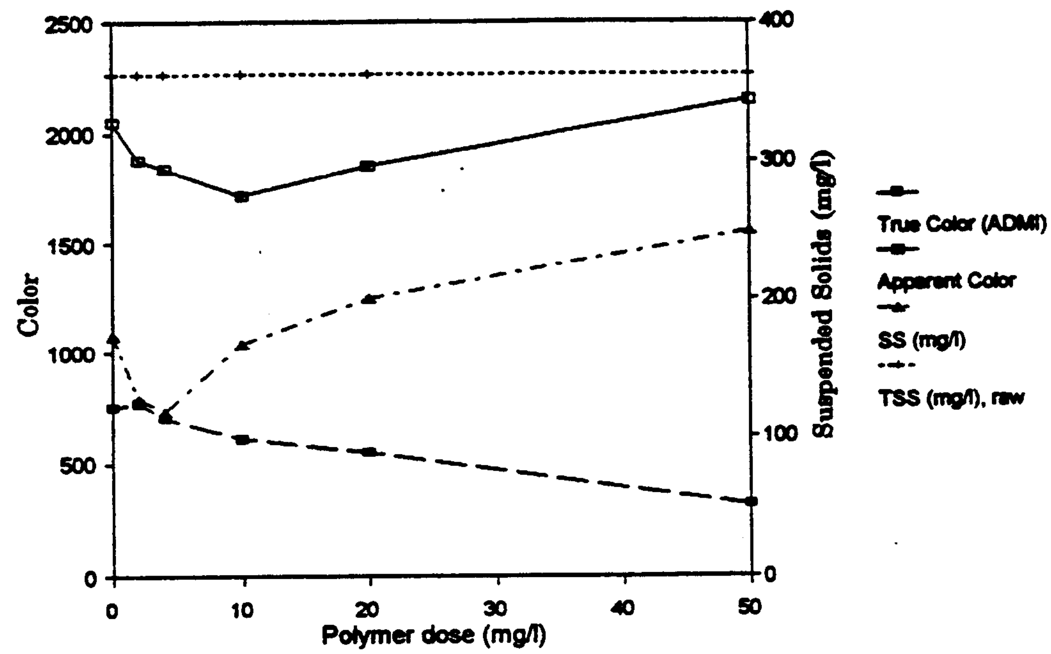


Figure 4.5: Coagulation with Cationic Polymer 577C, pH = 7.

are used, when the washer malfunctions or when the chemicals added form stable foams. As a result, the floor space between the washers is wet and slippery. Care should be taken not to use more chemicals than is absolutely necessary. A small strip between the washers is screened. This allows liquid to flow to a gutter underneath. The area of this screen should be expanded so that the liquid between the washers will drain more completely. It is also likely that automatic feed systems that can be programmed based on garment type, load and color would help reduce chemical costs and wastage.

The strength of the bleach can be checked by measuring the specific gravity of the bleach. A plot of the specific gravity versus the strength of the bleach should be made to discover variations in the bleach strength. The volume of bleach needed can be adjusted to the strength of the bleach.

Antichlor is used after each bleach cycle to stop the action of the bleach. The amount of antichlor added to the washers is 33% in excess of the theoretical amount needed. The amount added should be closer to the stoichiometrical amount needed. An excess of 5-10% is probably sufficient.

Acetic acid is used in this laundry for pH adjustment. This chemical has a high BOD (0.64 lb/lb) and therefore increases the waste load of the effluent. Substitution of this acid by formic acid (BOD 0.12 lb/lb) will reduce the organic load of the wastewater. This reduction can be significant on certain days and can be important if the management personnel decides to treat the wastewater on-site.

Flocculation of suspended solids and removal of color is possible through the addition of alum or cationic polymer, 577C. The TSS can be reduced from 362 to 145 mg/l by the addition of 200 mg/l alum. A reduction of 69% (from 362 to 118 mg/l) is achieved with 4 mg/l 577C. It is not clear if this is sufficient to produce water of reusable quality. Further investigation is required to identify practical treatment methods for the company. The poor settlement of the formed flocs suggests that the use of a DAF unit should be studied more closely. And, as mentioned earlier, there may be waters that can be collected and reused without treatment once the required quality of water for different washing operations is established.

Currently, no efforts ‘are made to recycle paper, plastic and metals. The fabric arrives at the laundry in cardboard boxes. These boxes are often damaged and reuse is not possible. After washing,-the clothes are bundled according to size and transported in open boxes. These boxes are covered with brown paper. The amount of paper used is often in excess of the amount needed. A more efficient way of transporting the washed clothes would be in plastic boxes with reusable lids. If reuse of material is not possible it should be collected and recycled. This will reduce the quantity of waste landfilled and therefore reduce disposal costs.

CHAPTER 5. FIBERGLASS PROCESSING PLANT

The insulating and fire resistant properties of fiberglass fabric make it useful in a variety of applications. Fabric produced at this plant is used in printed circuit boards, and as insulation wrappings for electrical components and cables. Other products of this mill are used as heavy weight asbestos replacement fabrics (lagging), insulating blankets, high temperature particulate filters, vertical blinds and ceiling board facings. A small amount of Kevlar fabric is manufactured.

5.1 PLANT DESCRlPTION

The yarn enters the plant wound on small bobbins or beams. During yam warping, yarn from up to 1500 bobbins is wound on one beam. If the yarn is used as warp yam, it goes to the slashing department. Here, the yarn passes through a pad pan containing sizing chemicals. The chemicals are heat set by passing the yam over steam cans. The yarn on up to four beams can pass simultaneously through one slasher. The yarn on those four beams will be collected on one beam. The number of beams used simultaneously in one slasher depends on the length and width of the fabric for which the yarn till be used. Two or more strands of yam are twisted before warping. Afterward, both fill and warp yarn go to the weaving area for the production of woven fabric..

After weaving, a portion of the fabric is subjected to mechanical processes (cutting, slitting, etc.) and shipped as greige fabric. When finishing is required, chemicals may be applied on the greige (loom-state) fabric, but usually the fabric is heat cleaned before finish application.

There are three types of heat cleaning. The majority (8040%) of the size chemicals and original yam binders are removed in a process called caramelizing. This involves passing the fabric through a gas fired oven at 800-125O^{o}F. The temperature in the oven depends on the fabric weight. At this point a portion of the fabric is sold for coating or leaching. Finishes that do not need complete removal of organics can be applied at this point. Heat treatment is continued in batch ovens at a temperature of 650-720°F for up to 72 hours if a clean (less than 0.04% residual organics) fiberglass fabric is required. Batch cleaning only (650-720°F for up to 72 hours) is used for very lightweight or very open constructed fabrics.

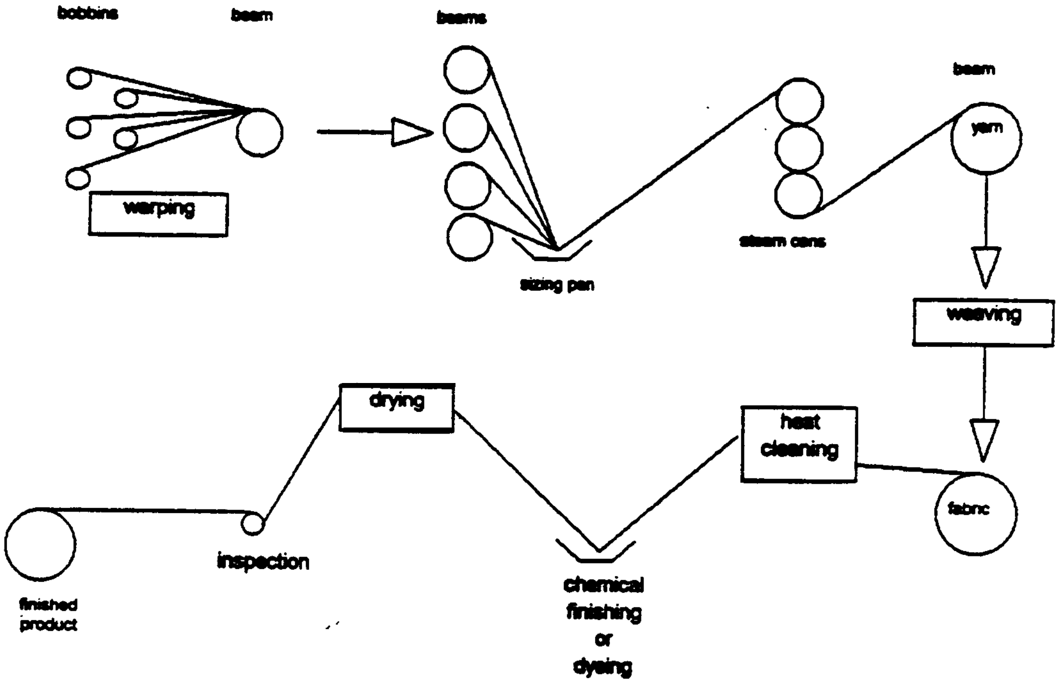


Figure 5.1: Flow Diagram of the Fiberglass Processing Plant

After heat cleaning, the majority of the fabrics are treated with hydrolyzed silane finishes. These finishes typically have a pH in the range 3.5-4 and a shelf life of less than 24 hours. A small portion of the fabric is treated with resin bonded pigments for coloration. All the operations in the mill are conducted continuously. Waste yarn is used to produce insulating mats in the special products department. A flow diagram of the production process is given in figure 5.1.

5.2 WATER USE

The three major uses of water in the production area of the mill are for non-contact cooling of machinery, chemical mixes and the HVAC system. Table 5.1 gives an estimate of the water use in the plant. This table shows that cooling machinery is responsible for almost 80% of the daily water consumption in the plant.

Most of the non-contact cooling water is required in the finishing department. The chemicals applied to the fabric are set by heating the fabric to 220-625°F. This process heats the rolls over which the fabric passes which can damage machinery parts and the fabric. City water flows through the rolls at a rate of 5 to 10 gallons per minute (gpm) with an average of 6 gpm. After the water passes through the rolls, it mixes with the wastewater and is discharged to the sewer. There are, in total, 26 non-contact cooling rolls and 4 non-contact cooling jackets in the plant. Non-contact cooling jackets can be found around chemical pans. There are 8 cooling rolls in the plant that produce water with a temperature of 140-150^{o}F. These rolls are only used when performing a special operation. Plant personnel estimated that each of these rolls operates 6 hours per day and that at any given time 25% of the rolls are operating. The remaining cooling rolls (18) are estimated to operate 65% of the time and the cooling jackets (4) during 75% of the time (estimates by the environmental engineer at the plant). The quantity of water discharged at a temperature of 140-150°F is 5,000 gpd. Ninety six percent (128,000 gpd) of the non-contact cooling water discharge has a temperature of 80-90°F. The non-contact cooling water also include water used for cooling 1 size pan and the guillotine. The guillotine is a machine that is used in the Special Products department to recycle waste yarn and ‘fabric. The flow rate of the cooling water was measured (6.3 gpm). The guillotine operates, on average, 9 hours per day.

The HVAC system includes airwashers and humidification equipment, absorption chillers, cooling towers and two boilers. The steam produced by the boilers is used to heat the building, produce warm water, and heat steam cans. A small amount of live steam is needed every two weeks to produce hot water for washing operations. The average boiler water make-up was estimated by plant personnel for the summer and the winter months. During the summer months (5 months), the boilers operate at 40% of their average winter capacity. The average boiler make-up is 21% during the summer months and 22% during the remaining 7 months of the year.

There are four air washers in the plant. Plant personnel estimated that each air washer uses 0.6 gpm. On average, two units (50% operation) operate 18 hours per day. The blowdown of one washer was measured (0.9 gallons per hour). The resulting total flowrate for the four washers was 65 gpd.

According to the environmental engineer at the plant, the cooling towers and chillers require 1.4 gallons of water per ton of cooling due to evaporation. The 1000 tons of cooling available at the plant are, used to cool the buildings during the summer and to provide cooling water for the air compressors. The blowdown (30% of amount evaporated) and percent operation was estimated by the HVAC maintenance personnel. The water used for the size and finish mixes was estimated by the plant chemist. The quantities of mixes dumped in 1993 were 560 gpd for the finish mixes and 85 gpd for the size mixes.

The water needed for cleaning of the units was e&mated by the personnel operating the machines. These estimates are given in the appendix (Table Bl). The environmental engineer at the plant estimated that 500 gallons per day is lost due to evaporation.

The domestic and cafeteria water use are estimated on basis of the number of employees and estimated flowrate of the equipment. For example, it was estimated that each employee uses the water fountain once during his/her shift. The water used was estimated to be equal to one glass of water. The washers are used once every two weeks. The flowrate measured in one of these washers was 10 gpm.

A detailed overview of the water use and wastewater generation is given in Appendix B (Table Bl). The estimated water supplied to each water component is given in Table 5.1. Table 5.2 gives the daily flowrates generated by each wastewater component.

Table 5.1: Estimated Water Supplied to the Fiberglass Processing Plant.

	Daily water consumption gpd	Percent of daily water use
Non-contact Cooling Water	133,000	79.2
HVAC	16,000	9.5
Chemical Mixes (size and finish)	9,100	5.4
Washing	1,000	0.6
Cleaning	5,000	2.9
Domestic	3.000	1.8
Cafeteria	700	0.4
Total	168,000	99.8

Table 53: Estimated Wastewater Generation at the Fiberglass Processing Plant.

	Daily wastewater generation, gpd	Percent of Daily wastewater Generated
Non-contact Cooling Water	133,000	88.1
HVAC	6,000	4.8
Chemical Mixes	650	0.5
washing	1,000	0.7
Cleaning	4,500	3.0
Domestic	3,000	2.0
Cafeteria	510	0.3
Total	149,000	99.6

5.3 WASTEWATER CHARACTERISTICS

This mill does not have a pretreatment facility. Wastewater generated in the different departments is combined and discharged to the POTW. The sewer charges imposed by the municipality are based on 90% of the mill's city water intake. The plant pays a fixed charge per gallon of water discharged, plus a surcharge if COD > 500 mg/l, TSS > 240 mg/l or BOD_5 > 240 mg/l. The company is not allowed to discharge wastewater with one of the following characteristics: BOD_5 > 965 mg/l or COD > 1850 mg/l. To calculate the surcharges, the wastewater treatment operator of the POTW takes four 24-hour composite samples every month and analyzes them for COD, BOD_5 and TSS. The average COD, BOD_5 and TSS were 582 mg/l, 103 mg/l and 135 mg/l, respectively, during the year.

Samples of the different types of wastewater were collected and analyzed. The results of the analyses are given in Table 5.3. Samples of domestic and cafeteria wastewater were not collected. The wastewater characteristics for these sources were obtained in "Introduction to Environmental Engineering" by Davis and Cornwell (1991). It was also not possible to collect a representative sample of general cleaning wastewater. Samples of two different types of finishing mix were taken. The finish mix of unit 3 represents the type of mix that is used to treat 70% of the fabric. It was therefore assumed that 70% of this wastewater is generated by this type of mix. The other type of finish mix is used to treat 10-15% of the fabric, 15-20% of the finishing processes are mechanical only or are types of finishing mixes not sampled. The company has four basic sizing mixtures. Two of these mixes were sampled. The mix with a COD = 160,800 mg/l was chosen, because it had the highest concentration of PVA and auxiliary chemicals used in the size mixes. The other mix analyzed had a low concentration of PVA and a small quantity of one auxiliary chemical. The composition of the other size mixes is different from the two analyzed, but the type and amount of chemicals used is similar to the ones analyzed.

Table 5.3: Material Balance for Fiberglass Processing Plant.

Source	Color ADMI	DOC mg/l	COD mg/l	pH	Temperature °C	TSS mg/l	Nickel µg/l	Chromium µg/l	Copper µg/l	Lead µg/l	Zinc mg/l	Flow gpd
Domestic*	-	-	500	-	-	200	-	-	-	-	-	3,000
Boiler	101	89	160	8.53	19	38	33	2.4	348	56	1.95	3,400
Cooling tower	5	17	40	8.33	21	0	7	3.9	34	8	0.30	2,400
Air Washer 2	56	67	160	8.03	13	20	6	3.4	76	9	0.52	60
Cooling Roll finishing	11	3	60	6.76	27	0	16	1.2	13	2	0.16	128,600
Finish mix unit 3	45	3,23	12,700	3.03	19	1	10	10.3	108	14	0.34	390
Finish mix unit 7	148,092	4,327	75,200	9.66	19	17,623	-	-	-	-	-	170
Size mix slasher 3	434	16,685	49,400	5.83	48	0	9	10.4	26	4	0.12	43
Size mix slasher 1	1,823	53,900	160,800	5.50	61	92	-	-	-	-	-	43
Cooling roll slasher 4	14	13	40	7.71	25	0	6	1.1	5	2	0.31	1,400
Guillotine	9	3	20	6.81	13	0	5	2.5	33	10	0.45	3,400
General cleaning	-	-	10,000	-	-	3,500	-	-	-	-	-	4,500
Cafeteria*	-	75	250	-	-	100	-	-	-	-	-	510
Washing	34	-	4,000	-	-	0	37	3.8	246	16	0.6	1,000
Total (Calc)	-	-	576	-	-	131	-	-	-	-	-	149,000
Total (analysis)	-	-	700	-	-	116	40	267.5	28	11	0.06	-
Total (POTW)**	-	-	582	-	-	135	-	-	-	-	-	141,700

* Values are taken from Davis and Cornwell (1991).

** Results obtained from the wastewater treatment plant operator.

The COD of the combined wastewater was calculated using the COD and flow of each wastewater component. The only unknowns in this table were the wastewater characteristics of general cleaning wastewater-s. Therefore, an estimate for the COD of the general cleaning wastewater was determined by trial and error and incorporated into the mass balance (Table 5.3). The flowrate (gpd) of each wastestream component was multiplied by its COD. The summation of these values was divided by the estimated flowrate of the combined wastewater to give the calculated COD (mg/l) of the combined wastewater. Three estimates for the COD of the general cleaning wastewaters are given in Table 5.4 together with the corresponding COD of the combined wastewater.

Table 5.4: Influence of the COD of General Cleaning on the COD of the Combined Wastewater.

COD general cleaning mg/l	Corresponding COD for the combined wastewater, mg/l
7,500	494
10,000	576
13,000	658

The estimated COD of the combined wastewater was close to the measured COD when the COD concentration of general cleaning was estimated to be 10,000 mg/l. This is an acceptable value since the chemical mixes used in the different machines can have very high COD values (up to 160,800 mg/l). During one visit, operators were cleaning one of the machines in the finishing department. The chemical mix used during the previous run was very tough to remove. Eight hours were needed to clean the machine. The wastewater from this cleaning operation was very strong in the beginning of the cycle, but dilute at the end. In addition, general cleaning is very Similar to the washing operations performed at the plant. Washing operations are performed on Kevlar to remove. sizing and on a portion of the fiberglass fabric as a pretreatment to heat cleaning. The COD of this water is 4,000 mg/l. General cleaning removes essentially the same chemicals, but from machinery parts rather than fabric or yarn. Cleaning the production floor for which detergents are used is also included under general cleaning. The same procedure was followed to estimate the TSS of the general cleaning wastewater. The best match was obtained with a TSS = 3,500 mg/l.

5.4 SOLID WASTE

The mill makes good efforts to reduce the amount of by-products generated and landfilled. The yarn arrives at the plant on reusable pallets and is wound on plastic creels. These creels are returned to the supplier. The only unrecycled by-product generated during yarn handling is the plastic wrapped around the shipping pallets. Waste yarn generated during warping, sizing and weaving goes to the Special Products department for the production of insulative mats. Fabric is wasted in the finishing department each time a new roll is started and when chemical baths are changed. Fabric is also wasted when machines break down. In 1993, 500 tons of fiberglass were recycled and 600 tons were landfilled.

5.5 FLOW REDUCTION

5.5.1 Approach

The material balance of Table 5.3 shows that almost 80% of the water consumed is used for non-contact cooling. It is estimated that 4% of this water has a temperature between 140° and 150°F. This water could be used to preheat the boiler make-up water. Afterwards, this non-contact cooling water could be cooled further by a cooling tower or chiller and reused.

The majority of the non-contact cooling water discharged has a temperature of 80-90°F. It is possible to reuse this water for preheating other waters or as non-contact cooling water once it is cooled to 65°F, the temperature required for cooling purposes. Cooling this water can be done by a chiller and/or cooling tower. A cooling tower could provide the necessary cooling when the wet bulb temperature of the outside air is below 55°F. Weather data from the Roanoke weather station (Ecodyne Corporation, 1980) indicated that the average dry-bulb temperature in Roanoke is at 56°F or below during five months of the year. The data also indicated that the wet-bulb temperature did not drop below the dry bulb temperature. The wet-bulb temperature is measured by a thermometer with a wetted wick over its bulb. The dry-bulb temperature is measured with an ordinary thermometer. Calculations were performed to evaluate the cost of cooling this non-contact cooling water. The following assumptions were used in the calculations:

1. The hot cooling water (140 - 150°F) is cooled to 100°F by using it to preheat the boiler feed water. It is then cooled by a cooling tower or chiller to 65°F.
2. The chiller has a Coefficient of Performance (COP) of 3. Chillers usually operate with a COP in the range of 2.5 to 3.5 (Liptak, 1987).
3. Weather data showed that the wet bulb temperature air will allow cooling of the water by a cooling tower during five months of the year. However, it is assumed in the calculations that a cooling tower is used during four months,
4. Installation costs for new pipes and pumps was not considered.
5. The electrical motors of the chiller have a efficiency of 70%.

The chillers and cooling towers available at the plant have a usable cooling capacity of 440 tons. According to the management at the mill, the available cooling towers have enough excess cooling capacity to cool the water during the winter months and probably during the summer months. Two scenarios were investigated since it is not clear if enough cooling capacity is available during the warmer months of the year. The first scenario assumes that an extra chiller (100 ton cooling capacity) is installed at a cost of $ 50,000 (installed cost estimated by the environmental engineer at the mill). A cooling tower would provide cooling during four months each year. In the second scenario cooling is provided by the equipment available at the mill.

The cooling required to cool the water, Q_H ,Btu/hr (Liptàk. 1987):

$$Q_H = M * C_p * (T_2 - T_1) \tag{5.1}$$

where

Q_H = heat transfer rate (Btu/hr)

M = mass flow (lbs/hour)

C_p = heat capacity of feed (Btu/lb/^{o}F)

T_2= inlet temperature (OF)

T_1 = outlet temperature (“F)

The mass flow of water that must be cooled, M (lb/hr):

$$M \ -\frac{133{,}000\text{gpd}}{24\text{hrs/day}} *8.341\text{bs/gal}=46{,}000 \quad *\text{lbs/hours} \tag{5.2}$$

The cooling required to cool ‘the water is then calculated using equation 5.1:

$$Q_H = 46{,}0001\text{bs/hr} \ * 1\ \text{Btu/lb/}^{o}\text{F} * 20°\text{F} = 920{,}000\ \text{Btu/hr} \tag{5.3}$$

The energy that the chiller compressor has to deliver, Q_c (kWh), is then calculated by equation 5.4:

$$Q_c \quad Q_H * \frac{1}{\text{COP}\ 3412\ \text{kWh/Btu}} = \frac{920{,}000}{3} * \frac{1}{3412} = 90\ \text{kWh} \tag{5.4}$$

The electrical energy that the chiller motor must deliver, Q_E (kWh):

$$Q_E \quad \frac{Q_c}{E} = \frac{90}{0.7} = 130\text{kWh} \qquad (5\text{-}5)$$

where

E = efficiency of the electrical motors of the chiller

It was assumed that the chiller will deliver this cooling capacity 8 months/year. According to the environmental engineer at the plant, electricity is bought at $0.05/kWh. It is assumed that the chillers operate 24 hrs/day, 30 days/month. The electrical cost of the chiller, C ($/yr):

$$C = 130\text{kWh} * 24\text{hrs/day} * 30\text{days/mo.} * 8\text{mo.} = \$\ 38{,}000/\text{yr} \qquad (5.6)$$

The total cost for the operation of the chiller is therefore $38,000/yr.

5.5.2 Water consumption

The water consumption in the plant will decrease significantly when the non-contact cooling water is recycled. The temperature of the water entering the chiller or cooling tower will be on average 85°F since it was recommended that the water with a temperature of 140-l50°F was used to preheat the boiler feed water. The increased use of the cooling towers and chillers will increase the water consumption for the HVAC system. Cooling the non-contact cooling water will require 920,000 Btu/hr (77 Tons of cooling). An extra 3,300 gpd of water are required to account for evaporation and blowdown (1.4 gal per ton of cooling plus 30% blowdown per gallon of water evaporated).

Holme reported in 1977 that water supply losses due to broken valves, leakages, etc., varied from 6 - 44 % of the total water supply with an average of

25%. Based on these numbers a make-up requirement of 15% in the closed loop system was assumed.

Table 5.5: Current and Recommended Water Consumption and Wastewater Generation.

	current		Recommended	
Description	Water use gpd	Wastewater generation gpd	**Water use gpd**	**Wastewater generation gpd**
Domestic	3,000	3,000	3,000	3,000
Non-contact cooling water	133,000	133,000	20,000	20,000
Washing	1,000	1,000	1,000	1,000
Sizing mix	1,100	85	1,100	85
Finish mix	8,000	560	8,000	560
HVAC	16,000	6,000	19,300	6,800
Cafeteria	700	500	700	500
General cleaning	5,000	4,500	5,000	4,500
Total (Gal/day)	168,000	149,000	58,100	36,000
cost (/yr)	$87,700	$105,500	$30,300	$25,500
Savings (/yr)			$137.400	

5.5.3 Net Savings

The costs related to recycling non-contact cooling water are given in Table 5.6. As mentioned earlier, the capital cost and operating costs of a chiller are estimated to be $50,000 and $38,000/yr, respectively. Thus, recycling the non-contact cooling water can result in financial savings the first year in both cases. This will, however, depend on the costs related to the operation of fans and pumps and to the cost of wastewater treatment.

Table 5.6: Cost Estimate of Water Recycling.

Option	**Expenses ($/yr)**	**Savings ($/yr)**	**Net Savings ($/yr) in first year**
Chiller installed	88,000	137,400	49,400
No chiller installed	38,000	137,400	99,400

5.5.4 Effects on Characteristics of Wastewater

Recycling the non-contact cooling water in a closed loop will have a major effect on the characteristics of the waste stream. The influence of the reduced wastewater flow on the COD and TSS concentration of the water are shown in Table 5.7. The results of the revised material balance show that the COD and TSS concentration of the combined wastewater will increase to 2,200 mg/l and 537 mg/l, respectively. The mill would not be allowed to discharge this wastewater, since the upper limit of the COD is 1850 mg/l. As a result, segregation and pretreatment of the most polluted waste streams will be required. The load of the combined wastewater is determined by three streams: dumped size mixes, dumped finish mixes and cleaning wastewater. Removing the chemical mixes from the combined wastewater would reduce the COD to 1500 mg/l, (a 33% reduction) and the TSS to 500 mg/l (see Appendix Table B2). The company would be allowed to discharge this wastewater, but would have to pay surcharges because the COD exceeds 500 mg/l.

5.5.5 Further Reducing the Flow

Sometimes water flows through rolls that do not need cooling or when a machine is not operating. Efforts should be made to check each roll in the finishing department to see if it needs to be cooled. An automatic valve could be installed on the cooling rolls so that no water flows through the rolls when the machinery is not operating.

Table 5.7: Revised Material Balance for fiberglass Processing Plant.

Source	Color ADMI	DOC mg/l	COD mg/l	pH	Temperature °C	TSS mg/l	Nickel µg/l	Chromium µg/l	Copper µg/l	Lead µg/l	Zinc mg/l	Flow gpd
Domestic*	-	-	500	-	-	200	-	-	-	-	-	3,000
Boiler	101	89	157	8.5	19	38	33	2.4	348	56	1.9	3,400
Cooling tower	5	17	38	8.3	21	0	7	3.9	34	8	0.3	3,300
Air Washer 2	56	67	157	8.0	13	20	6	3.4	76	9	0.5	60
Cooling Roll finishing	11	3	60	6.8	27	0	16	1.2	13	2	0.2	19,300
Finish mix unit 3	45	3,823	12,700	3.0	19	1	10	10.3	108	14	0.3	390
Finish mix unit 7	148,092	4,327	75,200	9.7	19	17,623	-	-	-	-	-	170
Size mix slasher 3	434	16,685	49,400	5.8	48	0	9	10.4	26	4	0.1	43
Size mix slasher 1	1,823	53,900	160,800	5.5	61	92	-	-	-	-	-	43
Cooling roll slasher 4	14	13	42	7.7	25	0	6	1.1	5	2	0.3	200
Guillotine	9	3	16	6.8	13	0	5	2.5	33	10	0.5	500
General cleaning	-	-	10,000	-	-	3,500	-	-	-	-	-	4,500
Cafeteria*	-	75	250	-	-	100	-	-	-	-	-	510
Washing	34	-	4,000	-	-	0	37	3.8	246	16	0.6	1,000
Total (Calc)	-	-	2,200	-	-	537	-	-	-	-	-	36,400
Total (analysis)	-	-	700	-	-	116	40	267.5	28	11	0.06	
Total (POTW)**	-	-	582	-	-	135	-	-	-	-	-	141,700

* Values are taken from Davis and Cornwell, (1991).

** Results obtained from the wastewater treatment plant operator.

5.6 RECOVERY OF PVA

The company has four basic size mix formulations. These formulations all contain water, PVA and auxiliary chemicals, but in different concentrations. It may be possible to use left overs of one mix as part of another mix after adjusting the amount of water and chemicals in the excess size mix. Calculations were performed to determine the amount of PVA dumped per year. The average pounds of PVA per gallon of size mix made is equal to, M_{PVA}(lb/gal):

$$M_{PVA} = \frac{\text{PVA (lb/yr)}}{\text{size (gal/yr)}} \tag{5.7}$$

Quantity of PVA dumped every year, Q_{PVA}(lb/yr):

$$Q_{PVA} = M_{PVA} * Q_{size} \tag{5.8}$$

where

Q_{size}= the quantity of size mix dumped yearly, gal/yr,

Cost of dumping PVA:

$$C_{PVA} = Q_{PVA} * P_{PVA} \tag{5.9}$$

with P_{2vA}= the unit price of PVA, $/lb

The numbers used in this calculation were provided by the environmental engineer at the plant. The results of this calculation showed that 7% of the PVA purchased is lost through dumps which amounts to $9,900 in last PVN/year. If this is not possible, the PVA could be recovered through membrane filtration (Cook, 1992). PVA molecules are big which makes it possible to separate them from smaller molecules like water and detergents. The concentrated PVA can then be stored and used to make fresh size mixtures.

5.7 PRETREATMENT OF CHEMICAL MIXES

According to the chemist at the plant, thirty percent of the finish mixes have a high pH and are high in suspended solids. Some lab experiments were performed with this type of finish mix. The mix was allowed to settle for 12 hours. The COD and suspended solids content of the mix was determined before and after settling. The results of the experiment are shown in Table 5.8. The results show that sedimentation removed 34% of the COD and 85% of the solids. These experiments are promising and more tests should be performed to evaluate the removal of COD by coagulation, flocculation, and sedimentation.

Table 5.8: Results of Settling Experiment Performed on Finish Mix from Fiberglass Processing Plant.

Sample	COD (mg/l)	Suspended solids (mg/l)
before settling	75,200	17,160
After 12 hours settling	49,600	2,500
Percent removal	34%	85%

The majority of the finish mixes (70%) have a shelf life of 24-hours. The pH of these mixes must be kept at 3 to keep the solution soluble. Neutralization of the mixes results in the formation of solids which settle out. (Research and Development Department at the company; Personal communication, 1995a). It should be investigated how much COD is removed by neutralization of these mixes.

5.8 RECOMMENDATIONS AND CONCLUSIONS

Modifying the non-contact cooling water system so it can be operated as a closed loop will reduce the wastewater flow by 76%. This will result in significant annual savings. Economic analysis showed that the first year savings would be

$49,400 if an extra chiller is installed. If no chiller is needed, the savings would be $99,400. Costs related to the operation of fans and pumps would not taken into consideration. The recycle system will result in a more concentrated wastewater since the non-contact cooling water contains few contaminants. The finishing and sizing mixes discharged account for 33 % of the COD load of the combined wastewater. However, the daily generation of these concentrated waste streams would be less than 700 gallons. It is therefore recommended that these strong chemical mixes be segregated from the other streams and treated on-site. The performed experiments revealed that some pretreatment can be achieved by plain sedimentation (Table 5.8). More research is required to develop a pretreatment system for these strong chemical mixes. For example, recovering PVA from left-over size mixes will reduce the COD concentration in the dumped, size mixes, therefore reducing the amount of pretreatment needed before the wastewater is discharged to the POTW. Seven percent of the PVA bought is lost through dumps. This accounts for $9,900 per year.

The management of the mill recognizes that the pad pans for chemical mixes are probably bigger than necessary. The size of the pad pan depends on the number of times the fabric needs to pass through the pan. In many mills, the fabric passes several times through the pan, although one pass is enough to give the desired characteristics to the fabric. Adjusting the number of times the fabric passes through the pan will make it possible to optimize the size of the pan and therefore the amount of chemical dumped at the end of the run. The pad pans used in this mill hold 30 to 100 gallons. It is likely that the size of the 100 gallon pans can be reduced.

According to the research and development department of the company, the size mixes should only be dumped at the end of a run. There is no limit on the life of the size mixes. Frequently, a size mix is used only for several days. This means that several tanks of this mix are used unnecessarily. A fresh batch of mix is made when the amount available is low. Under the current system, a full tank of mix made at the end of the week and partially stored until the next week. If the slasher operator, in that following week, detects that the mix has deteriorated (PVA breaking down due to bacterial growth), (s)he dumps it. On the basis of odors and the problem stated above, 100 to 200 gallons of size are dumped every two days. As an alternative to the current practice, it would be better to better match the amount of mix made to that actually needed. Also, a better system than off-odors, alone, is needed to ascertain the quality of a mix.

The amount of finishing mixes dumped (560 gpd) represents 7 % of the amount of mixes made (8,000 gpd). Half of the dumps are due to liquid left in piping and pad pans at the end of the run. The other half is dumped because of errors made when calculating the amount of mix needed. Calculation errors can be reduced were the quantity of finish mix needed per type, width and length of fabric recorded and adjusted each time that combination of mix and fabric is used.

The washers use hot water (170-180°F) at an estimated flow rate of 5 gpm. Currently, the water is heated by pumping live steam through the washers. These washers are near dryers that constantly operate at a temperature of 220 to 625°F. Heating the water by passing it though the dryers before it goes to the washers will save energy and steam. It is likely that the water can be heated to the desired temperature within the dryers.

CHAPTER 6. COTTON DYEING AND PRINTING MILL

This mill dyes and prints cotton and polyester/cotton blends for the production of bed linen and draperies. The end products are sheets and pillows used for industrial, commercial and institutional purposes. The mill also does commission work for companies such as Revmans, Laura Ashley, etc. The fabric processed at the mill arrives from weaving plants all over the world. This results in a significant variation in quality of the greige (i.e. raw, unfinished) goods.

6.1 PROCESS DESCRIPTION

All greige fabric is treated in the bleach and finishing range. The mill has two bleach ranges that produce 340,000 yards per day. The rolls of greige fabric are checked at the beginning of the range for correct fabric type, width, etc. If the fabric is used for the production of sheets, it is pulled through the singer. The gas-fired oven burns fibers from the surface of the fabric. This operation prevents the development of small balls of fiber during the use of the linen. The cooling rolls located after the singer in the bleach range are in part of the singer equipment. The fabric then passes through a quench box. This box contains hot water and detergent to remove the sizing chemicals from the surface of the fabric. Excess liquor is squeezed from the cloth and is returned to the quench box. The fabric is then pulled into a J-box. The dimensions of the J-box allow the fabric to stay in this box for 1 hour. Steam injected into the J-box maintains the temperature at 180^{o}F. The combination of detergent, steam and time ensures a complete breakdown of the sizing chemicals. The fabric then passes through a Tensitrol washer. This is a washer consisting of one basin through which water flows at a flowrate of 50 gpm and a temperature of 180°F. After the removal of sizes and detergent, the fabric passes through a saturator where it is saturated with the bleach solution. This solution contains hydrogen peroxide, caustic soda and auxiliary chemicals. The operator checks the concentration of H_20_2 and caustic soda every 30 min. If needed, the amount of H_2O_2 and/or caustic soda entering the saturator is adjusted. After it passes through a second J-box the fabric is washed in two Tensitrol washers in series. The fabric is stored in wet bins until further processing.

After it is bleached, the fabric passes a first time through the finishing range. The first operation in the finishing range is spreading the fabric evenly in the Sutton opener. The fabric is stored in the wet bins in rope form and needs to be spread open before further processing. The purpose of the wetout pan located at the beginning of the finishing range is wetting the fabric. Creases in the fabric are then removed by passing the fabric over steam cans. This simulates ironing the fabric. The fabric then passes through a pad pan containing pigment dyes. When processing fabric that will be dyed on the thermosol (or heat setting, dyeing process) dye range, a wetting agent and acetic acid facilitate the dyeing process. A resin finish to treat fabric that is already colored would also be added. The tenter frame located after the pad pan dries the fabric and sets the applied chemicals. This tenter frame consists of 10-l2 ovens in series. The temperature in each of the consecutive ovens increases gradually from 150°F in the first oven to 420^oF in the last oven. The physical finishing at the end of the range straightens the fabric before it is wound on a roll. The flow diagrams of the bleaching and finishing range are shown in Figures 6.1 and 6.2, respectively.

Some fabric passes twice through the finishing range: once to heat set for dyeing and once to apply resins after the fabric is dyed on the thermosol dye range. The fabric leaving the finishing range can be further processed on the thermosol dye range or the printers. Some fabric will go to the sheeting department for the production of sheets and/or pillowcases. Fabric that does not need further processing is shipped to the customer. The fabric processed on the finishing range can be visually inspected (graded).

The dyebath of the thermosol dye line contains vat dyes, pigment dyes or disperse dyes. Sometimes fiber reactive dyes are used instead of vat dyes. After the fabric leaves the dyebath, it passes through a gas-fired predryer, a set of steam cans and a curing oven.

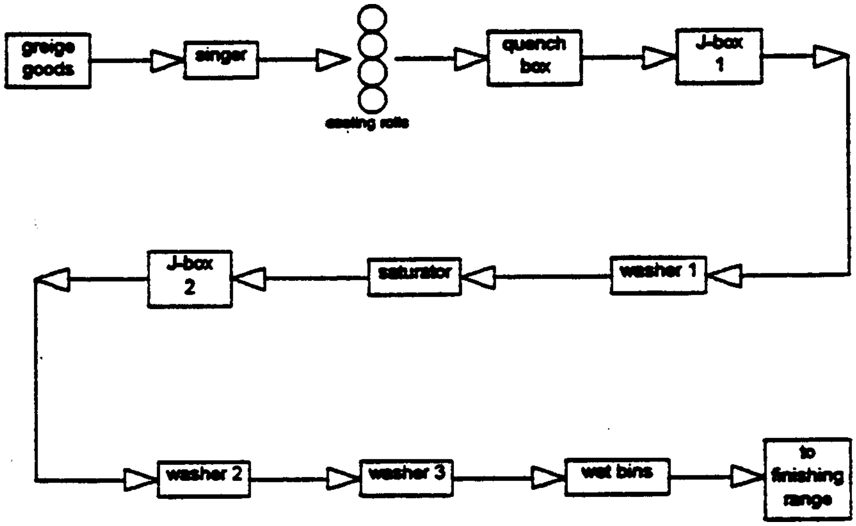


Figure 6.1: Flow Diagram of the Bleaching Operation.

This process allows the fabric to dry slowly and prevents the migration of the dyes. If the fabric contains polyester, disperse dyes will be set. A chemical pan after the curing oven contains sodium hydrosulfite and caustic. The sodium hydrosulfite reduces the vat dyes and makes them soluble. A steamer allows the reduced dyes to migrate into the cotton fibers. Removal of excess chemicals is achieved in 10 washers. The first two washers contain hot water to remove excess caustic and reducing chemicals before oxidation of the vat dyes. Hot water alone is insufficient to remove excess dyes from the surface of the fabric. The following two washers contain acetic acid and hydrogen hydroxide to oxidize the vat dyes to their insoluble form. Excess dyes on the surface of the fabric and chemicals are then removed by soap and hot water. The use of acetic acid results in the production of acetate. This chemical has to be removed by excess water, because it will stain the fabric. All fabrics treated on the thermosol range are sent back to the finishing range before further processing.

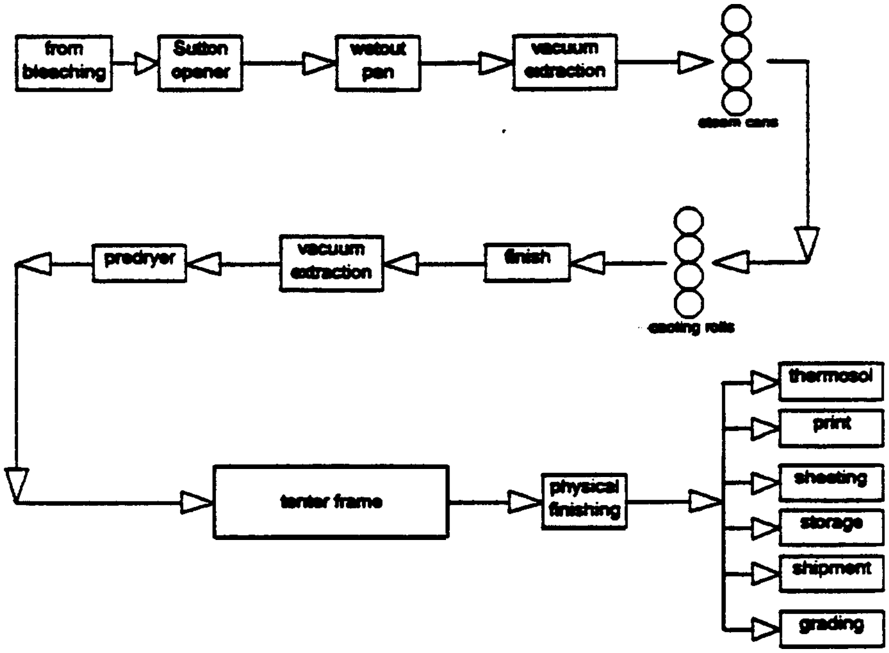


Figure 6.2: Flow Diagram of the Finishing Range.

The fabric dyed in the finishing range or thermosol can go to one of three printers that apply a pattern of colors to the fabric. Before the fabric touches the printer blanket, a layer of contact adhesive is applied to the printer blanket. This glue ensures good contact between the blanket transporting the fabric and the fabric itself, and prevents the movement of the fabric during printing. The fabric leaving the printers passes through a predryer and a curing oven. The glue on the printer blanket is washed-off. This operation requires a large amount of water. The print paste is made by an automated system that weighs the amount of dyes needed to obtain a certain shade. Afterward, a drum is placed under a mixer, and the paste is mixed for 1 to 2 minutes. The mixer lifts automatically and swings to another drum for rinsing. Flow diagrams of the thermosol dye range and the printing operations are given in Figures 6.3 and Figure 6.4, respectively.

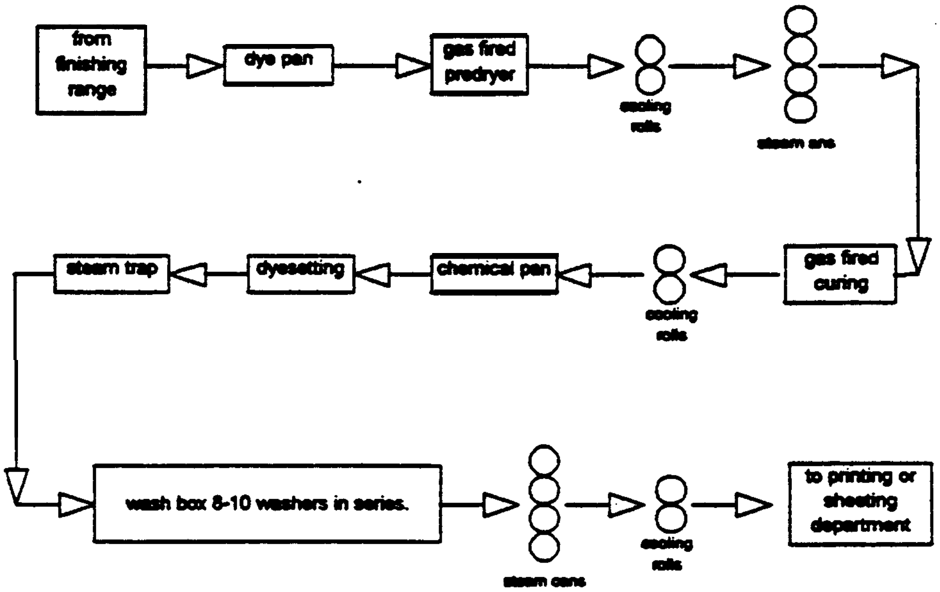


Figure 6.3: Flow Diagram of the Thermosol Dye Range.

6.2 WATER USE

This mill pumps 8 million gallons per week from a river and treats the water to safe drinking water standards. The water is used in the production facility, cafeteria, restrooms and drinking fountains. The production processes do not need water of this high quality, but all the water is treated to drinking water quality, because some is used for human consumption. The water needs to be softened for boiler feed water.

The boiler house has three coal-fired boilers and one gas-fired boiler. During usual production, two coal fired boilers produce 8 million pounds of steam per week. This steam is used for heating the buildings, in steam cans and for heating thousands of gallons of water per day to 140^{o}F. The boilers consume on average 300 tons coal per week.

The water from several operations was analyzed, and the results are given in Table

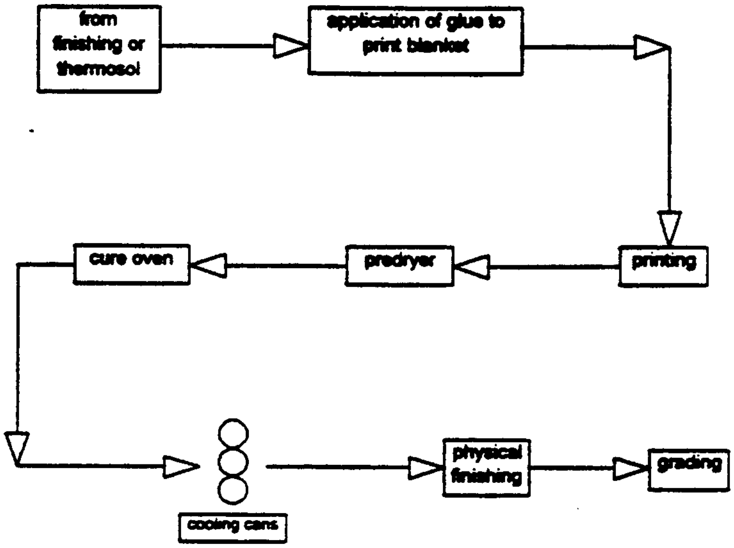


Figure 6.4: Flow Diagram of the Print Range.

6.1. Grab samples were only taken from the production processes that seemed eligible for pollution prevention. Samples of washer 7 and washer 9 in the thermosol dye range could not be taken since they were not in use at the time visits were made. The wastewater generated in the. different departments is collected and treated on site by physicochemical and biological methods and discharged the river.

63 RECOVERY OF NON-CONTACT COOLING WATER IN TEE BLEACH RANGE

When fabric is treated in the bleach range, it passes through the singer to remove excess fuzz from the surface. Afterward, the cloth is cooled by 6 cooling rolls. The flowrate of non-contact cooling water is estimated to be 5 gpm per roll at a temperature of 170^{o}F. Currently, the heat in this water is recovered before it is discharged to the

Table 6.1: Results of the Wastewater Analysis.

	Sample	COD mg/l	Color ADMI	TSS mg/l	Temperature °C	pH	Lead µg/l	Chromium µg/l	Copper µg/l	Nickel µg/l	Zinc µg/l
Bleach range	cooling water singer	6	30	0	76	6.7	ND	0.8	8	1	0.16
	scouring bath	8,041	694	184	72	7.2	-	-	-	-	-
	washer 1	23,00	693	308	65	7.5	-	-	-	-	-
	washer 2	2,340	565	204	75	10.1	-	-	-	-	-
	washer 3	280	261	96	73	9.2	-	-	-	-	-
Finishing range	wetout pan	150	83	37	65	8.0	ND	3.8	3.4	3	0.14
	cooling water steam cans	14	32	0	45	7.0	3	1.8	10	6	0.78
Thermosol	dyebath	2,350	105,704	188	31	7.2	-	-	-	-	-
	predryer cooling rolls	2	13	3	44	7.0	ND	0.9	11	4	0.55
	chemical pan	5,100	659	26	29	11.4	-	-	-	-	-
	steamer condensate	151	48	2	73	8.9	7	11.6	16	12	0.15
	water seal	720	510	9	34	11.3	-	-	-	-	-
	washer 1	67	57	2	15	11.7	-	-	-	-	-
	washer 2	210	92	14	13	11.7	-	-	-	-	-
	washer 3	1,145	34	3	34	4.9	-	-	-	-	-
	washer 4	1,690	65	3	45	4.4	-	-	-	-	-
	washer 5	690	51	2	65	5.4	-	-	-	-	-
	washer 6	2,120	73	2	80	6.7	-	-	-	-	--
	washer 8	420	64	6	73	7.3	-	-	-	-	-
	washer 10	204	26	3	27	7.4	-	-	-	-	-
Printer	blanket washer	580	2,209	272	283	7.1	-	-	-	-	-

treatment plant. The heat recovery system is not functioning well due to the number of leaks in the system. The characteristics of the water are given in Table 6.1.

The characteristics of the singer, non-contact cooling water were compared with quality standards of process water reported by Beckmann and Pflug (1983). According to these standards, the process water must be colorless. No value expressing color in ADMI units is given. Also, no values for chromium and surfactant concentration and pH are given. The comparison is given in Table 6.2. Visual observation of the samples showed that they were essentially colorless (30 ADMI units). Chromium and copper levels were also very low which means that, according to the criteria of Table 6.2., the cooling water can probably be reused directly. It is recommended that the water is used in the quench box following the cooling rolls. This quench box has a water demand of 25 GPM at a temperature of 160°F.

Table 6.2: Comparison of Water Characteristics of the Singer Non-contact Cooling Water with Water Quality Standard for Process Water.

	Non-contact cooling water	Quality standards for process water (beckmann and Pflug, 1983)
Color	30 ADMI	colorless[1]
Copper (mg/l)	0.008	< 0.1
Chromium (mg/l)	0.0008	usually non-existent[1]
Total ions (g/l)	-	< 0.5
COD (mg/l)	6	< 20
pH	6.7	near neutral[1]
Surfactants	-	none[1]

[1] no value given

This implementation can be achieved with minimal investment and can result in significant savings. The projected savings were calculated. It is assumed in these calculations that there are no savings in wastewater treatment since the pollution load of the wastewater does not change. The cost of treating the incoming water is estimated as \$1.4/1000 gallons (plant records). The incoming water has a maximum temperature of 60°F (plant records). The bleach range operates 5,600 hours a year. The company records show that the boiler house produces steam at a pressure of 140 psia. Hot water demand of the quench box is 25 gpm at 160°F. The heat required to produce this water, Q_H (Btu/yr), can be calculated with equation 6.1 (Liptàk, 1987).

$$Q_H = M * C_p * (T_2 - T_1) \qquad (6.1)$$

with

Q_H = heat transfer rate (Btu/yr)
M = feed mass flow (lb/yr)
C_P = heat capacity of feed (Btu/lb/^{o}F)
T_2 = outlet temperature (^{o}F)
T_1 = inlet temperature (“F)

Therefore,

$$Q_H = 25\text{gpm} * 60 * 5{,}600\ \text{hr/yr} * 8.34\ \text{*lb/gal} * \text{I Btu/lb/}^{o}\text{F} < 160°\text{F} - 6\text{O}^{o}\text{F}) = 7 * \text{l}0^{9}\text{Btu/yr} \qquad \mathbf{(6.2)}$$

The steam flow rate, F_s (lb/yr), is given by equation 6.4 (Liptak, 1987).

$$\mathbf{F_s = \frac{Q_H}{\Delta\ H_s}} \qquad \mathbf{(6.3)}$$

where
Q_H = heat transfer rate (Btu/yr)
F_s = steam mass flow (lb/yr)

AH, = latent heat of vaporization (Btu/lb) = 868.03 Btu/lb at 140 psia.

$$F_s = \frac{7 * lO^9}{868.03} = 8.1 * l0^6 \text{ lb/yr} \quad (6.4)$$

The consumption of coal can then be calculated. The coal produces 19,100 lbs of steam per ton of coal burned (Industrial Energy Center). The coal has a average heating value of 14,000 Btu/lb and a price of $50 per ton.

$$F_c = \frac{8.1 * l0^6}{19,100} = 424 \text{ tons/yr} \quad (6.5)$$

where,

F_C = mass flow of coal (tons/yr)

The projected annual costs savings per bleach range:

$$AS = F_C * (\text{unit cost of coal}) + F_W < \text{unit cost of water}) \quad (6.6)$$

$$AS = 425 * 50 + 8.4 * l0^6 * 1.4/ 1000 = \$33,000/\text{yr/quench box} \quad (6.7)$$

where

F_w = the flow rate of water in the quench box (gallons/yr)

$$F_w = 25 \text{ gpm } * 60\text{min/hr } * 56OO\text{hr/yr } = 8.4 * lO^6 \text{gal/yr} \quad (6.8)$$

6.4 REDUCTION OF WATER USE IN TEE WASHERS IN THE BLEACH RANGE

Each of the three washers in a bleach range has a water flow rate of 50 gpm at a temperature of 180°F. There is no counter-current flow between the washers. Washer

3 and washer 2 are interconnected, but fresh water is added to both washers. Comparing the water characteristics of the water in these washers (Table 6.1) shows that the COD, color and TSS of the water in washer 3 is lower or equal to the characteristics of washer 1 and 2. It can therefore be concluded that the water in washer 3 is less contaminated and can be recycled to washer 2 following the principle of counter current flow. The projected savings were calculated using the same technique as in section 6.3.

$$Q_H = 50\text{gpm} * 60\text{min/hr} * 5600\text{hrs/yr} * 8.34\text{lb/gal} * 1\ \text{Btu/ln/}^{o}\text{F} * (180°\text{F} - 60^{o}\text{F}) \tag{6.9}$$

$$Q_H = 1.7 * 10^{10}\text{Btu/yr} \tag{6.10}$$

The steam mass flow (lb/yr):

$$F_S = \frac{1.7 * 10^{10}}{868.03} = 2 * 10^{7}\ \text{lb/yr} \tag{6.11}$$

The mass flow of coal (tons/yr):

$$F_c = \frac{2 * 10^{7}}{19,000} = 1,050\ \text{Ton/yr} \tag{6.12}$$

The flowrate of water saved by recycling water from washer 3 to washer 2, gal/vr:

$$F_W = 50\text{gpm} * 60\text{min/hr} * 5600\text{hr/yr} = 17 * 10^{6}\ \text{gal/yr} \tag{6.13}$$

$$AS = 1,050 * 50 + 17 * 10^{6} * 1.4/1000 = \$76,000/\text{yr} \tag{6.14}$$

The total savings are estimated to be $154,000 per year because the company has two bleach ranges. These savings can be achieved without a large investment. However, the management of the company is currently thinking of replacing the Tensitrol washers by Menzel rope washers. The Menzel rope washers consist of two towers with guide tubes between the towers. Rollers in the towers guide the fabric through the tubes. The dirty cloth enters the machine at the bottom. Fresh water enters at the top of the machine. This results in counter-current flow of fabric and water. The washers will reduce the flowrate in each washer to 12 gpm. The parts that get in contact with the fabric are made of stainless steel and are therefore well suited for use in preparation of textile products. The price of these washers was estimated at $ 113,500 in 1992 by the manufacturer (Personal communication, Menzel, 1995b). Currently, the three washers together require 150 gpm. Replacing the existing washer by Menzel rope washers will reduce the flowrate to 36 gpm (12 gpm/washer), a reduction of 114 gpm. The projected energy savings and the resulting annual savings are calculated below.

$$Q_H = 3.8 * lO^{10} Btu/yr \tag{6.16}$$

$$Q_H = 114gpm * 6Omin/hr * 56OOhr/yr * 8.341b/gal * l\ Btu/°F * (180^{o}F60^{o}F) \tag{6.15}$$

$$F_S = \frac{3.8 * lO^{10}}{868.03} = 4.4 * l0^{7}\ lb/yr \tag{6.17}$$

$$F_c = \frac{4.4 * 10^{7}}{19{,}000} = 2{,}30Oton/yr \tag{6.18}$$

$$AS = 2{,}300 * 50 + 38 * l0^{6} * 1.4/1000 = \$168{,}000/yr \tag{6.19}$$

Calculations showed that replacing the existing washers by Menzel rope washers will save the company $168,000/yr per bleach range. The simple pay back period is 2.1 years.

6.5 WASHERS IN THE THERMOSOL DYE RANGE

The piping for operating the washers in counter-current flow is available. Removal of caustic and reducing agents before the addition of acid and oxidizing chemicals is crucial to reduce the consumption of chemicals. This can be achieved by counter-current flow between washers 4,3,2 and 1. The acid and hydrogen peroxide in the effluent of washer 3 and 4 will enhance the removal of caustic and reducing chemicals in washers 2 and 1. Acid and oxidizing chemicals added to washer 4 will flow to washer 3. This will probably reduce the addition of chemicals to washer 3. Measurement of the pH and redox potential can help to optimize the amount of chemicals added to washer 3. The same principle can be used in washer 4. The principle of counter-current flow can also be implemented between washers 5 and 6 and washers 7, 8, 9, and 10. Figure 6.5 shows the washing process schematically.

Currently, the amount of chemicals added to each washer is not adjusted to the needs of the fabric. The manager of the thermosol dye range knows that some fabrics do not need two washers with acid and hydrogen peroxide. It is therefore recommended that the chemical needs of each fabric be determined and that the chemical feed be adjusted accordingly.

The use of acetic acid in washers 3 and 4 results in the formation of acetate that can color fabric if not removed completely by large quantities of water. Acetic acid has a high BOD and can result in an increased BOD loading to the wastewater treatment plant. Substitution of formic acid or a inorganic acid for acetic acid will eliminate problems with the formation of acetate and can reduce the water use. The other acids will also reduce that BOD loading to the treatment plant. The BOD equivalent of formic acid is 0.12 lb/lb, whereas acetic acid has a BOD equivalent of 0.64 lb/lb. Formic acid also has a lower molecular weight, so less formic acid will be needed to achieve the same pH.

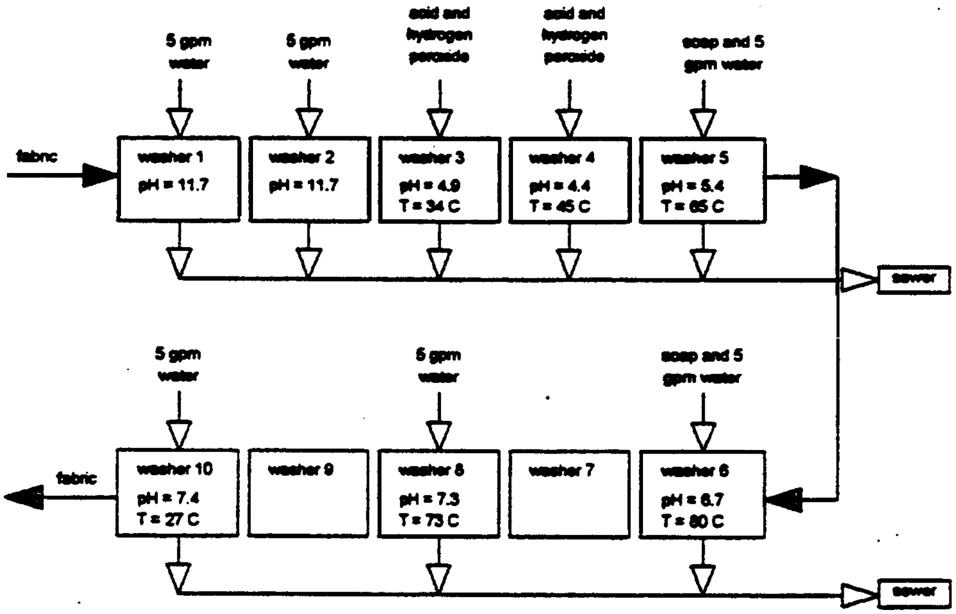


Figure 6.5: Schematic Overview of the Washers in the Thermosol Dye Range.

6.6 GENERAL RECOMMENDATIONS FOR THE BLEACH RANGE

The temperature in J-boxes is kept at 180°F by the introduction of steam. As a result, hot water containing bleach chemicals and contaminants is collected at the bottom the J-boxes. Currently, this flow is discharged to the treatment plant without recovery of heat. The configuration of the bleach range made it impossible to collect samples from the J-box, and the characteristics of the water leaving the J-box are not known. However, this water contains large amounts of caustic and H_20_2 and should be returned to the saturator. **Recycling the** J-box drain to the saturator will result in a lower consumption of bleach chemicals and hot water and, therefore, energy. The contaminants present in this water would probably have no detrimental effects on the quality of the products. The same is valid for the J-box after the quench box. This recycling system has been successfully implemented in other textile mills as mentioned in the literature review section of this study (Evans, 1991).

The washers in the bleach range operate at 180°F. It might be useful to investigate if the same washing efficiency can be achieved at a lower temperature, for example 170°F. This can be investigated by lowering the temperature of the water by 5 or lO°F and observing the effects on the quality of the products. The temperature should be lowered until detrimental effects are observed. The temperature should then be increased to the level where no effects were observed. It is possible that some fabrics require 180°F and that others can be treated at a lower temperature. In addition, the existing system for heat recovery needs to be repaired.

The concentration of the chemicals in the saturator is adjusted to the fabric. The flowrate of the water in the quenchbox, saturator and washers stays constant. However, it is well known that cotton needs more pretreatment than polyester and it therefore seems logical that the flowrate of water and soap should be adjusted to the type of cloth on the machine: the higher the cotton content of the cloth, the higher the flowrate.

6.7 RECOMMENDATIONS FOR THE FINISHING RANGE

The function of the wet-out stage is to wet the fabric so that creases can be removed during subsequent drying. The wet out pan is overflowing at a high rate (15-25 gpm). According to the manager of the finishing range it is necessary to overflow this box to prevent the buildup of solids in the pan. The wastewater analysis of Table 6.1 shows that some contaminants are removed from the fabric, but that the water is still of reasonable quality. Filtering the water leaving the wet out pan and recycling the water to this pan would result in significant savings.

Vacuum extraction and steam cans after the wetout pan remove the excess water before the cloth enters the finishing pan. A good vacuum extractor remove: all the unbound water. The steam cans could remove more water, but management agrees that these cans already remove too much. As a result, the cloth leaving the cans has a 30% moisture regain from the atmosphere. It should be investigated if the utilization of steam cans at this point in the process can be stopped.

Each steam can has a steam trap. This trap prevents steam from leaving the steam can. Some of the steamtraps are malfunctioning; steam can be observed passing through the steam trap. When this steam gets to the storage tank, it loses its energy to the atmosphere. Each of the steam traps in the plant should be checked and replaced, if necessary.

The finishing pans in the two finishing ranges have different dimensions. One holds 20 gallons, whereas the other one holds 100 gallons. The chemical mixes of these pans are, on average, dumped 15 times a day. This means that 1,200 gallons more of a strong chemical mix are dumped from the larger pan. These mixes are often expensive. The pans should therefore be as small as possible. Replacing the existing pan by a smaller one would probably be a large investment, but placing a dummy in the existing large pan would have the same effect with a lower investment. Implementing this recommendation would not only save water, chemicals and energy, but will also reduce the load to the wastewater treatment plant.

The cooling cans in the finishing range are two by two connected and discharge into a small tank. A thermocouple measures the temperature of the water in the storage tank. If the temperature of the water is below 120^{o}F, it is reused in the cooling cans. As the temperature reaches 120°F, fresh water is added to the tank until the temperature drops below 120^{0}F. At the same time, some water is discharged to the sewer. The system can be improved by recovering the heat in the discharged water and reusing the cooled water in the cooling cans.

6.8 GENERAL RECOMMENDATIONS FOR THE THERMOSOL DYE RANGE

The thermosol dye range is operated two shifts each day. Cleaning the machinery and dumping all the baths and washers is required when using a light color after a dark color. Efforts are made to use consecutively darker colors so that cleaning between each run can be avoided. However, on certain days cleaning is required after each run because light colors are used after darker colors. It would help if the production schedule established. This would require adjustment of the production schedule in the bleach and finishing range.

Sometimes two different fabrics are dyed to the same shade, but the composition of the dyebaths is different because the fabrics contain different percentages of cotton and polyester. In this case, the dyebaths are dumped but not the washers. There is a possibility that the remaining dye solution can be reused by simply adjusting the amount of chemicals in the solution.

There are several ways to reduce the water used in the cooling rolls. One way, is to collect the water leaving the rolls in a small storage tank and send it back to the rolls if the temperature is below a preset temperature. This is the same principle as is currently used in the finishing range. The characteristics of the water leaving the predryer, cooling rolls are given in Table 6.3 together with the water quality standard for the process water reported by Beckmann and Pflug (1983). Visual observation of these samples showed that they were essentially colorless (13 ADMI units). Chromium and copper levels were also very low. Therefore, according to the criteria of Table 6.3, the non-contact cooling water could be reused directly. Direct reuse is possible in the washers and water seal located behind the steamer.

6.9 GENERAL RECOMMENDATION FOR THE PRINT RANGE

The print range has a high water demand for cleaning. No water is used to rinse

Table 6.3: Comparison of the Water Characteristics of the Predryer Non-contact Cooling Water with Water Quality standards for Process water.

	Non-contact cooling **water**	Quality standards for process water (Beckmann and Pflug, 1983)
Color	13 ADMI	colorless
Copper (mg/l)	0.011	< 0.1
Chromium (mg/l)	0.0009	usually **non-existent**
Total ions (g/l)		< 0.5
COD (mg/l)	11	< 20
pH	7	near neutral
Surfactants	-	none

no value given

the fabric after application of the print paste. The print paste is thick and difficult to remove from the machinery parts and drums used to make up the different colors. Another source of water consumption is the print blanket. A glue is applied to the blanket at the beginning of the print range. This is to ensure good contact between the blanket and the fabric. This glue contains starch and PVA. Removal of the glue from the blanket after the printing operations requires large quantities of water. Perkins (1987) reported the removal of PVA from 50/50 polyester/cotton blend fabric through vacuum extraction. The fabric was wetted by passing it though a desize saturator or by spraying it with water before vacuum (13- 15 inches of mercury) was applied to the fabric. Fifty three percent of the size was recovered. The company should investigate if the removal of printer glue from the print blanket can be achieved by vacuum extraction. There are other water-based adhesive that are available which might function as well and be removed more easily.

The printer screens and other parts are removed from the printer when they are cleaned. These parts are cleaned with a hose until they are almost spotless. The screens are hollow inside and print paste is collected at the inside of the screen The inside of these screens would be cleaned with a cylinder shaped broom through which water is sprayed. The other parts of the equipment should also be cleaned with high pressure cleaning equipment. The possibility of using a vacuum to clean the printer parts and screens should also be investigated.

Another problem in the print range is the mixer and drums used for making the different print pastes. After the different chemicals are added to the drum, it is placed under the mixer and mixed for 1 to 2 min. The mixer then lifts from the drum and swings to another drum for cleaning. No time is allowed for excess print paste to drip off the mixer, back into the drum containing the paste. This paste is now collected in a pit under the mixing area and is discharged to the treatment system. More time should be allowed for the paste to drain from the mixer into the drum; and then, after the mixer swings to the drum, efforts should be made to collect as much of the concentrated paste from the mixer as possible before it is sprayed with water. The wasted, concentrated paste can probably be processed with the other chemical sludges at the plant.

6.10 RECOMMENDATIONS AND CONCLUSIONS

Opportunities for water and energy conservation can be found in each of the wet processing departments in this company. A summary of the recommended actions is given below. Details about the implementations can be found in the appropriate section of this chapter.

Non-contact cooling water in the bleach range has a temperature of 170- 180°F and can be reused as process water in the quench box. This implementation would be achieved with a minimal investment and would result in significant savings due to the reduction of water and energy consumption. The estimated savings are $66,000 per year. This estimate does not take any capital investment into consideration. Operating costs would be minimal.

The Tensitrol washers in the bleach range have high water demands. Counter-current flow between washer 3 and washer 2 would reduce water consumption in the washers by 50 gpm with an annual savings of $154,000. However, the company is considering replacing these washers by more efficient Menzel rope washers. It is recommended that the washers be replaced since this would result in significant water and energy savings. The simple payback period is 2.1 years if all the washers of one range are replaced. After payback, the reduced water and energy consumption would result in annual savings of $336,000. Other source reduction techniques that can help in the bleach range are:

- Recycle the J-box effluent to the saturator.
- Optimize the temperature and flowrate of the tensitrol washers. Some fabrics do not need a flow rate of 50 gpm at 180°F.

Recommendations for the finishing range:

- Adjust the flowrate of the wet-out pan to the requirements of the fabric. Recycle this water if possible.
- The combination of a vacuum extractor and steam cans after the wet-out pans seems redundant. A good vacuum extractor removes all the unbound water. Removal of the unbound water is sufficient at this point in the operation.
- Some of the steam traps connected to the steam cans do not function properly. Each steam trap should be checked and replaced/repaired if malfunctioning.
- The chemical pans of the two finishing ranges have different dimensions. The largest pan, should be replaced since it results in excess dumps.

The washers in the thermosol dye range should be operated in the counter-current mode. Acid and hydrogen peroxide are added to washers 3 and 4. Counter-current flow between washers 4,3,2, and 1 will improve the removal of caustic and reducing agents due to the presence of acid and oxidizing agents in the water. It is likely that counter-current flow will reduce the quantity of acid and oxidizing agents required. To optimize the addition of acid and oxidizing agents, the pH and redox potential of the water should be monitored. Counter-current flow between washers 5 and 6 and washers 10,9,8, and 7 will further reduce the water consumption in the washers. The use of acetic acid in the washers of the thermosol range increases the BOD load of the wastewater. Substituting acetic acid by formic acid or inorganic acids will not influence the efficiency of the washers, but will reduce the BOD load of the wastewater. The production schedule of the thermosol dye range should be organized over the course of one week. This will help to dye consecutively darker colors and reduce the quantity of water needed for cleaning. The number of chemical dumps will also be reduced. Dyebath reuse might be possible in some cases.

The use of water needed for cleaning in the print range can be reduced by using pressure cleaners. The inside of the rotary screens should be cleaned with a broom through which water is sprayed and/or a vacuum system. The mixer used for making the print paste should be allowed to drip before it is cleaned. The paste collected should be segregated from the wastewater and treated together with the solids from the wastewater treatment plant. The potential of cleaning the print blanket by vacuum extraction should be investigated.

CHAPTER 7. NYLON DYEING AND FINISHING PLANT

The company dyes nylon yams used for the production of industrial carpets. The yam is dyed in a continuous operation using acid, premetallized and/or basic dyes. Wastewater from the processes is treated in an on-site wastewater treatment plant.

7.1 PROCESS DESCRIPTION

The nylon yams arrives at the mill wound on tubes in shrink-wrapped containers or cardboard boxes. The yarn tubes are placed on creels at the head end of each dyeline. The cardboard tubes, boxes and shrink wrap are collected and sold to recyclers. In the first step of the process, the yam passes through a steam port for the reduction of static. During the following heat setting operation, yam is radiant heated to 360-400°F for approximately 55 seconds. This removes finishing agents previously applied to the yarn and straightens the yam strands. Printers then apply up to eight different colors to the yarn. The printers are rollers covered with dye solution. The solutions are transferred to the yarn by pressing the strands to the printers for a short period of time. Next, the colored yam passes through a dye-setting unit in which the yarn is steamed for 3 to 7 minutes at a temperature of ‘190-210°F. A steam trap prevents steam from leaving the steam box. After this, the yarn passes through a set of washers and padded rollers to remove excess dye and dye-setting chemicals. A dryer at the end of each line holds the yarn for one minute and removes excess rinse water. The dyed yarn is stored in J-boxes at the end of the dyeline. From these J-boxes, the yarn goes to the opening department where it is wound onto tubes. The color of the yarn is checked by graders before it is shipped to a customer. An overview of the production process is given in Figure 7.1.

The rinse waters, dyes and other chemicals are collected together with the boiler blowdown and the condensate from the dye-setting units at several points throughout the production process. This water flows to an on-site wastewater treatment plant which includes an aerated lagoon, and coagulation/flocculation, sedimentation, filtration and disinfection.

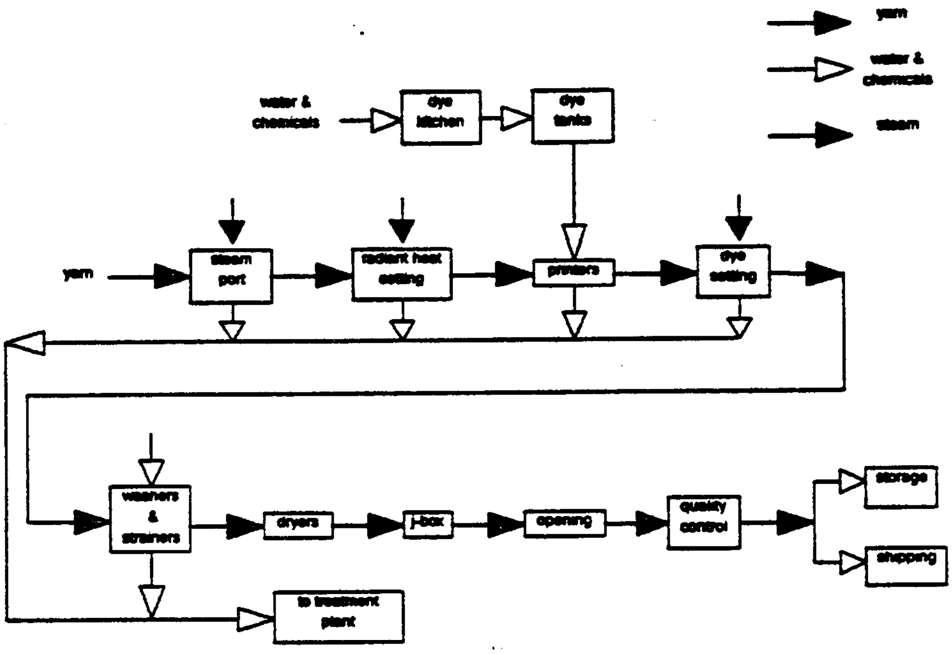


Figure 7.1: Flow Diagram of the Nylon Dyeing and Finishing Mill.

The dye solutions are made in a central dye kitchen. Here, water with a temperature of 180-190°F flows into a conical mixing tank. Powdered dyes, acid, defoamers and wetting agents are added to the hot water and mixed. The dye solutions are then pumped into 2400 1 tanks at the end of each dyeline. Each mixture is pumped into 800 1 tanks next to the printers when needed. The liquid in these tanks is stirred continuously. The company uses predominantly acid dyes, but basic and premetallized dyes are also used. The premetallized dyes can only be used on two dye-lines because they require a special heat-setting unit. The company has six dye-lines and one sample line also for small orders.

7.2 WATER USE AND TREATMENT

The mill generates approximately 100,000 gallons of industrial wastewater per day (gpd). The boiler house produces steam for the production of hot water and heating of the facilities. The biggest assignment of the boilers, however, is the production of steam for the dye-setting units. The wastewater generated from boiler blowdown accounts for 25% of the total amount generated. The steam trap and the rinsing procedures each generate 20,000 gal of wastewater per day. The remaining wastewater is derived from the dyeing operations (13,000 -15,000 gpd) and general cleaning.

As mentioned before, the on-site wastewater treatment facility consists of an aerated lagoon followed by flocculation, sedimentation and filtration. The biomass in the aerated lagoon is low and biological degradation is often not sign&ant. Presently, the treatment plant operators add a small amount of a bacterial culture to the lagoon to enhance biological treatment. The treatment plant operators feel that the addition of 100 lbs of the bacterial culture per week improves treatment of the wastewater, especially during periods that the wastewater is hard to treat.

The water then passes into two flocculation tanks. Polymers are added at this point. Sludge removed from the sedimentation basin is dewatered on a belt press. Prior to disposal at a landfill, the sludge is dried on drying beds. Partial anaerobic digestion occurs in the sedimentation basin and during sludge storage, causing a odor primarily due to hydrogen sulfide. The treatment plant operates at a higher flowrate than the company is allowed to discharge to the river. Some of the treated water is therefore stored in a storage tank so that water can be discharged when the treatment plant is not operating. In addition to the treatment plant effluent, there are several point sources of storm water which are discharged into the river. They include storm water from a bulk oil earthen dike, a concrete dike for above-ground storage of waste oil and a concrete truck loading area. A flow diagram of the wastewater treatment plant is given in Figure 7.2.

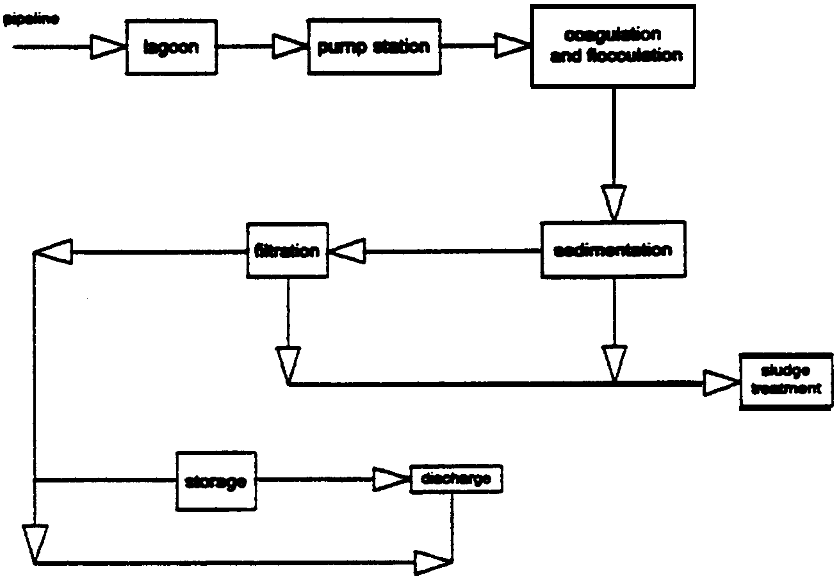


Figure 7.2: Flow Diagram of the On-site Wastewater Treatment Facility.

7.3 RESULTS AND DISCUSSION

7.3.1 Water quality analysis of the dye-lines

Figure 7.3 shows the washboxes and padded rollers of a dyeline. Water enters the steam trap (pointA) and the washbox (pointC) at a flow rate of >4gpm. After visual observation of this section of the various dye-lines, it seemed that the water leaving point D (second strainer) was relatively free of color. It was therefore recommended that this water be recycled to the steam trap (pointA). It was estimated that this can reduce the water used for rinsing by 50%.

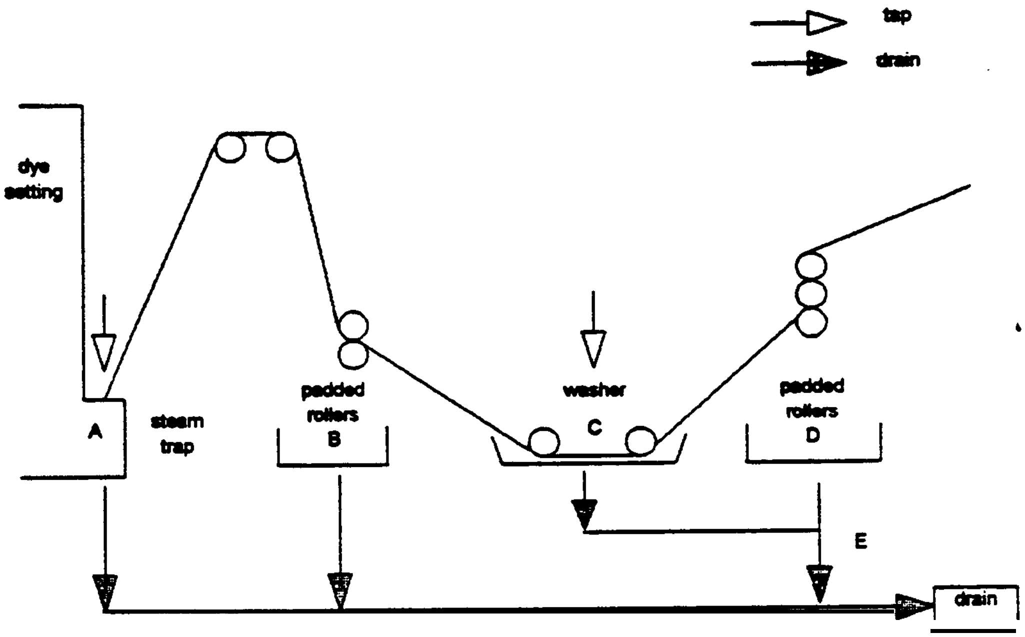


Figure 7.3: Schematic Representation of the Rinsing Operations in a Dy-line.

Plant personnel replumbed dye-line 1 to determine if the proposed recycle system was feasible. Fresh water entering at point C was recycled from point E to point A. Samples were collected at different times during a run. The four sampling points were: steamtrap (point A), first set of padded rollers (point B), washbox (point C) and second set of padded rollers (point D). Two samples of each dyeline were analyzed for cadmium, nickel and chromium. The results of the experiments are shown in Tables 7.1 and 7.2. Figures 7.4 and 7.6 show the color intensity of samples taken at the dye-lines. The amount of COD present in each sample is provided in Figures 7.5 and 7.7.

Table 7.1: Analysis of Samples Taken from Dye-line 1.

Hours after start-up	Sampling point	pH	Color ADMI	DOC mg/l	Cd µg/l	Cr µg/l	Ni µg/l
1	A	4.7	1,334	2,556	-	-	-
	B	4.7	1,283	2,649	-	-	-
	C	7.2	103	61	-	-	-
	D	6.0	413	687	-	-	-
2	A	4.7	1,205	2,165	-	-	-
	B	4.6	1,485	2,814	-	-	-
	C	7.2	87	49	-	-	-
	D	5.9	496	660	-	-	-
3	A	4.8	822	1,407	0.6	4.3	11.0
	B	4.8	957	1,630	0.6	5.2	11.0
	C	7.1	54	36	-	-	-
	D	6.6	609	407	-	-	-
4	A	4.9	879	1,466	-	-	-
	B	4.9	973	1,553	-	-	-
	C	7.1	96	23	-	-	-
	D	6.7	236	369	-	-	-
5	A	4.9	848	1,377	-	-	-
	B	4.8	964	1,563	-	-	-
	C	7.0	66	28	-	-	-
	D	6.5	277	304	-	-	-

Tapwater added to point A two hours after start-up.

Table 7.2: Analysis of Samples Taken from Dye-line 2.

Hours after start-up	Sampling point	pH	Color ADMI	DOC mg/l	Cd µg/l	Cr µg/l	Ni µg/l
0.5	A	5.1	1281	1350	-	-	-
	B	5.1	1617	1647	-	-	-
	C	7.1	140	148	-	-	-
	D	7.4	295	184	-	-	-
1.5	A	5.0	1385	1517	-	-	-
	B	4.9	1719	2009	-	-	-
	C	7.3	249	221	-	-	
	D	7.3	187	252	-	-	-
5	A	5.3	779	940	0.8	1.2	6.0
	B	5.3	884	1005	0.6	1.2	4.0
	C	7.3	174	216	-	-	-
	D	7.3	320	137	-	-	-
7.5	A	6.6	637	354	-	-	-
	B	6.2	697	588	-	-	-
	C	7.0	153	144	-	-	-
	D	7.3	152	137	-	-	-
8.5	A	5.8	860	641	-	-	-
	B	5.3	895	763	-	-	-
	C	7.0	144	128	-	-	-
	D	7.1	148	120	-	-	-

The color measurements of dyeline 2 are represented in Figure 7.4. The data show that the color content of the water much higher at point A and B than at C and D. The figure also shows that the color was higher at point B than at point A. This was expected since the first set of padded rollers is at B and excess water is removed. The DOC content of the samples (Figure 7.5) follows the same trend as the color intensity. The color and DOC content of samples taken at point C and D were much lower than in samples from points A and B. The color and DOC content decreased with time at point A and B. This was not detected at points C and D. The large difference in contamination between water from point A and point C indicates that most of the color was removed by the first rinse water. Water should therefore be recycled from point E

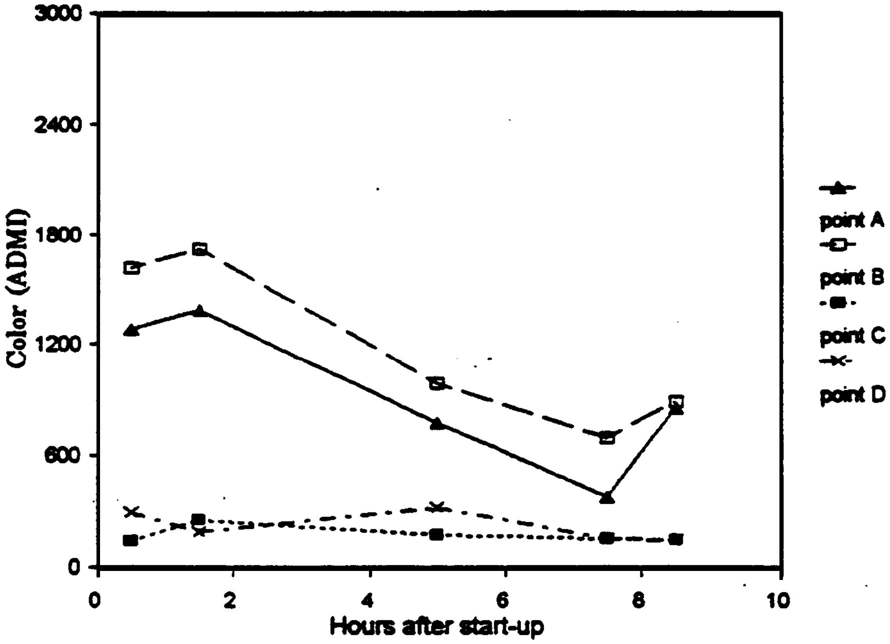


Figure 7.4: Color Intensity (ADMI) of Samples Taken in Dye-line 2.

to point A and wasted after strainer B (Figure 7.3).

The results of the water analysis from dyeline 1 are shown in Figures 7.6 and 7.7. Water from point D mixes with water leaving point C. This water was recycled to point A and then discharged. The color content of samples taken from point A and B increased during the first two hours of the run. Afterward, the color content decreased at sampling points A and B. The same-was observed in dyeline 2. It is not clear if this reduction was due to the addition of fresh water or if it is typical of the process. It is also an indication that recycling water did not have an impact on the rinse procedure and that it can be implemented without the addition of fresh water to the steam trap.

If this recycle system is implemented on each dyeline, the water and cost savings will be considerable. More then 80% of the dyes used at the company are acid dyes. ‘The results of the water analysis show that the proposed system can be used for acid dyes. However, when dark colors are used, the introduction of fresh water at point A

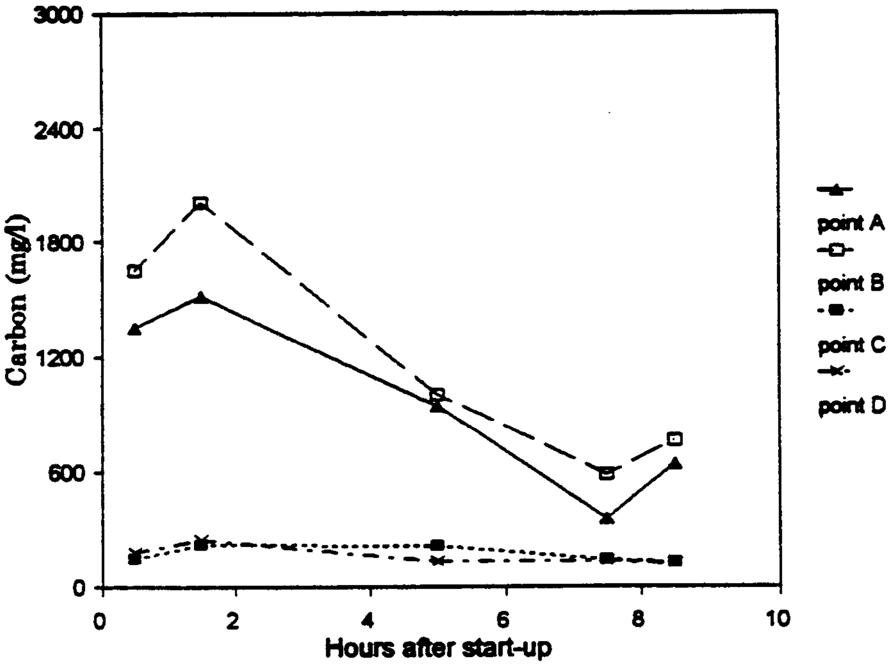


Figure 7.5: DOC Content (mg Carbon/l) of Samples Taken on Dye-line 2.

might be necessary. The affinity of premetallized dyes for nylon is lower then the affinity of acid dyes. As a result, more premetallized dyes leach from the yam and highly color the rinse water. It is therefore not likely that recycling rinse water is possible when premetallized dyes are used unless the water is pretreated.

As mentioned above, the water enters the steam trap and wash box of each dyeline at a flow rate of > 4 GPM. This results in the generation of 38,000 GPD if each dyeline operates for 16 hours a day. it was estimated that this recycle system would reduce the water consumption of the rinsing procedure by 33%. These water savings were calculated assuming that:

1. 90% of the dyes used allow for water to be recycled from the wash box to the steamtrap.
2. 50% of the time that water is recycled, 2 GPM of fresh water is added to the steam trap.

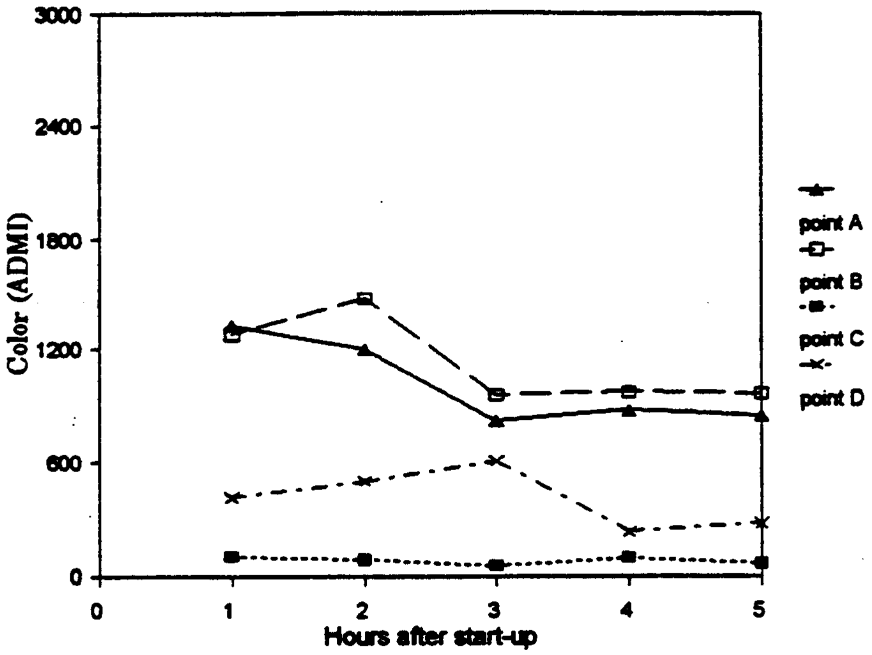


Figure 7.6: Color Intensity (ADMI) of Samples Taken on Dye-line 1.

3. Water is added to the wash box at a flow rate of 4 GPM.
4. Each dyeline operates for 20 hours a day.

7.3.2 Wastewater treatment

The purpose of these -experiments was to analyze the efficiency of the current wastewater treatment system, locate problems and investigate possible improvements. This was done by performing three sets of experiments. The first experiment consisted ofanalyzing samples from different points within the treatment system. Samples were taken from the combined wastewater leaving the textile plant, at the beginning and end of the aerated lagoon and at the point where the wastewater enters the physico-chemical part of the treatment system. The treated wastewater and the water leaving the storage tank were also sampled (Figure 7.2). A second set of experiments consisted of laboratory

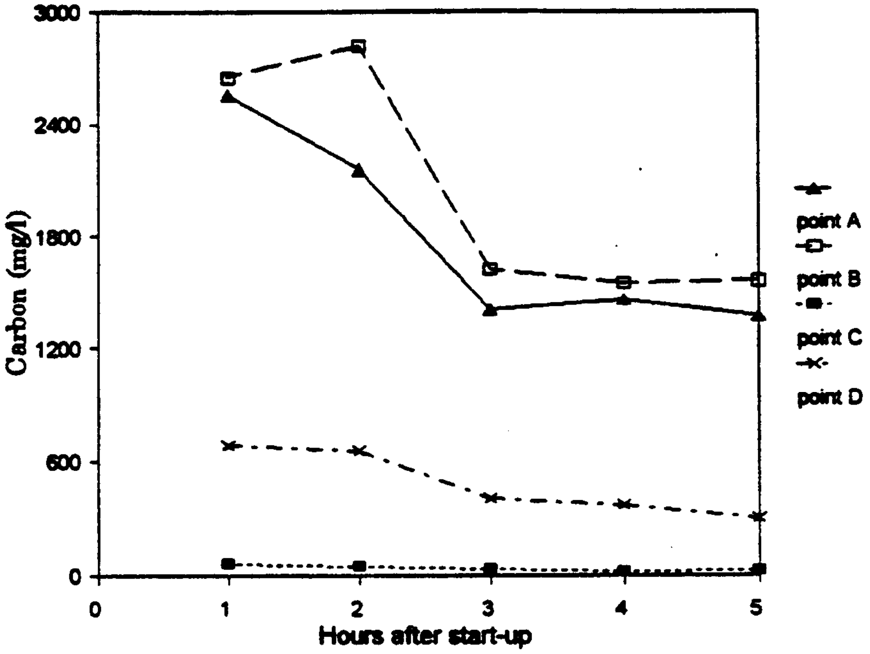


Figure 7.7: DOC Content (mg Carbon/l) of Samples Taken on Dye-line 1.

coagulation experiments in which the effect of different coagulants was evaluated. The following coagulants were used in the experiments: $FeCl_3$, Alum ($Al_2(SO_4)_3$), two cationic polymers (Al220 and Selfloc 1740) and one anionic polymer (A130). In addition, the biological treatability of the dyewaste was investigated under aerobic and anaerobic conditions.

Wastewater analysis

The results of the evaluation of the lagoon are given in Table 7.3 and Figure 7.8. A 24 hour composite sample was taken from the lagoon influent (pipeline). The samples at the beginning and end of the lagoon were grab samples. The results show that a significant amount of the COD in the lagoon was associated with the solids. A small amount of bacterial culture was added to the lagoon the day before sampling. The treatment plant operators at the company have learned that the lagoon can only reduce the color and COD of the wastewater when the bacterial culture is added to the lagoon on a regular basis. The total suspended solids concentration in the lagoon was 934 mg/l. The TSS levels on two other days during the summer were 550 mg/l and 254 mg/l. These concentrations of solids are too low to achieve significant biological treatment. The reduction of COD and color in the lagoon were therefore probably due to a combination of biodegradation, adsorption of color onto settleable solids and dilution effects. The biomass is not able to sustain itself since the addition of the bacterial culture is required on a regular basis. It is therefore recommended that the addition of this culture is stopped and that changes are made to the lagoon so that it can sustain the biological culture and thus operate as an activated sludge reactor. The results of the treatment achieved in the physicochemical part of the treatment plant are shown in Table 7.4 and Figure 7.9. This system provided a color reduction of 20% and a COD reduction of 25%. Other treatment options should be considered since these removal efficiencies are low and because the company has difficulties meeting discharge limits. The differences between the storage tank influent and effluent were negligible, indicating that there was no biological degradation in the tank.

Table 73: Results of the Wastewater Analysis of the Lagoon.

	Pipeline	Begin lagoon	End lagoon
pH	5.6	7	7.1
Temperature (^oC)	36	24	24
TSS (mg/l)	74	850	934
COD (unfiltered, mg/l)	2,990	776	582
COD (filtered, mg/l)	3,370	2,134	1,645
color (ADMI)	2,140	652	597
DOC (mg carbon /l)	1,016	169	210
Cadmium (µg/l)	1.2	0.9	0.7
Chromium (µg/l)	70	85	76
Nickel (µg/l)	IS	18	13

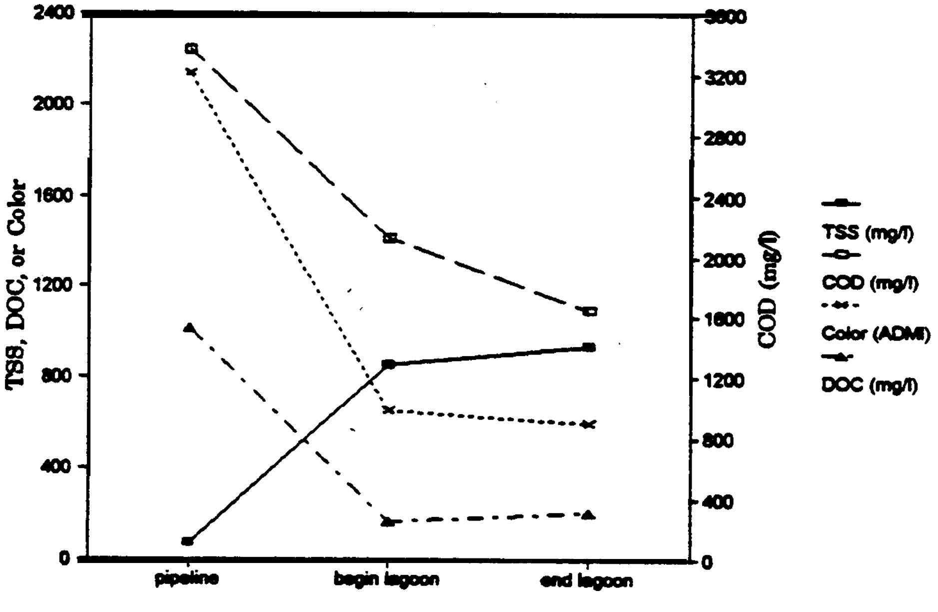


Figure 7-8: Treatment Achieved in the Lagoon.

Table 7.4: Treatment Achieved by the Physico-chemical Part of the Treatment Facility.

	Pump station	Finished water	Discharge
COD (filtered, mg/l)	375	275	258
DOC (mg carbon/l)	121	110	101
color (ADMI)	473	384	306
TSS (mg/l)	110	56	53

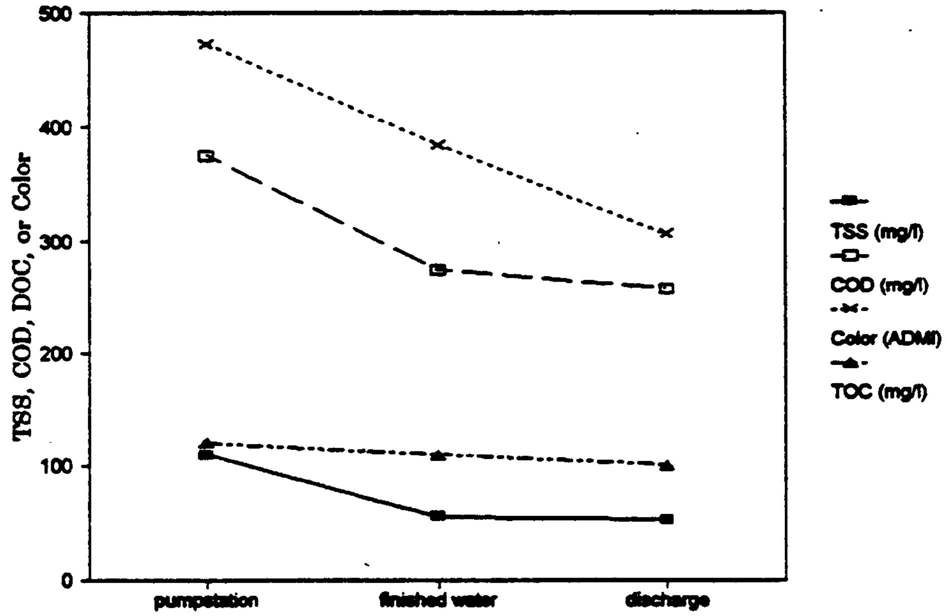


Figure 7.9: Treatment Achieved in the Physicochemical Part of the Treatment Plant.

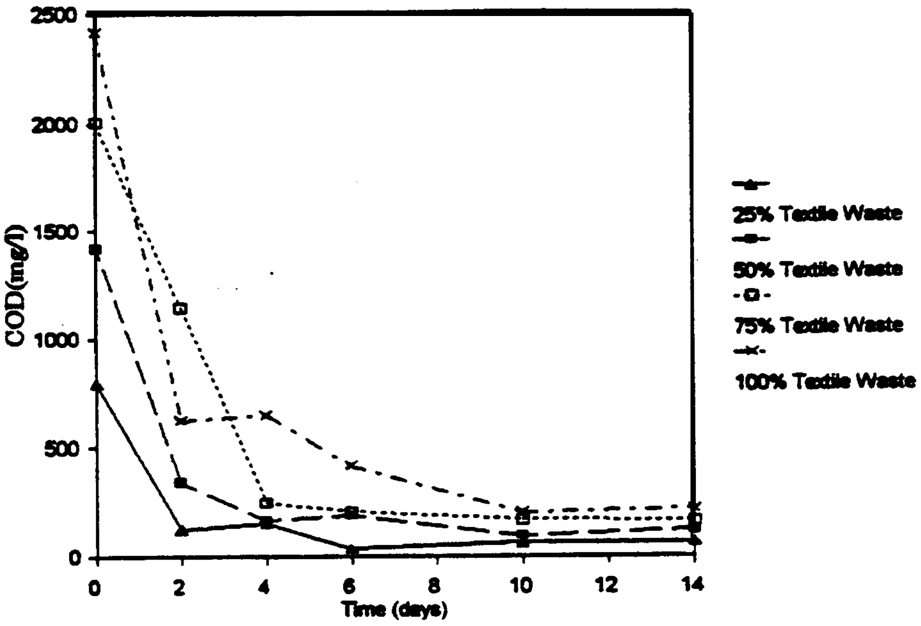
Coagulation experiments

Of all the coagulants used, Selfloc 1740 gave the best results at a dose of 10 mg/l. This is the cationic polymer presently used by the company. In a second part of the physicochemical treatment at the plant, an anionic polymer is added to improve the sedimentation of the formed flocs. However, the laboratory experiments showed no improvement when anionic polymer was added. When Al220 was used instead of Selfloc 1740, better removal efficiencies were achieved, but only at concentrations of 180 mg/l. The addition of anionic polymer after the addition of Al220 did not improve the treatment of the wastewater. The on-site physicochemical treatment system is, however, not efficient enough to enable to company to comply consistently with its NPDES permit.

Biological treatment

In the short-term biological treatability experiment, the plant's effluent was mixed with municipal wastewater in different ratios. Details about the set-up of the experiment are given in Chapter 3. The results of the aerobic treatability study are shown in Figures 7.10 and 7.11. Figure 7.10 shows a soluble COD removal of about 90% for all the biological systems after four days. No removal of COD was achieved in the anaerobic systems. The large reduction in COD was accompanied by a reduction in color, even after 2 days (Figure 7.12). This can be an indication that color adsorbs onto the particles.

The results of this research show that biological treatment of the dye wastewater is a promising solution for the plant's problems. The lagoon can probably be used as an activated sludge system, but steps need to be taken to sustain a bioculture. More research is required to determine the kinetic constants of the biological system and to investigate the variability of the wastewater.



figme 7.10: Removal of Soluble COD (mgIl) in the Aerobic Treatability Study.

7.4 RECOMMENDATIONS AND CONCLUSIONS

The experiments show that recycling rinse water from the washbox to the steam trap is possible when acid dyes are used. The recycle system should be installed on each dye-line so that it can be used when acid dyes are applied to the yarn. The addition of fresh water to the steam trap is required in some cases. Further research is required to investigate the use of the recycle system when dyeing with premetallized and cationic dyes.

Efforts should be made to optimize the quantity of dye solution made for each run. Recording the amount of dye left at the end of each run and the amount of yarn dyed in that run will help to estimate more accurately the quantity dye needed for a specific run. According to plant personnel, many of the acid dyes used can be recycled. In fact, the plant is currently recycling ***30-50*** % of the acid dyes. Excess dyes should be stored until

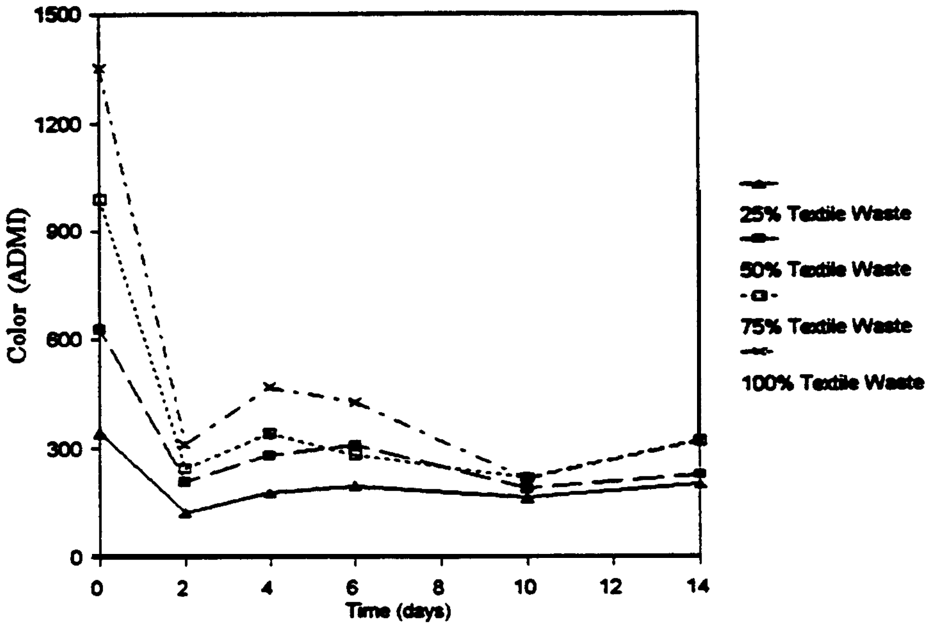


Figure 7.11: Removal of Color in the Aerobic Treatability Study.

further use if a large quantity of dye is left due to an error in calculations.

Each printer consists of eight dye pans. Each of these pans can contain a different dye solution. The amount of dye left in piping and pans at the end of a run is close to 1001. The volume of dyebaths in the printers is larger than required for the dyeing operation. It might be possible to fill much of the excess space with dummy blocks.

The flowrate of water entering the steam trap and washbox is not adjusted well to the type of dyes and yarn used. Combinations of certain dyes and yarn will require more water for rinsing then others. Efforts should therefore be made to optimize the flowrate of the rinse water.

Plant personnel know that in some cases prewetting the yarn before it enters the printers reduces the amount of dye picked up by the yarn. This is not practiced at the plant. Investigating and implementing this option will reduce the quantity of dye needed for a run and therefore results in savings.

The management has some good recycling programs for cardboard tubes and boxes and shrink wrap. The company should explore the use of plastic tubes and plastic pallets which can be returned to a supplier. This would make direct reuse of resources possible.

It was observed during one visit that a hose was left running. Hoses like this discharge water at a flowrate of 5-10 gpm. Such bad housekeeping practices result in the unnecessary consumption of resources and increase the hydraulic load to the wastewater treatment plant. Placing an automatic shut-off on each hose in the plant will easily solve this problem.

The on-site wastewater treatment plant does not function very well at times and changes should be made to optimize the system. The aerated lagoon is operated at a HRT of 7 days but the biomass in the system is too low to achieve significant biodegradation. Further research is required to determine biological kinetic coefficients of the lagoon. The lab-scale coagulation experiments showed that the characteristics of the wastewater vary significantly and influence the treatment achieved by coagulation. The influence of the wastewater characteristics on the treatment of the water can be reduced by equalization of the water. Care must be taken not to shock load a biological treatment system. It is therefore recommended that the strongest wastes are collected in a buffer tank or pretreated before being added to a biological treatment system at a constant flow.

CHAPTER 8. SUMMARY AND CONCLUSIONS

Pollution prevention (P2) methods are those measures that eliminate or reduce pollution prior to off-site recycling or treatment. P2 can be achieved by source reduction, reuse and on-site recycling. In source reduction., production processes are analyzed to reveal possibilities for reducing the amount of air, water and land pollutants released. This can be achieved by conservation\optimization of chemical use, substitution of chemicals, process changes, equipment modification, raw material control and improved maintenance and housekeeping. Reuse and recycling water and chemicals can also reduce the amount of pollutants released.

The objective of this research was to investigate P2 opportunities for the textile wet processing industry. This was achieved through an extensive literature review and P2 audits performed at textile companies. Textile wet processing operations were briefly discussed in the literature review. The main objective of the literature review was to describe the various source reduction and recycling opportunities available for the textile industry. Case studies were included to clarify the concepts and benefits associated with P2. P2 measures can help the textile processor to reduce the amount and strength of the waste produced and the costs related to waste treatment. Other benefits include reduction of chemical, water and energy consumption, reduced liability for the waste produced and increased compliance with regulations.

In the second part of the project, P2 audits were conducted at four textile mills. The companies considered cover a wide range of plants in the textile wet processing industry. Among the facilities were a stone and soft washing laundry, a large fiberglass processing plant, a large cotton printing, dyeing and finishing mill, and a nylon yam dyeing and finishing mill.

Each mill was visited several times. Information about the operations, consumption of water, chemicals and energy were obtained by several means. Interviews with employees operating machinery and the management personnel at the plant were performed to identify problems and points in the manufacturing process were P2 techniques might be successful. Visual observation of the manufacturing processes revealed problems overlooked by the personnel. The duration of the observations ranged from a few hours to 24 hours. This depended on the type of operation. Batch processes tend to consume more resources (dyes, auxiliary chemicals, water, etc.) and be more variable than continuous processes, so were observed longer. Formation obtained from plant records included design information, wastewater analysis data, permit applications (air and water), disposal records and data about the consumption and costs of energy and water. Other information collected were Material Safety and Data Sheets, treatment and disposal records, and water and sewer charges. Wastewater samples from several operations were analyzed for COD, BOD, color, TSS, pH and temperature. Lead, copper, zinc and chromium concentrations in were also determined.

The collected information was used to make recommendations to the management of each mill concerning possible implementations. The feasibility of the proposed measures was discussed with the mill's management. If enough information was available, an economic analysis of the proposed P2 measures was performed. The economical analysis showed that significant savings can be expected when the proposed P2 measures are implemented. Chemical substitutions appeared to be advisable at some plants. However, information about the characteristics of chemicals currently used and possible alternatives will be required before final decisions can be made.

Coagulation/flocculation tests were performed to investigate the physicochemical treatment of wastewaters from the stone and soft washing laundry and nylon yarn processing plant. The biological treatability of effluent of the nylon yam processing mill was investigated by performing a short-term batch biological study.

The following general conclusions were derived from this research. Recommendations and conclusions specific to the various mills can be found at the end of the respective chapters.

1. Significant reductions in water and energy consumption were possible at all mills. Water reductions will be achieved by reusing non-contact cooling water and counter-current flow in washers. Reusing hot water will significantly reduce the energy consumption at one mill. Improvements in housekeeping will also help to reduce water consumption; e.g.; by using automatic shut-offs on hoses.
2. The volume of many chemical pans in the mills was larger than required for the operation. Conservation of chemicals will be achieved by optimizing the volume of these pans.
3. Recording the amount of dye solution/chemical mix remaining after each run with a given amount and type of fabric will allow for more accurate calculation of the quantity of mix needed.
4. Scheduling operations over a longer time period (e.g. one week instead of one day) will help to minimize water and chemical use.
5. Dye reuse and the collection of residual, concentrated chemical mixes (dyes, print paste, finish and size mixes) before they are mixed with other liquid wastes will minimize the quantity of dye wasted and the strength of discharged wastewater-s at three of the plants studied.

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APPENDIX A: WORKSHEETS

firm ______ site ______ date ______	Pollution Prevention Assessment Worksheet proj. No. ______	Prepared by ______ checked By ______ Sheet ___ of ___ Page___ of ___

WORKSHEET
1

SITE DESCRIPTION

Firm: ______

Plant: ______

Department : ______

Area: ______

Street Address: ______

City: ______

State/Zip Code: ______

Telephone: ( )

Major Products: ______

______

SIC Codes: ______

EPA Generator Number: ______

Operations: ______

______

______

______

______

Facilities/Equipment Age: ______

______

firm ______________________________ site ______________________________ date ______________________________	**Pollution Prevention Assessment Worksheets** Proj. No. ________________	Prepared by____________________ checked by ____________________ Sheet ___ of___ Page___ of___

WORKSHEET
3

WASTE SOURCES

WASTE SOURCE :MATERIAL HANDLING	Significance in Plant		
	low	medium	high
Obsolete raw material			
Off-quality product			
Spills and leaks (liquids)			
Spills (powder)			
Empty container cleaning			
Container disposal (paper, plastic)			
Container disposal (metal)			
Laboratory wastes			
Other			
WASTE SOURCE: PROCESS OPERATION			
Equipment cleaning			
Desizing bath			
Dye fixation			
Bleaching			
Stonewashing with enzymes			
Stonewashing with stones			
finishing (softener, Brightner,...)			
Rinse water:			
Dye fixation			
Desizing			
Bleaching			
Stonewashing with enzymes			
Stonewashing with stones			
Finishing			

firm ____________________ site ____________________ date ____________________	**Pollution Prevention Assessment Worksheet** proj. No. ________________	**Prepared by** ______________ **checked By** ______________ **Sheet** ___ **of** ___ **Page**___ **of** ___

WORKSHEET
4A

WASTE MINIMIZATION: MATERIAL HANDLING

A. General handling techniques:

Are all materials tested for quality before being accepted from the supplier? ___ Yes ___ No

Describe safeguards to prevent the use of materials that may generate off-quality products: ______________________________

____

____

Is obsolete raw material returned to the supplier? ___ Yes ___ No

Is the inventory used in first-in first-out order? ___ Yes ___ No

Does the current inventory system adequately prevent waste generation? ___ Yes ___ No

What does the system track? ____

____

____

____

Is there a formal personnel training on raw material handling, spill prevention, proper storage techniques and waste handling procedures? ___ Yes ___ No

How often is the program given and by Whom? ________________________________

____

____

____

Is dust generated in the storage area during the handling of raw materials? ___ Yes ___ No

If yes, is there a dedicated dust recovery system in place? Are methods employed to suppress dust or capture and recycle dust?

Explain. ____

____

____

____

firm __________ site __________ date __________	**Pollution Prevention Assessment Worksheet** proj. No. __________	**Prepared by** __________ **checked By** __________ **Sheet** ___ **of** ___ **Page**___ **of** ___

WORKSHEET
4B

WASTE MINIMIZATION:
MATERIAL HANDLING

B. Bulk liquids handling:

What safeguards are in place to prevent spills and avoid ground contamination during the transfer and filling of storage and operation tanks? Describe the system: __________

Are all storage tanks routinely monitored for leaks? If yes, describe the procedure and monitoring frequency. __________

How are the liquids dispensed to the users? __________

What measures are taken to prevent spillage of liquids being dispensed? __________

Are pipes cleaned regularly? How are pipes cleaned and how is the resulting waste handled? __________

If spills occur, what cleanup methods are used (wet or dry) and how are the resulting wastes handled? __________

Would different cleanup methods allow for direct reuse or recycling of the waste? Explain. __________

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WORKSHEET
4C

WASTE MINIMIZATION: MATERIAL HANDLING

C. Drums, containers, and packages

Are drums, containers, and packages inspected for damage before being accepted? ___ Yes ___ No

Are employees properly trained in handling of spilled materials? ___ Yes ___ No

Are stored items protected from damage, contamination, or exposure to rain, snow, sun and heat? ___ Yes ___ No

Describe handling procedures for damaged items: ____

____

____

Does the layout of the plant result in heavy traffic through the raw material storage area? ___ Yes ___ No
(heavy traffic increases the potential for contaminating raw materials with dirt or dust and for causing spilled materials to become dispersed throughout the facility.)

Can traffic through the storage are be reduced? ___ Yes ___ No

To reduce the generation of empty bags and packages, dust from dry material handling and liquid wastes due to cleaning empty drums, has the plant attempted to:

- Purchase hazardous materials in preweighted containers to avoid the need for weighing? ___ Yes ___ No
- Use reusable/recyclable drums with liners instead of paper bags? ___ Yes ___ No
- Use larger containers or bulk delivery systems that can be returned to supplier for cleaning? ___ Yes ___ No
- Dedicate systems in the loading area so as to segregate hazardous from nonhazardous wastes? ___ Yes ___ No

scribe the results of these attempts: ____

____

Are all empty bags, packages, and containers that contained hazardous material segregated from those that contain nonhazardous wastes? Describe the method currently used to dispose of this waste: ____________________________________

____

____

____

firm ____________________ site ____________________ date ____________________	**Pollution Prevention Assessment Worksheet** proj. No. ____________	Prepared By ____________ Checked By ____________ Sheet ___ of ___ Page ___ of ___

WORKSHEET
5

INPUT MATERIALS SUMMARY

Attribute	Description		
Material name/ID			
Source/Supplier			
Hazardous component, which?			
Where used?			
Annual consumption rate			
Purchase Price, $ per ________			
Overall annual cost			
Material flow diagram available (Y/N)			
Delivery mode[1]			
Shipping container size and type[2]			
Storage mode[3]			
Transfer mode[4]			
Control mode[5]			
Empty container disposal management[6]			
Shelf life			
Supplier would			
accept expired material? (Y/N)			
accept shipping containers? (Y/N)			
Acceptable substitute(s), if any			
Alternate supplier(s)			

Notes: 1. e.g., pipeline, tank car, 100 bbl tank truck, truck, etc.
2. e.g., 55 gal drum, 100 lb paper bag, tank, etc.
3. e.g., outdoor, warehouse, underground, above ground, etc.
4. e.g., pump, forklift, pneumatic transport, conveyor, etc.
5. e.g., on-demand to all, select people only, sign out.
6. crush and landfill, clean and recycle, return to supplier. etc.

firm ______________ site ______________ date ______________	**Pollution Prevention Assessment Worksheet** proj. No. ____________	**Prepared by** ____________ **checked by** ____________ **Sheet** ___ **of** ___ **Page**___ **of** ___

WORKSHEET
6

PRODUCTS SUMMARY

Attribute	Description	
Shipping mode		
Shipping container size & type		
Onsite storage Mode		
containers returnable (Y/N)		
Customer would		
relax specifications (Y/N)		
Accept larger containers (Y/N)		

firm ______________________
site ______________________
date ______________________

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WORKSHEET
7

MATERIAL HANDLING

SUGGESTED WASTE MINIMIZATION OPTIONS	**Currently done? (Y/N)**	**Rationale/Remarks on option**
A. General Handling Techniques		
Quality Control Check		
Return Obsolete Material to Supplier		
Minimize Inventory		
Computerize Inventory		
Formal Personnel Training		
B. Bulk Liquids Handling		
High Level Shutdown/Alarm		
Flow Totalizers with Cutoff		
Secondary Containment		
Air Emission Control		
Leak Monitoring		
Spilled Material Reuse		
Cleanup Methods to Promote Recycling		
C. Drums, Containers, and Packages		
Raw Material Inspection		
Proper Storage/Handling		
Preweighed Containers		
Soluble Bags		
Reusable Drums		
Bulk Delivery		
Waste Segregation		

APPENDIX B: FIBERGLASS PROCESSING PLANT

Table B1: Estimated Water Use and Sewage Generation

	number of units	GPM	Hours of operation	% of units operating	GAL/DAY	GAL/MO	GAL/YR	Percentage of water use
DOMESTIC WATER USE								
Water Fountains	680	0.05			34	1,034	12,410	
Sinks	680	0.25			170	5,171	62,050	
Waterclosets	940	3.00			2,820	85,775	1,029,300	
Urinals	440	0.75			330	10,038	120,450	
Total Domestic Water Use					3,000	102,000	1,224,000	1.8%
Domestic water to sewer					3,000	91,000	1,092,000	2.0%
NON-CONTACT COOLING WATER								
water cooled rolls	26	5.98	18	0.65	109,161	3,320,314	39,843,765	
water cooled jackets & tanks	4	6.00	18	0.75	19,440	591,300	7,095,600	
size	1	2.00	18	0.65	1,404	42,705	512,460	
special products guillotine	1	6.30	9	1.00	3,402	103,478	1,241,730	
Cooling Water Use					133,000	4,045,000	48,540,000	79.2%
Cooling Water to sewer					133,000	4,045,000	48,540,000	88.1%
WASHING WATER								
Washing Water Use	7	10	18	0.02	1,000	30,000	360,000	0.6%
Washing Water to sewer					1,000	30,000	360,000	0.7%
FINISH MIX								
Water Use					8,000	243,000	2,916,000	4.8%
Finish Mix to Sewer					560	12,000	144,000	0.4%
SIZE MIX								
Water Use					1,100	33,000	396,000	0.7%
Size Mix to Sewer					85	2,000	24,000	0.1%
HVAC USE								
Air Wash & Humidification	4	0.6	18	0.50	1,296	36,792	441,504	
Cooling Tower Chill & Comp.	440 avg. ton; 1.4 gal ton evap + blowdn				10,126	308,001	3,696,008	
Boiler Use	based on average boiler make-up				4,300	130,792	1,569,500	
Total HVAC Use					16,000	476,000	5,707,000	9.5%
HVAC to Sewer					6,000	243,000	2,916,000	4.8%
CAFETERIA USE								
Ice Machine, Coffee, etc.	1,020	0.20			204	6,205	74,460	
Dishwashing & Cleaning	1	9	18	0.05	486	14,783	177,390	
Total Cafeteria Use					690	21,000	252,000	0.4%
Cafeteria to Sewer					510	16,000	192,000	0.3%
CLEANING								
General Housecleaning	20	3	1	1	50	1,521	18,250	
Slasher Cleaning	5	4	1	1	1,200	36,500	438,000	
Finish Unit Cleaning	10	4	18	0.08	3,600	109,500	1,314,000	
Total Cleaning Use					5,000	148,000	1,770,000	3.0%
Cleaning Water to Sewer					4,500	133,000	1,593,000	3.0%
ESTMATED CITY WATER USE		117 GPM		107%	168,000	5,065,000	60,769,000	
ESTIMATED WASTEWATER GENERATED		105 GPM		105%	149,000	4,572,000	54,861,000	
AVERAGE BILLED CITY WATER USE					157,345	0	0	
AVERAGE BILLED WASTEWATER					141,688	1,416,880	17,002,560	

Table B2: Material Balance

MASS BALANCE

Source	Color ADMI	DOC mg/l	COD mg/l	pH	Temp C	TSS mg/l	Nickel ug/l	Chromium ug/l	Copper ug/l	Lead ug/l	Zinc mg/l	Flow gpd
Domestic *	-	-	500	-	-	200	-	-	-	-	-	3,000
Boiler	101	89.5	160	8.5	19	38	33.00	2.40	348.00	56.00	1.95	3,400
Cooling Tower	5	16.6	40	8.3	21	0	7.00	3.90	34.00	8.00	0.30	2,400
Air Washer2	56	67.5	160	8.0	13	20	6.00	3.40	76.00	9.00	0.52	65
Cooling Roll finishing unit	11	3.1	60	6.8	27	0	16.00	1.20	13.00	2.00	0.16	128,600
Finish mix unit 3	45	3,823.0	12,700	3.0	19	1	10.00	10.30	108.00	14.00	0.34	390
Finishing mix unit 7	148,092	4,327.0	75,200	9.7	19	17,623	-	-	-	-	-	170
Size mix slasher 3	434	16,685.0	49,400	5.8	48	0	9.00	10.40	26.00	4.00	0.12	43
Size mix slasher 1	1,823	53,900.0	160,800	5.5	61	92	-	-	-	-	-	43
Cooling roll slasher 4	14	13.1	40	7.7	25	0	6.00	1.10	5.00	2.00	0.31	1,400
Guillotine	9	3.1	20	6.8	13	0	5.00	2.50	33.00	10.00	0.45	3,400
General cleaning	-	-	10,000	-	-	3,500	-	-	-	-	-	4,500
Cafeteria *	-	75.0	250	-	-	100	-	-	-	-	-	510
Washing Operations	34	-	4,000	-	-	0	37.00	3.80	246.00	16.00	0.60	1,000
Total (Calculated)	-	50.0	576	-	-	131	16.17	1.37	23.78	3.64	0.21	148,900
Total (analysis)**	-	-	700	-	-	116	40.00	267.50	28.00	11.00	0.06	-
Total (POTW)	-	-	582			135						

* values are taken from Davis and Cornwell, 1991.

** Values are averages from four 24-hours samples taken on 4/21/94,5/26/94,7/21/94 and 10/19/94

REVISED MASS BALANCE

Source	Color ADMI	TOC mg/l	COD mg/l	pH	Temp C	TSS mg/l	Nickel ug/l	Chromium ug/l	Copper ug/l	Lead ug/l	Zinc mg/l	Flow gpd
Domestic *	-	150.0	500	-	-	200	-	-	-	-	-	3,000
Boiler	101	89.5	157	8.53	19	38	33.00	2.40	348.00	56.00	1.95	3,400
Cooling Tower	5	16.6	38	8.33	21	0	7.00	3.90	34.00	8.00	0.30	3,300
Air Washer2	56	67.5	157	8.03	13	20	6.00	3.40	76.00	9.00	0.52	65
Cooling Roll finishing unit	11	3.1	60	6.76	27	0	16.00	1.20	13.00	2.00	0.16	19,300
Finish mix unit 3	45	3,823.0	12,700	3.03	19	1	10.00	10.30	108.00	14.00	0.34	390
Finishing mix unit 7	148,092	4,327.0	75,200	9.66	19	17,623	-	-	-	-	-	170
Size mix slasher 3	434	16,685.0	49,400	5.83	48	0	9.00	10.40	26.00	4.00	0.12	43
Size mix slasher 1	1,823	53,900.0	160,800	5.50	61	92	-	-	-	-	-	43
Cooling roll slasher 4	14	13.1	42	7.71	25	0	6.00	1.10	5.00	2.00	0.31	200
Guillotine	9	3.1	16	6.81	13	0	-	-	-	-	-	500
General cleaning	-	-	10,000	-	-	3,500	-	-	-	-	-	4,500
Cafeteria *	-	75.0	250	-	-	100	-	-	-	-	-	510
Washing Operations	-	-	4,000	-	-	0	-	-	-	-	-	1,000
Total (Calculated)		1,400.0	2,200			537						36,400

* values are taken from Davis, and Cornwell, 1991.

** Values are averages from four 24-hours samples taken on 4/21/94,5/26/94,7/21/94 and 10/19/94

REMOVAL OF CHEMICAL MIXES

Source	Color ADMI	TOC mg/l	COD mg/l	pH	Temp C	TSS mg/l	Nickel ug/l	Chromium ug/l	Copper ug/l	Lead ug/l	Zinc mg/l	Flow gpd
Domestic *	-	150.0	500	-	-	200	-	-	-	-	-	3,000
Boiler	101	89.5	157	8.5	19	38	33.00	2.40	348.00	56.00	1.95	3,400
Cooling Tower	5	16.6	38	8.3	21	0	7.00	3.90	34.00	8.00	0.30	3,300
Air Washer2	56	67.5	157	8.0	13	20	6.00	3.40	76.00	9.00	0.52	65
Cooling Roll finishing unit	11	3.1	60	6.8	27	0	16.00	1.20	13.00	2.00	0.16	19,300
Cooling roll slasher 4	14	13.1	42	7.7	25	0	6.00	1.10	5.00	2.00	0.31	200
Guillotine	9	3.1	16	6.8	13	0	-	-	-	-	-	500
General cleaning	-	-	10,000	-	-	3,500	-	-	-	-	-	4,500
Cafeteria *	-	75.0	250	-	-	100	-	-	-	-	-	510
Washing Operations	-	-	4,000	-	-	0	-	-	-	-	-	1,000
Total (Calculated)	-	-	1,500	-	-	500	-	-	-	-	-	35,800

* values are taken from Davis and Cornwell, 1991.