The Future of Pollution Prevention
An Alternative to Costly Waste Treatment

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Abstract

Pollution prevention for the textile industry is reviewed, including a brief summary of present practices and an analysis of future needs and opportunities. Barriers and facilitating factors are identified.

Introduction

The US textile industry has a major impact not only on the nation's economy but also the economic and environmental quality of life in many communities. In several states, textiles is the leading provider of manufacturing jobs, with North Carolina as the nation's number one state in primary textile employment and production. There are about 1,000 textile manufacturing facilities in North Carolina, and about 6,000 nationwide. In 1992, the textile complex generated a gross national product of $72.5 billion, an amount that surpasses the automotive industry, primary metals, or petroleum refining.(l)

Textile processing requires the use of vast amounts of water, chemicals and energy, and therefore it has important effects on environmental quality in textile manufacturing regions.(2,3) In North Carolina alone, there are about 200 NPDES permitted textile wastewater point discharge sources, as well as hundreds of municipal systems in which textile operations are significant industrial users. A wastewater pollutant reduction of merely one part per million average across the textile industry in North Carolina alone is equivalent to roughly 150 tons per year of pollutant discharged to the environment. This indicates the immense potential of pollution source reduction.

Air quality issues are also important in textiles, with 132 facilities in North Carolina alone reporting air toxics emissions of over 3000 tons in the aggregate.(4) In addition to air toxics concerns, most textile mills operate steam generation plants which produce boiler emissions. Although small in comparison to public utility electric power generating plants, textile sources are significant. In addition, the emerging issue of textiles and indoor air quality which is now under intense scrutiny.(5)

Solid waste is also produced in large quantities, and hazardous waste in small quantities in some operations.

In many cases, destruction of these wastes is not feasible for economic, technical or political reasons. For example, North Carolina ranks 11th nationally in the production of hazardous waste, but has no permitted hazardous waste disposal facility.

In light of all of the above, it is easy to see the regional and national importance of pollution control in textile operations.

State of the Art: Commercial Textile Pollution Prevention Practices

Textile waste amounts and characteristics are well documented, as are state of the art pollution prevention practices.(2,3,8-14) To summarize those documents, current commercial textile pollution prevention practices include

- Chemical alternatives, substitutions
- Consumer, installer, end user information
- Design stage planning of processes, products, facilities
- Developing markets for wastes
- Enhanced chemical expertise and general industry competence
- Equipment maintenance and operations audit
- Global, integrated view of manufacturing
- High extraction, low carryover process step separations
- Incoming raw material quality control
- Inventory control
- Maintenance, cleaning, nonprocess chemical control
- Material utilization in cutting and sewing
- New and improved equipment
- Optimized chemical handling practices
- Process alternatives
- Process modification,
- Raw material prescreening (prior to use)
- Raw material substitution
- Reducing disinformation, politics
- Risk assessment methods, data, and procedures
- Scheduling to minimize machine cleaning
- Segregation, direct reuse
- Standard tests, methods and definitions
- Technology transfer of pollution prevention successes
- Training programs, worker attitudes
- Waste audit

Several types of wastes have already been successfully targeted by the industry, with emphasis on four specific problem areas.

The first problem area is hard-to-treat wastes, ie wastes which are persistent or resistant to normal treatment. For textiles, these wastes include color, metal, phosphate, phenol and certain organic materials, especially surfactants which resist biodegradation. Because of the extremely expensive and difficult procedures involved in removing these via wastewater treatment, source reduction is an economical and attractive alternative to treatment.

A second major accomplishment of the textile industry is source reduction of waste which becomes widely dispersed when discharged. Wastes from textile processes often are reduced or captured for recycle/reuse by process modifications at the source because, once discharged, they tend to become widely dispersed and hard to treat. Machinery design, chemical substitution, procedure changes or primary control measures can often accomplish better results at lower cost than treatment. In addition, reclaimed waste in concentrated form (ie not dispersed) usually has its highest potential commercial reuse value.

The third type of waste is offensive or hazardous wastes, especially materials of high aquatic toxicity. For textiles, these include metals, various types of organic solvents and surfactants. In many instances, chemical substitutions can effectively reduce production of undesirable process by-products. Frequently, treatment of these hazardous or toxic process wastes leads to undesirable waste treatment solids, for example, metal bearing sludges.

The final problem area is large volume wastes. These have successfully been reduced by process modification, chemical substitution, and on-site or off-site reuse. Each of the above types of waste may originate from a variety of textile operations.

The textile industry has an outstanding documented record of pollution prevention activities.(l5)

Many case histories of reduction/conservation strategies are available415) Case histories, in-plant techniques, and actual production experiences have generally resulted in economic gains for the processor as a separate benefit from the waste reduction, as well as providing improved compliance with permits and/or pretreatment specifications.

One should go beyond this view of success, however, to define specific identifiable needs and opportunities for the textile industry to advance its already extensive efforts in the area of pollution prevention.

Technical Needs and Opportunities for Pollution Prevention

Several specific technical needs, if met, will increase the ability of the textile industry to reduce pollution at its sources. The two main opportunities for advancing pollution prevention in textiles are:

- Technology transfer of successful strategies
- Addressing global needs, not assignable to any specific process

General Needs

Overall technical needs and opportunities which conceptually should not be limited to any one specific process include

- Developing overall global views of pollution prevention,
- Applying known pollution prevention technologies,
- Information systems for optimal decision, and
- Improving process understanding.

Global View

Unlike most industries, textiles is highly fragmented, which makes developing an overall global outlook is particularly difficult. Most textile manufacturers have initiated pollution reduction on a process by process basis, but few have achieved the kind of global thinking which transcends individual process boundaries, and can produce maximum results.(6) At each processing step, decisions are made which impact downstream processes, beginning with product design, continuing through each process and ultimately involving even the consumer as well. In many cases, processing assistants are added only to be later removed by energy and chemically intensive scouring procedures. Additives include lubricants, spin finishes, agricultural chemicals, size materials, knitting oils, winding lubricants and tints. The challenge is to develop an overall global pollution prevention scheme which transcends individual operations. Such an outlook would consider the downstream impact of processing residues in terms of interferences and incompatibilities. To implement this global perspective requires better information exchange systems, which in most cases do not exist in the textile manufacturing complex. This information issue is discussed in more detail below. Another requirement is incentives, which can be difficult to establish in a fragmented manufacturing complex such as textiles.

Global needs include not only the issues of design, additives' effects on downstream processing and the need for later removal by scouring, but also developing an overall view of manufacturing in terms of containers, machine parts, print screens, drums, mix tanks, etc to reduce solvent loss, drag out, and impurity build up. This affects not only the process' pollution, but also the product quality. Such thinking should extend even to consumer use of product in terms of aftermarket treatments, cleaning solvents, use conditions, installation and maintenance; keeping in mind that the product itself will eventually become a waste.

Accurate Information

Application of known technologies based on documented studies often produces great benefits, however, accurate information about the pollution potential of various processes and products is needed, to ensure optimal results. A surprising amount of confusing information is distributed, however, for two fundamental reasons. One is the lack of standardized environmental terminology and testing methods, and the other is the propagation of obsolete data from old literature. The latter is a greater problem in textiles than other industries because, despite the fact that textiles is a mature industry, its chemistry has been developed relatively recently. The entire industry changed with the commercial commercialization of synthetic fibers in the 1940's and fiber reactive dyes for cotton in 1956. In addition, the entire chemistry of crosslinking resins has evolved since the 1930's, with modem finishes being developed almost entirely since 1970. Unfortunately, pollution information developed prior to 1950 is often quoted in textile reviews in spite of excellent and easily accessible information sources.(2,3) Most of this obsolete information was developed during a time when commercial processing was not comparable to modem practices. An improved comprehensive and critically accurate literature review is now in press for the textile mills. The opportunity is to accomplish great pollution reduction while at the same time increasing profits by using proven methods. The challenge is to critically review literature in terms of modem textile commercial practice as well as the best pollution prevention practices.

Information Distribution

Another major global need is to develop information distribution systems which will facilitate maximum pollution reduction practices. In essence there are two types of information structures which must be united. In textiles there is quite a large gap between the management information systems and technical information systems. The challenge is to provide management, sales and design personnel with information which enables proper decision making, eg product design, process selection, scheduling, and marketing. Although management and technical information must differ in format to accommodate differing backgrounds, ie less technical experience of management/sales/design vis a vis less business experience of chemists/engineers, it must have significant correlation and unification of technical and business concepts. There have been several attempts to develop such information systems with significant degrees of success.

Technical Understanding

At a fundamental level, even some of the most common and straightforward textile chemicals and processes are not well understood by experts, much less production supervisors, workers and managers. For example, conditions leading to unreacted monomer and catalyst in fiber, the process of bleaching, the role of spin finishes, surface phenomena (eg fouling), preparation processes, and dye aggregation are, in many cases, poorly understood. This is true for machines, fiber, chemical and process issues. Other examples include the role of chlorinated solvents in cleaning; optimal methods for use of non-production chemical cleaners for dye machines, pad rolls, printing screens and rollers; the role of knitting oils and warp sizes; and how silicate stabilizes peroxide bleaching. The opportunity is to reduce pollution through better fundamental understanding of processes and systems.

Textile Wastes of Concern and Emerging Issues

As indicated above, the textile industry has already developed a relatively comprehensive approach to pollution prevention by source reduction for several types of wastes. However there is still much to be done. Currently, the textile industry is being called on to address even more difficult challenges in pollution control. Further efforts and resources will be required to solve the new important emerging environmental issues, ie

Indoor air quality,
Color residues in textile dyeing/printing wastewater,
Massive discharges of electrolytes,
Toxic air emissions,
Improving treatability of wastes,
Elimination of low levels of metals from wastewater,
Aquatic toxicity, and
Technology transfer of existing pollution reduction knowledge.

In addition to these new regulatory challenges, there are some very high volume waste streams which deserve attention. These are salt, knitting oils and warp sizes.

One major technical challenge is to provide management, design, scheduling and planning departments with credible and convincing forecasting of future constraints and requirements based on technically accurate assessments of future regulatory issues, as listed above. A critical study defining best pollution reduction management practices for specific future regulatory problems would provide a basis for developing better industrial pollution prevention programs.

It is not feasible to solve the above problems by treatment systems alone. In fact, improving waste treatment processes themselves often depends on producing more treatable, less dispersable, or less persistent wastes. Also, treatment is in many cases more efficient on concentrated waste, therefore mixing together offensive or otherwise incompatible wastes is undesirable. Thus, future improvements in waste treatment are in a sense related to pollution prevention.

Product Design and Production Scheduling

One particularly important need is to introduce engineering considerations into fabric design and production scheduling. Presently, textile fabric design is primarily coloristic, artistic and aesthetic. Production scheduling is usually market driven with secondary consideration of problems created, for example, by excessive color changes and associated machine cleaning. Better design systems based on engineering and chemical principles will improve environmental and other process considerations. Designers and scheduling departments are rarely aware of product attributes (eg colors) which produce high pollution loads, cause scheduling difficulties or require excessive machine cleaning. The opportunity is to provide artificial intelligence or expert systems which will assist designers and process schedulers. Examples include not only color selection, but also fiber blend selection, knit or woven constructions, etc. The same reasoning applies to sales/customer relationships which should, but often do not, consider the environmental impact of product specifications.

Emissions Factors

Advancements in engineering methodology are also needed in risk assessment and waste audits. Most mills use either direct measurement of waste for existing processes, or mass balance estimates at the design stage to determine potential wastes from processes. Direct measurement of waste is often difficult, and of course can not be done at the design stage before process start up. Mass balance estimates have severe limitations, in that the difference between large volume of raw materials and large volume of product leaves a small difference for the waste number, which (being the difference of two large numbers) is highly uncertain. Thus one can see the need for standard emissions factors for textile operations.

Using emission factors to predict the ultimate fate of pollutants can greatly improve waste audit accuracy. Also, the simplicity of using standard emissions factors provides an opportunity to examine processes more efficiently, thereby reducing more pollution with a given amount of resources (eg time, personnel). This also offers an opportunity to better evaluate processes in terms of problem wastes and to target high volume wastes from inefficient processes (eg garment dyeing) as well as difficult waste from efficient processes (eg flame retardant backcoating). Finally, emissions factors are one of the few accurate ways to predict trace and fugitive emissions such as hydrocarbons and metals.

Textiles, unlike most industries, has no standard emissions factors for many specific raw materials and processes. There are two notable studies which estimate amounts of certain pollutants based on production volume, but the pollutants included in that data are very limited.(2,17) Since the completion of these studies, there have been further regulations of priority pollutants, locally regulated organic compounds and toxic air pollutants. The need is to understand the environmental fate of all process chemicals, to identify the precursors of chemical wastes, and to develop emissions factors for various production situations. Then, process engineers and schedulers will have the opportunity to control these pollutants at the planning stage. Emissions factors are a key to planning because many of the most offensive toxic air and water pollutants from textiles either are fugitive emissions or result from trace impurities in high volume raw materials. In this case, mass balance is essentially useless in any practical sense. It is very important that these studies include maintenance and machine cleaning chemicals as well as process chemicals.

Standard Tests and Nomenclature

Another need is for engineering definitions and standard test protocol of waste and environmental parameters. At present, even the term “biodegradable” is not defined. Well defined, quantitative understandable ratings for environmental and waste attributes (eg aquatic toxicity, treatability) will enable engineers to make better assessments of risk, process trade offs and the like.

Specific Opportunities for Unit Processes

The previous information defines global needs and opportunities which can be applied to specific processing situations as indicated in the following sections.

Fibers: Synthetic and Natural

There are several needs and opportunities from the fiber perspective. These include, for synthetics, the development of improved spin finishes and fibers with lower amounts of residual monomer and catalyst and for natural fibers, elimination of minerals, metals and agricultural residues including biocides. Also, better fiber selection could afford the opportunity to reduce the amount of chemical finishing required.

Spin Finishes

Proprietary spin finishes are added to synthetic fibers to provide fiber lubrication and other desirable properties, such as static electricity control. The chemical composition of spin finishes is a closely guarded trade secret but, in almost all cases, they must be removed prior to dyeing and finishing to ensure uniform penetration of fabric by dyes and finishes, and to avoid reaction or precipitation with incompatible downstream process chemicals. Also, volatile components of these spin finishes produce air pollution when vaporized by high temperature processes such as heatsetting, dye thermofixation, drying and curing of finishes. To prevent these problems, spin finishes must be scoured from the goods prior to dyeing and finishing, thereby producing polluted wastewater. Thus there is a need for better ways to control the surface and electrical properties of fibers without the use of additives which interfere with downstream processing, quality, and associated pollution potential. The challenge is first to better understand the role of fiber lubricity in textile processes and textile structures, and then to use that knowledge to develop better spin finishes, which do not interfere or pollute. Desirable lubricity and electrical properties could potentially be provided by polymer surface modifications, such as introducing permanent additives, or by physico-mechanical treatment (eg plasma).

High Purity Fibers

Another challenge is to produce synthetic fibers with minimum amounts of unreacted monomer, and to use less harmful catalysts and additives (eg delusterants) in polymerization reactions. Many toxic pollutants from textile wet processing operations have been identified (8). They are in many cases the same materials which can be extracted from raw fibers.(H) Making polymerization reactions more efficient and more robust to process variations potentially would reduce or eliminate these undesirable pollutants from wastewater streams of wet processors.

Natural fibers present a similar challenge, but different pollution issues are involved. Agricultural residues such as pesticides, herbicides and defoliants can lead to aquatic toxicity and other problems from preparation wastewater. Processing solutions tend to leach metals out of textile substrates. The challenge ***is*** to develop cleaner agricultural production practices, to inherently increase insect and disease resistance, requiring less chemical additives, or perhaps safer or less offensive additives.

Dyes

The first synthetic textile colorant was produced in the 1860's when Perkin oxidized aniline to produce Mauvine. By the early 1880's, diazotization was a known reaction, and chemists like Greiss, Walter and Boettiger attempted to synthesize commercially useful dyes with that method. During the ensuing century of dye development, thousands of synthetic colorants have been produced and used commercially. Traditionally, dye manufacturers' goals have been produce low cost dyes with high tinctorial value, brilliance, and good application and fastness properties; in particular, high resistance to washing, cracking, light, oxidation (ozone), reduction (gas fading), chlorine attack, acids and alkalis, etc. Although safety has, over time, become a consideration in the synthesis of dye from intermediates, treatability has not been a significant consideration in dye design. Dye research, until now, has focused on dyes with improved stability, thus more resistant to treatment. For example: in the 1880's, dyes would fade in 5 standard fading units (SFU) of light exposure. By 1980, 50 to 100 SFU light was the norm. The next generation of dyes under current development for automotive uses will withstand over 1000 SFU. Chemists, by their success at developing highly stable dyes, have produced very difficult to treat color wastes from dyeing and printing operations. The challenge is to resolve the competing objectives of product quality and dye waste treatability by developing dyes which are more treatable, less dispersable, less persistent and less offensive.

New Generation Dyestuffs

As indicated above, the textile industry needs a new generation of dyestuffs based on better treatability, higher exhaustion thus-less color residue in wastewater, and safer intermediates, while maintaining desirable tinctorial, cost and fastness properties. The application properties of these dyes of the future should be adequate in terms of repeatability, compatibility with existing equipment, controllability, etc. This new generation of dyes should require fewer chemical dyeing assistants, especially salt, retarders and accelerants. Fiber reactive dyes for cotton, which are the fastest growing class of dyes over the last 20 years, are promising for this major opportunity to reduce or eliminate some of the most intractable emerging problems enumerated above, ie

Color residues in dyeing and printing wastewater,
Massive electrolyte discharges,
Aquatic toxicity,
Toxic air emissions,
Improving treatability of wastes, and
Elimination of low levels of metals from wastewater.

One approach which has been proposed is to make dyes more reactive, however without higher affinity properties the above goals can not be accomplished.

Another important opportunity is the development of azo dyes baaed on iron instead of other more harmful metal ions such as cobalt, nickel, chromium, nickel, lead, and zinc. This line of research has already shown promise in substituting iron for cobalt in Acid Bed 182 and Acid Blue 171, and also iron for chromium in Acid Black 172.(19) These new dyes are non mutagenic and of course do not introduce undesirable metals in dyeing wastewater.

New Application Methods

There is also the need to develop new application methods especially for existing fiber reactive dyes on cotton. One successful approach is pad batch dyeing, which is well known. Other methods are also needed, especially for tubular knits and other substrates not adaptable to pad batch dyeing. Using alternative electrolytes or other methods to control dye affinity and exhaustion via solubility control and fiber zeta potential is another opportunity which begs investigation.(20-23)

Proprietary Issues

The need for better disclosure of chemical constitution of chemical specialties is important. The same challenge exists for dyes. In the past, dyes have been classified by chemical structure and applications factors in the ***CoZour Index.*** For nontechnical business reasons, this indexing system seems to be coming to an end, due to the withdrawal of support by many of the major dyestuff companies. In the future, dyes will become more proprietary, like specialty products, with associated loss of information for the user. Lack of information in the future will make evaluation of pollution problems, substitutions, etc even more difficult for textile mills because they will know less about the chemical constitution and structure of the dyes which they are using.

Chemical Specialties

Specialty textile processing assistants are a unique group of products, which are not understood very well by outsiders to the textile industry. They are used in large quantities with relatively little information about their pollution potential. A recent listing (24) contained over 5000 products in 100 categories which were marketed by 175 companies under 1800 trade names. Each product is a proprietary blend of chemical commodities. The composition is not revealed to the user, nor are the pollution characteristics (eg aquatic toxicity).

There is a clear need for disclosure of user information, which is in a sense a business issue, including potential incompatibilities with upstream process residues. But there are also technical needs of better data on these mixtures, as well as more accurate aquatic toxicity data. Toxicity reduction programs are often frustrated because comparative evaluation of substitute chemicals is almost impossible. Test results for aquatic toxicity often correlate poorly between labs due to nonstandardized test conditions, species variations, etc.

The incentive to establish a good pollution prevention program is often economic. These programs are often justified through a “pollution prevention pays profits” type of thinking. The need for better risk/benefit assessment and more realistic waste goals, as well as realistic forecasting of benefits and liabilities therefore is critical. The challenge is to eliminate the barrier of poor technical information described above. This also contributes to the better technical understanding of processes discussed earlier.

Chemical Commodities

In addition to specialties, textiles uses massive amounts of commodity chemicals, eg acid, alkali, salt, warp size, fiber, water. A typical cotton production facility might use commodities that is greater that the weight of product produced. It is not unusual to find cotton dyehouses which discharge 3000 ppm of salt in the wastewater. There are two needs in this area. The first challenge is to reduce the amounts of commodities, especially salt, required for dyeing. The second is to determine the trace impurities in commodities and to seek better sources of commodities, or better methods of manufacturing commodities, which reduce or eliminate offensive trace materials.

The second major need, to identify and eliminate trace impurities from commodity raw materials, is crucial. Tests of textile wastewater (8) have clearly shown the presence of toxic materials which also have been detected as impurities in fibers and chemical commodities. Further work (18) shows that these toxic wastewater pollutants are present in significant amounts in high volume raw materials (eg fibers) as well as salt and alkalis. Major needs exist in this area, especially related to zinc in salt, low level impurities in fibers (ie monomer, catalyst, delusterants), metals in caustic, and impurities (eg metals, organics) in raw water supplies.

The current practice of reusing waste commodities internally or from other industries can cut consumption and associated pollution discharge of commodities. This is generally a good practice, but impurities must be considered also. Caution and more information with respect to the above is needed in the reuse of commodities.

Yam Formation: Spinning

In yarn spinning, routine waste production is minimal and more or less unavoidable. Also, most waste is recycled into further uses. Therefore the main opportunities are related to additives and how they affect downstream processing, much like spin finishes discussed previously. Targets for consideration include tint oversprays, winding emulsions, coning oils, lubricants, and in some cases biocides used for mildew suppression. This is an area where global attitudes can contribute greatly. In some cases the yam mill also applies sizes or lubricants, which will be reviewed under fabric formation in the next section. The need is to assure compatibility of additives with downstream processes, and to eliminate potential interferences to later processes. The challenge is to develop specific products for spinning mill use which have minimal downstream impact. This has been done to a certain extent with low BOD winding emulsions and waxes which do not pollute when removed, but not with other spinning additives noted above.

Fabric Formation

Sizes and knitting oils added to yarns before and during fabric processing are one of the greatest routing intentionally created pollution stream in textiles.(25) Typically 6% or more of the weight of the goods is added as size or knitting oil, only to be removed and discarded in the next step of the process (preparation/desizing). Although size recovery is possible, knitting oils are never recovered. The amount of size material alone used in the USA is about 200 million pounds per year, making this one of the largest industrial waste materials. Although there are a few spectacularly successful size recovery systems in operation, the textile industry, for several valid reasons, makes limited use of size recovery. This is equivalent to thousands upon thousands of tons of intentionally created waste, making it along with water, salt and cutting room waste the highest volume waste materials in textile manufacturing, and perhaps all US manufacturing. The need is to dramatically reduce this. The challenges are to:

Remove logistical and technical barriers to size reclamation and reuse
Provide more incentives for recovery
Develop fabric forming methods which require minimal sizes and knitting lubricants
Design yarns and fabric structures which require less sizes and lubricants to create

Recovery can only be done with certain types of sizes, notably polyvinyl alcohol (PVA), which is roughly one third of the total size used. The remainder comprises non recoverable sizes, such as starch. Less than one third of all PVA is recovered. There are several technical and business barriers, including the practice of applying PVA in mixtures with sizes which inhibit recovery, high expense of shipping recovered PVA concentrate solutions, mixing goods containing different sizes at the desizing plant, and lack of understanding of recovery potential.

Regardless of the approach taken, there is a clear need for significant efforts to reduce what is undoubtedly two of the largest industrial waste streams in all of US industrial manufacturing: warp sizes and knitting oils.

Fabric Structures

Certain indoor air quality factors are also a function of fabric design, structure and formation. Preliminary modeling of pollutant exchange zones shows that fabric structure, air permeability and velocity slip factors are all important parameters in the emission, sorption and release of indoor air pollutants by textiles and multilayer textile containing products(5) The opportunity is to design textile containing products which inherently produce improved indoor air quality and minimize pollutant exchange by understanding fabric/air interactions at the microscopic level. Of course, another opportunity in indoor air quality is to design and produce fabrics which inherently require less chemical stabilization, thus eliminating the need for chemical finishing, with associated reductions in manufacturing pollution as well as lower risk of air emissions from applied chemicals, as previously noted.(25)

Wet Processing: Preparation, Dyeing, and Finishing

Typically over 50% of pollution from textile preparation, dyeing and finishing processes results from removal of upstream processing residues which, if not removed, would interfere with dyeing and finishing. A significant portion of pollution also results from application of chemical fabric stabilizers, stiffeners, softeners, etc to adjust the characteristics of the fabric to suit the intended end use. Thus, pollution prevention in wet processing is intimately related to the global views advocated throughout this document. If it were not for the need to remove contaminants via preparation and overcome technical design deficiencies via finishing, dyeing and printing would be the main tasks in textile wet processing.

Pollution reduction has been utilized very successfully in wet processing.(15) Even so, there are still significant opportunities for advancement. Many of these are related to chemical specialties and commodities discussed previously, as well as technology transfer of successful methods already used by more sophisticated operations.

Dyeing Controls

One important need is to improve process control, especially in dyeing operations. The resulting color consistency, coupled with appropriate numerical color specifications, could provide the opportunity to cut adjacent garment (product) panels or parts from widely separated areas of fabric, thus diminishing waste potential in cutting and sewing by improving marker efficiency. In order to do that, more uniform fabrics are needed. There are many factors which are beyond the dyer's control. The use of controllable factors to offset uncontrollable variations and thus produce more consistent color repeats has been proven in the laboratory, using non parametric methods such as neural network and fuzzy logic based real-time multi-channel adaptive control algorithms.(27) The economic and pollution control benefits of achieving this in commercial dyeing operations will be immense. This will not only apply to improved material utilization for piece dyed goods, but also yam waste will be reduced in weaving and knitting through better yam utilization in yarn dyed fabrics.

Another need is better parametric models of complex dye systems *(eg* fiber reactives) for control purposes. Quite sophisticated parametric thermodynamic and kinetic dyeing models are available for many dye classes(28), however there are still major opportunities for improving these models and also for utilizing them in parametric control algorithms or for the purpose of "training" non parametric control models. The challenge is to develop methods of parameter estimation which are simple and economical enough to apply in commerce. Another challenge is to develop parametric models which are simple enough to be useful in commerce, but at the same time robust and sophisticated enough to achieve highly accurate predictions of dyeing behavior. This may seem to be impossible to achieve, but recent work (28) indicates the possibility is real. A barrier to progress in this area is the perception that this research is too fundamental for industry to support, and simultaneously too applied to attract traditional basic research support.

Salt

One need which stands out in the near future for cotton dyeing is salt reduction. At this time, the salt requirements for fiber reactive dyes, which are the most important dye class for cotton, are 50% to 100% on weight of goods. It is not unusual to find textile mill effluents with 3000 ppm salt from cotton dyeing operations. The total quantity of salt discharged from textile dyeing operations may be on the order of magnitude of 400 million pounds annually. It all becomes waste. The role of salt in dyeing is to promote dye exhaustion from the dye bath on to the fiber by decreasing the solubility of dyes in water, and by electrical effects including fiber zeta potential.(20-23) Reduction of salt in cotton dyeing processes usually results in lower dyebath exhaustion, and therefore more color in dye wastewater. Reduction of salt from the current levels of up to 3000 ppm to desired limits of only 250 or less ppm will require significant developments in several areas including machinery, dyestuffs and dye application processes.

Machine Cleaning

At present, the textile industry schedules dyeing production based primarily on delivery times and cost factors. Two major pollution sources from continuous as well as batch operations are dumping unused portions of mixes and machine cleaning which may be necessary between shades. Machine cleaners are generally among the most toxic and offensive chemicals used in textile wet processing.

Dye machine cleaning requirements are highly dependent on the sequencing of colors; ideally grouping colors within chroma families (eg red, yellow, blue), and sequencing from light to dark and from brighter/brilliant to duller/greyish. At present, “smart” scheduling systems which can minimize machine cleaning are not used for dyehouse scheduling. The need is to schedule dyeing production in such a way as to reduce pollution by minimizing machine cleaning as well as mix dumps. The opportunity is fairly straightforward, and the technical barriers to this are minimal. The barriers are discussed under “Accurate Information”.

Scheduling improvements are not the only way to reduce machine cleaning requirements. There are opportunities also to understand fouling and cleaning processes better, and to develop

Dyeing systems which do not foul machines,
Machine configurations and easy to clean surfaces (eg Teflon(R))
Less toxic and more biodegradable machine cleaners.

Robust Dyeing Systems

Poor dye work and associated off quality, rework and pollution is often caused by the presence of upstream processing residues in fabric. The purpose of preparation is to remove these. However, preparation processes sometimes are not completely successful in removing all contaminants. There is a need for dyeing systems which are more robust toward previously added materials (eg spin finishes, agricultural chemicals, sizes, oils, tints, winding emulsions). Such systems could reduce or eliminate the need for preparation. The challenge is somehow to overcome the proprietary nature of specialties and globally select compatible processing assistants. The barriers to this are great, but the potential rewards of such an approach would be immense. There is a limited amount of work going on in this area by a consortium of textile companies and North Carolina Division of Environmental Management.

Automation

Equipment automation is a major focus of textile process improvement over the last 10 years. At a recent International Textile Machinery Association exhibition there were less than 100 companies showing dyeing machinery, but over 150 showing microprocessor controllers, chemical dispensing systems, etc. Automation can produce good results in quality, productivity and pollution reduction, because routine waste levels are decreased, cleanup is easier, mixes are made more accurately, and human errors are reduced. On the other hand, the relative importance of malfunctions and spills, increases. Also there is a tendency for technical supervision to lose contact with automated processes. When a process is automated, routine maintenance becomes relatively more important. Maintenance and supervisory practices which have been used in the past with less automated systems may not be optimum when automation is installed. The challenge is to determine the optimum technology of pollution control for automated processes, and to determine how that differs from current practices.

Finishing and Fabric Design

Finishes are applied to provide desirable end use characteristics, as well as to facilitate product formation (eg cutting and sewing). Proper engineering-oriented fabric designs can eliminate some or all of the need for finishing, particularly in terms of shrinkage, curling, and sewing lubricants. Also, it is possible to stabilize properly designed fabrics without chemicals by the use of mechanical finishes. Much finishing research in recent times has focused on chemical finishing, not mechanical. The opportunity is to substitute mechanical treatments (eg compacting, Sanforizing(R)) for chemical treatments. For these to be successful, it is necessary to correlate three items: fabrics designs which require less chemical stabilization, finishing machinery which can accomplish better end use performance, and compatible fabric specifications which accommodate the use of mechanical finishing through proper design of textile assemblies (eg garment constructions).

Indoor Air Quality

Finishing has direct impact on indoor air quality because many finish chemicals contain low molecular weight, reactive materials (eg formaldehyde) which may later be emitted in the consumer's use area. Also, certain finishes (eg soil release, water repellent) change the fiber's critical surface energy and thus alter the sorption/reemission characteristics of fabrics. There is a potential opportunity to improve indoor air quality by understanding these factors.(25)

Most textiles are combined with other items in the final consumer product, and the combinations are essentially innumerable. Textile manufacturers do not generally know which components will be combined nor in what manner. For example, an upholstery fabric could be combined with other fabrics, batting, fiberfill, open or closed cell foams, stiffening innerliners, etc. On the other hand, the product fabricator generally does not have good information about incompatible combinations in terms of emissions and sorption/reemissions. This makes product design difficult. Better information on combinations and synergisms will enhance indoor air quality.

Consumer Issues

The final link in the production chain is the consumer. Opportunities for source reduction include the development of post consumer recycling of textile products as mentioned above for denim, installation and maintenance improvements to improve life expectancy of textile products, installation and use information for improved indoor air quality, products which do not soil or do not show soil thus require less cleaning solvents and aftermarket care requirements(25) Discarded carpets are another potential source for post consumer recycled fiber.

Better information for consumers about environmental impact would require standardization of tests/terms such as "biodegradable".

Business Opportunities and Needs for Pollution Prevention

In addition to technical needs and opportunities above, there are some business issues which also deserve comment. Quite a lot of pollution prevention success has been achieved within individual production units in textile operations. Even greater opportunities exist in pollution reduction programs which transcend production facility boundaries.(6)A In many cases, the barriers and challenges are non technical. These will be reviewed here.

Priorities and Commitments
The need for global views and better information exchanges are controlled to a large extent by business priorities and commitments. The technical staff at a particular manufacturing site can develop and implement procedures for pollution reduction. But the need to develop global views of manufacturing can only be achieved by a higher level technical understanding across production unit boundaries. A prime requirement for this is better technical cognizance by those who operate across boundaries, ie management. Information exchange in this sense is not an end in itself, but only an enabling mechanism for actually understanding the predicament of other manufacturing stages. The opportunity is to develop special global business relationships among suppliers, various manufacturing sites and customers to reduce pollution.

Marketing of Waste
In some cases, wastes are unavoidable so it is important to view waste as a by product or secondary resource with value. Opportunities to market waste by products should be sought. The business barrier is that the waste almost always sells for less profit than the primary products, therefore the sales incentive is low. However, when costs of collection and disposal, as well as potential liability, are considered the situation may be more profitable than it first seems. There is also a technical barrier in the sense that many operations are reluctant to buy waste materials as raw material inputs for quality and safety reasons. With so many disincentives, valuable opportunities may be overlooked, based on generalized business views about marketing wastes.

Consumer Information
There is a need for to get more information on product use, installation and combination synergisms from manufacturing to the customers. Marketing is a critical link in this chain. Some industries do an excellent job of this. There is a need in textiles to emulate these other successful techniques (eg technical product bulletins, product specifications). As an example, a chair with upholstery will include particle board, foam, fiber fill, stiffeners, upholstery, paint, etc all in combination. The fabricator of the chair does not know how combinations will interact because technical information bulletins are normally not available on textile fabrics. The manufacturers of each component usually have no information concerning component combinations.

Conflicting Goals
One conflicting goal is dye stability us. dye waste treatability. There are even more difficult and hard to define conflicting goals in nontechnical areas.(6) Some of the more prevalent will be reviewed below.

Water Conservation Penalty
An often encountered example of nontechnical conflicting goals which inhibit pollution prevention is the relationship of textiles and municipal sewer systems. One particular dilemma, called the "water conservation penalty," is often encountered. Most cities charge a fee for excess BOD over a preset concentration limit. This causes textile mills typically to adopt specialty processing assistants with lower BOD. Textile operations are often encouraged by such BOD surcharge regulations to make undesirable substitutions of non-degradable (low BOD) surfactants. These tend to pass through treatment systems and increase aquatic toxicity in the treated effluent. Toxicity reduction in many cases is frustrated for several reasons

Difficult substitute chemical evaluation because of poor correlation between labs
Many chemical specialties are proprietary
Technically correct substitutions are punished by regulatory measures (eg. surcharges)

Another example is waste segregation and capture. If there is no way to dispose of captured hazardous concentrated wastes (which is often the case), then the processor has little incentive to capture the waste for disposal in its concentrated form. Keeping hazardous waste out of sewers is often desirable but not rewarded.

Situations such as the above are difficult to resolve with positive results, and attempts to do so usually develop into little more than long drawn out posturing. The need in this case is a greater understanding of the impact of regulations by those who write and adopt municipal sewer ordinances. The opportunity to accomplish genuine pollution prevention could be greatly advanced by genuine cooperation.

Quality Conflicts

Usually, the goals of economic gain and pollution prevention are very compatible, since high processing efficiency and low waste are essentially two sides of the same coin. Also, high quality attitude of workers and pollution control through orderly work practices, etc go hand in hand. But occasionally these goals conflict, and when that happens, the result can be one of the most difficult situations in which to implement a pollution prevention program.

Typically this happens in very high priced, high quality, low volume specialty manufacturing situations such as paper-making felts, coated fabrics, offset printing blankets, and high quality printing. In these cases, the cost of waste is insignificant in terms of product value. Without economic incentives, progress is slow in pollution prevention. Also, the cost of product loss (off quality, seconds) is so great that conversion efficiency is totally dominant and waste raw materials have essentially no value compared to product. The opportunity is to study these situations, and develop incentives and more applicable pollution prevention measures and techniques.

Risk/Benefit Assessments

Better risk assessment and more realistic waste goals are needed. In many cases, one part of the risk/benefit balance is clear, but the other part is vague, nebulous or poorly understood. Sometimes the barrier is poor technical understanding of processes. Another barrier is a cost system which views waste costs and liabilities as an overhead items, not direct cost items.(6)

Human Resources

There is a clear need for more technical understanding among textile managers. Cost and liabilities (civil and criminal) are the responsibility of management in most cases, so it behooves the industry to develop informed management teams. Strangely, the largest textile universities have somehow misinterpreted this as a need to include more management in textile curricula by diminishing technical content of programs. The numbers of graduating textile management majors, who have minimal quantitative skills and minimal understanding of science, technology and engineering, far surpasses the numbers of technical graduates. The need is to bring educational criteria for various textile groups (management, design, engineering, chemistry, technology) closer together in terms of educational experiences.

In the same vein, there is a need to embody pollution prevention concepts in higher education. University education provides for interaction of engineers and chemists with managers and designers in general curricula to foster communications and a common perspective between these groups. The opportunity is to develop human resources to tackle tough future pollution reduction problems. The challenge is to create technical environmental competence in graduates. Few if any, educational institutions have achieved this, but efforts are underway to implement such programs.(16)

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