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Project Summary

Wastewater Recycle and Reuse Potential for Indirect Discharge Textile Finishing Mills

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Over 80 percent of textile finishing mills discharge their wastewater to publicly owned treatment works. A variety of wastewater recycle technologies have been developed to allow these mills to reduce the volume of wastewater and amount of pollutants discharged.

Only a few of these technologies have become widely applied in the textile finishing industry. Specific technical and economic factors affect the application of most of these technologies at a given mill; thus each application must be considered under its own mill-specific conditions.

This report presents detailed information on textile wastewater recycle/reuse technologies. Included for each are a description of the technology, its environmental benefits, recycle system and treatment system schematics, design criteria, a discussion of technical factors that limit or enhance its application, capital and yearly cost, an examination of factors that affect its economic feasibility, lists of its current applications, and references for further information.

The information in this report is based on a survey of the literature, discussions with technology vendors and researchers, and engineering studies conducted at six textile finishing mills. The six mill engineering reports appear in Volume 2 of the report.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

About 4 million tons (3.6 x 10^9 kg) of textile products are finished annually in the U.S. About 2,000 finishing mills, involved in this production, annually discharge more than 100 billion gallons (3.8 x 10^{11} l) of wastewater. Most of the water use and wastewater discharge in the textile industry is in four industry sectors: (1) woven fabric finishing, (2) knit fabric and hosiery finishing, (3) carpet finishing, and (4) stock and yarn finishing.

More than 1,000 textile finishing mills were recently surveyed for the Effluent Guidelines Division of EPA. Survey results indicate that 81 percent of the surveyed mills in these industry sectors discharge their wastewater to publicly owned treatment works (POTW). The amount of wastewater produced by these indirect discharge mills is estimated to exceed 210 mgd. The survey further shows that much of this wastewater receives either no treatment (58 percent of mills) or only preliminary treatment (33 percent of mills) prior to discharge. Preliminary treatment includes: gross solids removal by settling or screening, equalization, and neutralization.

Because of the significant total volume of wastewater discharged to POTWs by textile finishing mills, EPA's Office of Research and Development, in support of the Effluent Guidelines Division, is evaluating textile mill wastewater recycle and reuse as a way to reduce water consumption and wastewater discharge rates.

In addition to the benefits of reduced water consumption and wastewater discharge, recycle and reuse can result in significant economic benefits to an indirect discharge textile finishing mill from savings in water costs, sewer use fees, end-of-pipe pretreatment costs, energy, and chemicals. Therefore, significant incentives for implementing wastewater recycle and reuse exist even in the absence of pretreatment regulations.

Many textile manufacturing processes have been identified in recent years as being suitable for the application of wastewater recycle or reuse. Various technologies have been investigated for these applications in tests ranging from bench- to full-scale demonstrations. Nevertheless, the application of recycle and reuse in textile finishing mills remains rather limited. Only a few recycle technologies (e.g., caustic recovery from mercerizing washwater, and direct in-process water reuse by countercurrent washing) have been adopted by a relatively large number of mills. Most other recycle technologies have been adopted by only a few mills.

Reasons for the limited use of recycle in the textile finishing industry include:

- Lack of specific technical knowledge about available recycle/reuse technologies, their benefits and limitations, and application of this information in performing a feasibility study.
- Concerns about the cost effectiveness of wastewater recycle (capital cost vs. return on investment).
- Competing areas for capital expenditures in the mill.
- Concerns about site-specific factors that could limit the applicability or cost effectiveness of recycle technologies.

The goal of this project, providing information that defines the applicability of recycle/reuse in the textile finishing industry, is achieved by performing the following tasks, grouped by project phase.

Phase I

1. Identify applicable recycle/reuse technologies and gather available information on them to define areas for potential application, benefits, limitations, and approximate cost data.
2. Identify a group of textile finishing mills that appear to have high potential for applying recycle/reuse technologies.
3. Select six representative mills from this group to participate in actual field studies of the applicability of wastewater recycle/reuse measures under Phase II.

Phase II

1. Visit the six mills to collect information on textile processing, machinery, fiber and chemical use, energy and water use, and wastewater discharge and characteristics.
2. Technically evaluate the feasibility of employing various recycle/reuse technologies at the six mills, including bench-scale tests of the technologies, when appropriate.
3. Economically evaluate the technically feasible technologies to define capital costs, operating costs, and textile production savings.

Phase III

1. Select one or more recycle technologies that have technical and economic promise for more widespread use.
2. Develop these technologies to laboratory- and full-scale at a textile finishing mill.
3. Prepare a detailed manual covering the investigations and application of the technologies.

This report gives results of the first two project phases. A separate report will be issued, detailing the third phase.

Textile Finishing

The major textile finishing processes, in terms of wastewater generation, are desizing, scouring, mercerizing, bleaching, dyeing, and printing. Other operations (e.g., applying functional finishes or latex backing) generally result in only a small quantity of wastewater.

Desizing, performed only on woven fabrics, is generally the first wet process performed. It consists of removing sizing compounds (e.g., starch, polyvinyl alcohol) that were added to the warp yarns prior to weaving. Wastewater from desizing, therefore, contains high concentrations of these organic substances.

Scouring removes impurities from the textile product prior to coloring and other finishing processes. Wastewater from scouring is generally alkaline and contains the impurities removed from the product.

Mercerizing, performed on cotton fibers, increases tensile strength, luster, sheen, dye affinity, and abrasion resistance. The product is contacted for a certain period with concentrated caustic, and then is washed to remove residual caustic from the fibers.

Bleaching whitens cotton and other cellulosic fibers prior to coloring or other finishing processes. Various oxidizing or reducing compounds can be used. Exhausted bleaching baths and rinsing water are the sources of wastewater from bleaching.

Dyeing is a complicated process that imparts color to textile fibers. Various dyestuffs are used depending on the fiber type, color, and desired product specifications. The most common classes of dyestuffs include acid, basic, direct, disperse, vat, sulfur, and reactive dyes. Various auxiliary chemicals are used in the dyeing process including salts, acids or bases for pH adjustment, reducing and oxidizing chemicals, wetting agents, sequestering agents, retarding and leveling agents, dispersants, and carriers. Exhausted dyebaths and rinsing water are the sources of wastewater from dyeing.

Printing imparts color to specific selected areas of the fabric. Wastewater results from washing the fabric after printing and from equipment cleaning.

Technology Survey

Many different types of recycle/reuse technologies can potentially be applied to the textile finishing operations just discussed:

- Direct recycle/reuse (no treatment).
- Reconstitution and reuse.
- Separation and reuse by filtration.
- Separation and reuse by membrane separation processes.
- Separation and reuse by precipitation.
- Separation and reuse by evaporation.
- Separation and reuse by coagulation /flotation.
- Separation and reuse by carbon or exchange resin adsorption.
- Chemical oxidation and reuse.

These technologies were surveyed to evaluate their applicability, technical and economic feasibility, costs, and potential for increased use within the textile industry. Equipment vendors and researchers were contacted, the literature was searched, and engineering studies were conducted at six textile finishing mills to evaluate these technologies.

Mill Studies

Four woven fabric finishing mills, one carpet mill, and one yarn mill participated in the program's engineering studies.

Mill C-2 is a nylon carpet mill that discharges 1 mgd wastewater, primarily from batch carpet dyeing. Various recycle /reuse measures were investigated including dyebath reconstitution, dye wastewater treatment and recycle by activated carbon or chlorine oxidation, and cooling water use reduction.

Mill W-3 prepares and finishes woven fabric for apparel. Desizing, scouring, mercerizing, bleaching, and printing are performed and result in the discharge of 1.4 mgd wastewater. Size recovery, caustic recovery, recycle of printing wastewater, and cross-process reuse of washwater were evaluated.

Mill W-4 discharges approximately 0.75 mgd wastewater from the weaving, desizing, scouring, and piece dyeing of woven polyester fabric. Reuse of water-jet loom water, size recovery, and reuse of dyeing wastewater by either reconstitution or decoloring (chlorine oxidation) were investigated.

Mill W-8 produces woven industrial fabric, interlining, and pocket fabric. Continuous ranges are used for preparing and dyeing the fabric, and result in 0.4 mgd of process wastewater. Size recovery and dyestuff recovery through membrane separation processes, and countercurrent reuse of washwater were evaluated.

Mill W-9 scours and dyes woven household fabrics. Approximately 0.3 mgd of wastewater results from these operations. Hyperfiltration for dyestuff recovery and water reuse on the continuous dye ranges were investigated. Other technologies studied included batch bleach bath and dyebath reconstitution, and reuse of rinse waters in batch operations.

Mill Y-4 discharges 0.8 mgd wastewater from the batch scouring, bleaching, and dyeing of yarn. Reconstitution of bleach baths and dyebaths was investigated along with treatment and reuse of dye wastewater by chlorine oxidation.

Results and Conclusions

Information developed on textile wastewater recycle/reuse technologies is summarized below. In general, the implementation of wastewater recycle/ reuse technologies is very mill-specific. As a result, much evaluation, planning, and testing must be performed to determine the applicability of any technology at a given mill.

Dry and Low Water-Use Processes

Dry operations include weaving, knitting, tufting, and spinning. No wastewater results from these operations.

Low water use operations include slashing (sizing), latex backing, and functional finishing. Wastewater is generated in cleanup operations. Little potential for recycle/reuse exists with these operations due to the small volume of wastewater generated. Improved housekeeping measures and better cleanup practices are seen as the most viable ways to reduce the wastewater discharge from such operations.

Desizing

Wastewater from desizing contains the sizing compound that was applied to the warp yarns prior to weaving. The goal of recycle/reuse, as applied to desizing, is to separate the sizing compound from the desize wastewater. The sizing compound is then reused in slashing (sizing), and the wash water is recycled to the desizing process.

Size recovery and reuse is mandatory if this recycle technology is to be economical. Thus, the fate of the size during the desizing operations is critical in deciding if recycle/reuse can be used. Starch sizes, hydrolyzed during removal, are therefore not reusable. Most polyacrylic and polyester based sizes are also partially degraded in the desizing step and are not reuseable. Thus, recycle/reuse technologies are limited to sizes that do not have to be degraded to be made water soluble. These sizes include polyvinyl alcohol (PVA), carboxymethylcellulose (CMC), and certain modified acrylic and polyester sizes.

Available technologies to separate and recover size include thermal precipitation, coagulation, evaporation, and ultrafiltration. Further use of these size recovery technologies in the textile industry seems to hinge on a few variables:

- Using thermal precipitation depends on whether sizing compounds can be developed that offer weaving efficiencies comparable to currently popular sizing compounds.
- Using coagulation and evaporation is not seen as likely because of many unresolved technical problems, and the existence of a proven, alternative technology (ultrafiltration).
- The major obstacle to further use of ultrafiltration for size recovery is the current practice of slashing (yarn sizing) at greige mills. Most large textile companies operate their own greige mills and can therefore control the type of sizing compounds used. The exclusive use of PVA or CMC sizing agents allows the sizing compound to be recovered. Also, a company-controlled greige mill is a ready outlet for the recovered PVA or CMC size. Some large textile companies have therefore already instituted recycle systems for size recovery. The potential for expanded use of size recovery in these types of mills is high. Payback periods are about 1 year.

Many finishing mills, however, especially smaller companies and commission finishers, obtain their greige fabric from sources outside their own company. These finishing mills have little or no direct control over the types and variability of the sizing compounds on the fabrics received. This seriously hinders the feasibility of adopting any size recovery technology. In general, sizing at greige mills is performed with fast and efficient weaving as the prime consideration rather than the potential for size recovery and reuse. The resultant mixtures of sizing compounds (especially mixtures of starch and PVA which are prevalent on cotton-polyester blends) and variability in sizing formulations hinder both size removal at the finishing mill as well as size recovery and wastewater reuse.

Scouring

Wastewater from cotton scouring contains up to 2 percent sodium hydroxide (caustic), but also a large amount of impurities. The caustic and impurities can be separated from the wastewater to allow water reuse, with technologies such as evaporation or hyperfiltration. But such recycle technologies cannot be economically justified on water savings alone. Separation of the caustic from the impurities to allow caustic recovery as well as water reuse would be not only difficult technically, but also very expensive.

Wastewater from the scouring of synthetic fibers contains little in the way of valuable chemicals to be recovered, but also contains much fewer impurities than cotton scouring wastes. Therefore, reuse of scouring wastewater (wash water) in the desizing process, where water quality requirements are less stringent, may be technically feasible. Further application of this technology must be on a mill-by-mill basis after examining its feasibility.

For all fiber types, the reuse of scouring wash water in a countercurrent fashion should be considered.

Mercerizing

Mercerizing wash water contains from 1 to 5 percent caustic along with a relatively small amount of fabric impurities and lint. The goal of reuse/recycle with regard to mercerizing is to recover a concentrated (30 to 40 percent) caustic solution from the wash water for reuse, and to recycle the treated wash water back to the mercerizer washers, the scouring washers, or the desize washers. Again, the cross-process reuse of treated wash water at the scour or desize washers must be evaluated on a mill-by-mill basis. Countercurrent flow is generally used in the mercerizer washers to minimize the flow of water to be treated.

Evaporation is the traditional technology used for caustic recovery at textile mills. Payback periods are about 1 year. However, many mills with large mercerizing operations have already installed multiple effect evaporators to recover caustic. In addition, the amount of textile products being mercerized has been steadily dropping due to the increased use of synthetic fibers. These two factors indicate that only a few additional applications for mercerizing caustic recovery exist in the textile industry at present.

Bleaching

Bleaching wastewater contains unreacted bleaching chemicals along with waste by-products of the bleaching operation. Reuse/recycle technologies in this area include the countercurrent use of bleaching wash water, cross-process reuse of bleaching wash water in scour or desize washers, and reconstitution of batch bleach baths.

Numerous full-scale applications of countercurrent use of wash water exist. Cross-process reuse of bleaching wash water in the scour of desize washers is less common and must be evaluated on a case-by-case basis before implementation. For example, unexhausted bleaching agents can react with and degrade sizes if returned to the desize washers. This would be undesirable if a size recovery system were in place. However, for many mills, the benefits of water and energy savings, as well as the low capital costs, suggest that more widespread application of this technology can be expected.

Bleach bath reconstitution is in rather limited use. More extensive use is expected due to the benefits of water and energy savings and low capital costs, but this may be limited to synthetic fiber bleaching. The bleaching of natural fibers will likely result in too many impurities in the bleach bath to allow for very many cycles of reuse.

Dyeing

Dyeing wastewater contains unexhausted dyestuffs and auxiliary chemicals used in dyeing. Several different types of recycle-reuse technologies have been developed for textile dyeing processes.

Reconstitution of batch dyebaths utilizes the unexhausted auxiliary chemicals and dyestuffs in the used dyebath. Dyes, water, and some chemicals are added to the used dyebath to permit additional cycles of dyeing.

Several other technologies also utilize the auxiliary chemicals remaining in the dyebath, but remove or decolorize remaining dyestuffs prior to water reuse. These technologies include dyebath decoloring by oxidation, activated carbon adsorption, or exchange resin adsorption.

A third class of technologies attempts to recover and concentrate unexhausted dyestuffs from continuous dye range wash water. Available technologies include hyperfiltration, ultrafiltration, and coagulation/flotation of the residual dyestuff. The treated wash water is often reusable.

In addition to these capital intensive technologies that rely on dye or chemical recovery and reuse to justify their economics, some less capital intensive recycle technologies exist. Countercurrent washing can be used on continuous dye ranges. In batch dyeing, the final rinse water can often be reused as dyebath makeup water. In the carpet industry, water extracted from the carpet after dyeing can also be reused in the dyeing process. Cross-process reuse of dyeing wastewaters is generally not feasible if any color or significant amounts of auxiliary dyeing chemicals are present. Further details on recycle technologies for dyeing are given below.

Reconstitution

Reconstitution has advanced from the many laboratory-scale tests conducted in the past several years to several full-scale installations. While at first it was believed that this recycle technology was limited to mills that performed much repeat dyeing, more recent experience has shown that sequences of different colors can readily be scheduled into dyebath reconstitution series. A large number of textile mills with batch dyeing operations are thus candidates for adopting this recycle technology, even if only at a few dye machines at a given mill. Dyebath reconstitution requires little capital investment, and generally has a payback period of less than 1 year.

Dyebath Decoloring

Dyebath decoloring by oxidation has been instituted full-scale at several mills. Chlorine is typically used as the oxidizing agent, but ozone can also be used. The technology is limited to dyestuffs that are amenable to decoloring. In general, acid, basic, direct, and disperse dyes are treatable, though not all dyestuffs in each class are treatable. More extensive use of this technology can be expected in the future, though the economics are not particularly promising (payback period of 3 to 5 years).

The economics of activated carbon adsorption for dyebath decoloring are also not promising. Technically, most soluble dyestuffs can be adsorbed, and a colorless water produced for recycle. Operating costs, however, are usually close to, or greater than, the cost savings realized through water, chemical, energy, and sewer use reduction. Thus, no incentive exists for more widespread use. Other less expensive adsorption technologies, tested in the laboratory, use various exchange resins to absorb the dyestuff molecules. Water recycle has not yet been demonstrated.

Membrane Separation Processes

Much laboratory and pilot-scale work has been done with membrane separation processes to recovery and reuse dyestuffs from dye wastewater. Most notable are the use of hyperfiltration on continuous dye range wash water, and the use of ultrafiltration on wastewater from indigo dyeing. Hyperfiltration has been demonstrated as capable of producing a high quality water that can be recycled. For the process to be economical, however, the concentrated recovered dyestuff stream must be reused. Full-scale testing at one finishing mill is presently attempting to resolve problems in this area.

Ultrafiltration of indigo dye wastewater has been demonstrated, and full-scale applications are now in place. The problem of dyestuff concentrate reuse is very much simplified in this application because only one dyestuff, rather than numerous mixtures, is used in dyeing. Limited future applications of membrane separation processes for dye wastewater recycle and reuse are seen at mills with large quantities of single dyestuff use, such as denim mills (indigo dye) and industrial fabric mills. More widespread use will depend on whether the problems with mixed dyestuff concentrate reuse can be resolved.

Coagulation

An alternate technology for dyestuff recovery has been investigated. Vat and sulfur dyes can be coagulated and removed from dye wastewater by the dissolved air flotation process. One full-scale application with indigo (vat) dye was built in the 1970's. While limited reuse was shown in the pilot-scale tests leading to full-scale design, dye recovery was never totally demonstrated before the mill closed, and treated water recycle proved too costly. Ultrafiltration appears to be a proven alternative to coagulation/flotation in this application; therefore, no future applications of coagulation technology for dyestuff recovery are expected.

Other Technologies

Numerous examples of countercurrent use of wash water exist, and more widespread use can be expected due to the benefits of water and energy savings as well as the low capital cost involved.

Reuse of final rinse water for batch dyebath makeup has also been demonstrated at many textile mills. More widespread use of this technology is also expected since it involves only procedural changes to attain the cost benefits of water savings.

Printing

Printing wastes contain excess pigments, dyes, and solvents used in the printing process. Equipment cleaning water can be treated by coagulation/flotation and filtration, if needed, to produce a water that can be recycled for cleaning. Solvents, if used, can be extracted from the float and recovered for reuse. In some cases, cleaning water may require only filtration prior to direct reuse.

In mills where soaping or washing of the printed fabric is performed, countercurrent flow of washwater can be instituted. Cross-process use of soaper water in other processes, such as backgray washing, may be feasible.

Many finishing mills with printing operations are primarily involved in dyeing fabrics and perform only a limited amount of printing. Institution of coagulation/flotation facilities at these mills is not considered to be cost effective. A smaller number of finishing mills have extensive printing operations; many of these have coagulation/flotation facilities in place but ony recover solvents or pretreat their printing wastewater prior to discharge. Expanded use of recycle of wastewater at these mills appears promising. But the further expansion of printwater recycle is not likely at printing mills that currently have no coagulation/flotation facilities, due to the high capital costs of the recycle technology and the long payback period involved. Further use of countercurrent flow on soapers can be expected due to the low capital cost and potential water and energy savings.

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The complete report consists of two volumes, entitled "Wastewater Recycle and Reuse Potential for Indirect Discharge Textile Finishing Plants:"
"Volume 1. Technical Report," (Order No. PB 84-174 150; Cost: $19.00"
"Volume 2. Six Mill Engineering Reports," (Order No. PB 84-174 168; Cost: $29.50"

The above reports are available only from: (cost subject to change)
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