

**Source Reduction Research Partnership**  
Metropolitan Water District of Southern California  
Environmental Defense Fund

## **Source Reduction of Chlorinated Solvents**

# **TEXTILES MANUFACTURE**

**Prepared for**

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## DISCLAIMER

The statements and conclusions of this report do not necessarily represent those of the State of California, the U.S. Environmental Protection Agency or any other contributors. The mention of any commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

PREFACE

This report is one of twelve reports that evaluate the opportunities for source reduction of chlorinated solvents in twelve specific industries. The twelve reports are part of a large-scale study sponsored by the Source Reduction research Partnership (SRRP), a joint venture by the Metropolitan Water District of Southern California and the Environmental Defense Fund. The reports cover the following industries and industrial practices:

1. Aerosols Manufacture
2. Adhesives Manufacture
3. Chemical Intermediates Manufacture
4. Dry Cleaning of Fabrics
5. Electronic Products Manufacture
6. Flexible Foam Manufacture
7. Food Products Manufacture
8. Paint Removal
9. Pesticides Formulating
10. Pharmaceuticals Manufacture
11. Solvent Cleaning
12. Textiles Manufacture

The objectives of the SRRP study include a survey and evaluation of existing and potential techniques for reducing the generation of halogenated solvent wastes, and thus their potential release into the environment, across a wide range of the industrial users of these solvents.

Each of the industry-specific reports begins with a description of the industry and processes where halogenated and solvents are used. Sources and causes of releases are described and regulatory regime discussed for waste streams of concern. Subsequent sections focus on source reduction opportunities through chemical substitution, process modification, product substitution and recovery/reuse. For major solvent using industries, select source reduction options were analyzed for their economic feasibility.

The information in the reports was compiled and analyzed by the SRRP project staff, employed by the Partnership to carry out the project research. Each report was reviewed by industry representatives and/or other experts familiar with the specific industry and the relevant technologies and issues, and then reviewed and edited by an additional expert consultant.

The intent of the sponsors is to provide all interested parties with useful information on available and potentially available methods for source reduction of halogenated solvents, in the context of specific industries and processes, and an evaluation in context of the various source reduction options.

## I. INTRODUCTION

The five major chlorinated solvents most widely used in commerce today include trichloroethylene (TCE), perchloroethylene (PERC), 1,1,1-trichloroethane (TCA), methylene chloride (METH), and 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113).

This report is one of several companion reports that focus on source reduction of chlorinated solvents and evaluate source reduction opportunities in a number of industries where these solvents are used for a variety of different purposes. This document specifically describes the use of chlorinated solvent in textile processing and provides an assessment of the source reduction potential in that industry.

Chlorinated solvents are used in a number of operations in the textile industry. Most of PERC and CFC-113 is used in textile processing for scouring--mainly of double knits, and polyester knits. Minor quantities of TCA, TCE and CFC-113 are used for the scouring of wool. PERC is used as a solvent for water repellents and for melting agents and dyes in dyeing operations. TCE is used as a swelling agent in disperse dyeing of polyesters and is also used for removal of basting threads. TCA and PERC are used as cleaning fluid for the removal of spinning oils and lubricants from equipment by textile processors.

The textile industry uses about 10.5 thousand metric tons (mt) of chlorinated solvents annually. About 7 thousand mt of TCA, 2 thousand mt of PERC, 1 thousand mt of TCE, and less than 0.5 thousand mt of CFC-113 are employed.

Chlorinated solvents have been and likely will continue to be used to some extent in the textile industry. The use of PERC, which is exclusively used for polyester double knit scouring, has declined largely because of a shrinking knit market in the last decade. Several factors including the flood of imports into the textile industry and the shutdown of some operations and their movement overseas to the sources of fabrics, has encouraged U.S. mills to become more efficient. Plant modifications have resulted in faster and cleaner production of goods which require less cleaning and scouring (Dow, 1987).

Health and environmental concerns which in the past have pushed companies away from chlorinated solvents, continue to do so. The common replacements for chlorinated solvents, such as aqueous scouring, use additives and other chemicals which pose other kinds of environmental problems.

Prior to 1970, TCE was the chlorinated solvent most widely used. Initially, many users moved to chlorinated solvents in the textile industry because of the problems with using aqueous systems. However, the use of TCE, a suspect carcinogen which was also linked to photochemical smog, declined considerably. TCE was initially replaced by PERC in the textile industry. Both TCE and PBRC historically have been regulated as contributors to photochemical smog.

In recent years, some users have converted back to water in cases where it is technically feasible because of increasing regulatory scrutiny of the chlorinated solvents. Aqueous scouring generally requires pretreatment prior to sewer discharge and appropriate sludge disposal. Aqueous scouring is also more energy intensive.

This document examines a number of source reduction opportunities including chemical substitution, process modification, recovery and reuse of vapors, recycling of waste solvent and housekeeping measures. These options together with their advantages and disadvantages are summarized in Table 1.1.

Chemical substitution on the average has "small" potential. Alternative chemical substitutes probably cannot totally replace chlorinated solvents in the textile industry in the near future, and the substitutes available have certain drawbacks. Low molecular weight organic solvents are potential alternatives for most chlorinated solvents but they are photochemically reactive and flammable. HCFC-123 and HCFC-141b are not believed to be suitable as replacements for CFC-113. HCFC-225, a product being offered by a Japanese firm, has properties that are very similar to those of CFC-113. If it does not prove to be feasible, additional R&D may be required to find a suitable alternative.

Process modification--especially conversion to aqueous and emulsion systems--is promising where technically feasible. Alternative systems are presently available and can be adopted immediately.

In dyeing and printing, some new technologies such as liquid ammonia dyeing, the "Air Lift" Dye System, and heat transfer printing have been introduced. The extent to which these technologies can replace chlorinated solvents is not known.

Solvent losses to the atmosphere can be reduced if vapor recovery methods are implemented at facilities. Use of waste recovery methods can reduce solvent use further. Because such methods are already employed by a large number of users, the potential for additional solvent use reductions through adoption

Table 1.1

SOURCE REDUCTION OPTIONS OF CHLORINATED  
SOLVENTS IN THE TEXTILE INDUSTRY

<u>SOURCE REDUCTION OPTION</u>	<u>ADVANTAGES</u>
<u>Chemical Substitution</u>	
o Low Molecular Weight Organic Solvents	<ul style="list-style-type: none"><li>o Solvents are currently available</li><li>o No stratopheric zone depletion potential</li></ul>
o HCFC-123, HCFC-141b and HCFC-225	<ul style="list-style-type: none"><li>o Low ozone depletion potential</li></ul>
<u>Process Modification</u>	
o Aqueous Scouring	<ul style="list-style-type: none"><li>o Non-toxic, non-ozone depleting chemicals available</li><li>o Technology has already been developed</li><li>o Can remove some impurities that solvents cannot</li></ul>
Emulsion Scouring	<ul style="list-style-type: none"><li>o Leaves a film that can protect some fabrics</li></ul>
Aqueous Dyeing	<ul style="list-style-type: none"><li>o Reduces BOD of waste</li></ul>
Liquid Ammonia Dyeing	<ul style="list-style-type: none"><li>o Short dyeing times</li><li>o Adaptable to many fibers and dyestuffs</li><li>o Can increase productivity of operation</li></ul>
"Air Lift" Dye System	<ul style="list-style-type: none"><li>o Low water and energy consumption</li></ul>
<u>Recovery &amp; Reuse of Vapors</u>	
o Carbon Adsorption	<ul style="list-style-type: none"><li>o Can recover PERC, TCE and CFC-113</li></ul>
o Polymeric Adsorption	<ul style="list-style-type: none"><li>o Suitable for recovering TCA and other solvents</li><li>o Easy to regenerate adsorbent</li></ul>
o Brayton Cycle Heat Pump	<ul style="list-style-type: none"><li>o Potential for low capital operating costs</li></ul>

Table 1.1/Advantages (cont'd)

- o Membrane Separation System o No secondary hazardous waste streams are generated

Recycling of Waste Solvent

- o On-site Recycling
  - o Avoids danger of releases during transport of wastes
  - o Use of on-site stills can reduce solvent consumption by 20%

- Off--site Recycling
  - o 50% to 90% by weight of solvent wastes can typically be recovered
  - o Recycled solvent is 30% to 90% the cost of virgin solvent

Housekeeping Measures

- o Low implementation costs
- o Quick returns on investment

Table 1.1/ (cont'd) Disadvantages

<u>SOURCE REDUCTION OPTION</u>	<u>DISADVANTAGES</u>
<u>Chemical Substitution</u>	
o Low Molecular Weight Organic Solvent	<ul style="list-style-type: none"><li>o Flammable</li><li>o Toxic</li><li>o Photochemical smog precursors</li></ul>
o HCFC-123, HCFC-141b and HCFC-225	<ul style="list-style-type: none"><li>o Limited commercial production at present</li><li>o Results of toxicity test not yet known</li></ul>
<u>Process Modification</u>	
o Aqueous Scouring	<ul style="list-style-type: none"><li>o Less effective than solvents for oil removal</li></ul>
o Emulsion Scouring	<ul style="list-style-type: none"><li>o Employs some solvents</li></ul>
o Aqueous Dyeing	<ul style="list-style-type: none"><li>o Increases COD of wastes</li><li>o High level of dissolved solids in waste waters</li><li>o Color contamination of waste waters</li></ul>
o Liquid Ammonia Dyeing	<ul style="list-style-type: none"><li>o Ammonia can contribute to the hazardous nature of the waste streams</li></ul>
o "Air Lift" Dye System	
<u>Recovery &amp; Reuse of Vapors</u>	
o Carbon Adsorption	<ul style="list-style-type: none"><li>o TCA recovery requires special equipment</li><li>o Secondary hazardous waste streams are generated</li></ul>
o Polymeric Adsorption	<ul style="list-style-type: none"><li>o Secondary hazardous waste streams can be generated</li></ul>
o Brayton Cycle Heat Pump	<ul style="list-style-type: none"><li>o Water must be removed from regeneration gas, or ice will form</li></ul>
o Membrane Separation System	

Table 1.1/Disadvantages (cont'd)

Recycling of Waste Solvent

- o On-Site Recycling
  - o Distillation generates still bottoms, a hazardous secondary stream
  
- o Off-Site Recycling
  - o Spills can occur during transport of wastes
  - o Quality control of recycled solvent can be difficult

SOURCE REDUCTION OPTION

REFERENCES

Chemical Substitution

- o Low Molecular Weight Organic Solvent
- o HCFC-123, HCFC-141b and HCFC-225

- o Cui et al, 1988
- o JAPCA, 1989

Process Modification

- o Aqueous Scouring
- o Emulsion Scouring
- o Aqueous Dyeing
- o Liquid Ammonia Dyeing
- o "Air Lift" Dye System

- o Cui et al, 1988  
GCA, 1983  
Cooper 1980  
Warner 1985  
Whitaker/Stewart 1985  
Christoe & Bateup 1987

Cooper, 1978

Recovery & Reuse of Vapors

- o Carbon Adsorption
- o Polymeric Adsorption
- o Brayton Cycle Heat Pump.
- o Membrane Separation System

- Nucon, 1989
- Wijmans et al,  
undated  
Mtr, undated

Recycling of Waste Solvent

- o On-Site Recycling
- o Off-site Recycling

SPAR, 1989

Housekeeping Measures

of vapor and waste recovery methods is small. Vapor recovery methods are relatively expensive and implementation might require up to 10 years. Furthermore, some of the vapor recovery technologies are unproven and require further investigation. On- and off-site recycling of contaminated solvent can be adopted immediately if the user purchases a still or if the services of an off-site recycler are employed.

Various housekeeping methods and operating practices can contribute to solvent use reduction. These methods offer small reduction potential but can be put into effect immediately.

Section II of this document focuses on the processes that use chlorinated solvents in the textile industry and provides characteristics of the industry structure. Section III provides a detailed description of source reduction options for reducing the use of solvent in the textile industry. Section IV examines recycling options. Finally, Section V summarizes the options and considers the future of the industry.

## II. BACKGROUND

### **PROCESS DESCRIPTION**

Chlorinated solvents are used for a number of operations in the textile manufacturing industry such as scouring, desizing, dyeing, and cleaning. The generic processes which may use one or more of the operations are discussed in more detail in this section.

### **Textile Construction**

Weaving and knitting are the principal methods of fabric construction. Prior to actual weaving or knitting operations, the yarn must be prepared by one or more of the following processes: winding, spooling, warping, and/or slashing (sizing). The purpose of these operations is to transfer the yarn from the type of package which resulted from a spinning or texturing operation onto a type suitable for fabric manufacturing.

As shown in Figure 2.1, the first step of a weaving process is warping. Warping is a winding process in which the warp yarn (longitudinal yarns in a piece of fabric) for either weaving or warp knitting is arranged side-by-side on a large spool (warp beam) to the desired width of the fabric to be woven. Following warping, the yarn which is used for weaving is commonly fed through a sizing (slashing) machine. This is done to consolidate the proper number of warp yarns on the warp beam for the fabric construction and, to coat the yarn with a size (chemical) prior to drying. Usually starch, polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) are used for sizing

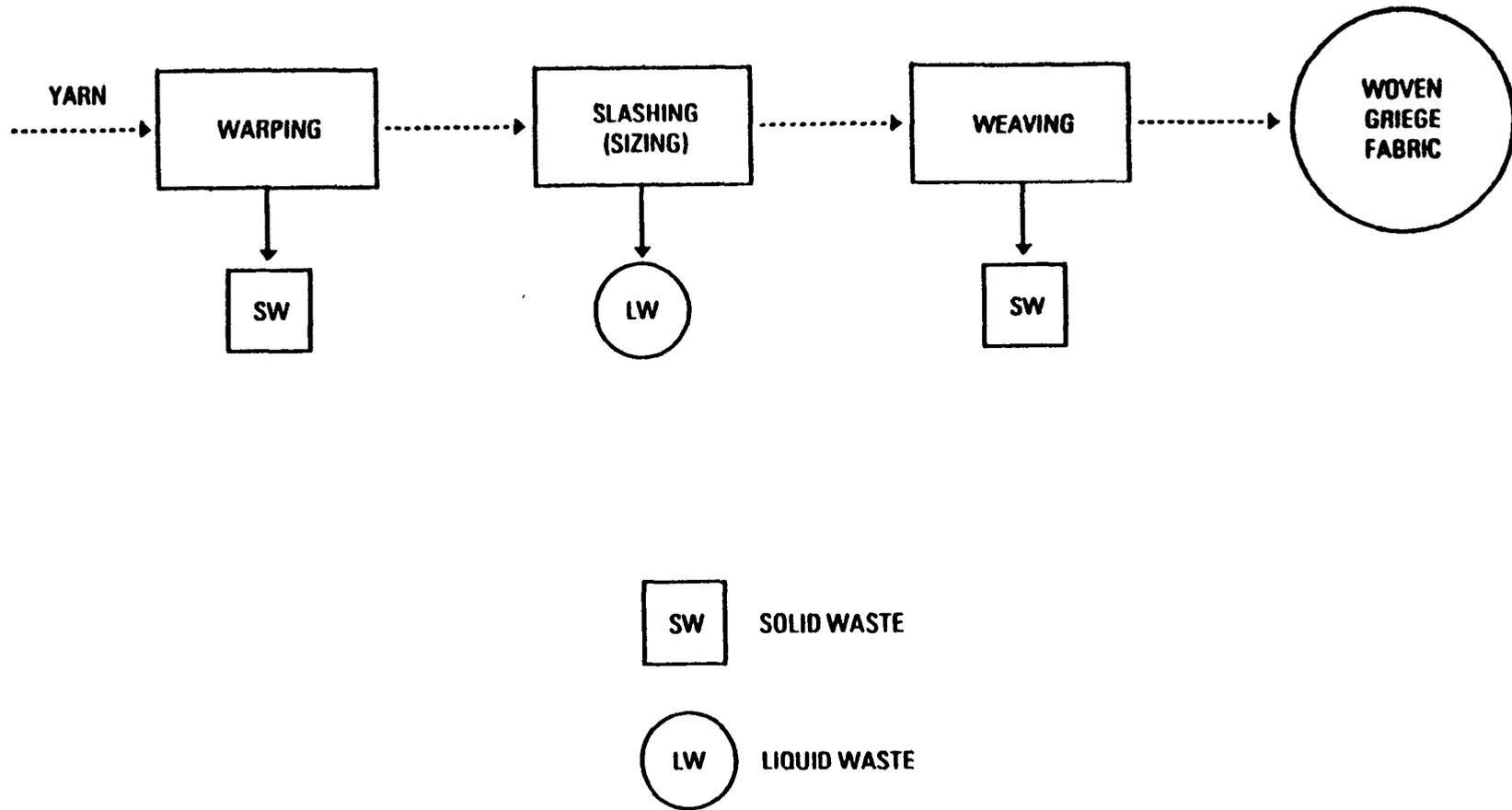


FIGURE 2.1  
*WEAVING PROCESS FLOW DIAGRAM*

SOURCE: COOPER, 1978

operations to allow the yarn to withstand the abrasion of the shuttle as it passes over the warp yarns.

Sizing is also performed to increase the strength of the yarn in preparation for the weaving operation. The sizing solution is contained in a steam-heated vat through which the warp yarns are passed and dried on a series of drying cans. After the sizing process, the fabric is woven and the prepared cloth is transferred to a textile finishing plant.

In knitting, rows (courses) of looped stitches are formed into various types of fabric structures such that each knitted course is looped through an adjacent course. Figure 2.2 shows a process flow diagram for knitting. In preparation for knitting, the yarn is oiled or waxed to lubricate the yarn and consequently increase the speed and ease with which knitting can be accomplished. This step may be accomplished in the knitting mill or during yarn formation.

Lubricating finishes applied to knitting yarns generally are based on mineral oils, vegetable oils, synthetic ester-type oils, or waxes, and may also contain antistatic agents, antioxidants, bacteriostats, and corrosion inhibitors. Specific formulations are held proprietary by the yarn supplier or throwster who applies the finish.

The amount of these lubricating finishes that are applied varies with the type of yarn. General levels of add-on finishes by weight-percent on yarn are: untexturized synthetic yarns, 1 to 2 percent; texturized synthetic yarns, 4 to 7 percent; and cotton yarns 3 percent or less. The knitting oils are in some cases emulsified or soluble in water, and are removed with the wastewater by washing prior to the dyeing operation.

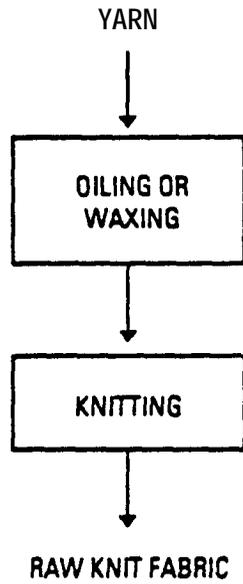


FIGURE 22

*KNITTING PROCESS FLOW DIAGRAM*

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SOURCE: COOPER, 1978

Solvent scouring is used mostly for cleaning synthetic knit and woven goods prior to finishing. Solvents are usually very effective in removing the oils but typically do not remove many of the chemicals that are employed in the preparation of woven goods. Solvent scouring is therefore limited for the most part to the knit fabric segment of the textile industry. Some solvent is also used, however, for scouring of raw wool.

The slashed or finished yarns are either woven or knitted into greige goods, the input of woven fabric and knit fabric dyeing and finishing, respectively. Plants may end processing after yarn preparation, after knitting, or after weaving. However, in larger integrated plants, greige goods production may occur in a sequence of operations beginning with yarn preparation and usually ending with either dyeing and/or finishing the woven goods or dyeing and/or finishing the knit goods. Few integrated plants dye and finish equal amounts of knit and woven greige goods.

### Textile Finishing

Textile finishing is a generic term which refers to the processes used to transform knit or woven greige goods into finished fabric or dye yarn. The basic processes that are employed at woven or knit fabric plants are discussed separately.

### Woven Fabric

Woven Fabric Finishing. The basic processes in a woven fabric finishing plant are fabric preparation, dyeing, printing, and finishing: each is followed by a drying step. The fabric preparation steps are shown in Figure 2.3. In certain cases, some processes may be omitted and the order of the processes in a particular plant may vary from that shown, depending on the

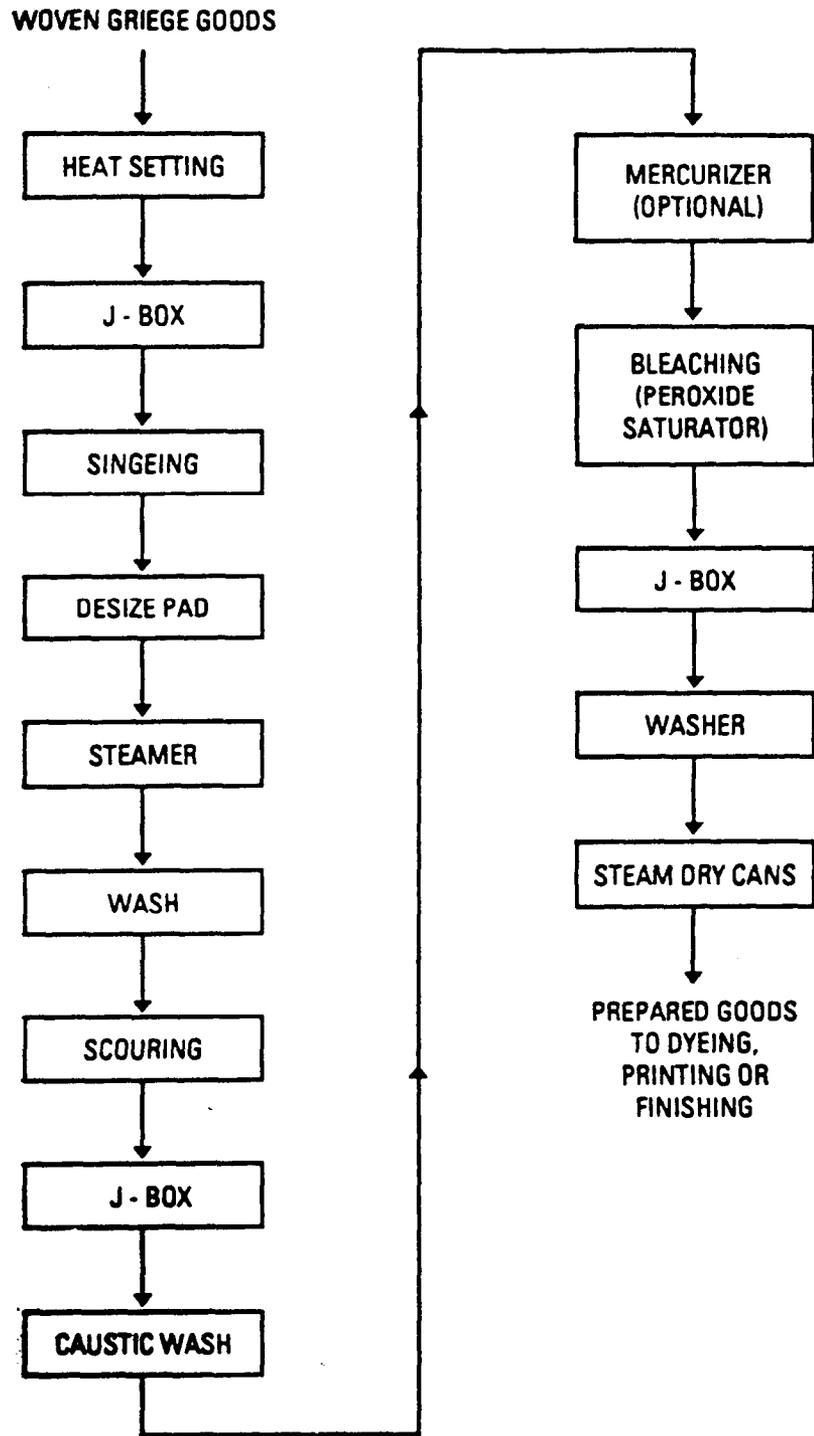


FIGURE 23

**WOVEN FABRIC PREPARATION PROCESS FLOW DIAGRAM**

SOURCE: COOPER, 1978

particular end product that is desired. The preparation process is discussed briefly since it may involve the use of chlorinated solvents.

Initially, heat setting is used on fabrics made of man-made materials in order to stabilize shrinkage which may occur as a result of exposure to hot water in subsequent processing operations. Heat setting is normally accomplished by the application of infrared radiation from a gas fired burner. J-Boxes, so named because they are constructed in the shape of a J, are used to provide the retention time necessary between processing steps to allow various chemical agents to act on the fabric under specific conditions and to provide limited storage on continuous lines to accommodate production surges.

Singeing is a continuous process in which the fabric is passed near a gas burner in order to remove fibers protruding from the surface of the fabric. The flame burns the infusible fibers and melts the thermoplastic fibers so that the surface of the fabric will be smooth.

Before the fabric can be properly dyed, the sizing chemicals applied to the warp yarns in the slashing process prior to weaving must be removed from the fabric. Starch, PVA and CMC are the most common sizing chemicals used. Starches are removed with enzyme systems or sulfuric acid solutions. PVA is removed by washing the fabric with a hot (190 degrees F) detergent solution, using a multiple dip operation with counter-current flow. The desizing solution is padded onto the fabric to achieve a 90 percent uptake and then steamed to increase the reduction rate. After an exposure time varying from a few minutes to 12 hours (depending on the type of equipment and the type of fabric), the desize solution is rinsed from the fabric.

Fabric scouring, where more chlorinated solvents are used, is performed to remove foreign substances such as hydrocarbon oils, Corning oils and silicone and fluorocarbon oil remaining on textile fiber during production of the fabric. In the case of cotton, the natural wax and the starch introduced during the sizing operation need to be removed. The continuous dyeing processes, which are now used, allow only a short time of contact of the cloth with the dye liquid, and hence the cloth must be prepared so as to absorb rapidly and adequately. In addition, scouring can lighten the color and remove moths and any non-cellulosic impurities which may spoil the appearance of finished cloth.

Fabric may be scoured in open width or rope form by applying a solution of caustic, some solvent to remove waxes from man-made and some blended fabrics, or a suitable detergent, and allowing adequate retention time for the solution to remove impurities from the fabric. The fabric is then washed in hot water (approximately 140 degrees F) to remove the scouring solution, only when caustic and detergent solutions are used.

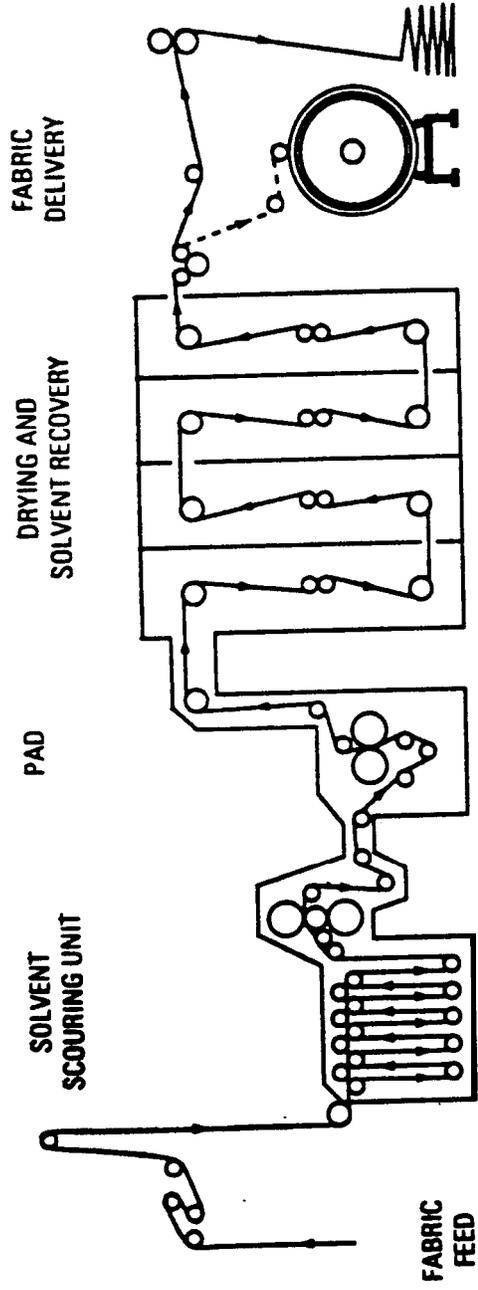
There are two solvent processes for scouring textiles: batch and continuous operations. In the batch process, the solvent is heated and the machine has a system to hold clean solvent, rinse liquor and finished liquors in four to six tanks. The fabric is contained in a perforated drum that rotates in the solvent which is being circulated through the drum. The solvent liquors are removed from the fabric by centrifugation. Fabrics are dried by hot air circulation and solvent is recovered by condensation and carbon adsorption. Contaminated liquid solvent is recycled on-site by distillation (GCA, 1983).

A continuous solvent scouring is depicted in Figure 2.4. Fabric is fed on rollers to the scouring unit. Here the fabric is dipped or sprayed with cold solvent, or immersed in solvent vapor. Following the scouring process, the fabric is wrung and fed to the drying operation. The solvent vapors from the drying operations are condensed and recovered. The spent solvent and the condensate are distilled and reused. Following drying, the fabric is folded, rolled, or sent to a dyeing process. Generally, during the scouring operation, the fabric is supported and tensionless.

During solvent scouring, hydrochloric acid can be formed in the fiber. A 5 to 10 percent moisture content is common in fibers, particularly cotton and polyester/cotton fabrics and this moisture can react with the solvent, forming hydrochloric acid. The solvent remaining in the fabric cannot be completely recovered. About eight percent of the solvent remains in the fabric. The ratio of solvent consumption to fabric in pounds is about one to 10. That is for every 10 pounds of fabric, approximately one pound of solvent is lost (Camp, 1990).

No solvent scouring equipment is manufactured in the U.S. today. CFC-113 machines are manufactured in Switzerland and Germany, and PERC machines are manufactured in Italy as well as Germany (Ramsey, 1990).

CFC-113 is reported to have some advantages over PERC in scouring. The oil recovered by distillation as a part of the scouring process can sometimes be directly reused for sizing of yarns, if the plant employs such processes. Otherwise, it can be mixed with other high BTU oils and sent off-site to a cement kiln or a resource recovery facility. The oil recovered from PERC scouring would commonly contain some PERC residue (because of PERC's high boiling point) and can not be reused for sizing operations (Ramsey, 1990).



**FIGURE 2.4**  
**CONTINUOUS SOLVENT SCOURING RANGE**

SOURCE: GCA, 1983

Table 2.1 shows the effectiveness of CFC-113 conducted in Permasol'> F machines scouring various types of fabrics. Residual oil levels of 0.05 to 0.3 percent generally can be achieved with the scouring agent (Ramsey, 1980). Scouring of polyester fabrics with PERC can also be very effective. It can reduce initial oil content of 4 percent to a residual oil content of 0.05 to 0.3 percent (GCA, 1983).

Some types of fibers that are not commonly solvent scoured are cotton and cotton synthetic blends, although solvent scour patents for cotton fabric exists (U.S. Patent, 1976). In processing cotton fabrics, the cloth may be kier scoured boiled) in a caustic bath to remove any unwanted impurities. In the patented process, cotton goods can be scoured with an emulsion of an aqueous solution of an alkaline compound in a chlorinated solvent. The formulation contains between 40 and 99.5 percent water and 0.5 to about 60 percent of alkaline compound.

Some processes that may use solvents for scouring are finishing of 100 percent synthetics, bast fibers, glass, silk, and metallic fibers. Occasionally fabrics made of wool and other animal hair fibers or blends of wool and synthetics (both woven and knit) are solvent scoured, using PERC or CFC-113.

Scouring of raw wool has been a concern because of the 30 to 50 percent non-wool impurities which have to be removed before processing (Cui et al, 1988). Compositions of these impurities are quite complex and may be divided into the following components: wool wax or lanolin, water soluble material (suint) including dried sweat, urine and protein degradation products, and insoluble particulate material including sand, soil, vegetable and fecal matter.

Table 2.1  
PERMASOL<sup>(R)</sup> F SCOURING TEST RESULTS

Fabrics	Wt Percent Oil on Fabric	
	Before Scouring	After Scouring

A. Knitted Construction

o 100% Polyester Interlock Knit-100 Denier	4.15	0.20
o 100% Polyester Interlock Knit-70 Denier	1.70	0.10
o 100% Polyester Jersey Crimplene	2.40	<0.05
o 100% Polyester Single Knit	2.90	<0.05
o 100% Polyester Single Knit, Processed in Tubular Form	4.10	0.10
o 100% Texturized Polyester Double Knit	1.60	<0.05
o 100% Polyester Double Knit, processed in Tubular Form	2.20	0.10
o 100% Polyester Double Knit, 7.5 oz/yd	3.80	<0.05
o 100% Polyester Tricot Knit	3.60	0.10
o 100% Polyester Lace Knit, 2.4 oz/yd	3.75	<0.05
o 100% Polyester Warp Knit, Texturized Poly Ends, 11.0 oz/lin. yd., 62" Wide	2.10	0.20
o 100% Polyester Double Knit, Yarn-Dyed, 11.5 oz/lin. yd., 64" Wide	1.60	0.10
o 75/25 Acetate/Polyester Knit	2.30	0.20
o 70/30 Polyester/Wool, Yarn-Dyed Knit	7.50	0.30
o 100% Wool, Yarn-Dyed Knit	3.00	0.30
o 100% Nylon Knit, Processed in Tubular Form	4.30	<0.05
o 100% Nylon Knit, Flat Web	5.30	<0.05
o 100% Nylon Lace Knit, 2.6 oz/yd	2.50	0.20
o 100% Nylon Type 66 Knit (4.5 oz/yd )	5.40	0.20
o Acetate/Nylon Knit	3.90	0.20
o 100% Qiana.=. Type 472 Knit, Texturized Yarn	4.30	0.10

B. Woven Construction

o 100% Polyester, Type 54 Dacron.#' Face, Type 242 Dacron.=. Back	2.20	0.10
o 100% Dacron<#. Polyester T-26 Woven Goods	0.80	<0.05
o 20/80 Polyester/Wool Blend	2.30	0.20
o 100% Qiana.#. Type 470 Woven Goods	1.35	0.10

Source: Ramsey, 1980.

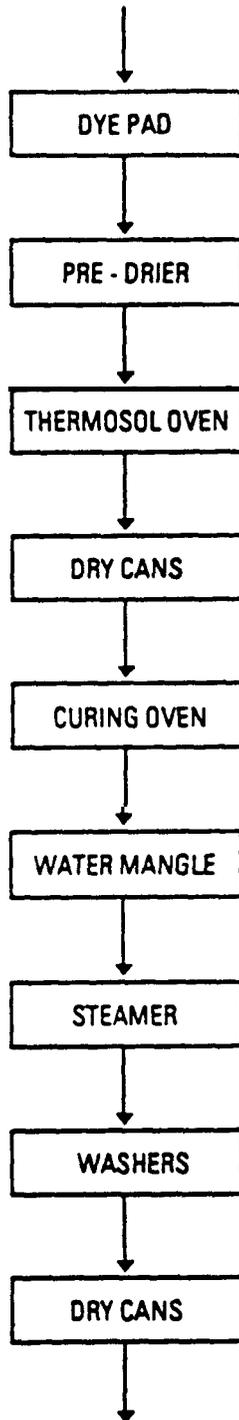
If an aqueous scouring process is employed, the water insoluble wool grease has to be emulsified to remove it from the fiber. The subsequent destabilization to recover grease and minimize pollution is difficult. Wool scouring of a typical 1,000 kg per hour train can produce a considerable effluent load equivalent to that of a town of 30,000 people. Not only PERC, but other hydrocarbon solvents such as kerosene, hexane and petroleum distillates have been used in scouring of raw wool material (Cui et al, 1988) .

Woven Fabric Dyeing. There have been indications of a trend toward solvent dyeing in the early 1980s (Cooper, 1978). This is a process in which a dyestuff is dissolved in a solvent (usually perchloroethylene or methanol) and the fabric is then padded with this solution. The dissolved dyestuff penetrates the fiber and the fabric much more readily than it could in an aqueous solution where many of the dyestuffs are insoluble. The solvent is evaporated leaving the dyestuff chemically entrapped in the fiber. Experimental work on solvent dyeing has been in progress for several years, but the process is not widely used (Cooper, 1978).

Solvent dyeing is commonly employed for 100 percent polyester material, and is reported to have a lower yield than aqueous dyeing. For example, solvent dyeing has a 60 to 70 percent color yield, while aqueous dyeing has a color yield of 85 to 95 percent (Camp, 1990).

Fabric dyeing may be accomplished by either a continuous or batch process. The majority of woven fabric is continuously dyed as shown in Figure 2.5 with pad-squeeze type equipment. In this process, the dye is transferred to the fabric by passing the fabric across rollers which are partially submerged in the dye solution. The moisture content of the fabric is then reduced

GOODS FROM PREPARATION



GOODS TO FINISHING OR PRINTING

FIGURE 25

*WOVEN FABRIC DYEING PROCESS NOW DIAGRAM*

SOURCE: COOPER, 1978

with squeeze rollers in order to conserve dyestuff and hot water or solvent and to reduce drying time. A predrier, usually infrared gas fired, is used to begin the drying process in such a way that the dyes remain evenly distributed through the fabric when water is used. The fabric is then heat-fired in a thermosol oven (for polyesters), dried, and cured. Excess dye is sometimes removed by rewetting and drying the fabric.

Batch dyeing of fabric is most often accomplished in atmospheric or pressure becks or in jet dyeing machines. The particular method selected often depends on characteristics such as level dyeing, batch size, and type of fabric. Methods are somewhat interchangeable. There is a trend toward pressure becks and jet dyeing because they offer better production efficiency and energy savings. Following batch dyeing, pieces of batch dyed fabric are sewn together and dried and cured on a continuous range.

Woven Fabric Printing. Printing is normally accomplished by a semicontinuous flat screen process, a continuous rotary screen process, or a roller printing process. The operation is depicted in Figure 2.6. Either solvent or water based pigments or a mixture of the two can be used. Solvent based printing is normally more energy consumptive than water based printing; a larger volume of air must be exhausted from solvent systems in order to prevent dangerous build-ups of volatile hydrocarbons in the drier atmosphere.

In both flat screen and rotary printing, pigment is applied to fabric in a process similar to silk screening. In roller printing, the pigment is transferred to the fabric with an engraved roller. Following application to the fabric, the pigment is fixed in a brief high temperature curing process and then dried. Synthetic fabrics also require washing with hot

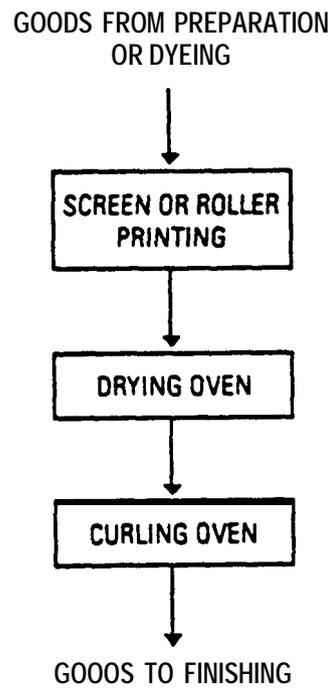


FIGURE 26

*WOVEN FABRIC PRINTING PROCESS*

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SOURCE COOPER,1978

water and detergents to remove excess dye materials with subsequent drying.

Woven Fabric Finishing. Finishing operations normally involve the padding of a specific chemical onto the fabric, drying, and curing to fix the finish. Finishes such as antistatics, fire retardants, softeners, water repellents, and durable press resins may be applied. The chemicals stay on the fabric while the carrier (usually water) is evaporated when the fabric is dried. Drying is accomplished with predriers and drying ovens, and the fabric is then cured in order to stabilize the finish. Levels of waste or wastewater from fabric finishing operations are small because the chemicals are applied by padding.

One industry source indicated that METH--which is not commonly used in the textile industry--was used to coat weather balloons with plastic (Ostrowski, 1990). Other chlorinated solvents are also used in fabric finishing. Some other finishing operations that could involve solvents are application of Scotchgard, Zepel and flame retardants. Dow has marketed solvent ranges for these applications (Oakes, 1987).

### Knit Fabrics

Knit Fabric Finishing. The operations normally utilized in the knit fabric finishing process are shown in Figure 2.7. They may include processes such as scouring that can involve the use of chlorinated solvents.

Scouring of knit fabrics is employed to remove impurities and it can be accomplished by kier boiling, open width or rope form scouring, or solvent scouring. Kier boiling was the original knit fabric cleaning operation. In this process,

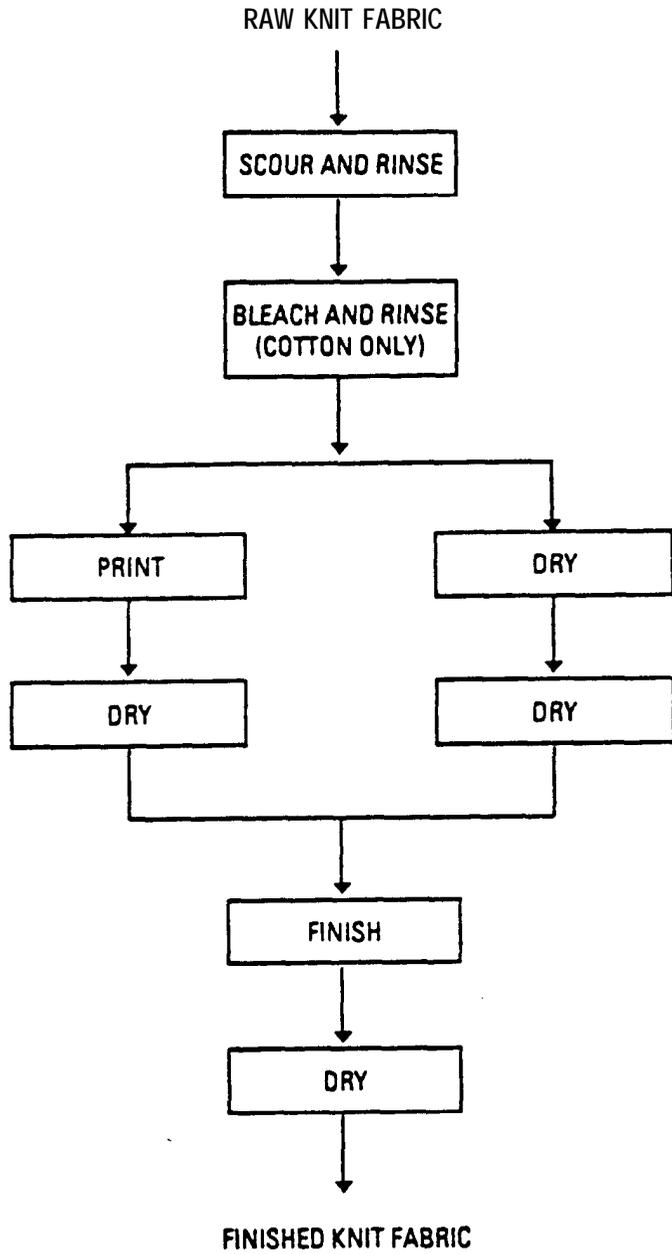


FIGURE 27

**KNIT FABRIC FINISHING PROCESS FLOW DIAGRAM**

SOURCE: COOPER, 1978

several tons of clothes are impregnated with a heated solution of caustic, soap, chelating agents, and sodium silicate for 6 to 12 hours, after which the fabric is rinsed with cool water. Use of the process is primarily limited to lightweight fabrics since heavy weight fabrics show dye creases if scoured in this manner.

Open width and rope form scouring use a more concentrated caustic solution with added antioxidants. Steaming of the fabric assures even swelling and rapid destruction of impurities, which are removed during the subsequent rinsing of the fabric. In the case of fabrics knitted from synthetic yarns, scouring consists of washing with a detergent solution to emulsify the knitting oils, followed by rinsing.

Solvent scouring of synthetic knits has been used in other countries but has not found widespread application in the United States. The solvent used is PERC or CFC-113 and the equipment must be airtight to prevent air pollution and the escape of the expensive or regulated solvent. The solvent may be applied by either high velocity jets or by an immersion method. The process has the advantages that the wastewater load from the scouring operation is eliminated and the cost and energy consumption of subsequent fabric drying operations are significantly reduced. However, solvent purchase costs are high in scouring operations and the use of some solvents can present a worker exposure hazard.

The knit fabric finishing of 100 percent cotton and cotton/synthetic blends uses scouring processing with detergents, soaps or solvents to remove natural and artificial waxes, oils, tints, and other substances in preparation for dyeing. The knit fabric finishing of 100 percent synthetic fabrics includes polyesters, cellulose, nylon and acrylics, and covers both hosiery and outerwear fabrics. These latter operations are

distinguished from the knit fabric finishing of 100 percent cotton and cotton/synthetic blends by the characteristics and volume of the waste: in the case of the cotton and cotton blends, different dyes and solvent scouring are used. A process description of this subcategory is shown in Figure 2.8.

The first step in processing some fabrics using dyed yarns is dry cleaning with a chlorinated solvent rather than scouring in a water solution, eliminating the need for drying. Dry cleaning is only employed by about 10 percent of plants.

A number of other operations in the textiles industry may involve use of chlorinated solvents. These processes are not discussed here, but the reader may refer to Cooper for further information (Cooper, 1978). These processes include yarn dyeing, wool and animal hair scouring for carpet manufacturing, dyeing of raw stock, top or yarn of wool or other animal hair fibers, and floor covering manufacture.

Knit Fabric Dyeing. The majority of woven fabrics are batch dyed using one of a variety of processes, most often pressure or atmospheric becks or jet dyers. However, large lots of knit fabric may be continuously dyed in a manner similar to that described for woven fabrics. Recently, jet dye machines have been introduced for dyeing sensitive fabrics.

In this process, the fabric is placed in the jet dye machine in a continuous loop, which is propelled by a continuous jet of dye liquor. The advantage of this process is that the relaxed fabric allows development of a full hand. The venturi jet turbulence assures good dye penetration, and the process uses less energy and water than other methods of dyeing.

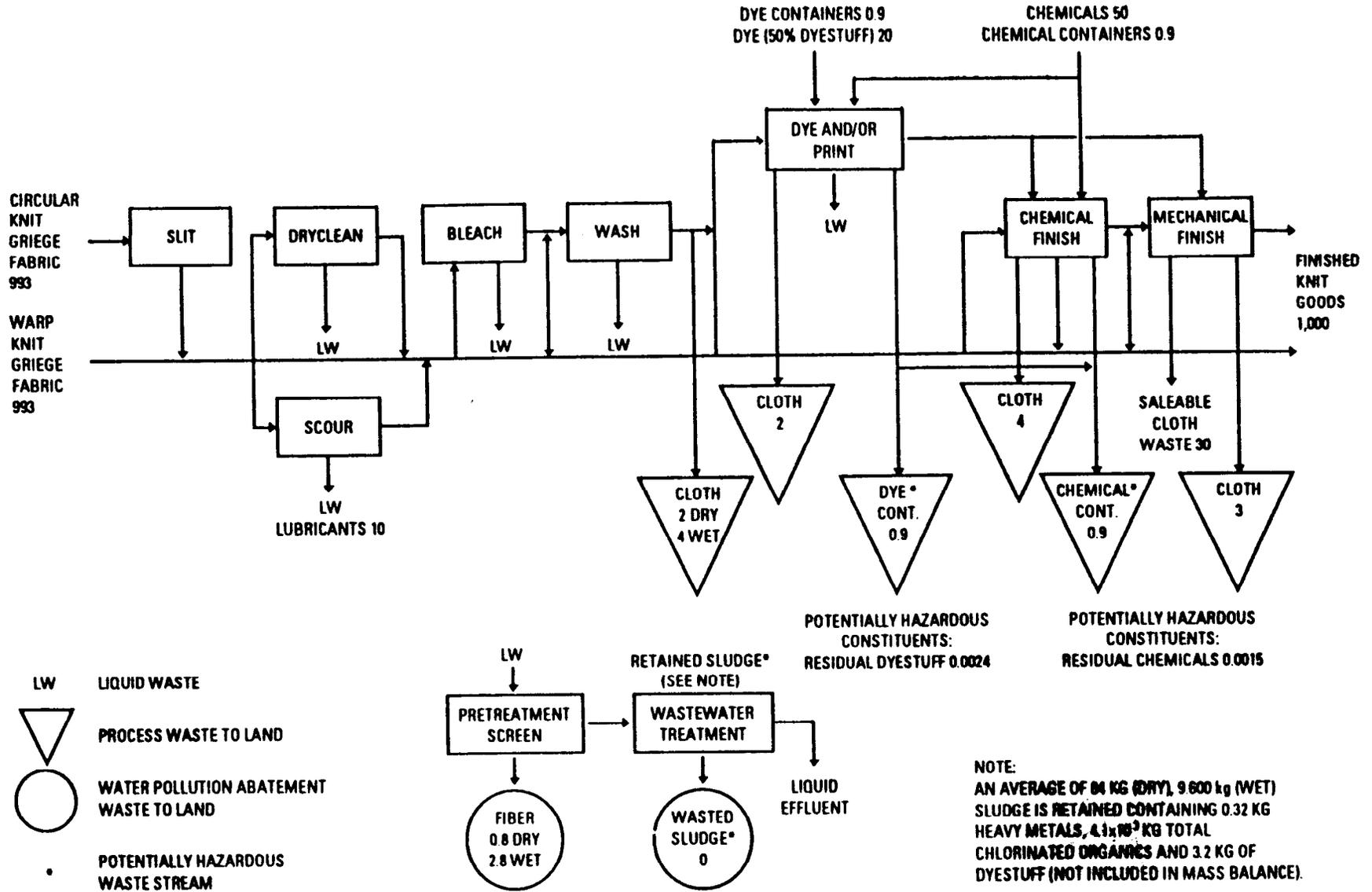


FIGURE 2.8  
**KNIT FABRIC FINISHING OF 100% SYNTHETICS**

SOURCE: COOPER, 1978

Knit Fabric Printing. Printing of knit goods is less common than for woven goods, but may be accomplished with any of the same processes. Heat transfer printing is more common for knit goods than for wovens. The relative importance of the various printing processes in knit goods production is not yet well defined since the knit industry is so new.

Knit Fabric Finishing. Finishing can merely involve washing and subsequent drying of the fabric, or it can involve the application of any of a number of different applied finishes like permanent press or fire retardants. Mechanical finishing operations are less commonly used than for woven fabric.

### Cleaning Operations

Cleaning equipment with chlorinated solvents is a common practice in the textile industry. Chlorinated solvents such as PERC, TCA, and TCE are used to remove oil, wax, grease, and lubrication fluids from equipment. The solvents are applied as cold cleaning agents and they are popular because of their good solvency for organic materials and low heat of evaporation. They are nonflammable, noncorrosive, and relatively stable.

Solvent cleaning is a source of chlorinated solvent emissions and hazardous waste generation. The level of these releases depends on individual operations. The reader is referred to the companion document on Solvent Cleaning for more information on solvent cleaning and possible source reduction measures that may reduce the use of chlorinated solvents.

### AMOUNT OF CHLORINATED SOLVENT USE IN THE TEXTILE INDUSTRY

Chlorinated solvents are used in a number of operations in the textile industry. The extent to which each operation

involves the use of chlorinated solvents or alternative chemicals is not known. Industry sources estimate that a total of approximately 10.5 thousand mt of these solvents are used in a variety of operations. The use breakdown for each solvent is given in Table 2.2.

The use of PERC, which was reported at 16 to 18 thousand mt in 1974, and 18 to 20 thousand mt in 1977 has dropped substantially (SRI, 1982). Table 2.2 indicates that only 2 thousand mt are used currently. This drop could be attributed to regulation of PERC as a photochemical smog contributor and its status as a suspect carcinogen. Many users who employed PERC in scouring operations have converted to aqueous systems entirely. TCA has replaced PERC in spotting and cleaning operations and, as Table 2.2 indicates, its current use is estimated at 7 thousand mt.

CFC-113 is used at only five facilities nationwide. Each employs approximately 150 gallons of the chemical annually (Ramsey, 1990). The use of CFC-113 has declined in recent years because of the threat of the regulation of the chemical as an ozone depleter. The cost of CFC-113 has increased substantially in recent months and a tax of \$1.37 per pound multiplied by an ozone depletion potential of 0.8 was added to its price. This will deter users from adopting the chemical, and it will probably be phased out by the end of the century. TCA may also be regulated as an ozone depleter and could be included in the next revision of the Montreal Protocol, the international agreement that regulates the production of ozone depleting substances.

#### SOURCES OF RELEASE IN THE TEXTILE INDUSTRY

There are three major chlorinated solvent loss mechanisms in the textile industry. The first--emissions to the atmosphere--are process emissions. The second loss mechanism is

Table 2.2

CHLORINATED SOLVENT USE IN THE TEXTILE INDUSTRY  
(thousand mt)

<u>Solvent</u>	<u>Amount Used</u>
PERC	2
TCA	7
TCE	1
CFC-113	0.5
Total	10.5

Source: Dow, 1987; Ramsey, 1990.

waste generation. The third is the water releases. These releases are depicted in Figure 2.9 for a woven fabric finishing plant. Each of these releases are discussed in more detail below.

The textile industry falls into the Standard Industrial Classification (SIC) Code 22. A review of Toxic Release Inventory Data for PERC for SIC Codes 2221, 2231, 2253, 2257, 2258, 2262, 2269, 2287, 2284 shows a range of PERC use among the reporting plants. PERC was used for a variety of reasons: in ancillary uses, as a manufacturing aid, as a formulation component, and as a chemical processing aid. The releases of PERC were reported inconsistently. Some firms reported no waste generation or water releases, while other reported releases to all media. The amount of releases varied greatly among the firms (TRI, 1987).

#### Atmospheric Releases

Although the solvent equipment used for scouring is believed to be equipped with vapor control and the units are totally enclosed, some solvent may still escape such processes. Causes of emissions include carry out of the solvent on fabric, loss of solvent from equipment due to diffusion, filling/draining losses, wastewater losses, solvent recovery still losses, storage tank vent losses, and fugitive equipment leaks from pipes, valves, or pumps. The level of these emissions depends on the type, design, and size of the equipment, the number of hours of operation, and the operating techniques.

#### Hazardous Waste

Chlorinated solvents are used in the textile industry in the scouring operation as degreasing agents and as dye carriers.

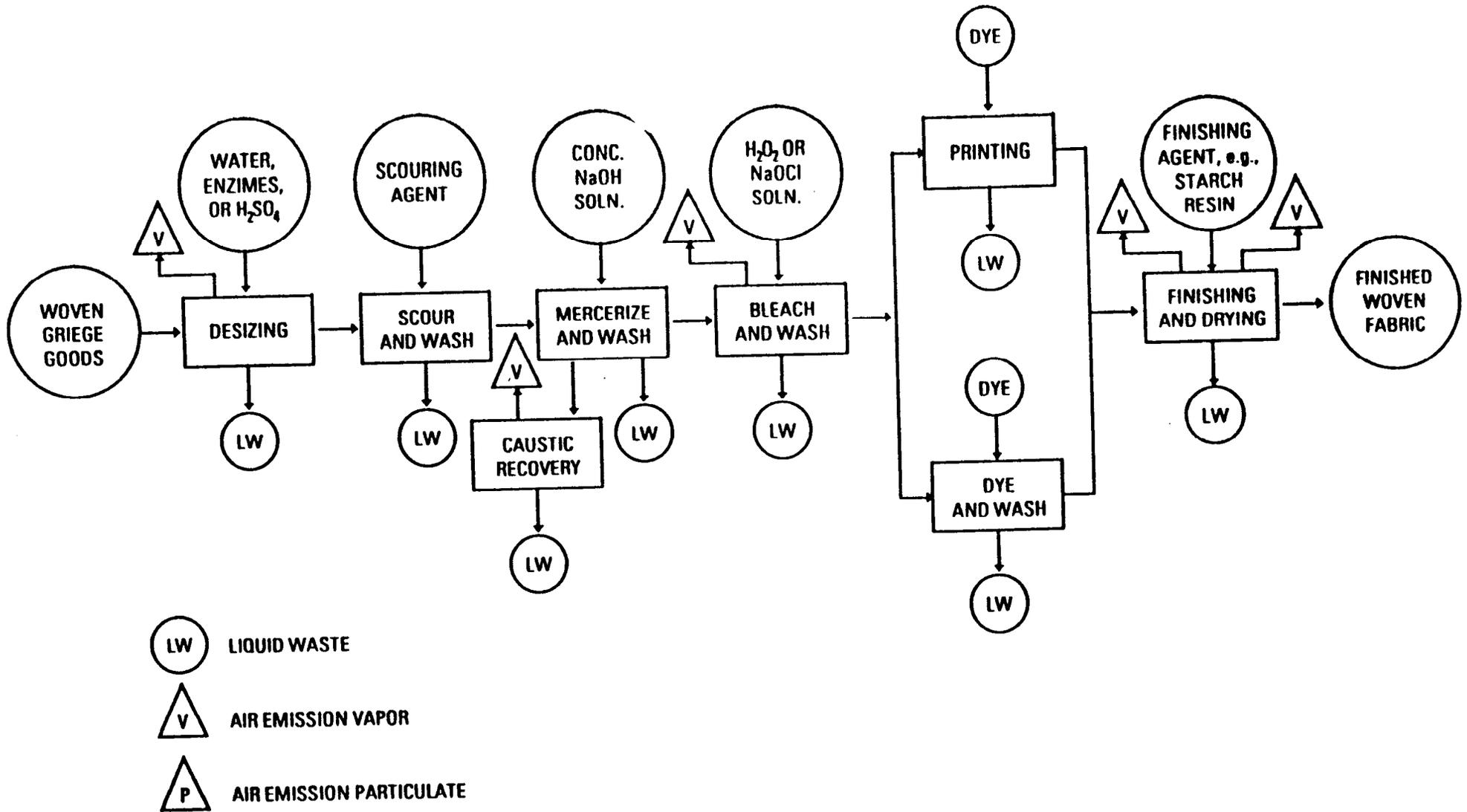


Figure 2.9  
**WOVEN FABRIC FINISHING MILL**

SOURCE: BARNEHARD, 1989

Chlorinated solvents become hazardous waste after use in these operations,

The solvents used as dye carriers contain various dyestuffs which are complex organic compounds that are refractory (nonbiodegradable) and hazardous. Dyestuffs contain heavy metals, such as chromium, copper and zinc, and organics. Only about 50 weight percent of commercial dye is dyestuff. The remainder is usually nonhazardous filler (such as sugar) and surfactant. The dyestuff ends up in the waste solvent which may be recovered on-site or sent for off-site recycling. Some spent dyes may be released to the water treatment systems.

The scouring hazardous waste includes contaminated liquid solvent, bottoms from solvent stills when on-site recycling is practiced, and bottom sludge that arises in cleaning the scouring equipment.

The land disposal ban on chlorinated solvents, which was implemented on November 8, 1986, requires the generators of chlorinated solvents to dispose of these waste by either using the services of an off-site recycler or a destructive incinerator. Recycling companies commonly pick up the waste solvent or the contaminated still bottoms and return virgin, or a mixture of virgin and reclaimed solvent to the company.

#### Water Releases

Chlorinated solvents may be released to water when the fabric is rinsed with water after scouring, as a result of vapor control and water/solvent separation, or when the dyestuff and printing chemicals containing chlorinated solvents are mixed with the wastewater from other parts of the plant.

Wastewater from scouring and rinsing contains natural and processing impurities removed by the hot alkaline detergents or soap solution used in scouring. The waste contains significant levels of BOD, dissolved solids, oil and grease and color. Processing of synthetics alone requires only light scouring, and the waste has lower BOD and dissolved solids, but shows significant increases in COD.

Wastewater concentrations from dyeing and printing are dependent on the process and the various add-ons used. Printing and dyeing wastes are comparable in many respects. In addition to color, the waste can contain high concentrations of BOD and dissolved solids. Printing pigments also introduce suspended solids into the waste stream. Waste flows from finishing are low. Chemicals are applied by padding followed by drying and curing. The chemicals used are diverse, but only small amounts of them enter the wastewater, and the intent is to capture a very high fraction of the active agent on the cloth.

Combined waste from woven fabric finishing mills usually contains 250 to 850 mg/l BOD, 45 to 475 mg/l TSS, 425 to 1,440 mg/l COD, 325 ADMI units of color, and it has a pH of 7 to 11.

The major chemical used in scouring cotton, caustic soda, appears in the wastewater stream. A surfactant and a small amount of sodium phosphate are frequently used, and these also appear in the waste stream. The waste also contains cotton waxes (about 3 to 4 percent of the cotton used). Consequently, scouring liquors are strongly alkaline (pH greater than 12), and dark-colored due to cotton impurities. They contain significant levels of dissolved solids and oil and grease. A modest level of suspended solids results from the presence of cotton impurities. The natural cotton impurities removed from greige fabric by scouring contribute BOD and are biodegraded rapidly.

The scouring of raw wool produces two major waste streams, the scour liquor and the rinse water. The scour liquor comprises 30 to 50 percent of the total waste flow and contains most of the natural, acquired and applied impurities from the grease wool. Waste scour liquor is high in BOD, COD, solids, and grease and is turbid brown in color. Sulfur and phenols or other organics may also appear in the liquor.

#### STATE OF THE INDUSTRY

The textile industry, SIC Code 22, includes the conversion of natural and man-made fibers into fabrics and other textile products. Fibers are processed into yarns which are woven, knit, or otherwise processed into fabric. The fabrics are then dyed, printed, and/or finished.

Products of textile mills are primarily the fabrics that other industries convert into apparel or into household, commercial, or industrial products like upholstery, sheeting, and draperies. A large number of other products are produced by members of SIC 22, the most notable being floor covering (carpets and rugs). Other specialized segments of the industry produce sewing thread, tire cords, twine and rope, and many other products.

The raw material consumption of all textile mills in the country has slowly increased. In the past, cotton was the principal raw material. In 1968, however, man-made fiber consumption surpassed that of cotton and has claimed a progressively larger share of the raw material market. In 1975, 70 percent of the fiber utilized was man-made. The usage of wool has steadily declined to its one percent share of fiber utilized in 1975 Cooper, 1978).

Internationally, textile manufacturing is among the first industries to be established in almost every developing nation. For these and many other reasons, the world textile situation is continuously changing. Textile mills were among the first types of industrial plants established in this country. The early centers of the industry were New England and the Middle Atlantic States.

The textile industry is one of the most fragmented industries in the United States. According to the 1986 Census of Manufactures, 6,152 establishments are part of the industry. However, few carry out all the functions associated with textile manufacturing. The manufacturing processes are conducted by a number of specialists which carry the entire process one or more steps toward completion before transferring (selling) the product to another plant where further processing is conducted. The textile industry contains 10 major SIC classifications and 30 subclassifications. California does not have all types of establishments in this industry. A breakdown of the classifications by number of establishments is listed in Table 2.3. The figures indicate that the number of plants in California accounts for 11 percent of the total plants nationwide.

Table 2.3

NUMBER OF TEXTILE ESTABLISHMENTS (1986)

<u>SLC CODE</u>	<u>NAME</u>	<u>NUMBER OF ESTABLISHMENTS</u>	
		<u>Nation</u>	<u>California</u>
2211	Weaving Mills - Cotton	222	17
2221	Weaving Mills - Manmade Fiber	456	29
2231	Weaving and Finishing Mills - Wool	113	6
2241	Narrow Fabric Mills	262	11
Total	Weaving Mills	1,053	377
2251	Women's Hosiery	164	2
2252	Hosiery NEC	372	2
2253	Knit Outerwear Mills	875	78
2254	Knit Underwear Mills	66	2
2257	Circular Knit Fabric Mills	307	13
2258	Warp Knit Fabric Mills	162	3
2259	Knitting Mills NEC	70	
Total	Knitting Mills	2,138	105
2261	Finishing Plants - Cotton	248	30
2262	Finishing Plants - Manmade Fiber	241	15
2269	Finishing Plants NEC	168	7
Total	Dyeing and Finishing Textiles (except wool fabric & knit goods)	658	52
2271	Woven Carpets & Rugs	57	8
2272	Tufted Carpets & Rugs	311	37
2279	Carpets & Rugs NEC	77	10
Total	Floor Covering Mills	457	55
2281	Yarn Mills, except wool	331	8
2282	Throwing and Winding Mills	149	2
2283	Wool Yarn Mills	76	
2284	Thread Mills	65	
Total	Yarn & Thread Mills	631	10
2291	Felt Goods	38	4
2292	Lace Goods		4
2293	Padding & Upholstery Filling	92	11
2294	Processed Textile Waste	87	5
2295	Coated Fabrics	179	16
2296	Tire Cord & Fabric	20	
2297	Non-Woven Fabrics	113	5
2298	Cordage & Twine	164	13
2299	Textile Goods NEC	189	15
Total	Miscellaneous Textile Goods	1,075	80
22	Total Textile Goods	6,152	679

Source: Bureau of Census, 1986.

### III. SOURCE REDUCTION OPPORTUNITIES

This section examines a variety of source reduction options for the textile industry. They fall into the general categories of chemical substitution, process modification, and improved operating practices and housekeeping measures.

#### CHEMICAL SUBSTITUTION

There are a number of chemicals that are technically feasible substitutes for the chlorinated solvents in textile applications. In what follows, these are identified and some of the most important of these substitutes are described. The three classes of substitutes include the low molecular weight organic solvents, higher molecular weight organic solvents, and alternative HCFC solvents.

#### Low Molecular Weight Organic Solvents

These solvents include the aliphatic, aromatic and oxygenated compounds. Low molecular weight organic solvents comprise one of the possible categories of substitutes that might be used to replace chlorinated solvents in the scouring process.

Table 3.1 shows some of the low molecular weight solvents currently used in scouring operations. These chemicals can be used as substitutes for chlorinated solvents in scouring conducted at room temperature.

One source reports standard batch processes employing flammable solvents. In one batch process called the Maertens process, flammable solvents are used. Another solvent based

LOW MOLECULAR WEIGHT ORGANIC SOLVENTS USED FOR SCOURING

<u>Solvent</u>	<u>PEL (ppm)</u>	<u>Flash Point (° C)</u>	<u>Boiling Point (° C)</u>	<u>Latent Heat Evaporation (cal/gm)</u>	<u>Flammable</u>
N-Hexane	50	-21	68.5	80	Y
Kerosene	NA	38-74	175-325	80	Y
Stoddard Solvent	100	38-49	220-300	80	Y
Methanol	200	11	65.5	28.3	Y
Acetone	750	-18	37.1	131.87	Y

NA is not available.

Source: Cui, et al, 1988.

process using hexane, white spirits, and isopropanol and water, called the Sover process, is a continuous process (Cui et al, 1988).

#### Hydrochlorofluorocarbons (HCFCs)

The CFC producers are investigating a variety of new HCFCs for their solvent properties. These chemicals contain hydrogen which means that they have shorter atmospheric lifetimes than the CFCs, and are thus only minor contributors to ozone depletion.

HCFC-123 (1,1-dichloro-2,2,2-trifluoroethane). A consortium of CFC producers has organized a toxicity program to test HCFC-123 for chronic toxicity effects. DuPont has recently announced that it will build the first large scale HCFC-123 plant in Maitland, Ontario (JAPCA, 1989).

HCFC-123 has a very low ozone depletion potential because it contains hydrogen, it has low photochemical reactivity, good solvent power and stability, low surface tension and it is nonflammable. The chemical has a low boiling point (28.7C) which is advantageous for some applications, but disadvantageous for others. It is likely to be technically appropriate for some cleaning applications. The low boiling point suggests that losses of the chemical would be greater than the other solvents. The HCFC's heat of vaporization and vapor density are higher than those of CFC-113 but lower than those of TCA.

EPA is currently considering a restriction or ban on TCA because it contributes to ozone depletion. HCFC-123 has an ozone depletion potential of 0.02 compared with CFC-11 which has a defined ozone depletion potential of 1.0. This is much less than

TCA's ozone depletion potential of about 0.1. EPA may ultimately regulate other minor contributors to ozone depletion if they achieve widespread use. The regulatory future of HCFC-123, like other new HCFCs, is therefore in question even before it has been produced.

Although HCFC-123 holds promise as a substitute cleaning agent in the textile industry, it probably will not be available for another three to four years until animal testing is complete. HCFC-123 is expected to be much more expensive than other chlorinated solvents. In spite of these disadvantages, HCFC-123 may be used in new, tighter equipment which reduces solvent emissions dramatically.

HCFC-141b (1,1, -dichloro-1-fluoroethane), like HCFC-123 is not a fully halogenated CFC, although it contains chlorine. HCFC-141b has an atmospheric lifetime that is comparable to that of TCA. Like HCFC-123, HCFC-141b has been exempted as a photochemical smog contributor by EPA (Fed. Reg., 1989). The boiling point is low, which means that it needs to be used in tight equipment.

Some major drawbacks of HCFC-141b are that it is moderately flammable, and is somewhat toxic. Flammability can cause workplace problems and would increase the cost for meeting building codes and equipment needs. HCFC-141b has also been found to be a weak mutagen in short-term tests: the CFC producers are now sponsoring chronic tests on the chemical and the results will not be available until 1993. HCFC-141b has an ozone depletion potential of 0.08, almost the same as that of TCA which could mean that EPA may eventually regulate the chemical.

There is an existing commercial production process for HCFC-141b which allows coproduction with HCFC-142b using TCA as a chemical intermediate. The commercial production of HCFC-141b

cannot be initiated until the chemical receives sanction under the Toxic Substances Control Act.

HCFC-123 may actually be a better solvent for fabric scouring purposes. Although HCFC-141b will be cheaper than HCFC-123, the latter chemical is not flammable. Furthermore, the lower ozone depletion potential of HCFC-123--0.02 compared with 0.08 for HCFC-141b--may leave it unrestricted for a longer time period.

It is likely that combinations of the two HCFCs will ultimately be used and they may prove suitable for use in the textile industry.

#### HCFC-225c

This HCFC is a mixture of two different isomers--HCFC-225ca or 1,1,1-trifluoro-2,2-difluoro-3,3-dichloropropane. The properties of the isomer mixture are very similar to those of CFC-113. The solvency (KB value) of HCFC-225a and HCFC-225b are 34 and 30 respectively; this can be compared with the solvency of CFC-113 at 31.

HCFC-225c has not yet undergone animal testing and it will be years before results are available. Asahi Glass of Japan plans to build a semi-commercial plant in the summer of 1990.

#### PROCESS SUBSTITUTION

##### Scouring Operations

Aqueous Scouring. Aqueous scouring is accomplished in batch or continuous processes, and is similar to the solvent scouring process.

Aqueous scouring is currently used in the textile industry to scour fabrics. It employs alkali reagents and anionic or nonionic surfactants to remove the fabric impurities. Alkali compounds commonly used are sodium hydroxide, potassium hydroxide, lithium hydroxide, ammonia and alkali metal alkoxides.

In continuous open-width fabric scouring, the fabric dips into a tank containing detergent and then passes through a pneumatically loaded nip to ensure thorough penetration of the liquor into the fabric. It is then plaited down into a tank containing wash liquor. The fabric sinks through the liquor and is drawn from the bottom of the pile by rollers through opening scroll rolls and a centralizing device onto an endless mesh belt onto which it is held by suction boxes situated under the belt.

While on the belt the fabric is subjected to high pressure sprays of rinsing liquor. The suction boxes draw the rinse liquor through the fabric, removing most before it leaves the belt, at which point the fabric is given a final light pressing.

The substitution of aqueous scouring for solvent scouring necessitates equipment replacement. The equipment to be replaced is dependent on the processes to which the fabric will be subject after scouring. In solvent scouring, the fabric leaves the process dry, while after aqueous scouring the fabric is wet. When the next step in the processing of the fabric is aqueous processing as in the dyeing process, the wet fabric coming from the aqueous scouring machine need not be dried. In this case, the solvent scouring machine would be replaced only by a machine designed for aqueous scouring. However, if the fabric needs to be dry for the next process, as in fabric printing, or if scouring is the last process in the finishing of fabric, which

may be the case for yarn dyed goods, then in addition to substituting the aqueous scourer for solvent scouring equipment, a dryer needs to be added.

Aqueous scouring is generally less effective than solvent scouring in removing oils. As mentioned earlier, aqueous scouring uses alkali reagents to remove oils by the formation of soap with free fatty acids or by decomposition of oils with the formation of soap as part of the reaction. The soap then behaves as an emulsifying agent and removes those substances on which the alkali has no chemical action. Aqueous scouring on the average results in residual oil concentrations of 0.3 to 0.4 percent by weight. Although these levels are higher than those remaining with solvent scouring, aqueous scouring is adequate since a residual oil content under 0.5 percent typically does not pose significant problems. Higher oil concentrations in fabric may make the fabric resistant to dye or print paste (GCA, 1983). Lower residual oils are beneficial when fabric is heat set. The lower oil residue reduces yellowing and oil "mist" thus helping to maintain occupational standards. Thus, the oil level in a fabric depends on specific operation and is case specific.

Aqueous systems can remove impurities in cotton that solvents cannot, and thus can be used for scouring cotton-synthetic blends, as well as 100 percent synthetics.

Aqueous processing can generally achieve process rates comparable to those of solvents. In cases where drying of aqueous systems would not have an impact on processing time, they can be substituted for solvent systems. In cases where the fabric needs to be dried, this additional step would have an effect on production time.

Aqueous scouring is one of the major sources of wastewater from textile operations. Other wastewater sources are from wool scouring, wool finishing, greige goods mills, woven fabric finishing, knit fabric finishing, carpet mills, stock and yarn dyeing and finishing and specialized finishing. Treatment of wastewater from wool scouring using aqueous system has historically posed problems for the wastewater treatment systems (Cooper, 1980; Cui et al, 1988).

A variety of wastewater treatment methods--such as anaerobic digestion and decanter centrifuge, for instance, have been employed (Warner, 1985; Whitaker and Stewart, 1985). Throughout the world, in the last fifteen years, many wool aqueous operations were converted to solvent scouring operations because of the heavy pollution loading of such operations. Raw wool contains wool grease (wax or lanolin, suint water soluble material) and dirt (insoluble) that has to be removed during scouring operations. Wool scouring is one of the highest sources of 5-day BOD ( $BOD_5$ ) in the raw wastewater discharge. The high concentration of mineral dirt and proteinaceous matter in these wastewater streams from wool scouring have led to a high effluent disposal cost (Warner, 1985). The processes commonly employed to treat these contaminants are sedimentation--either by gravity in a settling tank, or by centrifugal acceleration in a decanter centrifuge-- filtration and flotation.

As the wool is moved through the aqueous scouring liquor, the possibility of felting is introduced. If alkali agents such as sodium carbonate are used in scouring heavily soiled wool, fiber damage is possible. The use of an aqueous process means that the water-insoluble wool grease has to be emulsified to remove it from the fiber. The subsequent destabilization of the emulsion to recover grease is difficult (Cui et al, 1988).

Solvent scouring has been adopted as an alternative to wool scouring operations to some extent. The Sover process and the Toa process specify use of chlorinated solvents for wool scouring. The Toa process uses TCA for scouring of wool fibers. An aqueous scour then removes suint and dirt (Christoe and Rateip, 1987). The extent to which this process is used is not known.

### Emulsion Scouring

This process is another possible substitute for chlorinated solvent scouring. Emulsion scouring is a combination of solvent and aqueous scouring techniques. In emulsion scouring, an organic solvent is dispersed or suspended as fine droplets with the aid of emulsifying agents, which disperse the solvent into water, and coupling agents, which control the size of the droplets. The organic components of the emulsion consist of mineral spirits or a similar petroleum fraction sometimes blended with a chlorinated, aromatic, or naphthenic solvent to improve solvency.

Emulsions have neutral to slightly alkaline pH so are not harmful to metals. Emulsion scouring is sometimes followed by alkaline cleaning to remove the last traces of films. Emulsion cleaners leave a light film residue or oil on the parts. Depending on the specific application, the film residue left by emulsion cleaning may be good for protection and resistance of the fabric.

### Dyeing Operations

Aqueous Dyeing. Aqueous dyeing processes can replace solvent-based processes, but can also contribute substantially to textile wastewater generation. Color is a visible problem and a

high level of dissolved solids is expected. Carriers, which are essential for dyeing polyester, and acetic acid have high BOD. With thermosol dyeing of cotton/polyester blends, carriers may be avoided, thus reducing BOD and COD loads.

**Substitution of aqueous dyeing of synthetics would reduce BOD and dissolved solids concentrations but increase the COD of the waste. The wastewater will generally contain 75 to 340 mg/l BOD, 25 to 75 mg/l TSS, 220 to 1,010 mg/l COD, have a pH of 7 to 12, and 600 ADM1 color units (Cooper, 1978).**

Liquid Ammonia Dyeing. This is a new and patented system which uses anhydrous ammonia to dye textiles and other fibers. It seeks to eliminate the problems of water quality, temperature control, long dyeing cycles, steam for heating dye baths and close pH control. As compared to the aqueous system of dyeing, this system uses liquid ammonia instead of water as a medium to carry dyestuffs to the fiber. Liquid ammonia is an excellent solvent which dissolves the dyestuff and allows it to penetrate into the fiber and fabric. At this point the dye particles have little or no chemical affinity for the fiber at low temperatures. The fiber is then subjected to live steam which drives off the ammonia and leaves the dye chemically entrapped in the fiber.

Due to the low boiling point of liquid ammonia (28 degrees F below zero), the ammonia is driven off very quickly, resulting in extremely short dyeing times. The fiber or fabric is then given a light washing to remove excess dye. This system is said to be adaptable to cellulosic and noncellulosic fibers. It is compatible with 95 percent of existing conventional dyestuffs and has the possibility of eliminating most of the preparation processes for dyeing. The ammonia has also been

found to impart a mercerizing and shrinking effect to cellulosic fibers which is very similar to caustic mercerization.

The processing equipment necessary for this system includes a unit for the recovery of ammonia. The ammonia recovery system would mean a large capital investment, but with the increasing cost of all chemicals including anhydrous ammonia, it would be essential to include this recovery unit.

This system requires further experimentation and acceptance by the industry but it appears to have more potential for increasing productivity and decreasing the cost of dyes, chemicals and energy than the standard solvent dyeing methods. It appears to be a very promising alternative to use of chlorinated solvents for dyeing.

"Air Lift" Dye System. The traditional system of dyeing, with a few exceptions, uses a basic jet machine. In the air lift system, the fabric is carried through the machine in a jet of air instead of in a jet of water. This necessitates a large blower system but eliminates the need for a large water pump. Another major change is that the jet machine has to be made larger since the fabric is relatively dry and bulky instead of floating in a 10 to 1 or 20 to 1 water solution. The method of mixing and applying the dye to the fabric must be altered. The dye is mixed in a foaming chemical and applied onto the fabric in the form of a mist.

In the air lift system, the basic dye cycle for polyesters, wool and other synthetics is as follows:

- (1) Application Cycle - The dyestuff is mixed with the foaming chemical and sprayed on the fabric so that a total of approximately 15 percent moisture is applied to the fabric.

- (2) Distribution of Dye - Because of the mechanical action of the foaming agent, heat and a frothy foam is created, which allows the dye to distribute evenly throughout the fabric.
- (3) Rinse Cycle - The rinsing is performed in the same manner as the application of dye, that is, by injecting a water spray into the air stream rather than using a high volume of water.

The total water consumption in this process is approximately 8 to 10 pounds of water per pound of polyester (one gallon per pound) as compared with 40 to 50 pounds of water per pound of polyester (5 to 6 gallons of water per pound) on the regular jet machine. This represents a water reduction in the range of 90 percent at the dyeing operation. Besides eliminating the need for chlorinated solvent in the dyeing process, this method of dyeing appears to be very important in reducing water and heat requirements.

#### RECOVERY AND REUSE OF VAPORS

Recovery and reuse technologies for chlorinated solvent vapors have been available and practiced for years in the textile industry. Several of these techniques are examined that are used today or that are promising for use in the future by the textile industry. These include carbon adsorption, polymeric adsorption, the Brayton Cycle Heat Pump and the membrane separation system.

#### Carbon Adsorption

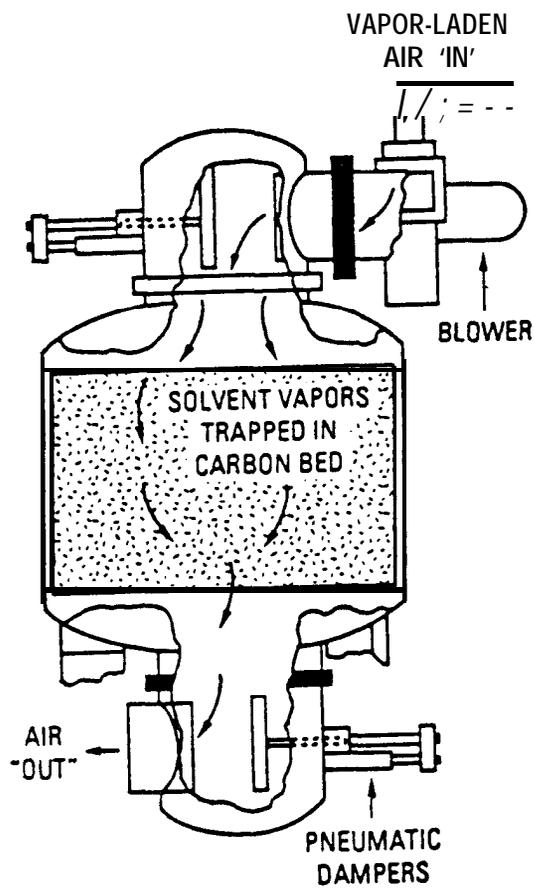
This technology can be used to recover various chlorinated solvents from a vapor waste stream. The solvent vapor and air stream can be channeled to a carbon adsorption unit

for recovery. Higher exhaust velocities do not necessarily result in increased recovery of the material. The higher airflow draws more solvent vapor and can result in disruption of the air/vapor interface causing an increase in emissions. Carbon adsorption systems may be most appropriate for use on large scouring units where the credit from solvent recovery helps to offset the high capital equipment cost.

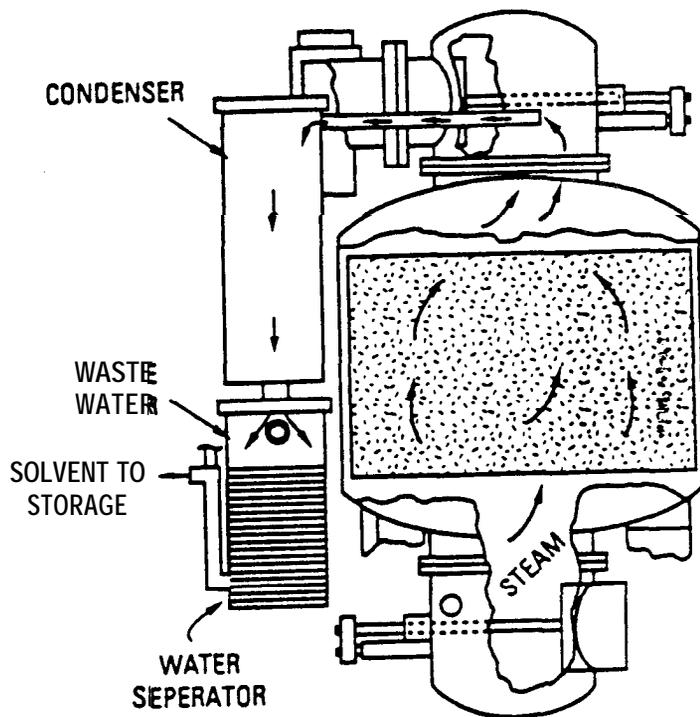
In the adsorption step, the solvent is adsorbed using activated charcoal as indicated in Figure 3.1. The desorption step is generally accomplished with steam. For desorption, the bed is initially heated with steam for 5 to 15 minutes, and then the solvent vapors leave the bed and are routed to the condenser. The solvent and the water phases are then separated by gravity or by distillation.

Proper operation and maintenance procedures are critical to maintain the efficiency of the carbon bed. Examples of operating procedures that have an effect on the operation of carbon bed are: 1) dampers which do not open and close properly to allow the solvent vapor/airstream to pass the bed, 2) use of carbon that does not meet the specifications, and 3) improper timing of the desorption cycles. Desorption cycles must be frequent enough to prevent breakthrough of the bed, but not so frequent to cause excessive energy consumption.

PERC, TCE and CFC-113 can be recovered using carbon adsorption, but TCA requires special equipment. For TCE and PERC, carbon adsorption equipment is normally constructed of mild steel covered with a solvent-resistant coating. TCA is very susceptible to hydrolysis. Consequently, its recovery equipment is often constructed of Hastelloy C and can cost much more than coated mild steel adsorbers.



**ADSORPTION CYCLE**



**DESORPTION CYCLE**

**FIGURE 3.1**

**CARBON ADSORPTION SYSTEM**

Carbon adsorption subjects the recovered solvent to water. This removes the water soluble components, and the recovered solvent may not be directly suitable for recycle and reuse. In the case of TCA, for example, contact with water condensate will remove water soluble stabilizers and the new unstable TCA may decompose and form HCl which can easily corrode equipment. Water pollution problems also may result from the materials dissolved in the discarded water. Indeed, water soluble stabilizers removed during steam desorption will end up in water, and eventually enter the sewer system. For this reason, it may be necessary to use special construction material such as Hastelloy which raises the cost of carbon adsorption even higher. Some chlorinated solvent may also remain in the steam condensate but the residuals are very small.

The carbon used in the carbon adsorber bed must be periodically discarded. Although carbon regeneration is practiced either on-site or off-site, it is recommended that the carbon be completely replaced every 10 to 15 years.

#### Polymeric Adsorption (PA)

PA is a new process developed by Nobel Industries in Sweden, for solvent recovery and purification. The process is based on the adsorption of solvent on macroporous polymer particles, using a fluidized bed technology. Specially developed polymers have been optimized for use as absorbents; they consist of crosslinked polymer particles of styrene divinyl benzene, with an average pore diameter of 80A, and a surface area of about 8600 ft<sup>2</sup>/gr. The diameter of the polymer particles is about 0.02 inches and the specific weight is about 18 pounds/ft<sup>3</sup>. The polymer adsorbent has several advantages according to the manufacturer. First, it is easy to regenerate. Second, it has a

long lifetime, and third, it has no catalytic effect on the degradation of unstable solvents. It is therefore suitable for use with TCA.

The adsorption capacity of the solvents is strongly dependent on the boiling point; the lower the boiling point, the lower the adsorption capacity. Thus it has good potential for use with CFC-113 which has a boiling point of 117 degrees F.

The solvent is adsorbed by the polymer particles as the air passes through the adsorption beds. The flow of air also causes the polymer adsorber to fluidize, and behave like a liquid. A continuous flow of adsorbent through the bed is maintained as the saturated adsorbent is removed from the bottom and regenerated and simultaneously fed at the top of the adsorption section. Adsorbent is then heated to a suitable temperature in the desorber, the released solvent is picked up by stripping air, and the released solvent and air are collected and routed to the condenser. This process continues indefinitely. The process is attractive because it has fewer moving parts and lower energy consumption.

According to the manufacturer, the PA process is specially suited for continuous emission airflows from about 300 scfm to 100,000 scfm and for solvent concentration between 0.005 and 0.1 pounds/1,000 cubic feet. It is especially favorable for humid air, for water soluble solvent, or ones that oxidize in warm humid air. This process is also recommended for solvents with low boiling points (<105 degrees F); however, the incoming temperature should be kept below 90 degrees F. Presently, a pilot test unit and a full scale AB plant are operating in Sweden.

Brayton Cycle Heat Pump (BCHP)

The Department of Energy (DOE) has been supporting the development of the BCHP in conjunction with 3M and Garrett Air Research since 1978. The technique uses a reverse Brayton refrigeration cycle to condense solvents to liquids. It cools gas streams to very low temperatures--commonly -298 degrees F--and condenses the components for collection.

Another regeneration technique has been developed that requires the use of inert gas in combination with BCHP and allows direct reuse of the solvent in the process. The activated carbon adsorbent catalyzes a reaction that produces unwanted by-products and also releases heat which has led to carbon fires. The BCHP eliminates the need for distillation by eliminating water and uses special absorbents which minimize catalytic reaction. The system is identical to a conventional adsorption system during the adsorption cycle. The organic materials are then regenerated using the BCHP process. Hot, inert gas passes through the adsorbent bed and desorbs the adsorbed material. The solvent laden inert gas is cooled, compressed, cooled further and sent through the compressor side of a free-spindle turbo unit. It is further cooled in an interchanger and enters the expander side where it is cooled to as low as -80F.

To prevent ice formation, water must be eliminated from the regeneration gas. Use of either drying steps or appropriate water rejecting absorbents can eliminate the problem. BCHP eliminates the use of steam for regeneration of adsorbents. Because it operates in low pressure vessels, the capital and operating costs of the BCHP are substantially lower than for other systems, according to the manufacturer. This method has been demonstrated at 3M for solvent recovery on commercial sized

magnetic tape manufacturing facilities (Nucon, 1989). But it has never been demonstrated in other facilities for the recovery of chlorinated solvents.

There are two thermodynamic advantages to the BHP method. First, in the Brayton cycle, an increased pressure is used. The dew point temperature of a substance in the gas stream increases as the gas pressure increases. This cycle operates more efficiently than other systems which condense the components at atmospheric pressure. Second, the Brayton cycle employs a turboexpander where most of the work input to the compressor stages is recovered.

#### Membrane Separation System

Another new system is being proposed to collect vapors from airstreams. Synthetic membranes have recently been used to separate aqueous and gas mixtures, and for recovery of hydrogen from petrochemical purge gas streams and other chemical production processes. Since membranes can be tailored to fit a certain mass separation task, they seem to be appropriate for separation problems which are difficult to handle, such as removal of organic solvent from waste air streams. A semipermeable composite membrane is used to separate the organic solvent from air. The membrane modules, which are composite structures made by coating a tough relatively open microporous support membrane with a very thin, dense film, allow a large membrane surface area to be packed into a small volume. The support membrane provides mechanical strength and the thin dense coating performs the separation. Organic solvents are preferentially drawn through the membrane by a vacuum pump and the solvent is condensed and removed as a liquid.

The firm manufacturing the membranes claims that comparison with carbon adsorption shows that the membrane process is more cost-effective if the solvent concentration is relatively high--0.5 percent or higher--and the airstream to be treated is small--between about 100 and 1,000 standard cubic feet per minute (Wijmans et al, undated). It should be noted that the membrane systems do not generate secondary waste streams like carbon adsorption units. Capital costs of the systems are in the range of \$400 to \$1,000 per standard cubic feet per minute (scfm) of airflow with an operating cost of \$0.5 to \$1.00 per 1,000 scfm treated (MTR, undated).

### Housekeeping Measures

A variety of different practices adopted on-site can minimize solvent losses. Proper procedures to start-up/shutdown the solvent scouring machine include starting the condenser coolant flow prior to turning on the sump heater and keeping it on after the sump heater is turned off.

Losses during transfer of solvent into and out of the scouring machine can be minimized if solvent filling, draining, and transfer are performed with enclosed piping systems. Pumping the solvent directly from the drum to the scouring machine could cut down on spills and diffusional losses. If the solvent is pumped into the scouring machine with little or no splashing, such as with submerged fill piping, less solvent would be lost. Leakproof couples can also reduce transfer losses. Emission monitoring can commonly lead to helpful information to evaluate plant practices.

Finally, other measures such as good planning and inventory control, repair of visible leaks and conduct routine equipment inspections, can lead to reduction in solvent use.

#### IV. RECYCLING OF WASTE SOLVENT

There are several methods of reducing the use of virgin chlorinated solvent by recycling contaminated liquid solvent. A number of methods for treating contaminated solvent so that it can be reused are discussed. The techniques evaluated are on-site recycling and off-site recycling.

##### On-site Recycling

Solvent reclamation is one of the most common methods of handling waste solvents on-site. All solvent scouring machines are commonly designed with a distillation system in place. On-site recycling has become attractive because of the high cost of virgin solvent, especially for expensive solvents like CFC-113. The use of on-site stills to recover solvent can result in up to a 20 percent reduction in solvent use.

Chlorinated solvent reclamation is technically feasible because of the stability of most chlorinated solvents and their relatively low boiling points. There are many on-site reclamation techniques that can be employed to reduce solvent use, including single plate distillation, aqueous extraction, sludge or nonvolatile residue removal, and fractional distillation. The most common of these are evaluated below.

On-site distillation equipment falls into three categories: 1) process stills, 2) on-site solvent recovery stills and 3) semiportable ministills. Process stills are used in conjunction with scouring machines. Dirty solvent from the sump of the scouring tank is pumped to the still for distillation, then returned to the tank. Continuous

distillation, which allows continuous cleanup of contaminated solvent, does not require the unit to be shut down as often as required without use of the still. Batch distillation is performed when enough volume of spent solvent is accumulated. The spent solvent is then pumped into the still, distilled and put back in drums or storage tanks.

Single plate distillation, illustrated in Figure 4.1, is the most commonly employed method of recovering solvent: it involves boiling and vaporizing the solvent. The lowest boiling materials distill first and then the high boiling constituents come off. The higher boiling impurities and sludges remain at the bottom of the still. In-house distillation is appropriate for pure solvents and for azeotropes; it is less appropriate for blends or formulations with stabilizers because the solvent must be reformulated before reuse. Stills can be steam-heated, electrically-heated or gas-fired. Still bottoms that result from the distillation process can contain up to 50% solvent: they can be processed further by using steam stripping or thin film evaporation to recover even more solvent. They can also be sent to off-site recyclers (see below) who will reclaim additional solvent.

Repeated single stage distillation can be used to separate close boiling solvents such as CFC-113 [with a boiling point of 117 degrees F) and TCE [with a boiling point of 189 degrees F). Multistage or fractional distillation is accomplished by providing vapor/liquid contact by using column trays or packing.

Another possible method of reducing the amounts of waste being shipped off-site is use of a mobile on-site solvent reclaimer. This service is offered by Solvent Processors and Reclaimers Corporation (SPaR) of Fairfield, Ohio. Mobile on-site

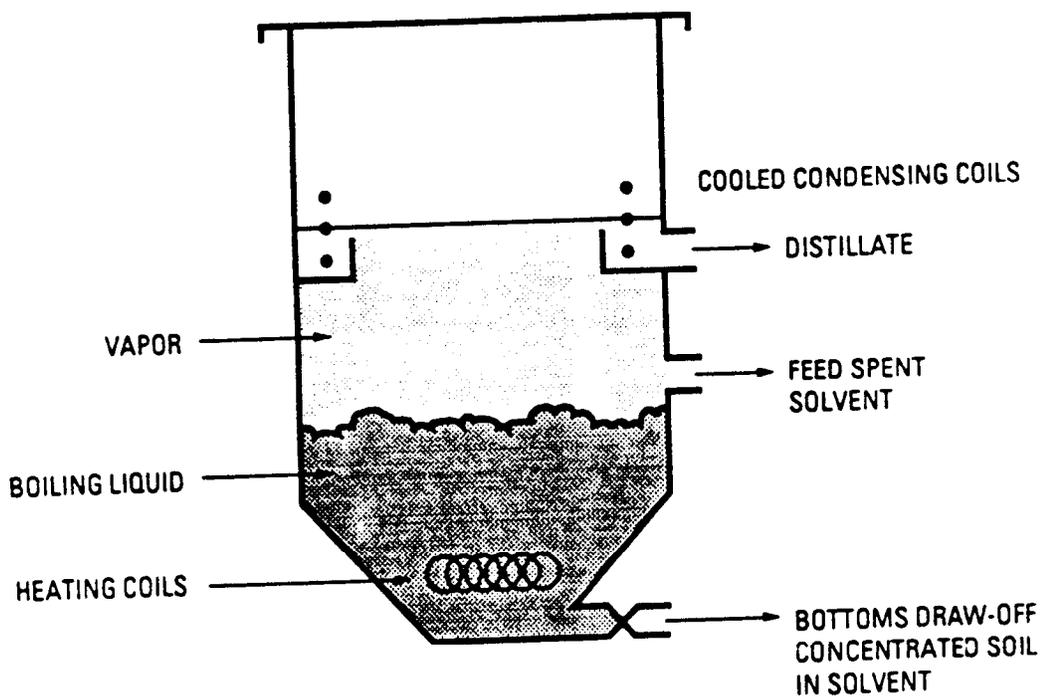


FIGURE 4.1

**SINGLE PLATE, BATCH OR CONTINUOUS STILL**

SOURCE: FREON PRODUCT BROCHURE, DUPONT CHEMICAL COMPANY

recycling is simply a solvent distillation system. The unit pays regular visits to the plant to perform the recycling operation and the recycled solvent is returned to the unit or storage, while arrangement is made to dispose of the still bottoms. SPaR charges a single fixed price for their service which depends on the type and quantity of the solvent to be processed. The charges include the cost of disposal, a payment for the contaminated solvent and the replacement of virgin solvent. The charges are for disposal of the still bottom at about \$5.36 per gallon plus the cost of make-up solvent at \$4.90 per gallon, less the cost of reclaimed solvent at \$4.90 per gallon. For a typical 100 gal spent PERC which contains 40 percent oils, the net cost is about \$299.80 or \$3.00 per gallon (SPaR, 1989).

Mobile on-site reclamation offers a number of benefits including no capital outlay for equipment, elimination of training and other labor costs associated with on-site distillation and elimination of the need for reformulation with dangerous stabilizers.

Aqueous extraction can be used to remove water soluble impurities. Pulsed extraction columns (reciprocating plate), countercurrent, flow-packed columns and simple agitated mixing vessels also allow good mixing and separation of water contaminated solvent. It should be noted that if the solvent contains any water soluble components such as methanol or ethanol, they would be removed in this process.

If the boiling point of the solvent is high (over 200F), as with PERC, for example, the distillation can be done under a vacuum to minimize thermal decomposition of the solvent. Another technique is to inject live steam into the solvent which forms an azeotropic mixture that boils at a lower temperature. The condensate of water and solvent is then separated by gravity.

There are many commercially available distillation systems ranging in capacity from 0.5 to 100 gal/hr with capital costs beginning at about \$5,000 and operating costs of \$1,000 per gallon per hour. The operating costs of the distillation apparatus includes labor, energy, cooling water, and maintenance. The largest component is labor. Of course, solvents have to be segregated in order for the distillation to be effective.

### Off-site Recycling

For generators who are not able either economically or technically to use in-house recovery techniques, off-site reclamation is an option. The recycler, under a contractual agreement, picks up the generator's contaminated solvent which can contain 50 to 90 percent by weight recoverable solvent, recycles it, and delivers purified solvent back to the generator or sells it back to other users. The sludges that result from the off-site reclamation contain small concentrations of solvents and are usually sent for destructive incineration.

In areas with large numbers of users, solvent reclamation is practiced profitably. In rural areas where large distances limit collection and transportation of the waste solvent, off-site recycling is less profitable.

Since the land disposal ban was implemented, reclamation has gained widespread use because of the high cost of other available options like incineration. However, many users question the quality of reclaimed solvent. The reluctance to use recycled solvents is justified to some extent since various kinds of contaminants may be found in some recycled material and no two reclamation firms follow the same quality control standards in recycling. Today, most reclaimers perform analysis and supply

customers with fairly high purity solvent. The cost of recycled solvent varies depending on the situation, but ranges from 30 to 90 percent of the cost of virgin solvent.

## V. RESULTS AND CONCLUSIONS

The chlorinated solvents, although not in widespread use today in the textile industry, will continue to be employed to some extent in the industry.

The flood of imports into the U.S. textile market, and the movement of industry to the sources of fiber, has resulted in a decline in the use of chlorinated solvents and has forced U.S. mills to become more efficient. Although plant modifications have forced the industry to adopt faster and cleaner production methods and perform less cleaning, the use of chlorinated solvents will continue to some extent. Many companies concerned about the health impacts and regulatory future of chlorinated solvents have moved back to aqueous scouring or other replacements.

In recent years, some users have converted back to water in cases where it is technically feasible because of increasing regulatory scrutiny of the chlorinated solvents. Aqueous scouring generally requires pretreatment prior to sewer discharge and appropriate sludge disposal. Aqueous scouring is also more energy intensive.

This document examines a number of source reduction and recycling opportunities including chemical substitution, process modification, recovery and reuse of vapors, recycling of waste solvent and housekeeping measures.

Chemical substitution on the average appears to offer "small" source reduction potential at this time. Available chemical substitutes have certain technical and economic

drawbacks, making one hundred percent replacement of chlorinated solvents unlikely. Low molecular weight organic solvents are potential alternatives for most chlorinated solvents but they are photochemically reactive and flammable. Conversion to available low molecular weight organic solvents would take up to five years. HCFC-123 and HCFC-141b are believed to be not suitable as replacements for CFC-X13. HCFC-225, a product being offered by a Japanese firm, has properties that are very similar to those of CFC-113. If it does not prove to be feasible, additional R&D may be required to find a suitable alternative.

Process modification--especially conversion to aqueous and emulsion systems--is possible where such conversions are technically satisfactory. These systems are presently available and can be adopted immediately.

In dyeing and printing, some new technologies such as liquid ammonia dyeing, the "Air Lift" Dye System, and heat transfer printing have been introduced. The extent to which these technologies can replace chlorinated solvents is not known.

Various housekeeping methods and operating practices can contribute to solvent conservation and use reduction. These methods each offer modest reduction potential, but can be put into effect immediately.

Solvent losses to the atmosphere can be reduced if vapor recovery methods are implemented at facilities. Use of waste recovery methods can reduce solvent use further. Because such methods are already integrated into many textile machines and are employed by a number of users, the potential for additional solvent use reductions through adoption of vapor and waste recovery methods are small. Vapor recovery methods are relatively expensive and implementation might require up to 10

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years. Furthermore, some of the vapor recovery technologies are undemonstrated and require further investigation. On- and off-site recycling of contaminated solvent can be adopted immediately if the user purchases a still or if the services of an off-site recycler are employed.

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