Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

02-Dec-2004

English - Or. English

ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY

Environmental Exposure Assessment

DRAFT EMISSION SCENARIO ON TEXTILE MANUFACTURING WOOL MILLS

Mr. Eisaku Toda
Tel: +33 1 45 24 79 07, Fax: +33 1 45 24 16 73, E-mail: Eisaku.Toda@oecd.org

JT00175156

This document includes a draft emission scenario document (ESD) on textile manufacturing wool mills, submitted by Canada. This document is intended to provide additional information about the published ESD on Textile Finishing Industry [ENV/JM/MONO(2004)12].

Emission Scenario Document for Wool Fabric Dyeing and Finishing Mills

Prepared for

Environment Canada
Environmental Protection Service
New Substances Branch
Place Vincent Massey, 351 St. Joseph Blvd., 14th Floor

GATINEAU, QUEBEC, CANADA K1A 0H3

Contact: Mr. Jonathan Tigner
Tel: (819) 997-5804 Fax: (819) 953-7155

E-MAIL: JONATHAN.TIGNER@EC.GC.CA

Prepared by

Crechem Technologies Inc.
1438 Bradshaw Crescent
Ottawa, Ontario, Canada K1B 5G2
www.crechem.com
Contact: Jesse Shen
Tel: (613) 744-6001 Fax: (613) 744-0573
E-mail: jesse@crechem.com

In association with

JANCO
4 De Caria Blvd.
Perth, Ontario, Canada K7H 3H6
Contact: Joël Jossinet, P. Eng.
Tel: (613) 267-0022
Email: njjoss@superaje.com

July 2004

TABLE OF CONTENTS

TABLE OF CONTENTS 4

1 – INTRODUCTION 6
2 – CANADIAN WOOL FABRIC WET PROCESSING SECTOR 6
3 – WOOL FABRIC WET PROCESSING OPERATIONS 8
3.1 – Process Description 8
3.1.1 – Yarn Spinning 8
3.1.2 – Knitting or Weaving 9
3.1.3 – Fabric Dyeing and Finishing 9
3.2 – Chemical Use 12
3.2.1 – Chemicals Used in Scouring 12
3.2.2 – Chemicals Used in Bleaching 13
3.2.3 – Chemicals Used in Wool Carbonizing 13
3.2.4 – Chemicals Used in Wool Fulling 14
3.2.5 – Chemicals Used in Dyeing 14
3.2.6 – Chemicals Used in Printing 14
3.2.7 – Chemicals Used in Chemical Finishing 14
4 – RELEASE ESTIMATION 15
4.1 – Wastewater 16
4.2 – Solid Waste 17
4.3 – Air Emissions 17
5 – EMISSION SCENARIOS 18
5.1 – Fate of Chemical Agents 18
5.2 – General Approach to Aqueous Emission Estimation 19
5.3 – Emission Estimation Calculations 19
5.3.1 – Emission to Wastewater 19
5.3.2 – Total Chemical Agent 20
5.3.3 – Air Emission 21
5.3.4 – Reaction Loss 21
5.4 – Parameter Defaults 22
5.4.1 – Container Residue 22
5.4.2 – Process Residue 22
5.4.3 – Air Emission 22
5.4.4 – Reaction Loss 23
5.4.5 – Annual Wool Fabric Production 23
5.4.6 – Annual Operation Days 23
5.4.7 – Use Rate, Active Substance Concentration and Fixation Rate 23

GLOSSARY 26
ABBREVIATIONS 27
REFERENCES 28

1 – INTRODUCTION

The purpose of this emission scenario document (ESD) is to provide a realistic worst-case emission scenario for chemicals used at wool fabric dyeing and finishing mills. The information about the processes and chemicals used is derived from a field study, literature data, and several reports from the European Union and the U.S. The emission estimation methods given in this ESD are based on those developed by the Organization for Economic Cooperation and Development with parameter defaults reflecting Canadian operations.

2 – CANADIAN WOOL FABRIC WET PROCESSING SECTOR

The textile industry can be divided into dry processing and wet processing from a standpoint of water usage (USEPA, 1996). The dry processing uses small amounts of water and contributes insignificant load to wastewater generation. On the other hand, the wet processing involves many operations which consume large quantities of water and is, therefore, the primary source of the textile industry wastewater.

In Canada, the wet processing sector consisted of the following six types of mills according to the Environment Canada's 1997/98 survey (Environment Canada, 1998):

- knit fabric dyeing and finishing mills
- woven fabric dyeing and finishing mills
- wool dyeing and finishing mills
- stock/yarn dyeing and finishing mills
- carpet dyeing and finishing mills
- non-woven fabric dyeing and finishing mills

The Canadian wet processing textile mills are concentrated in the provinces of Quebec and Ontario. As given in Table 1, 134 mills out of the total of 145 were located in the two provinces (Crechem Technologies Inc., 1998). The remaining 11 mills are located in New Brunswick, Nova Scotia, Prince Edward Island, and British Columbia.

Table 1 – Distribution of Canadian Wet Processing Textile Mills

Type	**Knit**	**Woven**	**Stock/Yarn**	**Carpet**	**Wool**	**Non-woven**	**Unclassified**	**Total**
Quebec	36	25	8	5	5	0	5	84
Ontario	24	9	5	2	0	7	3	50
New Brunswick	0	2	0	0	1	0	1	3
Nova Scotia	2	2	0	1	0	0	0	5
Prince Edward Island	0	0	0	0	1	0	0	1
Manitoba	0	0	0	0	0	0	0	0
Alberta	0	0	0	0	0	0	0	0
British Columbia	1	0	0	0	1	0	0	2
Total	**63**	**38**	**13**	**8**	**8**	**7**	**8**	**145**

Source: Crechem Technologies Inc., 1998

Wool dyeing and finishing mills were a minor component of the Canadian wet processing sector. As given in Table 2, they accounted for 6% of the total mills, 2% of the fabric processed by the wet processing sector, and 6% of the wastewater generated (Crechem Technology Inc., 2000).

Table 2 – Wool Fabric Mills in Canadian Wet Processing Sector

	Number of Mills	**Quantity of Fabric Processed**	**Quantity of Wastewater Generated**
Wool Mills	8	7.8 million kg/yr	6,300 m^3/d
Industry Total	145	319.7 million kg/yr	103,700 m^3/d
Industry Share	5.5%	2.4%	6.1%

Source: Crechem Technologies Inc., 2000.

3 – WOOL FABRIC WET PROCESSING OPERATIONS

3.1 – Process Description

Figure 1 shows a typical process for wool fabric dyeing and finishing. It consists of three stages: 1) yarn spinning; 2) knitting or weaving; and 3) fabric dyeing and finishing. Water and wastewater treatment are commonly integral parts of a woven mill.

3.1.1 – Yarn Spinning

In the yarn spinning stage, incoming raw materials known as wool tops are first blended with man-made fibres such as nylon, polyester, or acrylic (USEA, 1978; Corbman, 1975; Hall, 1975). Wool tops are wool fibres with the short fibres removed by combing. The wool blend is bleached white by steeping the wool in a warm dilute solution of hydrogen peroxide and then rinsed. The bleached wool blend is scoured with a soap solution and the general method used is to move the fibre through a series of long shallow bowls. This series of bowls contains a warm and slightly alkaline soap solution whose composition varies from bowl to bowl. The first bowl contains a relatively strong soap liquor, whereas the last bowl contains pure running water so as to completely wash out the dirty detergent liquor brought forward by the wool from the previous bowls. The fibre thus becomes cleaner as it passes through each succeeding bowl. Finally it emerges from the last bowl and is then dried.

The wool blend is dyed before yarn spinning (Hollen & Saddler, 1973; Corbman, 1975). The method used is to wind the blend into balls which are in turn placed on perforated spindles and enclosed in a tank. A dye solution is pumped back and forth through the fibre. Upon the completion of dyeing, the fibre is thoroughly washed.

To prepare for yarn spinning the wool blend is further treated with oil followed by carding. As it is unmanageable after washing, the wool blend is usually treated with various oils, including animal, plant, and mineral, or a blend of those to keep it from becoming brittle and to lubricate it for the spinning operation (Corbman, 1975). Carding then follows to partially straighten the fibres and to form them into a thin web (Hollen & Saddler, 1973). Carding is an operation to disentangle fibres by working them between two closely spaced, relatively moving surfaces clothed with pointed wire, pins, spikes, or saw teeth (Farnfield, 1975). It is performed by passing the fibre between cylinders faced with fine wire teeth (Joseph, 1981). That procedure also removes a considerable amount of plant matter, such as twigs and burrs that remain in the fibre after scouring.

The oil-treated, carded wool fibre is then drawn out and twisted into yarn (Corbman, 1975; Hollen and Saddle, 1973; Farnfield, 1975). Two types of yarns can be made from the wool fibre: woolen yarns and worsted yarns. Woolen yarns consist of short staple wool fibres and are chiefly spun on the mule spinning machine, while worsted yarns consist of long parallel wool fibres and are spun on any kind of spinning machines - mule, ring, cap, or flyer. Mule is an intermittent spinning machine, while ring, cap and flyer are all continuous spinning machines. After spinning, the yarn is scoured to remove remaining plant matter.

3.1.2 – Knitting or Weaving

In the knitting or weaving stage, the yarn from the previous stage is dyed in order to have the dyestuff penetrate to the fibres in the core of the yarn (Corbman, 1975). The package dyeing method may be used and involves mounting packages of yarn on posts in a dye beck and forcing a dye solution through the packages from the centre to the outside (Joseph, 1981). The yarn is thoroughly washed after dyeing.

The yarn is further subjected to sizing to prevent damage during the knitting or weaving operation (Joseph, 1981). The sizing is an application of stiffening materials to the yarn with starch being a common agent. Other sizing materials include polyvinyl alcohol, carboxymethyl cellulose, water-soluble salt of acrylic acid and water-dispersible polyester-based material (Olson, 1983). In the sizing operation, the warp yarn passes through a starch solution and then between rollers that pad the starch into the yarn and remove excess solution. The yarn is then knitted or woven into fabrics.

3.1.3 – Fabric Dyeing and Finishing

Prior to dyeing and finishing, the knitted or woven wool fabric is carbonized to eliminate the plant matter contained in the fabric (Joseph, 1981). Carbonization is a chemical finishing operation applied particularly to wool fabrics. Wool yarns and fabrics frequently contain plant matter that is not completely removed during carding and scouring. To eliminate the plant matter, the wool fabric is immersed in a solution of sulphuric acid and then subjected to high temperatures for a brief period of time. Under the combined action of the acid and heat the plant matter is converted into carbon. The fabric is then scoured and rinsed to remove the carbon. Solvents may be used during the scouring.

Fulling is then applied to produce a compact fabric (Joseph, 1981; Corbman, 1975; Hollen and Saddle, 1973). Fulling is a finishing process in which the cloth is washed in a thick soap solution. The fabric is loose and hard in texture prior to fulling. It becomes compact and soft after it is fulled. The fulling involves the use of moisture, heat, and friction to shrink and soften the fabric to the desired texture. The fulling operation is followed by a cold rinse. The compact, soft fabric is further bleached with hydrogen peroxide and then rinsed. It is also subjected to scouring and washing.

The fabric is further dyed using one of three methods: jig dyeing, atmospheric dyeing, and pressure-jet dyeing (Joseph, 1981). In the jig dyeing the fabric moves from one take-up roll to the other through a dye solution and then moves back to the first roll. The procedure is repeated until the desired colour is obtained. The fabric is washed to remove unfixed dyes.

The fabric is finally subjected to both chemical and mechanical finishing operations. Mothproofing is a common finishing operation applied to wool fabrics to prevent damage by moths. Mechanical finishing includes shear and press.

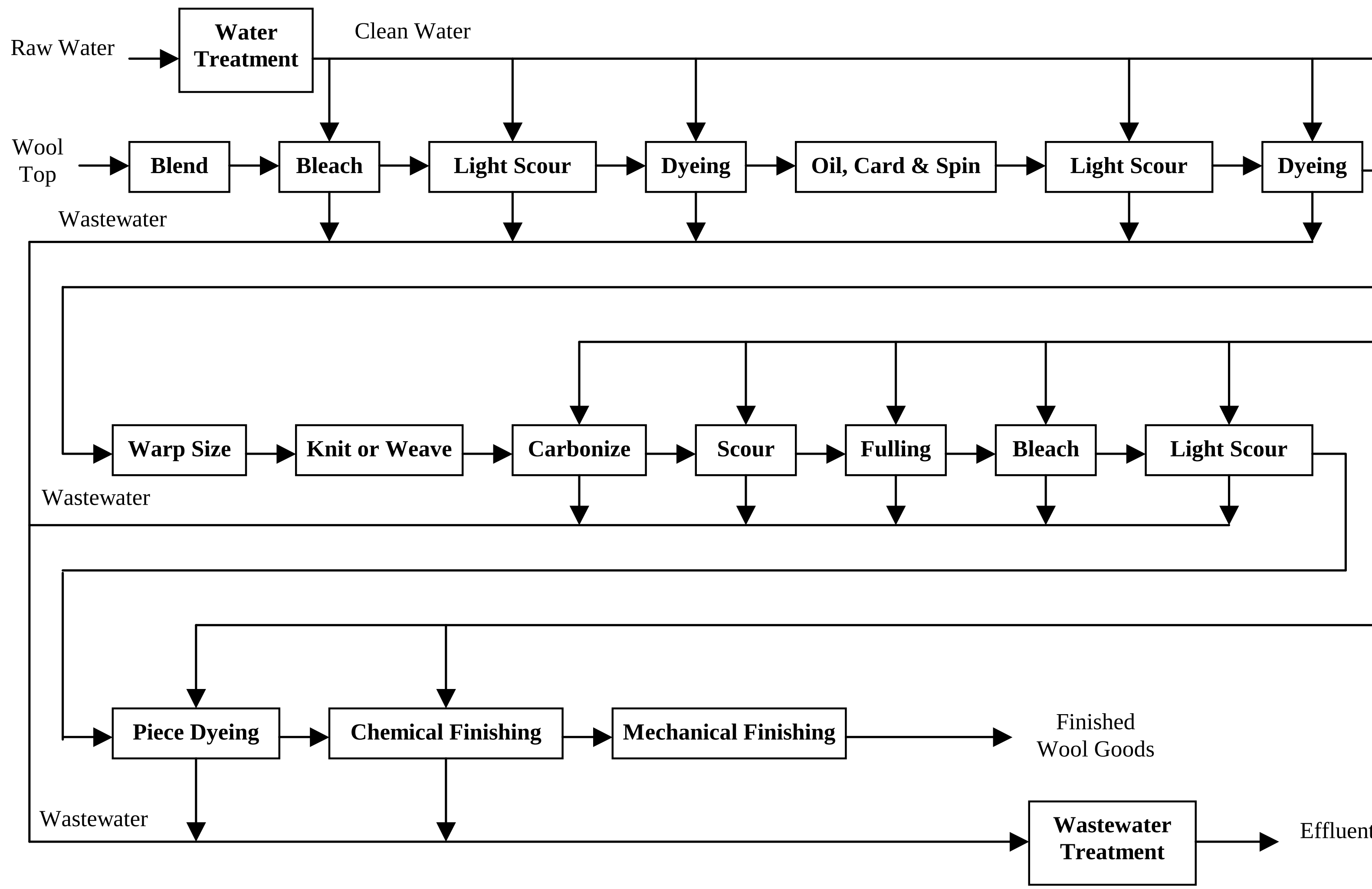

Figure 1 - Typical Process for Wool Fabric Dyeing and Finishing Mills

3.2 – Chemical Use

Chemicals used at wool fabric wet processing mills may be classified into the following categories (Crechem Technologies Inc., 2003):

1) Surfactants
2) Dyes and pigments
3) Dye carriers and auxiliaries
4) Solvents
5) Phosphates
6) Bleaching agents and assistants
7) Salts
8) Alkalis
9) Acids
10) Buffering agents
11) Thickeners
12) Chelating agents
13) Biocides
14) Cleaners
15) Chemicals for boiler and cooling water treatment
16) Chemicals for water treatment
17) Chemicals for wastewater treatment

3.2.1 – Chemicals Used in Scouring

Chemicals employed in scouring can be divided into seven groups (Olson, 1983). The first group contains only caustic soda with which water-insoluble natural oils and waxes react in the presence of water to form water-soluble soaps which are easily removed.

The second group includes soaps and detergents which emulsify oils and waxes (Olson, 1983). In a general sense, soaps and detergents are very similar in terms of chemistry, and the basic principles underlying their action are the same (Carr, 1995). Detergents are, however, much more effective in their action, and their chemical structures can be substantially altered to achieve a variety of effects in a way that is not possible with simple soap molecules.

The third group consists of surfactants which reduce water surface tension and water-oil interfacial tension (Olson, 1983).

The fourth group consists of chelating agents, also known as sequestering agents (Nettles, 1983; Olson, 1983). As important textile auxiliaries, they are used to block active sites of heavy metal ions and, therefore, prevent them from entering undesired reactions.

The fifth group includes penetrants which assist other chemicals to penetrate into the lignin mass of cellulosic materials (Olson, 1983). Sodium silicate is a common penetrant.

The sixth group includes builders which increase the activity or the effect of soaps and detergents (Olson, 1983). Builders are generally salts such as borates, silicates, phosphates, sodium chloride, sodium sulphate, etc.

The seventh and final group consists of solvents which are frequently used in conjunction with detergents in order to dissolve and, therefore, remove more water-insoluble fats and waxes (Olson, 1983).

3.2.2 – Chemicals Used in Bleaching

Chemicals used in bleaching can be organized into five groups (Olson, 1983). The first group consists of bleaching agents which react with colouring matter present in fabrics. Bleaching agents can be further broken down to oxidative and reductive agents (Nettles, 1983). Hydrogen peroxide is a typical oxidative bleaching agent and sulphur dioxide is a typical reductive agent.

The second group consists of buffering agents which are used to control the pH level of a bleaching bath. Buffering agents are either alkalis or acids (Nettles, 1983).

The third group consists of surfactants which reduce water surface tension as well as water-oil interfacial tension. Surfactants may be anionic, nonionic, cationic, amphoteric, or blends of all four types (Nettles, 1983). The most common bleaching surfactants appear to be the anionic type including sulphate, phosphate, carboxymethylate, and methyltaurine. Also in common usage are the nonionic types including ethoxylated primary alcohols, ethoxylated secondary alcohols, mercaptan thioethers, and ethoxylated fatty acids.

The fourth group consists of fluorescent whitening agents which are used to improve the whiteness of textile materials (Adanur, 1995; Nettles, 1983). Fluorescent whitening agents, also known as optical brighteners, function by absorbing ultraviolet light and reflecting it in the blue-white spectrum, thereby exerting an intensifying effect on whiteness.

The fifth group consists of a variety of additives which are used to facilitate bleaching. They include defoamers, antiredeposition agents, sequestrants, etc. Stabilizers such as sodium silicate and sodium nitrate are also included in this group (UK Environmental Agency, 1997).

3.2.3 – Chemicals Used in Wool Carbonizing

Chemicals used in wool carbonizing are divided into two groups. The first group includes acids used as carbonizing agents and sulphuric acid is the most popular choice (Joseph, 1981). The second group includes neutralizing agents with sodium carbonate being commonly used.

3.2.4 – Chemicals Used in Wool Fulling

Fulling or milling is a mechanical finish and accomplished by applying proper amounts of steam, heat, and friction to make wool fabrics compact and soft (Olson, 1981; Hollen & Saddler, 1973). Soap is used in the operation and washed off fabrics in a subsequent rinsing procedure.

3.2.5 – Chemicals Used in Dyeing

Dyes, salts, dye carriers, and many auxiliaries are used in dyeing. Auxiliaries include buffering agents, acids/alkalis, dye-bath lubricants, dispersing agents, chelating agents, anti-redeposition agents, etc. (USEPA, 1996, p.179-183).

The use of reductive agents is also found in dyeing (Smith, 1988). They help remove surface dye from fabric (after-clearing) and from dyeing machines. In addition, they function as antichlor agents to destroy residual chlorine from hypochlorite, chlorite bleaching or stripping prior to dyeing which uses potentially chlorine-sensitive dyes.

3.2.6 – Chemicals Used in Printing

Pigments or dyes, and various auxiliaries are used in printing. Auxiliaries include thickeners, binders, reductants, etc. Thickeners are used in printing to ensure the printed design is precisely located with clean defined edges (Carr, 1995). Many polysaccharides derived from starch-containing plants, seaweeds yielding alginates, plant gums, and cellulose derivatives, particularly cellulose ethers, are used as thickeners in textile printing. They have been developed to substitute for kerosene (USEPA, 1996, p.198). Common binders are acrylic copolymers which allow for 100% fixation of prints. Reductants are used in discharge printing which involves destroying an existing dye in pre-dyed fabrics to replace it with another or to let the ground shade shine through (Cognis, Div. of Henkel Canada, www.cognis.com).

3.2.7 – Chemicals Used in Chemical Finishing

Chemical finishing involves the application of a wide range of chemicals to improve and enhance various properties of a fabric (Chen, 1989). These chemicals are classified into the following groups:

- Abrasion-resistant finishes that improve the resistance of fabrics to abrasion damage.
- Absorbent finishes that increase the moisture-holding power and speed up the drying action of textile.
- Antislip finishes that keep yarns in their proper position in fabrics and reduce seam fraying.
- Antistatic finishes that reduce the static charge of fabrics.

- Antiseptic finishes that control the spread of disease and reduce the danger of infection following injury; help inhibit the development of unpleasant odours from perspiration and other soil in fibrous structures; and reduce damage to fabrics from mildew-producing fungi and rot-producing bacteria.
- Flame retardants that reduce the flammability, charring, or afterglow of fabrics.
- Mothproofing finishes that are applied to fibres, especially wool and wool blends, to prevent damage by moths and carpet beetles.
- Waterproof and water-repellent finishes that coat or seal fabrics so that water does not pass through them.
- Stain- and soil-resistant finishes that prevent stain and soil from penetrating fibres.
- Soil-release finishes that provide a hydrophilic surface attracting water and permitting it to lift off soil or coat fibres so that soil never penetrates.
- Durable-press finishes that enable fabrics to retain an attractive appearance during wear and to return their original smooth surface and shape after laundering.

4 – RELEASE ESTIMATION

Environmental releases from wool fabric wet processing are divided into: 1) wastewater; 2) air emissions; and 3) solid waste. The chemical nature of each group from individual operations is summarized in Table 3 (USEPA, 1997, p.43).

Table 3 – Environmental Releases from Wool Fabric Wet Processing

Process	**Wastewater**	**Air Emissions**	**Solid Waste**
Knitting	little or no wastewater generated	little or no air emissions generated	packaging waste; yarn and fabric scraps; off-spec fabric
Scouring	disinfectants and insecticide residues; NaOH; detergents, fats; oils; pectin; wax; knitting lubricants; spin finishes; spent solvents	volatile organic compounds	little or no residual waste generated
Bleaching	hydrogen peroxide, sodium silicate or organic stabilizer; high pH	little or no air emissions generated	little or no residual waste generated
Dyeing	metals; salt; surfactants; toxics; organic processing assistants; cationic materials; color; BOD; COD; sulphide; acidity/alkalinity; spent solvents	volatile organic compounds	little or no residual waste generated
Printing	suspended solids; urea; solvents; color; metals; heat;	solvents, acetic acid from drying and curing oven	little or no residual waste generated

Process	Wastewater	Air Emissions	Solid Waste
	BOD; foam	emissions; combustion gases; particulate matter	
Finishing	BOD; COD; suspended solids; toxics; spent solvents	volatile organic compounds; contaminants in purchased chemicals; formaldehyde vapours; combustion gases; particulate matter	fabric scraps and trimmings; packaging waste

Source: USEPA, 1997, p.43

4.1 – Wastewater

The Health Canada 2003 field study found that there were several sources of wastewater from wool mills (Crechem Technologies Inc., 2003). The principal source was spent processing baths and rinse water from neutralization, scouring, fulling, bleaching and dyeing. Other sources included cleaning of finish liquor troughs and cleaning of chemical containers.

On average, wool fabric wet processing mills in Canada generated 295 litres of wastewater per kg of wool fabric processed according to the Environment Canada 1997/98 survey (Environment Canada, 1998). This is in line the water use data from the U.S which was reported in the range of 111-658 L/kg with an average of 284 L/kg for wool mills (USEPA, 1996). In general, the wastewater generated can be assumed to be equal in volume to the water used. Table 4 provides water use data on an operation basis.

Table 4 – Water Use by Different Operations and Dyeing Methods in U.S.

Section	Operation or Method	Water Consumption		Liquor Ratio
		gallon/lb	L/kg	kg of water/kg of fabric
Preparation	Scouring	2.3-5.1	19-43	
	Continuous bleaching	0.3-14.9	2.5-124	
Dyeing	Continuous	20	167	1:1
	Beam	20	167	10:1
	Beck	28	233	17:1
	Jet	24	200	12:1
	Jig	12	100	5:1
	Paddle	35	292	40:1
	Skein	30	250	17:1
	Stock	20	167	12:1
	Pad-batch	2	17	
	Indigo dyeing	1-6	8-50	
Finishing	Chemical	0.6	5.0	
	Mechanical	nil	nil	

Sources: USEPA, 1996; Smith, 1988

4.2 – Solid Waste

The Health Canada 2003 field study indicated that small quantities of solid waste were generated from wool mills (Crechem Technologies Inc., 2003). Waste materials designated for landfills were: 1) paper bags and boxes; 2) paper and plastic drums; 3) solids collected from wastewater screening; 4) sludge collected from raw water treatment; 5) plastic bags for raw fibre materials; and 6) residual finishing liquor remaining in finish troughs and collected into plastic drums.

4.3 – Air Emissions

The Health Canada 2003 field study observed many sources of air emissions from wool mills. Air emissions were expected to occur during carbonizing, neutralizing, and drying operations which were open to the atmosphere and partly vented. Volatile substances were also expected to release to the atmosphere when spot removing agents were applied with spray guns. In wet finishing operations, air emissions were expected during drying, curing and heat-setting. Volatile substances could also be released to the atmosphere if any part of on-site wastewater collection and treatment was exposed to air. Dyeing machines did not appear to be a source of air emissions since they were enclosed completely during operations and opened only when rinsed fabrics were loaded or unloaded.

5 – EMISSION SCENARIOS

5.1 – Fate of Chemical Agents

Described in Figure 2 is the fate of a chemical agent used at a facility. The agent is shipped to the facility using one or more types of containers. It is then unloaded or unpackaged and transferred to the production process. The agent leaves the facility via the following routes:

- Container residue that remains in containers after unloading or unpackaging and ends up in wastewater or is disposed of by other means.
- Process residue that remains in process vessels and transfer pipelines and also ends up in wastewater or is disposed of by other means.
- Liquid loss that enters wastewater streams during normal applications.
- Air emission that occurs if the agent contains volatile components.
- Reaction loss that occurs if the agent undergoes chemical reactions during its use.
- Product retention that accounts for a portion of the agent fixed onto finished products.

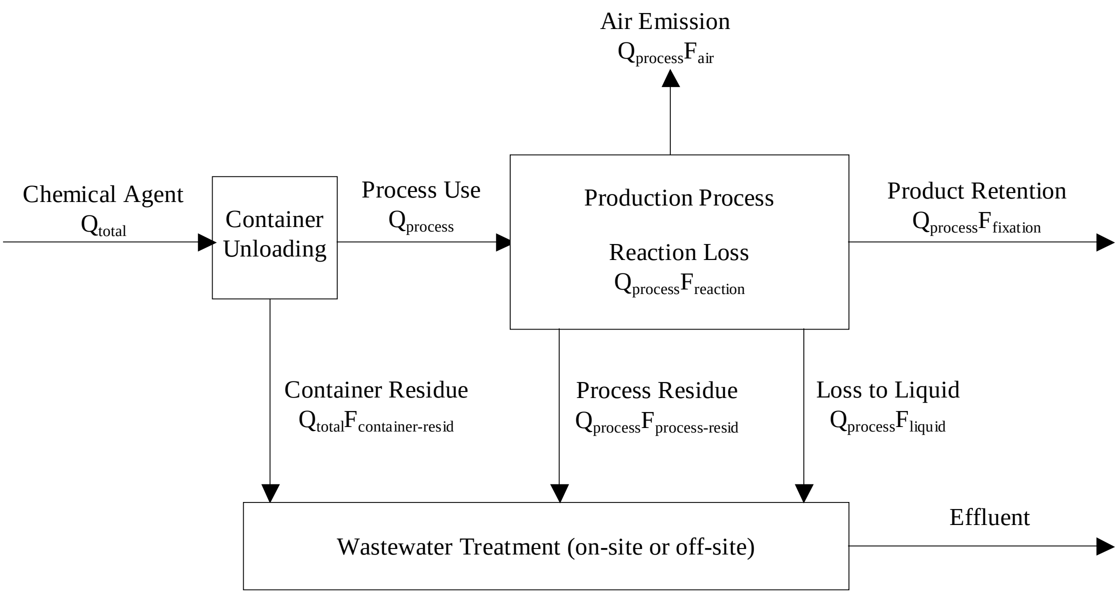

Figure 2 – Fate of a Chemical Agent Used at a Facility

Various wet operations were identified for wool mills in a field study conducted for Health Canada (Crechem Technologies Inc., 2003). These operations included carbonizing, scouring, fulling, bleaching, dyeing and wet finishing.

5.2 – General Approach to Aqueous Emission Estimation

A general approach to aqueous emission estimation was recommended by the Organization for Economic Cooperation and Development in 2000 in a publication entitled "Guidance Document on Emission Scenario Documents" (OECD, 2000). The approach is based on the fixation of chemical agents onto finished products and can be described by the following equation assuming no air emission and reaction loss:

$$E_{water} = \frac{Q_{product} Q_{agent} C_{substance} (1 - F_{fixation})}{T_{operation}}$$

The equation includes a set of input variables on the right and one output variable on the left. The definitions and value types of these variables are provided in Table 5.

Table 5 – Input and Output Variables of Aqueous Emission Estimation Equation

Variable		**Symbol**	**Units**	**Value Type**
Output	Aqueous emission of a substance in chemical agent	E_{water}	kg/d	Calculated
Input	Annual production	$Q_{product}$	tonne/yr	User input without default available
	Chemical agent use rate	Q_{agent}	kg/tonne	Provided with default which can be modified by users
	Substance concentration in chemical agent	$C_{substance}$	%	
	Fixation rate (fraction of chemical agent retained by product)	$F_{fixation}$	%	
	Annual operation days	$T_{operation}$	d/yr	

Source: OECD, 2000.

5.3 – Emission Estimation Calculations

5.3.1 – Emission to Wastewater

The emission to wastewater from a knit mill can be estimated according to a scheme described in Figure 2. The scheme is based on a spreadsheet formula used by the USEPA for exposure estimation. The emission consists of three portions: 1) liquid loss; 2) container residue; and 3) process residue. Liquid loss is incurred when a fraction of a chemical agent is not retained by finished products and enters wastewater, while container and process residues are common losses resulting from chemical handling and transferring. The following equation can be used for the aqueous emission estimation:

$$E_{water} = liquid\ loss + container\ residue + process\ residue$$

$$= \frac{Q_{total} C_{substance}}{T_{operation}} (1 - F_{container-resid} - F_{process-resid})(1 - F_{air} - F_{reaction} - F_{fixation}) +$$
$$\frac{Q_{total} C_{substance}}{T_{operation}} F_{container-resid} + \frac{Q_{total} C_{substance}}{T_{operation}} F_{process-resid}$$

where

E_{water}: daily aqueous emission of a substance in chemical agent, kg/d
Q_{total}: total chemical agent received by or shipped to a facility, kg/yr
$C_{substance}$: substance concentration in chemical agent, %
$F_{container-resid}$: container residue as percentage of total chemical agent received by or shipped to a facility, %
$F_{process-resid}$: process residue as percentage of total chemical agent received by or shipped to a facility, %
F_{air}: air emission as percentage of chemical agent used in production process, %
$F_{reaction}$: reaction loss as percentage of chemical agent used in production process, %
$F_{fixation}$: fixation rate, i.e., fraction of chemical agent retained by finished products, %
$T_{operation}$: annual operation days, d/yr

5.3.2 – Total Chemical Agent

The total amount of a chemical agent received by or shipped to a facility can be estimated from the use rate of the agent if it is not provided directly.

$$Q_{total} = \frac{Q_{product} Q_{agent}}{(1 - F_{container-resid} - F_{process-resid})}$$

where

Q_{total}: total chemical agent received by or shipped to a facility, kg/yr
$F_{container-resid}$: container residue as percentage of total chemical agent received by or shipped to a facility, %
$F_{process-resid}$: process residue as percentage of total chemical agent received by or shipped to a facility, %
$Q_{product}$: annual wool fabric production, tonne/yr
Q_{agent}: chemical agent use rate based on product mass, kg/tonne

5.3.3 – Air Emission

The fraction of a substance in a chemical agent emitted to the atmosphere is defined as

$$F_{air} = \frac{E_{air}}{Q_{use}} \times 100\%$$

where

F_{air}: fraction of a substance in a chemical agent released to air, %
E_{air}: quantity of a substance in a chemical agent released to air, kg/d
Q_{use}: quantity of a substance in a chemical agent used in production process, kg/d

The air emission of a target substance can be estimated from a reference substance based on vapour pressure if the two substances are involved in the same operations (USEPA, 2000).

$$F_{air} = F_{air-ref} \frac{P_{air}}{P_{air-ref}}$$

where

F_{air}: fraction of a target substance released to air, %
$F_{air-ref}$: fraction of a reference substance released to air, %
P_{air}: vapour pressure of a target substance, Pa
$P_{air-ref}$: vapour pressure of a reference substance, Pa

A reference substance should be volatile so that its air release reaches a sufficient quantity, while at the same time, it should be found in aqueous discharge to ensure reasonable partitioning between water and air. To simplify calculations it is necessary to assume that the reference substance is not retained by finished products and is released to air and water only. Under these conditions, the air emission of the reference substance can be estimated by the equation.

$$F_{air-ref} = \frac{E_{air-ref}}{E_{air-ref} + E_{water-ref}}$$

where

$E_{air-ref}$: quantity of reference substance released to air, kg/d
$E_{water-ref}$: quantity of reference substance released to water, kg/d

5.3.4 – Reaction Loss

The loss due to chemical reactions is substance specific. In general, it is assumed at zero, i.e., the substance in question does not undergo chemical transformation. Some substances may, however, change chemically and need to be evaluated from the data available.

5.4 – Parameter Defaults

5.4.1 – Container Residue

Container residue results from chemical unloading and its quantity depends primarily upon the type of containers used. Listed in Table 6 are container residue defaults used by the USEPA for exposure estimation. Drums and totes (semi-bulk) are common container types used by the textile industry. It is recommended that a value of 3.0% instead of 4.0% be used to estimate liquid drum residue for Canadian facilities.

Table 6 – Container Residue Defaults

Container Type	**Residue as % of Total Quantity Received**	
	Dry	Liquid
Bag	0.1	0.2
Keg	0.3	0.6
Drum	1.0	4.0
Semi-bulk	0.1	0.5
Bulk	0.1	0.2

Source: USEPA spreadsheet exposure estimation, 2004

5.4.2 – Process Residue

Process residue results from the use of process vessels and transfer pipelines. Listed in Table 7 are process residue defaults used by the USEPA for exposure estimation.

Table 7 – Process Residue Defaults

Process Hardware	**Residue as % of Total Quantity Received**	
	Dry	Liquid
General	0.1	1.0
Batch vessel	0.2	1.0
Transfer pipeline	0.1	1.0

Source: USEPA Spreadsheet Exposure Estimation, 2004

5.4.3 – Air Emission

The fraction of a substance in a chemical agent released to air depends upon its volatility. Its default is zero assuming the substance is a non-volatile compound. The value for a volatile substance may be estimated using emission factors or engineering calculations.

5.4.4 – Reaction Loss

The default for reaction loss is zero assuming no chemical reaction takes place as a chemical agent is used in production processes.

5.4.5 – Annual Wool Fabric Production

The annual wool fabric production varied from mill to mill. The figure ranged from 160 tonne/yr for a small mill with 70 employees to 2,200 tonne/yr for a large mill with 640 employees (Environment Canada, 1998). The average production was estimated at 975 tonne/yr.

5.4.6 – Annual Operation Days

The value for annual operation days ($T_{operation}$) was found to be 300 d/yr for a wool mill in a field study conducted for Health Canada (Crechem Technologies Inc., 2003). This value can be used as a default.

5.4.7 – Use Rate, Active Substance Concentration and Fixation Rate

The use rate and fixation rate for chemical agents used at wool mills were determined in a field study conducted for Health Canada (Crechem Technologies, 2003). These figures are presented in Table 8 and can be used as defaults. The active substance concentration was not determined in the study, but can be assumed to be 100% by default. It should be noted that the fixation rate for dyes (except fugitive dyes) is based on USEPA data (USEPA, 1997, p.35).

Table 8 – Use Rate and Fixation Rate for Chemical Agents Used at Wool Mills

Chemical Agent	Use Rate (kg/tonne)		Fixation Rate (%)	
	Default	Range	Default	Range
Lubricants	22.9	no data	0	
Surfactants	14.7	no data	0	
Acid dyes	3.01	no data	87[1]	80-93[1]
Basic dyes	0	no data	98[1]	97-98[1]
Direct dyes	3.01	no data	83[1]	70-95[1]
Disperse dyes	3.01	no data	86[1]	80-92[1]
Reactive dyes	0	no data	65[1]	50-80[1]
Sulphur dyes	0	no data	65[1]	60-70[1]
Vat dyes	0	no data	88[1]	80-95[1]
Premetallized dyes	3.01	no data	97[1]	95-98[1]
Fugitive dyes	3.01	no data	0	0
Dye carriers & auxiliaries	25.3	no data	0	0
Dye stripping agents	0.24	no data	0	0
Sequestrants	1.2	no data	0	0
Solvents	0.24	no data	0	0
Bleaching agents	0.27	no data	0	0
Salts	30.6	no data	0	0
Alkalis	40.4	no data	0	0
Acids	41.2	no data	1	0-2
Finishes	11.4	no data	2.8	0.5-5
Biocides	0.98	no data	0	0
Chemicals for boilers and cooling water	1.3	no data	0	0
Water treatment chemicals	18.4	no data	0	0
Wastewater treatment chemicals	11.5	no data	0	0

Source: Crechem Technologies Inc., 2003

[1]Data used by USEPA (1997, p.35)

GLOSSARY

Aging – a treatment method with which printed fabric is exposed to a hot moist atmosphere.

Bleaching – a wet processing operation to improve the whiteness of textile materials by removing natural colouring and/or extraneous substances.

Carbonization – a chemical finishing operation applied particularly to wool fabrics to remove plant matter present in the fabrics using sulfuric acid.

Carding – an operation to disentangle fibres by working them between two closely spaced, relatively moving surfaces clothed with pointed wire, pins, spikes, or saw teeth.

Chemical finishing – use of chemical agents to improve the appearance, texture and performance of fabric, same as wet finishing.

Dry finishing – use of mechanical means to cause physical changes to fabric.

Finishing – use of chemical or mechanical means to modify the property of fabric.

Fulling – a finishing operation in which fabric is washed in a thick soap solution and treated with moisture, heat, and friction to soften the fabric to the desired texture.

Knitting – use of needles to form a series of interlocking loops from a yarn or from a set of yarns.

Preparation – any wet processing operation, such as scouring, desizing, bleaching, mercerizing, etc., to prepare yarn or fabric for dyeing and finishing.

Scouring – a wet processing operation to remove natural fats, waxes, proteins, and other constituents, as well as dirt, oil, and other impurities.

Size – a sizing agent, i.e., a stiffening material applied to yarns prior to weaving to increase their abrasion resistance.

Sizing – a wet processing operation to apply stiffening materials to yarns or fabrics to increase their abrasion resistance.

Steaming – a treatment method with which printed fabric is exposed to hot steam.

Wet finishing – use of a variety of agents in a solution to improve the appearance, texture, and performance of fabric.

ABBREVIATIONS

ADMI – American Dye Manufacture Institute

BOD – Biochemical oxygen demand

COD – Chemical oxygen demand

ESD – Emission scenario document

TSS – Total suspended solids

UK – United Kingdom

USEPA – United States Environmental Protection Agency

REFERENCES

Carr, C. M. (1995), *Chemistry of the Textiles Industry*, Blackie Academic & Professional, London, 1995.

Chen, E. C. (1989), "Environmental Assessment of the Canadian Textile Industry," Report No. EPS 5/TX/1, June 1989, Environment Canada, Chemical Industries Division, Industrial Programs Branch, Ottawa, Ontario, Canada.

Corbman, B. P. (1975), *Textiles: Fiber to Fabric, 5th ed.*, McGraw-Hill, New York, 1975.

Crechem Technologies Inc. (2003), "Determination of Aqueous Releases of Chemicals from Wet Processing Textile Mills," prepared for Health Canada, Ottawa, Ontario, February 17, 2003.

Crechem Technologies Inc. (2000), "Background Study on Canadian Wet processing Textile Mills Industry and Their Effluents," prepared for Environment Canada, Environmental Protection Branch, 105 McGill Street, 4th Floor, Montreal, Quebec H2Y 2E7, August 30, 2000.

Crechem Technologies Inc. (1998), "Canadian Wet Processing Textile Mills – Industry Categorization, Process Description, Water Consumption, Chemical Usage, and Wastewater Generation," prepared for Environmental Protection Branch of Environment Canada, Dartmouth, Nova Scotia, February 10, 1998.

Environment Canada (1998), "Survey of Wet Processing Textile Mills," 1997/98, Environmental Protection Branch, 105 McGill Street, 4th Floor, Montreal, Quebec H2Y 2E7.

Farnfield, C. A. (1975), *Textile Terms and Definitions, 7th ed*., The Textile Institute, Manchester, 1975.

Hall, A. J. (1975), *The Standard Handbook of Textiles*, John Wiley & Sons, New York, 1975.

Hollen, N.; and J. Saddler (1973), *Textiles, 4th ed.*, The MacMillan Company, New York, 1973.

Joseph, M. L. (1981), *Introductory Textile Science, 4th ed*., Holt, Rinehart and Winston, New York, 1981.

Nettles, J. E. (1983), *Handbook of Chemical Specialties - Textile Fiber Processing, Preparation, and Bleaching*, John Wiley & Sons, New York, 1983.

Olson, E. S. (1983), *Textile Wet Processes, Volume I – Preparation of Fibers and Fabrics*, Noyes

Publications, New Jersey, 1983.

Smith, B. (1988), "A Workbook for Pollution Prevention by Source Reduction in Textile Wet Processing," prepared under a grant from the Pollution Prevention Pays Program of the North Carolina Division of Environmental Management, October 1988.

UK Environment Agency (1997), "Water and Chemical Use in the Textile Dyeing and Finishing Industry," Environmental Technology Best Practice Programme, London, UK, 1997.

USEPA (1997), "Profile of the Textile Industry," U.S. Environmental Protection Agency, Washington, DC, EPA/310-R-97-009, September 1997.

USEPA (1996), "Best Management Practices for Pollution Prevention in the Textile Industry," US Environmental Protection Agency, Washington, DC, EPA/625/R-96/004, September 1996.

USEPA (1978), "Environmental Pollution Control Textile Processing Industry," U.S. Environmental Protection Agency, Washington, DC, EPA-625/7-78-002, October 1978.