National Pollutant Inventory

Emission Estimation Technique Manual

for

Textile and Clothing Industry

First published in July 1999

EMISSION ESTIMATION TECHNIQUES
FOR
TEXTILE AND CLOTHING INDUSTRY

TABLE OF CONTENTS

TEXTILE AND CLOTHING INDUSTRY

LIST OF FIGURES, TABLES AND EXAMPLES

1.0   Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in textile and clothing product manufacture.

This Manual covers facilities engaged in spinning natural and man-made fibres into yarns and threads. These materials are then converted by weaving and knitting into fabrics. Finally, the fabrics, and in some cases the yarns and threads used to make them, are dyed and finished.

The primary focus of this Manual is on weaving and knitting operations, with a brief mention of the processes and pollutants from carpet manufacture.

> EET MANUAL: Textile and Clothing Industry
>
> HANDBOOK: Textile Product Manufacturing
>
> ANZSIC CODES :   222 series (also 2212, 2213, 2214 and 2215)

This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

2.0   Processes and Emissions

The following section presents a brief description of the textile and clothing industry and identifies likely sources of emissions.

2.1   Process Description

This section describes the major industrial processes within the textile and clothing manufacturing industry, including the materials, equipment used and the processes employed. This section is designed to gain a general understanding of the industry and the inter-relationship between the industrial process and the topics discussed in subsequent sections of the Manual - emissions of listed substances, estimating emissions, control technologies and emission abatement opportunities.

This section specifically contains a description of commonly used production processes, associated raw materials, the by-products produced, the NPI- listed substances emitted, and the materials either recycled or transferred off-site. This section also describes the potential fate - to air, water, or land - of these emissions and waste products.

The textile industry is comprised of a diverse, fragmented group of establishments that produce and process textile-related products (fibre, yarn, fabric) for further processing into apparel, manchester, home furnishings, and industrial goods. Textile facilities receive and prepare fibres; transform fibres into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and finish these materials at various stages of production. The process of converting raw fibres into finished apparel and non-apparel textile products is complex and is largely why most textile mills in Australia specialise in particular products.

In the broadest sense, the textile industry includes the production of yarn, fabric, and finished goods. There are primarily four production stages as shown in Figure 1.
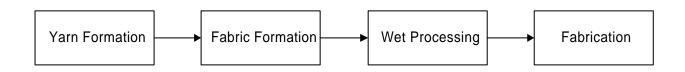

Figure 1 - The Four Main Production Stages in Textile Manufacturing
Source: Queensland Department of Environment and Heritage, 1998

2.1.1   Yarn Formation

Textile fibres are converted into yarn by grouping and twisting operations used to bind them together. Although most textile fibres are processed using spinning operations, the processes leading to the spinning vary depending on whether the fibres are natural or man-made.

Natural fibres, known as staple when harvested, include animal and plant fibres, such as cotton, silk, and wool. These fibres must go through a series of preparation steps before they can be spun into yarn, including opening, blending, scouring, carding, combing, and drafting. The *Wool Scouring* EET Manual is a separate Manual in this series and looks at the wool scouring process and emissions arising. This and other NPI Manuals are available from State and Territory environment agencies.

Man-made fibres may be processed into filament yarn or staple-length fibres so that they can be spun. Filament yarn may be used directly or following further shaping and texturing.

2.1.2   Fabric Formation

The major methods for fabric manufacture are weaving and knitting. Weaving or interlacing yarns, is a common process used to create fabrics. Weaving mills classified as broad woven mills consume the largest proportion of textile fibre and produce the raw textile from which most textile products are made. Narrow wovens, non wovens and ropes are primarily for use in industrial applications. Knitting is another method of fabric construction. Manufacturers of knit fabrics also consume a sizeable amount of textile fibres. Knit fabrics are generally classified as either weft (circular-knit goods) or warp knit (flat-knit goods). Tufting is a process used to make certain types of carpets.

2.1.3   Wet Processing

Woven and knit fabrics cannot be processed into apparel and other finished goods until the fabrics have passed through several water-intensive wet processing stages. Wet processing enhances the appearance, durability, and serviceability of fabrics by converting undyed and unfinished goods, known as greige goods, into finished consumer goods. Also collectively known as finishing, wet processing has been broken down into four stages in this section for simplification: fabric preparation, dyeing, printing, and finishing. These stages, involve treating grey or greige goods with chemical baths and often require additional washing, rinsing, and drying steps.

In terms of emissions, wet processing is the most significant textile operation. Methods used vary depending on end-products and applications, site-specific manufacturing practices, and fibre type. Natural fibres typically require more processing steps than man-made fibres. For most wool products and some man-made cotton products, the yarn is dyed before weaving; thus, the pattern is woven into the fabric. Processing methods may also differ based on the final properties desired, such as tensile strength, flexibility, uniformity, and lustre.

Most manufactured textiles are shipped from textile mills to commission dyeing and finishing shops for wet processing, although some firms have integrated wet processing in their operations. A wide range of equipment is used for textile dyeing and finishing. Much of the waste and emissions generated from the industry are produced during the wet processing stages. Relatively large volumes of wastewater are

generated, containing a wide range of contaminants that must be treated prior to disposal. Significant quantities of energy are spent heating and cooling baths and drying fabrics and yarn.

2.1.3.1 Fabric Preparation

Most fabric that is dyed, printed or finished must first be prepared. Preparation, also known as pretreatment, consists of a series of various treatment and rinsing steps critical to obtaining good results in subsequent textile finishing processes. In preparation, the mill removes natural impurities or processing chemicals that interfere with dyeing, printing, and finishing. Typical preparation treatments include desizing, scouring, and bleaching. Preparation steps can also include processes, such as singeing and mercerising, designed to chemically or physically alter the fabric. For instance, the mercerising stage chemically treats the fabric to increase fibre strength and dye affinity, or ability to pick up dyes. This in turn, increases the longevity of fabric finishes applied during finishing. Many of the pollutants from fabric preparation result from the removal of previously applied processing chemicals and agricultural residues. These chemical residues can be passed on to subsequent stages with improper preparation.

Most mills can use the same preparation for the entire range of products they produce. In most cases, facilities favour continuous rather than batch preparation processes for economic and pollution control reasons. A number of mills however, prepare goods, particularly knits, batch wise on dyeing machines to simplify scheduling and handling. Sometimes facilities operate batch wise to reduce high capital cost required for high productivity and the complexity of storing and tracking goods through continuous wet processing operations.

Because preparation is relatively uniform across most of a mills' production, preparation is usually the highest volume process in a mill and hence an important area for pollution prevention. If fabrics contained no contamination upon arrival for wet processing, some preparation processes would be unnecessary, eliminating about half the pollution outputs from wet processing and a significant amount of wastewater. NPI-listed substances in preparation wastewater include a number of metals and organics and phosphorus contained in the surfactants and detergents used. There are many preparation techniques, some of which are described below.

- *Singeing.* If a fabric is to have a smooth finish, singeing is essential. Singeing is a dry process used on woven goods that removes fibres protruding from yarns or fabrics. These are burned off by passing the fibres over a flame or over heated copper plates. Singeing improves the surface appearance of woven goods and reduces pilling. It is especially useful for fabrics that are to be printed or where a smooth finish is desired. Pollutant output associated with singeing include relatively small amounts of exhaust gases (SO_2, NO_x and CO) from the burners.

- *Desizing*. Desizing is an important preparation step used to remove size materials applied prior to weaving. Man-made fibres are generally sized with water-soluble sizes that are easily removed by hot-water wash or in the scouring process. Natural fibres such as cotton are most often sized with water-insoluble starches or mixtures of starch and other materials. Enzymes are used to break these starches into water soluble sugars, which are then removed by washing before the cloth is scoured. Removing starch before scouring is necessary because they can react and cause colour changes when exposed to sodium hydroxide in scouring.

- *Scouring*. Scouring is a cleaning process that removes impurities from fibres, yarns, or cloth through washing. Alkaline solutions are typically used for scouring; however, in some cases solvent solutions may also be used. Scouring uses alkali, typically sodium hydroxide, to break down natural oils and surfactants and to emulsify and suspend remaining impurities in the scouring bath. The specific scouring procedures, chemicals, temperature, and time vary with the type of fibre, yarn and cloth construction. Impurities may include lubricants, dirt and other natural materials, water soluble-sizes, antistatic agents, and residual tints used for yarn identification. Typically, scouring wastes contribute a large portion of biological oxygen demand (BOD) loads from preparation processes. Desizing and scouring operations are often combined. The *Wool Scouring* Manual looks at emissions from scouring processes in more detail.

- *Bleaching*. Bleaching is a chemical process that eliminates unwanted coloured matter from fibres, yarns, or cloth. Bleaching decolourises coloured impurities, that are not removed by scouring, and prepares the cloth for further finishing processes, such as dyeing or printing. Several different types of chemicals are used as bleaching agents, and selection depends on the type of fibre present in the yarn, cloth, or finished product and the subsequent finishing that the product will receive. The most common bleaching agents include hydrogen peroxide, sodium hypochlorite, sodium chlorite, and the listed substance; sulfur dioxide gas. Hydrogen peroxide is by far the most commonly used bleaching agent for cotton and cotton blends and is typically used with caustic solutions.

The bleaching process involves several steps:

1) the cloth is saturated with the bleaching agent, activator, stabiliser, and other necessary chemicals;
2) the temperature is raised to the recommended level for that particular fibre or blend and held for the amount of time needed to complete the bleaching action; and
3) the cloth is thoroughly washed and dried.

Peroxide bleaching can be responsible for wastewater with high pH levels. Because peroxide bleaching typically produces wastewater with few contaminants, water conservation and chemical handling issues are the primary pollution concerns.

- *Mercerising*. Mercerisation is a continuous chemical process used for cotton and cotton/polyester goods to increase dyeability, lustre, and appearance. This process, which is carried out at room temperature, causes the flat twisted ribbon-like cotton fibre to swell into a round shape and to contract in length. This causes the fibre to become more lustrous than the original fibre, increase in strength by as much as 20 percent, and increase its affinity for dyes. Mercerising typically follows singeing and may either precede or follow bleaching.

During mercerising, the fabric is passed through a cold 15 to 20 percent solution of caustic soda, and then stretched out on a tender frame where hot-water sprays remove most of the caustic solution. After treatment, the caustic is removed by several washes under tension. Remaining caustic may be neutralised with a cold acid treatment followed by several more rinses to remove the acid. Wastewater from mercerising can contain amounts of high pH alkali, accounting for about 20 percent of the weight of goods.

2.1.3.2 Dyeing

Dyeing operations are used at various stages of production to add colour and intricacy to textiles and increase product value. Most dyeing is performed either by the finishing division of vertically integrated textiles companies, or by specialty dyehouses.

Textiles are dyed using a wide range of chemicals and dyestuffs, techniques, and equipment. Dyes used by the textile industry are largely synthetic, typically derived from coal tar and petroleum-based intermediates. Dyes are sold as powders, granules, pastes, and liquid dispersions, with concentrations of active ingredients ranging typically from 20 to 80 percent.

Methods of Dyeing

Dyeing can be performed using continuous or batch processes. In batch dyeing, a certain amount of textile substrate is loaded into a dyeing machine and brought to equilibrium, or near equilibrium, with a solution containing the dye. Because the dyes have an affinity for the fibres, the molecules leave the dye solution and enter the fibres over a period of minutes or hours, depending on the type of dye or fabrics used. Auxiliary chemicals and controlled dye bath conditions (mainly temperature) accelerate and optimise the action. The dye is fixed in the fibre using heat and/or chemicals, and tinted textile substrate is washed to remove unfixed dyes and chemicals. Common methods of batch, or exhaust, dyeing include beam, beck, jet and jig processing. Pad dyeing can be performed by either batch or continuous processes.

In continuous dyeing processes, textiles are fed continuously into a dye range at speeds usually between 50 and 250 metres per minute. Continuous dyeing accounts for about 60 percent of total volume of product dyed in the industry. Continuous dyeing processes typically consist of dye application, dye fixation with chemicals or heat, and washing. Dyeing fixation is a measure of the amount of percentage of dye in a bath that will fix to the fibres of the textile material. Dye fixation on the fibre occurs much more rapidly in continuous dyeing than in batch dyeing.

Each dyeing process requires different amounts of dye per unit of fabric to be dyed. This is significant since colour and salts in wastewater from spent dyes are often a pollution concern for textile facilities. In addition less dye used results in energy conservation and chemical savings. The amounts of dye used depends on the dye exhausted from the dye baths which determines the required dye bath ratio. The dye bath ratio is the ratio of the units of dye required per unit of fabric and typically ranges between 5 and 50 depending on the type of dyes, dyeing systems, and affinity of the dyes for the fibres.

Dyeing processes may take place at any of several stages of the manufacturing process (fibres, yarn, piece-dyeing). Stock dyeing is used to dye fibres. Top dyeing is used to dye combed wool silver. Table 1 outlines the common textile dyes used and the likely emissions points of common pollutants and NPI-listed substances. NPI-listed substances may be identified in the MSDSs for the dyes.

Table 1 - Typical Characteristics of Dyes Used in Textile Dyeing Operations

Dye Class	Description	Method	Fibres Typically Applied to	Typical Fixation (%)	Typical NPI-Listed SubstancesAssociated with Various Dyes
Acid	water-anionic compounds	Exhaust / Beck / Continuous (carpet)	wool, nylon	80-93	listed acids, including H_2SO_4, HCl, HNO_3; unfixed dyes containing listed metals
Basic	water-soluble, applied in weakly acidic dye baths; very bright dyes.	Exhaust / Beck	acrylic, some polyesters	97-98	N/A
Direct	water soluble, anionic compounds; can be applied directly to cellulosics without mordants (or metals like chromium or copper)	Exhaust / Beck / Continuous	cotton, rayon, other cellulosics	70-95	unfixed dye; cationic fixing agents; surfactants; defoamers; leveling and retarding agents; finish; dilutents; that may contain listed acids, metals, phosphorus, and organics
Disperse	not water-soluble	High temperature exhaust, Continuous	polyester, acetate, other synthetics	80-92	listed acids; carriers; leveling agents; phosphates; defoamers; lubricants; dispersants; delustrants; dilutents
Reactive	water-soluble, anionic compounds; largest dye class	Exhaust / Beck, Cold pad batch / Continuous	cotton, other cellulosics, wool	60-90	alkali; unfixed dye; surfactants; defoamers; dilutents; finish
Sulfur	organic compounds containing sulfur or sodium sulfide	Continuous	cotton, other cellulosics	60-70	alkali; oxidising agents; reducing agents; unfixed dye
Vat	oldest dyes; more chemically complex; water-insoluble	Exhaust / Package / Continuous	cotton, other cellulosics	80-95	alkali, oxidising agents; reducing agents

Adapted from USEPA, *Office of Compliance Sector Notebook: Profile of the Textile Industry*, September 1997.

2.1.3.3 Textile Fabric Printing

Textile fabric printing is part of the textile finishing industry. In fabric printing, a decorative pattern or design is applied to constructed fabric by roller, flat screen or rotary screen methods. Listed pollutants in fabric printing are volatile organic compounds (VOCs) from mineral spirit solvents in print pastes or inks.

In the roller printing process, print paste is applied to an engraved roller, and the fabric is guided between it and a central cylinder. The pressure of the roller and central cylinder forces the print paste into the fabric. Because of the high quality it can achieve, roller printing is the most appealing method for printing designer and fashion apparel fabrics.

In flat screen printing, a screen on which print paste has been applied is lowered onto a section of fabric. A squeegee then moves across the section, forcing the print paste through the screen and in to the fabric. Flat screen machines are used mostly in printing terry towels.

In rotary screen printing, tubular screens rotate at the same velocity as the fabric. Print paste distributed inside the tubular screen is forced into the fabric as it is pressed between the screen and a printing blanket (a continuous rubber belt). Rotary screen printing machines are used mostly but not exclusively for bottom weight apparel fabrics or fabric not for apparel use. Host knit fabric is printed by the rotary screen method, because it does not stress (pull or stretch) the fabric during the process.

Major print paste components include clear and colour concentrates, solvents and, in pigment printing a low crock or binder resin. Print paste colour concentrates contain either pigments or dyes. Pigments are insoluble particles physically bound to fabrics. Dyes are in solution applied to impart colour by becoming chemically or physically incorporated into individual fibres. Organic solvents are used almost exclusively with pigments. Very little organic solvent is used in non-pigment printing pastes. Clear concentrates extend colour concentrates to create light and dark shades. Clear concentrates do contain some VOCs but contribute less than one percent of total VOC emissions from textile printing operations. Defoamers and resin are included in print paste to increase colour fastness. A small amount of thickening agent is also added to each print paste to control print paste viscosity. Print defoamers, resins, and thickening agents do not contain VOCs.

The majority of emissions from print paste are from the solvent, which may be aqueous, organic (mineral spirits), or both. The organic solvent concentration in print pastes may vary, with no consistent ratio of organic solvent to water. Mineral spirits used in print pastes vary widely in physical and chemical properties.

Although some mineral spirits evaporate in the early stages of the printing process, the majority of emissions to the atmosphere are from the printed fabric drying process, which drives off volatile compounds. For some specific print paste/fabric combination, colour fixing occurs in a curing process, which may be entirely separate or merely a separate segment of the drying process.

Two types of dryers are used for printed fabric, steam coil or natural gas fired dryers, through which the fabric is conveyed on belts, racks, and steam cans. Most screen printed fabrics and practically all printed knit fabrics and terry towels are dried on steam cans, which have lower installation and operating costs and which dry the fabric more quickly than other dryers.

Fugitive air emissions are released from the flat screen printing process. Fugitive VOC emissions to the atmosphere occur from the evaporation of mineral spirits from the print paste during application to the fabric before drying. The largest VOC emission source from the flat screen printing process is the drying and curing oven stack, which vents evaporated solvents (mineral spirits and water) to the atmosphere. Fugitive VOC emissions to waste water occur as mineral spirits from the print paste are washed with water from the printing blanket (continuous belt) and discharged to waste water.

In the roller printing process, fugitive VOC emissions from the 'back grey' (fabric backing material that absorbs excess print paste) are emitted to atmosphere as the back grey is dried before being washed. In processes where the back grey is washed before drying, most of the fugitive VOC emissions from the back grey will be discharged into waste water. In some roller printing processes, steam cans for drying printed fabric are enclosed, and drying process emissions are vented directly to the atmosphere. Table 2 shows typical textile fabric printing run characteristics, for roller, flat screen, and rotary screen printing methods.

Table 2 - Typical Textile Fabric Printing Run Characteristics

Characteristics	Roller		Rotary Screen		Flat Screen	
	Range	Average	Range	Average	Range	Average
Wet pickup rate, kg print paste consumed/kg of fabric	0.51-0.58	0.56	0.10-1.89	0.58	0.22-0.83	0.35
Fabric weight, kg/m^2	-	0.116	-	0.116	-	0.314
Mineral spirits added to print paste, weight %	0-60	26	0-50	3	-	23
Print paste used per fabric area, kg/m^2	0.059-0.067	0.065	0.012-0.219	0.067	0.069-0.261	0.110
Mineral spirits used per fabric area, kg/m^2	0-0.040	0.017	0-0.109	0.0002	0.016-0.060	0.025
Print paste used in run, kg	673-764	741	137-2497	764	787-2975	1254

Source: USEPA, *Office of Compliance Sector Notebook: Profile of the Textile Industry*, September 1997.

2.1.3.4 Finishing

Finishing encompasses chemical or mechanical treatments performed on fibre, yarn or fabric to improve appearance, texture, or performance. Mechanical finishes can involve brushing, ironing, or other physical treatments used to increase the lustre and feel of textiles. Application of treatments can impart a variety of properties ranging from decreasing static cling to increasing flame resistance. The most common chemical finishes are those that ease fabric care, such as permanent-press, soil-release, and stain resistant finishes. Chemical finishes are usually followed by drying, curing, and cooling steps. Application of chemical finishes are often done in conjunction with mechanical finishing steps. Selected mechanical and chemical finishing techniques are described below.

Mechanical Treatment

- *Heatsetting*. Heatsetting is a dry process used to stabilise and impart textural properties to synthetic fabrics containing high concentrations of synthetics. When man-made fibres are heatset, the cloth maintains its shape and size in subsequent finishing operations and is stabilised in the form in which it is held during heatsetting. Textural properties may include interesting and durable surface effects such as pleating, creasing, puckering, and embossing. Heatsetting can also give cloth resistance to wrinkling during wear and ease-of-care properties attributed to improvements in resilience and elasticity. Pollution outputs may include volatile components of finishes if heatsetting is performed before bleaching processes. These components are introduced during the manufacture of synthetic fibres, when proprietary spin finishes are applied to provide lubrication and impart special properties, such as antistatic, to the fibre.

- *Brushing and napping*. Brushing and napping decrease the lustre of fabrics by roughening or raising the fibre surface and change the feel or texture of the fabric. These processes involve the use of wires or brushes that pull individual fibres.

- *Softening*. Calendering, or ironing, can be used to reduce surface friction between individual fibres, thereby softening the fabric structure and increasing sheen. In calendering, the fabric passes through two or more rollers. The steel roller may also be heated using gas or steam. Once fabrics pass through the machine rollers they are rolled up at the back of the machine.

- *Optical finishing*. Lustre can be added to yarns by flattening or smoothing the surfaces under pressure. This can be achieved by beating the fabric surface or passing the fabric between calendering rollers. The lustre can be further increased if the rollers are scribed with closely spaced lines.

- *Shearing*. Shearing is a process that removes surface fibres by passing the fabric over a cutting blade.

- *Compacting*. Compacting, which includes the sanforising process, compresses the fabric structure to reduce stresses in the fabric. The Sanforising Process reduces residual shrinkage of fabrics after repeated laundering. The fabric and backing blanket are fed between a roller and a curved braking shoe, with the blanket under tension. The tension on the blanket is released after the fabric and blanket passes the braking shoe. Compacting reduces the potential for excessive shrinkage during laundering.

Chemical Treatment

- *Optical Finishes.* Optical finishes are added to either brighten or delustre the textile.

- *Absorbent and soil release finishes.* These finishes are designed to alter surface tension and/or other fabric properties to increase water absorbency or improve soil release.

- *Softeners and abrasion-resistant fibres.* Softeners and abrasion-resistant finishes are added to improve feel/softness to handle or to increase the ability of the textile to resist abrasion and tearing.

- *Physical stabilisation and crease resistant finishes.* These finishes which may include formaldehyde-based resin finishes, stabilise cellulosic fibres to laundering and shrinkage, imparting permanent press properties to fabrics.

2.1.4   Fabrication

Finished cloth is fabricated into a variety of apparel and household and industrial products. The simpler of these products, such as bags, sheets, towels, blankets, and other manchester items, often are produced by the textile mills themselves. The cutting trades usually fabricate apparel and more complex housewares. Before cutting, fabrics must be carefully laid out. Accuracy in cutting the lay fabric is important since any defects created at this point may be carried through other operations and end up in the final product. For manchester and industrial products, sewing is relatively straight forward. Product may then be pressed to flatten the fabric and create crisp edges.

2.2   Emission Sources and Control Technologies

2.2.1   Emissions to Air

Air emissions may be categorised as:

Fugitive Emissions

These are emissions that are not released through a vent or stack. Examples of fugitive emissions include dust from stockpiles, volatilisation of vapour from vats, open vessels, or spills and materials handling. Emissions emanating from ridgeline roof-vents, louvres, and open doors of a building as well as equipment leaks, and leaks from valves and flanges are also examples of fugitive emissions. Emission factor EETs are the usual method for determining losses through fugitive emissions.

Point Source Emissions

These emissions are exhausted into a vent (excluding roof vents) or stack and emitted through a single point source into the atmosphere. Table 3 highlights common air emissions from textile and clothing processes. The *Combustion in Boilers* EET Manual, along with other Manuals in this series, is available from State and Territory environment agencies. The *Combustion in Boilers* EET Manual is designed to provide

guidance on estimating emissions from combustion sources such as combustion of natural gas, LPG, or oil, which may be of particular relevance to the textile and clothing industry.

Table 3 - Common Air Emissions from Textile and Clothing Processes

Substances	
Volatile Organic Compounds (VOCs)	Sulfur Dioxide (SO_2)
Oxides of Nitrogen (NO_x)	Carbon Monoxide (CO)
Particulate Matter (PM_{10})	

Source: Queensland Department of Environment and Heritage, 1998

Air emission control technologies, such as electrostatic precipitators, fabric filters or baghouses and wet scrubbers, are commonly installed to reduce the concentration of particulates in process off-gases before stack emission. Where such emission abatement equipment has been installed, and where emission factors from uncontrolled sources have been used in emission estimation, the collection efficiency of the abatement equipment needs to be considered. Guidance on applying collection efficiencies to emission factor equations is provided in later sections.

With regards to emission controls for PM_{10} emissions (particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less ie. $\leq 10\mu m$), in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

2.2.2   Emissions to Water

Emissions of substances to water can be categorised as discharges to:

- Surface waters (eg. lakes, rivers, dams, and estuaries);
- Coastal or marine waters; and
- Stormwater.

Because of the significant environmental hazards posed by emitting toxic substances to water, most facilities emitting NPI-listed substances to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions. This existing sampling data can be used to calculate annual emissions.

If no wastewater monitoring data exists, emissions to process water can be calculated based on a mass balance or using emission factors.

The discharge of listed substances to a sewer or tailings dam does not require you to report to the NPI. However, leakage and other emissions (including dust) from a tailings storage facility are reportable. (See also Section Three of *The NPI Guide*.)

2.2.3   Emissions to Land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids and may contain listed substances. These emission sources can be broadly categorised as:

- surface impoundments of liquids and slurries; and
- unintentional leaks and spills.

3.0   Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility. The four types described in the *NPI Guide* are:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations; and
- emission factors.

Select the EET (or mix of EETs) that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of emission estimation techniques that are not outlined in this Handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this Manual does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

> **You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.**

In general, direct measurement is the most accurate method for characterising emissions and, where available, such data should be used in preference to other EETs presented in this Manual. However, additional direct measurement is not required under the NPI Measure. Direct monitoring may be undertaken as an element of other EETs.

You should note that the EETs presented in this Manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage*** of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

* Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

3.1 Direct Measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement. For the sampling data to be adequate and able to be used for NPI reporting purposes, it would need to be collected over a period of time, and to be representative of operations for the whole year.

3.1.1 Sampling Data

Stack sampling test reports often provide emissions data in terms of kg/hr or g/m^3 (dry). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

This Section shows how to calculate emissions in kg/hr based on stack sampling data, and how to convert this to an annual emissions figure. Calculations involved in determining particulate emissions are used as an example, although the same calculations are applicable for most of the substances listed on the NPI.

An example of test results is summarised in Table 4. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in m^3/s. The filter weight gain is determined gravimetrically and divided by the volume of gas sampled, as shown in Equation 1 to determine the TSP (total suspended particulates) concentration in grams per m^3. Note that this example does not present the condensable PM emissions.

Equation 1 indicates how to calculate the concentration if a substance from the weight of the substance and the air sampled:

Equation 1

$$C_{PM} = C_f / V_{m, STP}$$

where:

C_{PM}	=	concentration of PM or gram loading, g/m^3
C_f	=	filter catch, g
$V_{m,STP}$	=	metered volume of sample at STP, m^3

Equation 2 can be used to convert the concentration of a substance calculated in Equation 1 to an hourly emission of the substance:

Equation 2

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273 / (273 + T)]$$

where:

E_{PM}	=	hourly emissions of PM, kg/hr
C_{PM}	=	concentration of PM or gram loading, g/m^3
Q_d	=	stack gas volumetric flow rate, m^3/s, dry
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
T	=	temperature of the gas sample, °C

Table 4 - Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7 200	7 200	7 200
Moisture collected (g)	g_{MOIST}	395.6	372.6	341.4
Filter catch (g)	C_f	0.0851	0.0449	0.0625
Average sampling rate (m^3/s)		$1.67 * 10^{-4}$	$1.67 * 10^{-4}$	$1.67 * 10^{-4}$
Standard metered volume (m^3)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m^3/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m^3)	C_{PM}	0.0718	0.0387	0.0537

Queensland Department of Environment and Heritage 1998

Example 1 - Using Stack Sampling Data

PM emissions calculated using Equation 1 and Equation 2 and the stack sampling data for Test 1 (presented in Table 4, and an exhaust gas temperature of 150°C (423 K)). This is shown below:

```
C_PM    =       C_f / V_m, STP
        =       0.0851 / 1.185
        =       0.072 g/m³

E_PM    =       C_PM * Q_d * 3.6 * [273/(273+T)]
        =       0.072 * 8.48 * 3.6 * [273/(273 + 150)]
        =       1.42 kg/hr
```

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use Equation 3 to calculate the dry particulate emissions in kg/hr.

Equation 3

$$E_{PM} = Q_w * C_{PM} * 3.6 * \left(1 - \frac{moist_R}{100}\right) * \left[\frac{273}{(273 + T)}\right]$$

where:

E_{PM} = hourly emissions of PM in kilograms per hour, kg/hr

Q_w = wet cubic metres of exhaust gas per second, m³/s

C_{PM} = concentration of PM or gram loading, g/ m³

3.6 = 3600 seconds per hour multiplied by 0.001 kilograms per gram

$moist_R$ = moisture content, %

273 = 273 K (0°C)

T = stack gas temperature, °C

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, it may be necessary for facility operators to first undertake a size analysis of the stack filter catch. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to produce PM_{10} emissions. Alternatively, assume that 100% of PM emissions are PM_{10}; ie. assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. ≤10μm.

To calculate moisture content use Equation 4.

Equation 4

Moisture percentage = 100 % * weight of water vapour per specific volume of stack gas/ total weight of the stack gas in that volume.
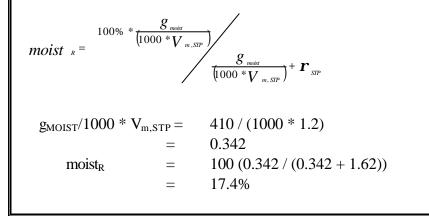
$$moist_R = \frac{100\% * \frac{g_{moist}}{(1000 * V_{m,STP})}}{\frac{g_{moist}}{(1000 * V_{m,STP})} + r_{STP}}$$

where

moist$_R$	=	moisture content, %
g$_{moist}$	=	moisture collected, g
V$_{m,STP}$	=	metered volume of sample at STP, m^3
ρ_{STP}	=	dry density of stack gas sample, kg/ m^3 at STP
		{if the density is not known a default value of 1.62 kg/ m^3
		may be used. This assumes a dry gas composition of
		50% air, 50% CO_2}

Example 2 - Calculating Moisture Percentage

A 1.2 m^3 sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use Equation 4.

$$moist_R = \frac{100\% * \frac{g_{moist}}{(1000 * V_{m,STP})}}{\frac{g_{moist}}{(1000 * V_{m,STP})} + r_{STP}}$$

g$_{MOIST}$/1000 * V$_{m,STP}$ =		410 / (1000 * 1.2)
	=	0.342
moist$_R$	=	100 (0.342 / (0.342 + 1.62))
	=	17.4%

3.1.2 Continuous Emission Monitoring System (CEMS) Data

A continuous emission monitoring system provides a continuous record of emissions over time, usually by reporting pollutant concentration.

Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate of that pollutant.

It is important to note that prior to using CEMS to estimate emissions, you should develop a protocol for collecting and averaging the data in order that the estimate satisfies your relevant environmental authority's requirement for NPI emissions estimations.

3.2 Mass Balance

A mass balance identifies the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance within the equipment should be accounted for in your calculation.

3.3 Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (eg. vapour pressure) of the substance and mathematical relationships (eg. ideal gas law).

3.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO_2, metals, and other emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements, such as sulfur, which may be converted into other compounds during the combustion process.

The basic equation used in fuel analysis emission calculations is the following:

Equation 5

$$E_{kpy,i} = Q_f * \text{pollutant concentration in fuel}/100 * (MW_p / EW_f) * OpHrs$$

where:

$E_{kpy,i}$ = annual emissions of pollutant i, kg/yr
Q_f = fuel use, kg/hr
OpHrs = operating hours, hr/yr
MW_p = molecular weight of pollutant emitted, kg/kg-mole
EW_f = elemental weight of pollutant in fuel, kg/kg-mole
Concentration of pollutant i in fuel expressed as weight percent, %

For instance, SO_2 emissions from oil combustion can be calculated based on the concentration of sulfur in the oil. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur ($EW_f = 32$) burned, two kilograms of SO_2 ($MW_p = 64$) are emitted. The application of this EET is shown in Example 3.

Example 3 - Using Fuel Analysis Data

This example illustrates how SO_2 emissions can be calculated from oil combustion based on fuel analysis results and the fuel flow information from a processing facility. The facility is assumed to operate 1500 hours per year.

$E_{kpy,SO2}$ = may be calculated using Equation 5.

Fuel flow (Q_f) = 2000 kg/hr
Weight percent sulfur in fuel = 1.17%
MW_p = 64 kg/kg-mole
EW_f = 32 kg/kg-mole
OpHrs = 1500 hr/yr

$$E_{kpy,SO2} = \quad Q_f * \text{pollutant concentration in fuel}/100 * (MW_p/EW_f) * OpHrs$$
$$= \quad (2000) * (1.17 / 100) * (64 / 32) * 1500$$
$$= \quad 46.8 kg/hr * 1500 \ hr/yr$$
$$= \quad 70\ 200 \ kg/yr$$

3.4 Emission Factors

An emission factor is a tool that is used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted divided by the unit weight, volume, distance, or duration of the activity emitting the substance.

Emission factors are used to estimate a facility's emissions by the general equation:

Equation 6

$$E_{kpy,i} \quad = \quad [A * OpHrs] * EF_i * [1 - (CE_i/100)]$$

where :

$E_{kpy,i}$	=	emission rate of pollutant i, kg/yr
A	=	activity rate, t/hr
OpHrs =	operating hours, hr/yr	
EF_i	=	uncontrolled emission factor of pollutant i, kg/t
CE_i	=	overall control efficiency for pollutant i, %

Emission factors developed from measurements for a specific process may sometimes be used to estimate emissions at other sites. Should a company have several processes of similar operation and size, and emissions are measured from one process source, an emission factor can be developed and applied to similar sources. You are required to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

3.4.1 Industry-Wide Emission Factors

Table 5 - Textile Fabric Printing Organic Emission Factors[a]

VOC	Roller	Rotary Screen	Flat Screen[b]
kg/t fabric	142	23	79
t/yr/print line	130	29	29

Source: USEPA, AP-42 section 4.11, 1995.

Emission factor uncertainty rating: C

[a] Transfer printing, carpet printing, and printing of vinyl-coated cloth are specifically excluded from this compilation.

[b] Flat screen factors apply to terry towel printing. Rotary screen factors should be applied to flat screen printing of other types of fabric (eg. sheeting, apparel etc)

Table 6 - Emission Factors for Specific Organic Compounds to Air[a,b] for Printing

Substance	CASR[c] Number	Emission Factor (kg/t)
Biphenyl	92-52-4	3.01
Dibutyl phthalate	84-74-2	0.7242

Source: USEPA, VOC/Speciation data system, October 1992
[a] Emission factor uncertainty rating: E
[b] Factor units are kg of substance emitted/ per tonnes fabric processed
[c] CASR = Chemical Abstract Service Registry

Table 7 - Emission Factors for Emissions to Wastewater[a]

Substances	CASR[b] Number	Emission Factor (kg/t)
Chromium (total)	7440-47-3	1.33
Phenol	108-95-2	0.17

Source: Economopolous, 1993. Factor units are kg of substance emitted per tonne of fabric manufactured.
  Emission factor uncertainty rating = U
[a] Process-Specific activities include scouring, dyeing, washing, carbonising and beaching.
[b] CASR = Chemical Abstract Service Registry.

3.4.2   Predictive Emission Monitoring (PEM)

Predictive emission monitoring is based on developing a correlation between pollutant emission rates and process parameters. A PEM allows facilities to develop site-specific emission factors, or emission factors more relevant to their particular process.

Based on test data, a mathematical correlation can be developed which predicts emissions using various parameters.

4.0 Emission Estimation Techniques: Acceptable Reliability and Uncertainty

This section is intended to give a general overview of some of the inaccuracies associated with each of the techniques. Although the National Pollutant Inventory does not favour one emission estimation technique over another, this section does attempt to evaluate the available emission estimation techniques with regards to accuracy.

Several techniques are available for calculating emissions from textile and clothing manufacturing facilities. The technique chosen is dependent on available data, available resources, and the degree of accuracy sought by the facility in undertaking the estimate. In general, site-specific data that is representative of normal operations is more accurate than industry-averaged data, such as the emission factors presented in Section 3.4 of this Manual.

4.1 Direct Measurement

Use of stack and/or workplace health and safety sampling data is likely to be a relatively accurate method of estimating air emissions from textile and clothing facilities. However, collection and analysis of samples from facilities can be very expensive and especially complicated where a variety of NPI-listed substances are emitted and where most of these emissions are fugitive in nature. Sampling data from a specific process may not be representative of the entire manufacturing operation and may provide only one example of the facility's emissions.

To be representative, sampling data used for NPI reporting purposes needs to be collected over a period of time, and to cover all aspects of the manufacture of textile and clothing.

In the case of CEMS, instrument calibration drift can be problematic and uncaptured data can create long-term incomplete data sets. However, it may be misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and the corresponding emissions data.

4.2 Mass Balance

Calculating emissions from a textile and clothing manufacturing facility using mass balance appears to be a straightforward approach to emission estimations. However, it is likely that few Australian textile and clothing manufacturing facilities consistently track material usage and waste generation with the overall accuracy needed for application of this method. Inaccuracies associated with individual material tracking or other activities inherent in each material handling stage can often result in large deviations of total facility emissions. Because emissions from specific materials are typically below 2 percent of gross consumption, an error of only $\pm$ 5 percent in any one step of the operation can significantly skew emission estimations.

4.3 Engineering Calculations

Theoretical and complex equations or *models* can be used for estimating emissions from textile and clothing manufacturing processes and facilities.

Use of emission equations to estimate emissions from textile and clothing manufacturing facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors but they do provide an emission estimate that is based on facility-specific conditions.

4.4 Emission Factors

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in Section 5.0 of this Manual. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

5.0   References

EMEP/CORINAIR. 1996. *AIR: Atmospheric Emission Inventory Guidebook.* European Environment Agency, Copenhagen, Denmark.

Economopoulos A. P. 1993. *Assessment of Sources of Air, Water, and Land Pollution. A Guide to Rapid Source Inventory Techniques and their use in Formulating Environmental Control Strategies. Part One: Rapid Inventory Techniques in Environmental Pollution.* World Health Organisation, Geneva, Switzerland.

USEPA.   October 1992. *VOC / PM Speciation Data System - Version 1.50.*   United States Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, NC, USA.

USEPA. September 1995. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, *fifth edition, AP-42. Section 4.11 Textile fabric printing.*   United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, USA.
http://www.epa.gov/ttn/chief/ap42.html

USEPA. September 1997. *EPA Office of Compliance Sector Notebook Project: Profile of the Textile Industry.* United States Environmental Protection Agency, Office of Enforcement and Compliance Assurance, Washington DC, USA.

The following Emission Estimation Technique Manuals are available at the NPI Homepage (*http://www.npi.gov.au*) and from your local environmental protection
agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Combustion Engines;
- Emission Estimation Technique Manual for Combustion in Boilers;
- Emission Estimation Technique Manual for Fuel & Organic Liquid Storage; and
- Emission Estimation Technique Manual for Sewage & Wastewater Treatment.