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Number 22**

EMISSION SCENARIO DOCUMENTS ON COATING INDUSTRY (Paints, Laquers and Varnishes)

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Series on Emission Scenario Documents No. 22

**EMISSION SCENARIO DOCUMENT
ON COATING INDUSTRY
(PAINTS, LACQUERS AND VARNISHES)**

IOMC

**INTER-ORGANISATION PROGRAMME FOR THE
SOUND MANAGEMENT OF CHEMICALS**

**A cooperative agreement among
UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD**

Environment Directorate

**ORGANISATION FOR ECONOMIC CO-OPERATION AND
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**OECD Environment Directorate,
Environment, Health and Safety Division**

**2 rue André-Pascal
75775 Paris Cedex 16
France**

Fax: (33-1) 44 30 61 80

E-mail: ehscont@oecd.org

EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns and release pathways of chemicals used in the coatings industry (paints, lacquers and varnishes), to assist in the estimation of releases of chemicals into the environment.

This ESD should be seen as a ‘living’ document, which provides the most updated information available. As such, an ESD can be updated to take account of changes and new information, and extended to cover the industry area in countries other than the lead (the United Kingdom). Users of the document are encouraged to submit comments, corrections, updates and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Environmental Exposure Assessment, which will review the comments every two years so that the lead country can update the document. The comments will also be made available to users within the OECD web-site (www.oecd.org/env/riskassessment).

How to use this document

The user of this ESD needs to consider how the information contained in the document covers the situation for which they wish to estimate releases of chemicals. The document could be used as a framework to identify the information needed, or the approaches in the document could be used together with the suggested default values to provide estimates. Where specific information is available it should be used in preference to the defaults. At all times, the values inputted and the results should be critically reviewed to assure their validity and appropriateness.

Coverage

This ESD covers the use of chemicals in the production of coatings and their subsequent application, the service life of the coated products and the disposal of the products. The industry category relevant for this ESD is IC 14, paints, lacquers and varnishes. The equivalent NAICS code used in North America is 3255 – Paint Coating and Adhesives Manufacturing, or more specifically 32551 – Paint and Coating Manufacturing. It should be noted that the application of coatings can be considered to take place in a number of industry categories, and the coated products can clearly be used in a wide range of areas. However it is useful to consider the production and use of coatings in one ESD.

The Use Categories included in this ESD are as follows:

Component	UC	Description
<i>Main use categories</i>		
Binders	2	Adhesive and binding agents
Pigments and dyes	10	Colouring agents
Solvents	48	Solvents
Fillers	20	Fillers

<i>Additives in smaller quantities</i>		
Anti-skinning agents, rheology modifiers	52	viscosity adjusters
Biocides*	37	Biocides, non-agricultural
Catalysts, defoamers	43	Process regulators
Dispersants, surfactants	50	Surface active agents
Flame retardants	22	Flame retardants and fire protecting agents
Flattening agents	0	Other
Plasticisers	47	Softeners

* - this relates to general inclusion of biocides, and not to specific uses such as in wood preservation treatments or anti-fouling treatments.

It should be noted that the choice of emission factors in this ESD is not related directly to the use category of the substance, but more to its general properties. The main criterion used is whether the substance is considered volatile; for formulation a distinction is also made between soluble and non-soluble substances. These properties do relate to the function of the substance to some extent.

How this document was developed

This ESD is based on two original source documents. A draft ESD on coatings manufacture was prepared in 2000 by INERIS in France (INERIS, 2000), focussing on the formulation of coatings (i.e. mixing of the raw materials to produce the coating product). An ESD for the coatings industry was developed for the Environment Agency for England and Wales R&D Project P2-203 'Development of Emission Scenario Documents for Use in Environmental Risk Assessment - Coating Materials Industry: Paints, Lacquers and Varnishes' (Environment Agency, 2002), by Risk & Policy Analysts in the UK.

These two documents were combined for the Environment Agency by Risk & Policy Analysts in 2003. As part of the process of combination, the coatings industry in the UK were consulted on the relevance of the INERIS report for the production of coatings in the UK. Following this, a wider consultation was conducted in Europe, including the European Association of Coatings Manufacturers (CEPE), a number of experts from individual European coatings manufacturers and a number of downstream users (as represented by their associations at the European level), leading to the combined document. This was submitted to the OECD Task Force in 2003.

Comments on this version came from The Netherlands and from various parts of the coatings industry. These mainly related to the inclusion of formulas for use in the calculation of emissions, the development of examples for the coating production (formulation) stage, and the modification of the examples for coating application and subsequent service life. These aspects were addressed in a revised version produced by the Building Research Establishment for the Environment Agency. A number of other minor modifications and corrections were made.

This revised document was circulated to the OECD Task Force in summer 2006. Comments were received from the US EPA, Environment Canada and Verband der deutschen Lackindustrie (VdL, Germany). The current version has been revised in the light of these comments. The US

EPA has indicated some additional US generic scenerios are available, however these have not been incorporated into this version and will be considered in a future version of the document.

The information was collected for the original reports over the period 2000-2003 and no new information collection exercise has been conducted for the last two versions of the ESD. The information for the original reports was largely provided by practitioners in the industry with a wide breadth of knowledge and experience. Published sources are cited where appropriate, but much of the information did not come from such sources and was based on the knowledge and experience of experts consulted. Unless a specific source is cited for a piece of information, it should be assumed to be derived from the experience of the consulted experts. Where no specific statistical information about a value is included (for example, a mean value) then it is intended to be used as a realistic worst case value.

TABLE OF CONTENTS

EXPLANATORY NOTES	7
TABLE OF CONTENTS	10
PART I: GENERAL INFORMATION	17
1 BASICS ABOUT COATINGS.....	17
1.1 Film formation.....	17
1.2 Structure of a coating film.....	18
1.3 Coating constituents	19
1.4 Lifecycle of coatings	23
1.5 Coatings-related legislation in the EU	24
1.5.1 Background.....	24
1.5.2 The IPPC Directive.....	24
1.5.3 The Solvent Emissions Directive	25
1.5.4 The End-of-Life Vehicles Directive.....	26
1.5.5 The National Emission Ceilings Directive	26
1.5.6 Directive 2004/42/EC on decorative paints and varnishes and vehicle refinishing coatings.....	27
1.6 Classification of coatings	27
2 THE EUROPEAN COATINGS INDUSTRY	28
2.1 Volume and value of paint sales in the EU in 2001	28
2.2 Breakdown of coatings sold in the EU in 2001.....	29
2.3 The EU powder coatings industry.....	30
PART II: COATINGS MANUFACTURE.....	32
1 CONTENT OF PART II.....	32
2 COATINGS MANUFACTURE PROCESSES AND EMISSIONS	32
2.1 General coatings manufacture.....	32
2.2 Process description	33
2.2.1 Overview	33
2.2.2 Dispersion.....	35
2.2.2.1 Batch assembly.....	35
2.2.2.2 Storage.....	36
2.2.2.3 Pre-weigh	36
2.2.2.4 Transfer of bulk materials	36
2.2.2.5 The dispersion process	37
2.2.3 Milling	39

2.2.4	Finishing	40
2.2.4.1	Make up	40
2.2.4.2	Mixing	40
2.2.4.3	Sampling	41
2.2.4.4	Tinting	41
2.2.4.5	Adjustment	41
2.2.5	Product filling	41
2.2.5.1	Transfer	41
2.2.5.2	Filtration	42
2.2.5.3	Filling	42
2.3	Other processes related to coatings manufacture	43
2.3.1	Cleaning of vessels	43
2.3.1.1	Cleaning of fixed vessels	43
2.3.1.2	Cleaning of mobile vessels	44
2.3.2	Production of waste	44
2.3.2.1	Overview	44
2.3.2.2	Landfilling and incineration of coatings waste	46
2.3.2.3	Process waste minimisation	46
2.3.2.4	Disposal of liquid raw material containers	47
2.3.2.5	Disposal of washings	47
2.4	Releases to the environment	47
2.4.1	Overview	47
2.4.2	Emissions to air	48
2.4.3	Emissions to water	49
2.4.4	Releases to soil	49
3	PREVENTION AND ABATEMENT OF EMISSIONS	50
3.1	Prevention of emissions	50
3.1.1	Vessel design	50
3.1.2	Pipework design	50
3.1.3	Vessel extraction or Local Exhaust Ventilation (LEV)	50
3.1.4	Extraction design: area ventilation	51
3.1.5	Condensers	51
3.1.6	Other emission prevention measures	51
3.2	Abatement of emissions	51
4	MANUFACTURE OF ORGANIC SOLVENT-BORNE COATINGS	52
4.1	Organic solvent-borne coatings	52
4.1.1	General information	52
4.1.2	High solids coatings	53
4.2	Manufacturing process	54
4.3	Waste generation	54
4.4	Releases to the environment	56
4.4.1	Emissions to air	56
4.4.2	Emissions to wastewater	58

4.5	Onsite emission treatment techniques (treatment of VOCs emissions to air)	58
4.6	Calculations and release table for standard batch manufacture of organic solvent-borne coatings	59
4.7	Recycling of waste	60
4.8	Manufacture of large batches	61
4.8.1	Overview	61
4.8.2.	Emissions during large batch manufacture of organic solvent-borne coatings	62
4.8.3.	Calculations and release table for large batch manufacture of organic solvent-borne coatings	63
4.9	Example calculations	65
4.9.1	Pigment	65
4.9.2	Solvent	67
5	MANUFACTURE OF WATER-BORNE COATINGS	68
5.1	Types of water-borne coatings	68
5.1.1	Overview	68
5.1.2	Aqueous dispersions	68
5.1.3.	Water-reducible coatings	68
5.1.4	Colloidal dispersions	70
5.2	Manufacture of aqueous dispersion coatings	71
5.2.1	Overview	71
5.2.2	The manufacturing process	71
5.2.3	Waste generation	71
5.2.4	Releases to the environment	72
5.2.4.1	Releases to air	72
5.2.4.2	Emissions to wastewater	73
5.2.4.3	Emissions to soil	73
5.2.5	On site emission treatment techniques (treatment of VOCs emissions to air)	74
5.2.6	Calculations and release table for the standard batch manufacture of aqueous dispersion coatings	74
5.2.7	Recycling of waste	75
5.2.8	Manufacture of large batches of aqueous dispersion coatings	75
5.2.8.1	Overview	75
5.2.8.2	Emissions during large batch manufacture of aqueous dispersion coatings	76
5.2.8.3	Calculations and release table for large batch manufacture of aqueous dispersion coatings	76
5.3	Manufacture of water-reducible coatings and colloidal dispersions	79
5.3.1	Overview	79
5.3.2	Waste generation	79
5.3.3	Emissions to the environment	79

5.3.3.1	Emissions to the air	79
5.3.3.2	Emissions to wastewater	80
5.3.3.3	Emissions to soil	80
5.3.4	Onsite emission treatment techniques (treatment of VOCs emissions to air)	80
5.3.5	Calculations and release table for standard batch manufacture of water-reducible coatings and colloidal dispersions	81
5.3.6	Large batch manufacture of water-reducible coatings and colloidal dispersions.....	82
5.3.6.1	Overview	82
5.3.6.2	Emissions during large batch manufacture of water-reducible coatings and colloidal dispersions	83
5.3.7	Calculations and release table for large batch manufacture of water-reducible coatings and colloidal dispersions	83
5.4	Example.....	86
6	MANUFACTURE OF POWDER COATINGS.....	87
6.1	Overview of manufacturing processes	87
6.2	Types of powder coatings	87
6.2.1	Overview	87
6.2.2	Thermoplastic powder coatings.....	88
6.2.3	Thermoset powder coatings.....	88
6.3	Melt-blend manufacture of powder coatings	88
6.3.1	Description of the process	88
6.3.2	Waste generation	90
6.3.3	Releases to the environment.....	90
6.3.3.1	Emissions to air.....	90
6.3.3.2	Emissions to wastewater	92
6.3.3.3	Emissions to soil	92
6.3.4	Calculations and release table for standard batch manufacture of melt-blend powder coatings.....	92
6.3.5	Recycling techniques.....	96
6.3.6	Melt-blend manufacture of powder coatings in large batches	97
6.3.7	Calculations and release table for large batch manufacture of melt-blend powder coatings.....	97
6.4	Dry-blend manufacture of powder coatings.....	102
6.4.1	Description of the process	102
6.4.2	Production losses	103
6.4.3	Waste generation	103
6.4.4	Releases to the environment.....	105
6.4.4.1	Emissions to air.....	105
6.4.4.2	Emissions to wastewater	105
6.4.4.3	Emissions to soil	106

6.4.5	Calculations and release table for the manufacture of dry-blend powder coatings	106
6.4.6	Recycling techniques	107
6.5	Example	107
7.	EMISSION ESTIMATES ASSUMPTIONS	110
8.	DATA GAPS/LIMITATIONS/IMPROVEMENTS	114
PART III:	APPLICATION AND DISPOSAL OF COATINGS	115
1	PRESENTATION OF EMISSIONS ESTIMATES	115
1.1	Calculation of emissions	116
2	GENERAL OVERVIEW OF COATINGS APPLICATION	117
2.1	Coatings application, drying and curing methods	117
2.2	Trends and technology in coatings application	118
2.3.1	Applicability of abatement options to different coating processes	123
2.3.2	Abatement options available to the coatings application sectors	123
3	WOODEN FURNITURE COATINGS	123
3.1	General overview of the sector	123
3.2	Process description and coating products used	124
3.2.1	Coating types and trends	124
3.2.2	Coating processes	126
3.3	Emissions estimates	126
3.4	Example calculations	129
4	DECORATIVE PAINTS	130
4.1	General overview of the sector	130
4.2	Process description and coating products used	131
4.2.1	Coating products	131
4.2.2	Coating processes	133
4.3	Emissions estimates	133
4.4	Example calculations	136
5	AUTOMOTIVE COATING AND REFINISHING	136
5.1	General overview of the sectors	136
5.2	Processes description and coating products used	138
5.2.1	Automotive OEM	138
5.2.2	Automotive refinishing	140
5.2.2.1	Basic steps and coatings used	140
5.2.2.2	Implications of European legislation on VOCs	141
5.2.2.3	Types of spray booths used in vehicle refinishing	144
5.3	Emissions estimates	145
5.3.1	Automotive OEM	145
5.3.2	Automotive refinishing	146
5.4	Notes on the revisions to existing estimates	148
5.5	Example calculations	149
6	METAL PACKAGING COATINGS	150

6.1	General overview of the sector.....	150
6.2	Process description and coating products used	150
6.2.1	Introduction	150
6.2.2	Beer and beverage cans	151
6.2.3	Food cans and general line cans	152
6.3	Emissions estimates.....	153
6.3.1	Beer and beverage cans	153
6.3.2	Food cans and general line cans	156
6.4	Example calculations.....	157
7	COIL COATINGS	158
7.1	General overview of the sector.....	158
7.2	Process description and coating products used	159
7.2.1	Coating types and quantities.....	159
7.2.2	Coating process	160
7.3	Emissions Estimates	161
7.4	Example calculations.....	164
8	MARINE COATINGS.....	164
8.1	General overview of the sector.....	164
8.2	Process description and coating products used	165
8.2.1	Overview	165
8.2.2	Surface pre-treatment	165
8.2.3	Coating application.....	166
8.3	Emissions estimates.....	167
8.3.1	Surface preparation.....	167
8.3.2	Coating application.....	167
8.3.3	Equipment cleaning and other residuals.....	167
8.3.4	Summary of emissions estimates	168
8.4	Example calculations.....	169
9	COATINGS IN THE AEROSPACE INDUSTRY	170
9.1	General overview of the sector.....	170
9.2	Process description and coating products used	170
9.2.1	Overview	170
9.2.2	Surface preparation.....	170
9.2.3	Coating application.....	171
9.2.3.1	Types of coatings	171
9.2.3.2	Spraying	171
9.2.4	Equipment cleaning	172
9.3	Emissions estimates.....	172
9.3.1	Overview	172
9.3.2	Summary of emissions estimates	173
9.4	Example calculations.....	174
10	RAIL VEHICLE COATINGS	175
10.1	General overview of the sector.....	175

10.2	Process description and coating products used	175
10.2.1	Overview	175
10.2.2	Surface preparation.....	176
10.2.3	Painting.....	177
10.2.4	Equipment cleaning	178
10.3	Emissions estimates.....	178
10.3.1	Shot blasting	178
10.3.2	Spray painting.....	178
10.3.3	Equipment cleaning	179
10.3.4	Summary of emissions estimates	179
10.4	Example calculations.....	179
11	TREATMENT OF COATINGS WASTES	181
11.1	General overview	181
11.2	Process description.....	181
11.3	Emissions estimates.....	183
11.4	Example calculations.....	185
12.	DATA GAPS/LIMITATIONS/IMPROVEMENTS.....	185
PART IV: GLOSSARY AND REFERENCES		186
1	GLOSSARY.....	186
2	REFERENCES.....	195

PART I: GENERAL INFORMATION

1 BASICS ABOUT COATINGS

For the purpose of this document, “coating” is used to describe any material which may be applied as a thin continuous layer to a surface. The terms paint, lacquer or varnishes all describe certain forms of coatings, but their use is not uniform and often leads to misunderstandings. The following definitions have been provided by the European Association of Coatings Manufacturers (CEPE) and are based on European and American standards (CEPE, 2003a):

A **paint** is a pigmented coating material, in liquid or in paste or powder form, which when applied to a substrate, forms an opaque film having protective, decorative or specific technical properties (EN 971-1:1996).

A **lacquer** is a coating composition that is based on synthetic thermoplastic film-forming material dissolved in organic solvent that dries primarily by solvent evaporation (ASTM D 96-00). *Air drying lacquer* is transparent coating material that may be coloured and that dries solely by evaporation of solvents, while a *stoving lacquer* is a coloured transparent stoving finish that does not dry solely by evaporation of the solvent (BS 2015:1992).

Clear coating material is a coating material which when applied to a substrate forms a solid transparent film having protective, decorative or specific technical properties. A clear coating material drying exclusively by oxidation is known as a **varnish** (EN 971-1:1996).

Today, coatings are applied for their following functions:

- Protection of the coated substance from corrosion, UV degradation, chemical effects and other environmental effects.
- Providing decorative, aesthetic and other surface effects.
- Providing warning, safety and general information.

1.1 *Film formation*

The essential job of a surface coating is to build a continuous, adhesive layer on a surface. This process, generally known by the expression ‘drying’, is called film formation. There are several mechanisms for the process of film formation:

- Evaporation of solvents from solutions or dispersions of macro molecular substances.
- Solidification of melted substances.
- Chemical reactions.

The first two cases describe a physical process. In physically drying coatings, no chemical reaction between the compounds takes place. After volatilisation of the solvents (water or organic solvents), the binder, consisting of substances of high molecular weight, forms the film. The evaporation of the solvents may be accelerated by high temperatures. Coatings of this kind can be re-dissolved or at least softened when exposed to the original solvents. Powder coatings are an exception. They contain no solvents and have to be heated above the melting point of the binder to form a film (Baumann & Muth, 1995 in INERIS, 2000).

Binder systems in chemically drying coatings are typically mixtures of high and low molecular weight compounds, containing reactive groups. Film formation occurs through reaction between the reactive groups. According to Baumann & Muth (1995), these reactions are essentially:

- Oxidative cross-linking of aliphatic double bonds due to the impact of the oxygen in the air.
- Polycondensation at high temperature or through the impact of acid.
- Polymerisation between oligomeric resins and active solvents serving as co-monomers either due to catalysts (ionic polymerisation) or due to radiation in the form of heat, UV-radiation or due to the addition of reactive chemicals (radical polymerisation).
- Polyaddition of epoxy or isocyanate groups with reactive curing agents serving as promoters.

Certain coatings can contain specific low molecular weight compounds known as reactive diluents, which reduce the viscosity of the coating for application and then react with the other film-forming compounds during drying or curing of the film. Although they are volatile organic compounds (VOCs) by definition, these reactive diluents are not VOCs under the particular conditions of use and do not contribute to VOC emissions from the coating.

1.2 Structure of a coating film

Many substrates are coated with several layers of different coatings. These combinations are called multilayer systems. Each layer serves different purposes and the coatings used have different properties. One example of a multilayer system may comprise (Valspar, 2003; Baumann & Muth, 1995 in INERIS, 2000):

- Pre-treatment (impregnation of the substrate or pre-treatment of metals for passivation/neutralisation).
- A size coat (optionally used to improve properties such as adhesion).
- Primer.
- Basecoat.
- Undercoat.
- Surfacer (filler).
- Topcoat or finisher.

The use of multilayer systems depends on the specific end use or in-service requirements. Typical applications are decorative coatings on wood and vehicles (such as automobiles, ships, aeroplanes

or trains). The thickness of a coating film varies according to the painted substrates, the application method and the type of coating used.

1.3 *Coating constituents*

A coating is essentially a mixture of different materials, the percentage and type of which may vary in different types of coatings. The generic categories of these materials are given below.

Binders (frequently referred to as ‘resins’) form the paint film by binding together the various other components of the paint, as the name suggests. Binders are the most important ingredient of coatings since they undergo a hardening process (usually cross-linking or coalescence) during the drying stage and by this they impact upon many of the coatings’ basic properties, especially: a) adhesion and resistance to blistering, cracking and peeling; b) resistance to scrubbing, chalking and fading and wash ability; and c) application properties like flow, levelling, film build and gloss development. Synthetic binders account for more than 90% of those used today and include alkyds, acrylics, vinyl, epoxy, urethane, and polyester binders and specialty materials such as silicates (organic or mineral) and silicones (FIPEC, 2003; PQI, 2000b; Tikkurila, 1997; PCRC, not dated). Table 1.1 provides an overview of common binders used in the manufacture of coatings.

Pigments are small particle powders that are insoluble in water or organic solvents. They are added to give the coating colour and good hiding power. Some pigments also provide protection against the sun’s ultra-violet radiation, while others enhance the paint’s corrosion resistance and various other features (optical properties, conductivity, metallic or pearlescent appearance, etc.). The most commonly used pigments are yellow and red iron oxides, carbon black and white titanium dioxide. These inorganic pigments mixed with small quantities of organic ones can produce most of the colours of the spectrum (Tikkurila, 1997; PCRC, not dated). **Tinting pastes** are concentrated pigments which are added at the point of sale to tint bases and to white paints designed for tinting (PQI, 2000c).

Dyes are materials that are soluble in the carrier phase (see below) and that have no or very low opacification potential (ability to hide the previous colour layer or the surface itself) as compared to pigments (BCF, 1999). Three different groups of substances are most commonly used as dyes in coatings: metal-complex dyes, anionic-dyes and azo-dyes. Table 1.2 gives an overview of possible dye-solvent combinations and their fields of application.

The **carrier phase** is typically a liquid such as an organic solvent, water or a mixture of these. This liquid component evaporates after application enabling film formation to occur (note that powder coatings have no carrier phase). The most widely used carrier phases are: alcohols; aromatic, aliphatic and cycloaliphatic hydrocarbons; esters; glycol ethers; ketones; and water (C-EPA, 1995). Carriers such as White spirit and lacquer thinners are mixtures of these chemical substances. In the case of organic solvents, the carrier phase:

- Dissolves the binder (resin).
- Aids the dispersion of the pigment during manufacture.
- Maintains stability and homogeneity prior to use.

- Provides the correct fluidity for the application process.
- Ensures that the desired appearance and finish is achieved (BCF 1999).

Table 1.1: Common binders used in coatings

Chemical group of the binder	Examples	Remarks, substrate or category of appliance
Oleoresinous binders	Linseed oil, soy oil, oiticica oil	Wood, artists coatings, water reservoirs
Cellulose polymers	Cellulose nitrates, cellulose ester	Often used in combination with alkyd resins for: wood and furniture coating; often used in 2-component polyurethane coatings for the coating of metal, wooden or concrete surfaces
Rubber derivatives	Chlorinated rubber	Pure chlorinated rubber demands a high percentage of softener. Used for installations in the (chemical) industry, primer, marine, swimming pools
Vinyl resins	Polyvinyl ester, polyvinyl alcohol	Dispersions, water thinnable coatings
Acrylic polymers	Thermoplastic acrylic resins: polymethyl-methacrylate homo- or copolymers Thermosetting acrylic resins: polymethyl-methacrylate with incorporated hydroxy groups	Synthetic leather coatings, primer for plastic surfaces, gloss finish for non ferrous substrates; automotive topcoats; can coatings
Alkyd resins	Acrylic alkyd resins urethane-, silicone- or epoxy-modified alkyd resins	Automotive, marine, fire proof coatings, home appliances, gloss finishes for wood, primer, emulsions, surfacer
Polyester resins	Unsaturated- and saturated polyesters	Coil coatings, furniture coatings, surfacer
Epoxy resins	Bisphenol-A resins	Primer, powder, automotive, aeroplanes, metal, concrete, pipes, paper coatings
Polyurethane resins	Poly-isocyanate, polyhydroxyls	Nuclear power installations, automotive, marine, aeroplanes, trains, plastics, leather, wood coatings
Phenolic resins	Novolac, resol	Marine, cans, electrical isolations
Asphalt		Corrosion protection, furnaces
Silicate binders	Alkyl-silicates	Construction, humid areas

Table 1.2: Overview of different types of dyes (Baumann & Muth, 1995)

	Metal-complex dyes	Anionic-dyes	Azo-dyes
Solvents	Water; water/organic solvents; glycol ethers	Alcohol; ester; ketone	Mineral oil; aromatic hydrocarbons; wax
Application	Wood stains; wood preservation and impregnation products	Wood stains; foil coating; can and metal-effect coatings	Wood stains; wax stains; oily wood preservatives

Table 1.3 describes the most common carrier phase chemicals.

Table 1.3: Carrier-phase chemicals commonly used in coating formulation (Valspar, 2003; Baumann & Muth, 1995)

Chemical Group	Examples	Used for example in the following coatings or binder systems
Water	Water	Water thinnable coatings, colloidal dispersions
Aliphatic hydrocarbons	White spirit	Chlorinated rubber, alkyd resin coatings, oleoresinous coatings
Aromatic hydrocarbons	Solvesso 100, 150 & 200 (solvent naphthas which have different compositions – distillation cuts), xylene, toluene	Stoved coatings (industrial, can and coil coatings); also in some force-dried coatings and ambient drying coatings
Alcohol	<i>N</i> -butanol, ethanol, cyclohexanol	Epoxy-resin coatings, oil and alkyd resin coatings, diluent/thinner for water coatings
Esters	Ethyl acetate, butyl acetate, ethylhexyl acetate	Nitrocellulose coatings, polyurethane coatings, epoxy coatings, alkyd resin coatings
Ketones	Acetone, methyl isobutyl ketone, cyclohexanone, isophorone	Epoxy-resin coatings, nitro-cellulose coatings, alkyd resin coatings
Glycol ethers	Butyl glycol, butyl diglycol, ethoxy propanol	Nitrocellulose coatings, epoxy resin coatings, water-reducible coatings

Note: it is also possible to have carriers that are not volatile and either remain in the film or react during film formation.

Extenders/fillers are generally inorganic products that provide bulking at relatively low cost. They have less hiding power (ability to hide previous coating or the surface) than pigments, but contribute properties such as sheen, scrub resistance, exterior colour retention, rheology and others (PQI, 2000c; BCF, 1999). Some commonly used extenders are aluminium silicates (clay), diatomaceous silica, calcium carbonate, talc and lime (Tikkurila, 1997; C-EPA, 1995). Fillers can be classified with regard to their particle size as follows:

Table 1.4: Classification of fillers according to the particle size (Baumann & Muth, 1999)

<i>Description</i>	<i>Particle size</i>
Coarse powder	>250µm
Medium powder	50 < x < 250 µm
Fine powder	10 < x < 50µm
Very fine powder	<10 µm

Additives include constituents used in very small quantities that modify specific properties relevant to manufacture, storage, application and use of the coating. Table 1.5 sets out the types of additives that are most commonly used in coatings.

Table 1.5: Types of additives used in coating mixtures (PQI, 2000a; BCF, 1999; Amato, 1998; CEC, 1996; C-EPA, 1995)

Additive type	Description
Anti-skinning agents	Additives that prevent the formation of an oxidised top film/skin upon storage of the paint
Biocides	Bio-active substances used to protect liquid paints, dry coatings and production sites from biodegradation; also known as preservatives which are classified as in-can preservatives (for preservation of wet paints stored in containers and tanks) or film preservatives (which protect dry films and susceptible substrates)
Catalysts	Additives that facilitate chemical reactions (polymerisation, etc.)
Defoamers	Additives that inhibit the production of foam
Deodorants	Additives that reduce unpleasant or introduce tolerable odours from the coating (not frequently used)
Dispersants	Agents that facilitate the dispersion process and ensure a fine particle size and stabilised pigment suspension (could be classified as a type of surfactants)
Flame retardants	Additives that provide protection from fire
Flattening agents	Ingredients used in lacquers and varnishes to give a flat or hand-rubbed effect (i.e. to reduce gloss); calcium, fumed silica, aluminium or zinc stearate are used
Plasticisers	Additives that allow higher degree of flexibility of the coating
Surfactants	Agents that reduce surface tension; conventionally, they are classified according to their charge: anionic (negative); cationic (positive); nonionic (no charge); amphoteric (both positive or negative)
Rheology modifiers	Additives that allow modification of the viscosity characteristics of the coating

Table 1.6 provides an overview of different types of additives and of the range in which they are applied in coatings. It is a revision of a similar table provided in the existing EU Technical Guidance Document. The updated information was provided by UK decorative coatings industry consultees during the preparation of the UK Emission Scenario Document for Coatings Application in February 2001 (Environment Agency, 2002).

The revised figures all relate to the minimum values and are shown in bold. It should be noted that all of these revisions relate to a decrease in the minimum concentrations of the various additives within paints with the exception of coalescent agents.

The composition of a coating will be dependent upon a number of factors, namely:

- The substrate to which the coating is to be applied on.
- The intended method of application.
- The service environment.
- The desired role of the coating (PRA, 2000a).

Table 1.6: Typical concentrations of different types of additives in decorative coatings

Type of Additive	Minimum concentration (%)	Maximum concentration (%)
Anti skin agents ¹	0.1	0.3
Spreading agents	0	0.1
Dispersant agents	0.0	2.0
Thickening agents	0.0	3.0
Coalescence agent ²	0	10.0
Preservatives in cans ²	0.01	0.3
Drying catalyst agents	0.01	0.1
UV protective agents	0.05	0.1
Film preservation agents	0.15	1.0
Antifoam/antibubble agents ²	0.2	0.3
Antiblocking agents	0.5	1.0
Sanding agents	0.2	1.0

Notes: ¹Only for, or essentially in, organic solvent-borne products.

²Only for, or essentially in, water-borne products.

1.4 Lifecycle of coatings

Figure 1.1 illustrates the various stages involved in the lifecycle of typical coating products.

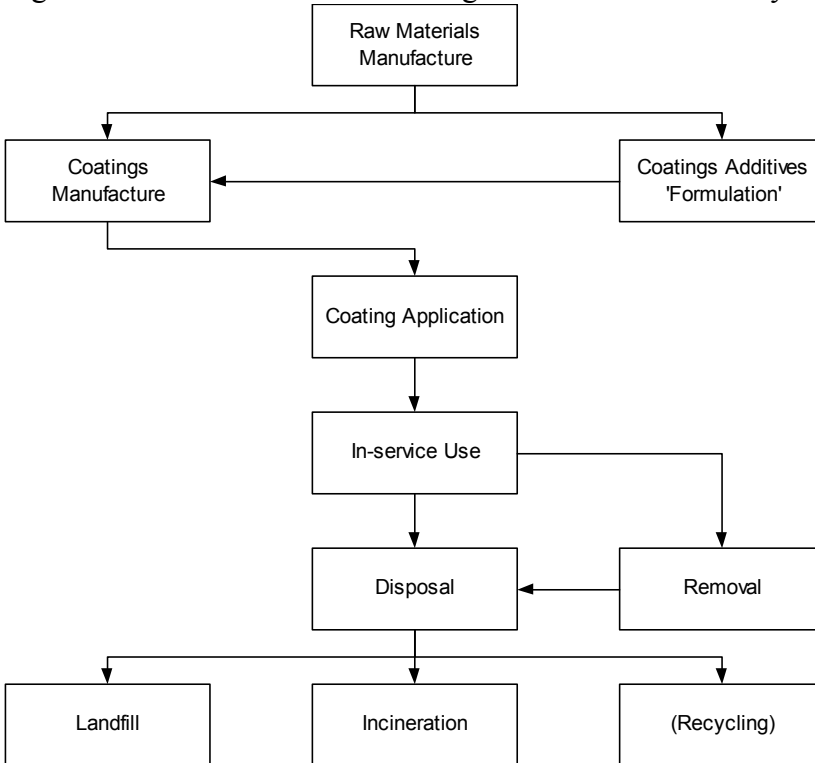


Figure 1.1: Lifecycle of coating materials

The stages include: manufacture and transportation of the raw materials; mixing of the raw materials to formulate the coating; application of the coating on a surface (such as through spraying, dipping or roll coating); use of the coated product (such as a piece of furniture or a car); removal of the coating, if required; and disposal of the coated product or removed coating.

1.5 Coatings-related legislation in the EU

1.5.1 Background

As well as technical innovation and industry considerations of occupational health and safety and environmental protection, EU and national legislation has played a major part in changing practices within the industry in the manufacture, application, use and disposal of coatings and of coated products.

The main focus for much of this has been on the solvents used and emitted to the environment. According to the European Solvents Industry Group (ESIG), the coatings industry is the largest consumer of solvents in Western Europe, with a 46% market share. In both Europe and America, the predominant type of solvent is hydrocarbons, with this accounting for more than 50% of total solvent use in paints (Environment Agency, 2002).

Advances in technology and new legislation have led to a more extensive use of water-borne coatings in certain industrial coatings sectors, and with this an increasing demand for coalescing solvents/agents (low-volatility, partially water soluble liquids used to improve particle coalescence, facilitate the formation of coherent films and lower the minimum film forming temperature (mfft) of paints).

As a consequence, over the last decade the industrial coatings sector has witnessed a gradual transition from hydrocarbons towards oxygenated solvents (mainly glycol ethers) (PRA, 2000b). A shift towards high solids coatings and solvent-free two component coatings has also taken place.

The remainder of this section provides a brief overview of some of the main legislative drivers underlying changes in the industry as a whole. It should be noted that the main driver behind recent changes has been legislation not specifically aimed at the coatings sector but rather at a range of industrial sectors and processes.

1.5.2 The IPPC Directive

Directive 96/61/EC on Integrated Pollution Prevention and Control addresses the reduction of emissions into all media from a large number of industrial sectors. The purpose of this Directive is to achieve integrated prevention and control of pollution arising from the activities listed in Annex I to the Directive. It lays down measures designed to prevent or, where that is not

practicable, to reduce emissions to the air, water and land from the abovementioned activities, including measures concerning waste, in order to achieve a high level of protection of the environment taken as a whole.

With regard to coating-related processes in particular, paragraph 6.7 of Annex I includes “installations for the surface treatment of substances, objects or products using organic solvents, in particular for dressing, printing, coating, degreasing, waterproofing, sizing, painting, cleaning or impregnating, with a consumption capacity of more than 150 kg per hour or more than 200 tonnes per year”. It should be noted that this relates to solvent used in surface treatment, and not to solvents in the coatings themselves.

The IPPC Directive accordingly does not apply to coatings *manufacture*, although a number of large industrial coatings users will be in scope. A BREF (Best Available Techniques Reference document) on surface treatments using organic solvents is in draft form (September 2005).

1.5.3 *The Solvent Emissions Directive*

Directive 1999/13/EC of 11 March 1999 is the main EU instrument for the reduction of the emissions of VOCs from particular activities and installations. It is commonly referred to as the Solvent Emissions Directive (SED).

The key aims of the Directive are:

- **The prevention of tropospheric ozone creation**
- **The protection of human health** through replacement of a few solvents that are classified as carcinogenic, mutagenic or toxic to reproduction.

The SED applies to processes and industrial sectors which use relatively large quantities of organic solvents and which directly or indirectly emit VOCs to the atmosphere. As such, the SED aims to reduce VOC emissions from EC Member States by 57% by 2007, based on 1990 emission levels. Coatings manufacture and application of coatings in industrial processes are two of the industrial sectors using organic solvents which are included in the SED. According to the SED, sectoral Emission Limit Values (ELVs) have been agreed on the presumption that appropriate Best Available Techniques (BAT) have been established for the sector. CEPE, the European association for coatings manufacture, has developed this guidance on BAT for the sector, to enable the requirements of the SED to be met. The SED requires coatings manufacturers to meet the 3 or 5% total emissions limit or to meet either the 3 or 5% fugitive emissions limit plus the contained (stack) emissions limit of 150 mg.m⁻³, as set out in section 17 of Annex IIA of the SED (CEPE, 2003b).

The Directive was required to have been transposed into national legislation by April 2001, with existing installations having to comply fully by 2007. This lengthy procedure for implementation is aimed at ensuring minimal disruption of investment cycles and supports the penetration of process-integrated and substitution solutions instead of end-of-pipe techniques utilisation.

Table 1.7 illustrates the VOC emission reductions that would be achieved through the implementation of the SED in the UK as an example of national legislation covering both coatings manufacture and use. The UK Local Air Pollution Control/Integrated Pollution Control regulations are predicted to result in a 61% decrease in VOC emissions from 1990 levels (from 423 kilotonnes per annum to 166 kilotonnes per annum), with a further reduction of 21% (from 166 kilotonnes per annum to 131 kilotonnes per annum) arising from implementation of the SED.

Table 1.7: Reductions for the UK achieved by compliance with the EU VOC Solvents Directive 1999/13/EC (in thousand tonnes) (Entec, 1999)

1990 Baseline VOC Emissions	423
VOC Emissions under LAPC/IPC (1999)	166
VOC Emissions with implementation of Directive (2000)	131
VOC Emissions Reduction 1999-2007	35

As SED is based on a permitting system in order to achieve the required reduction of emissions from installations, there have been practical limitations with regard to the implementation and enforcement of the SED given the size and number of installations amenable to a permitting approach. Consumption thresholds have been introduced to exclude trivial and small emitters and to avoid an unrealistically excessive administrative burden and diminishing environmental benefits. For certain sectors, not fully subject to, or amenable to, SED-type process controls, the Commission is introducing product-based legislation (see Section 1.5.6).

1.5.4 The End-of-Life Vehicles Directive

For the vehicles industry in particular, Directive 2000/53/EC on end-of-life vehicles may necessitate changes in the use of coatings on vehicles. The Directive emphasises the need to reduce the use of hazardous substances when designing vehicles and that their design and production should facilitate the dismantling, reuse, recovery and recycling of end-of-life vehicles. Also, an increasing use of recycled materials in vehicle manufacture must be pursued. This may necessitate changes to current coating operations within the vehicle industry sector, including development of alternative coating technologies. It should be noted that uses of specified metal compounds (lead, mercury, cadmium and hexavalent chromium) have already been extensively phased out from vehicle manufacturing processes.

1.5.5 The National Emission Ceilings Directive

Directive 2001/81/EC aims to limit emissions of acidifying and eutrophying pollutants and ozone precursors in order to improve the protection in the Community of the environment and human health against risks of adverse effects from acidification, soil eutrophication and ground-level ozone. It also aims to move towards the long-term objectives of not exceeding critical levels and loads and of effective protection of all people against recognised health risks from air pollution by

establishing national emission ceilings, taking the years 2010 and 2020 as benchmarks, and by means of successive reviews as set out in Articles 4 and 10 of the Directive.

After lengthy negotiations in the Council and the European Parliament, Member States committed to national emission ceilings for 2010 which give a combined Community ceiling of 6,510 kilotonnes of VOCs. Member States agreed that additional measures targeting the VOC contents of products would need to be introduced to achieve further VOCs emissions reductions (CEC, 2002).

1.5.6 Directive 2004/42/EC on decorative paints and varnishes and vehicle refinishing coatings

On the basis of a number of studies the European Commission identified a number of sectors as large users of VOCs and also sectors that are currently not covered adequately (or not covered at all) by Community legislation on VOCs emissions. These are the following (along with their estimated solvent consumption, as presented in CEC, 2002):

- **Decorative coatings:** annual solvent usage of 1.5 million tonnes (of which 50% are decorative coatings used by the general public and professionals, and emissions of which are not covered by the SED).
- **Ink industry:** annual solvent usage of 125 kilotonnes (emissions from which are covered by the SED).
- **Cosmetics, toiletries and perfumes industry:** annual solvent usage of 200 kilotonnes (the emissions of which are not covered by the SED).
- **Cleaning materials and polishes industry:** annual solvent usage of 300 kilotonnes.
- **Vehicle refinishing sector:** annual solvent usage of 45 kilotonnes (emissions of which are covered in part by the SED).

Directive 2004/42/EC sets limits on the total content of VOCs in decorative paints and varnishes, and in vehicle refinishing products. For decorative paints and varnishes, initial limits come into force at the beginning of 2007, with lower limits in phase II from the start of 2010. A single set of limits for vehicle refinishing come into force at the beginning of 2007. Products falling within the scope of the Directive must comply with the limits in order to be marketed in the EU, and must be labelled when placed on the market.

1.6 *Classification of coatings*

Coatings can be classified according to different criteria, however, the use of different categories can make the comparison of data (especially statistical data) difficult. Coatings can be distinguished according to:

The market sector (automotive coatings, marine coatings, furniture coatings, architectural coatings, etc.).

The curing method (oven curing coatings, air dried one- and two-component coatings, radiation curing coatings, etc.).

Their role in a multilayer coating film (primer, surfacer, finish, etc.).

The composition of the substrate coated (wood coatings, metal coatings, leather coatings, plastic coatings, etc.).

The binder system used (see Table 1.1 above).

The nature of the coating (powder coatings, high solids coatings, etc.).

The solvent used (organic solvent borne coatings, water borne coatings, powder coatings).

The application method (coatings for sprayed finish, roller coating, dipping, etc.).

As far as emissions from coatings manufacture is concerned, a coating classification according to the solvent used has been chosen for the purposes of Part I of this Emission Scenario Document, while for Part II a classification by market sector has been followed.

2 THE EUROPEAN COATINGS INDUSTRY

2.1 Volume and value of paint sales in the EU in 2001

The total tonnage of domestic coatings sales in the EU in 2001 amounted to approximately 5.5 million tonnes, according to figures from the European Association of Coatings Manufacturers, CEPE (CEPE, 2002a). The total tonnage sold in 2001 was 0.4% lower than the respective figure for the year 2000. It should be noted that the overall figure includes the sales in Norway and Switzerland, however, the combined total sales for these two non-EU Member States are well below 200,000 tonnes for the year 2001. There are more than 1,400 manufacturers of paints and inks that are members of the national trade associations that are in CEPE membership (CEPE, 2003b).

The leading countries in terms of tonnage sold are Germany, Italy, France, the UK, Spain and the Netherlands. The estimates of their consumption are provided in Table 2.1. The term 'paints' used by CEPE includes all coatings sold in the EU plus in Norway and Switzerland.

With regard to the value of the paint products sold, total paint sales in the EU accounted for €15.6 billion, down by 0.4% compared to 2000 figures.

Leading countries are, again, Germany, France, Italy, the UK, Spain and the Netherlands, although here the value of the French market slightly exceeds that of the Italian market, despite

the considerably larger volume of sales in Italy compared to France. The estimates for annual sales value are provided also in Table 2.1.

Table 2.1: Estimated annual sales of paints in the EU (including Norway and Switzerland) in 2001 (CEPE, 2002a)

Country	Domestic Sales Volume		Domestic Sales Value	
	Tonnes	% of EU total	€billion	% of EU total
Germany	1,430,000	26	3.31	21
Italy	840,000	15	2.35	15
France	740,000	14	2.39	15
UK	730,000	13	2.27	15
Spain	550,000	10	1.07	7
Netherlands	295,000	5	0.76	5
EU total	5,500,000	100	15.60	100

For comparison, sales in the USA in 2001 were 1.39×10^9 gallons (3,200,000 tonnes), value 17.3 billion dollars (US Census Bureau, 2006).

2.2 Breakdown of coatings sold in the EU in 2001

Decorative coatings represent by far the biggest coatings category in the EU (plus Norway and Switzerland) in 2001 both in terms of sales volume and sales value. Table 2.2 provides a breakdown of the types of coatings sold in the EU in 2001 and the respective estimates of tonnage and value estimates.

Table 2.2: Types of paints sold in the EU (plus Norway and Switzerland) in 2001 – Estimated annual sales volume and value (CEPE, 2002a)

Type of paints	Domestic Sales Volume Percentage	Domestic Sales Value Percentage
Decorative	63	46
General industry	11	13
Wood	6	7
Powder	5	7
Automotive OEM ¹	5	7
Protective	3	3
Vehicle refinishing	2	10
Coil	2	3
Can	2	3
Marine	1	2

Note: ¹Original Equipment Manufacture.

For comparison, a breakdown of use in the USA for 2001 is included in Table 2.3; the basis of the classification is different and so comparison is not straightforward. More recent data are available from the same source.

Table 2.3: Breakdown of paints used the USA in 2001 (US Census Bureau, 2006)

Type of paints	Domestic Sales Volume Percentage	Domestic Sales Value Percentage
Architectural	48	41
Product coatings OEM	29	32
Special purpose coatings	12	20
Miscellaneous allied paint products	11	7

2.3 The EU powder coatings industry

Coating powders are an alternative coatings technology. They differ from ‘traditional’ coatings in that they do not have a carrier phase, i.e. a solvent that has to be removed by evaporation or other means for the film to be formed.

The European consumption of coating powders in 2000 was 330,000 tonnes; this figure includes national figures for the entire continent plus Turkey. Table 2.4 provides a breakdown of the major applications of coating powders in Europe. One of the latest developments in the field of powder coatings is acrylic coating powders. In comparison with the widely used polyester coatings, they are reported to have superior flow characteristics and higher transparency and they could possibly be used effectively in sectors such the automotive industry (as topcoats) (CEPE, 2002b).

Table 2.4: Applications of coating powders in Europe in 2000 (CEPE, 2002b)

Application sector	Percentage of European consumption
General industrial OEM	29
Building	22
Trade coaters	16
Household appliances	13
Automotive OEM	10
Electrical engineering	6
Other	4

Within the EU, one can find the biggest players in the European powder coatings market. Italy, Germany, the UK, France and Spain have a combined production and consumption of approximately 80% of the European totals. Table 2.5 provides an overview of the production and consumption of powder coatings across Europe.

Estimates for the year 1998 show that the coating powders market represented around 9.4% of the total market of industrial coatings in Europe, a percentage considerably higher than in any other region globally (CEPE, 2002b).

Table 2.5: Coating Powders market in Europe in 2002 – production and consumption (CEPE, 2002b)

Country (or Region)	Production Percentage	Consumption Percentage
Italy	30	25
Germany	18	21
UK	12	12
France	10	12
Spain	11	10
Nordic region	4	5
Turkey	4	6
Rest of Europe	10	9
European total	100 (360,000 tonnes)	100 (325,000 tonnes)

PART II: COATINGS MANUFACTURE

1 CONTENT OF PART II

This part of the emission scenario document deals with emissions from the manufacture of coatings. The structure of this part is as follows:

- Section 2 provides an overview of the techniques and technologies used in the manufacture of coatings and how emissions to different compartments of the environment arise.
- Section 3 gives an overview of current emission prevention and abatement techniques.
- Sections 4, 5 and 6 provide an overview of the materials and processes used for the manufacture of organic solvent-borne, water-borne and powder coatings and the associated emissions to the environment, and include examples of emission calculations.
- Section 7 summarises the assumptions made in the estimation of emissions.

2 COATINGS MANUFACTURE PROCESSES AND EMISSIONS

2.1 General coatings manufacture

In this document, the term ‘manufacture’ means the process where substances (raw materials) are combined by blending and mixing, to obtain a stable product or preparation. This corresponds to the term ‘formulation’ which is used in the Technical Guidance Documents (CEC, 1996). The following descriptions apply to most kinds of liquid coatings (not coating powders). Any variations relevant to certain types of coatings are described in the corresponding section, later on in the document.

Coating manufacture is a batch process which involves mixing of polymers, pigments, extenders, organic solvents or water and additives. These are normally purchased as raw materials that are formulated to produce a finished product. Usually the process requires no chemical reaction (CEPE, 2003b). The aim of coating manufacture is to obtain a stable, homogeneous suspension of the pigment particles in the film-forming solution, i.e. in the mix of binder, filler and solvents (Kittel, 1979 in INERIS, 2000).

Each type and colour of coating is manufactured in a separate batch. Typically, batch sizes can vary from 10-1,000 litres for small paint manufacturing plants, to 1,000-25,000 litres for larger facilities (CEPE, 2003b). Some manufacturers often produce their own binders, although most

manufacturers buy them, as well as pastes of pigments or fillers (Baumann & Muth, 1995 in INERIS, 2000). This emission scenario assumes that the materials used in the manufacturing process are in their original form, not pre-mixed or pre-prepared.

2.2 *Process description*

2.2.1 *Overview*

The ‘traditional’ manufacture of coatings includes four basic stages:

- Dispersion.
- Milling.
- Finishing.
- Filling.

The manufacture of coatings uses many technical terms, which are used in different ways, some are synonyms with the same meaning as others (e.g. polymer = resin = binder), (milling = grinding) while some can be used generally or specifically (e.g. dispersion can include the addition of pigments to liquid or refer specifically to wetting and particle size reduction) (CEPE, 2003b).

The four stages above involve the following processes (depicted in Figure 2.1 below):

Dispersion is the assembly of raw materials and the addition of all powder pigments and extenders to part of the liquid constituents to form a pigment concentrate. This process is also known as premix, pre-dispersion, and, usually where there is no milling stage, ‘high-speed dispersion’.

Milling is the reduction of the particle size of pigments and extenders by means of a milling device (pebble mills, steel mills, horizontal bead mills, sand mills, etc). This process is also known as grinding.

Finishing refers to the mixing of the concentrate with all remaining liquid components sometimes also known as ‘make up’ or ‘let down’ and quality sampling and includes tinting of the mix to the correct colour and adjustment of viscosity and other parameters.

Filling includes filtration and filling into the final packages.

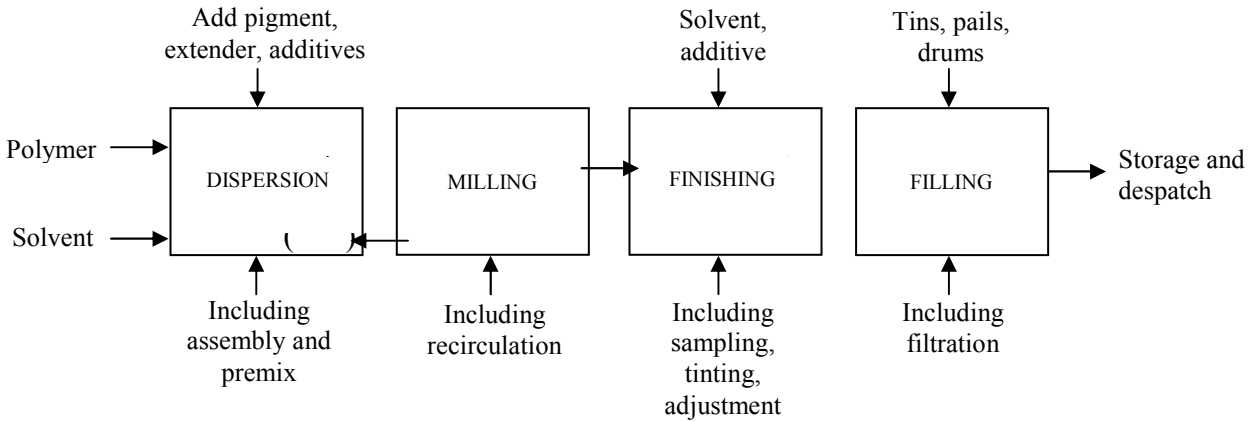


Figure 2.1: ‘Traditional’ coatings manufacture process (adapted from CEPE, 2003b)

With regard to milling, in certain applications this may be superseded by high-speed dispersion. This is particularly true for titanium dioxide (white) coatings, which constitute a significant proportion of all coatings. It has been suggested that pigments are often treated to enable them to be high-speed dispersed (Valspar, 2003). In general, however, mills (of the horizontal type) are still very much in use and even many whites, particularly for thin film finishes, are passed through mills for consistency and grind size (CEPE, 2003a). The use of high-speed dispersers would be considered on a case-by-case basis.

The process of production for coatings has changed overall in the last 10 years with a focus on the reduction of cycle time and waste and on in-time delivery. Modern processes can involve blending using dispensing equipment. All components are prepared (many by the traditional process above) and are stored in liquid form known as ‘intermediates’. The storage tanks holding the different materials are linked to a dispensing machine equipped with dosing heads. The intermediates are dispensed directly into the shipping containers in which they are mixed in order to produce the end-product.

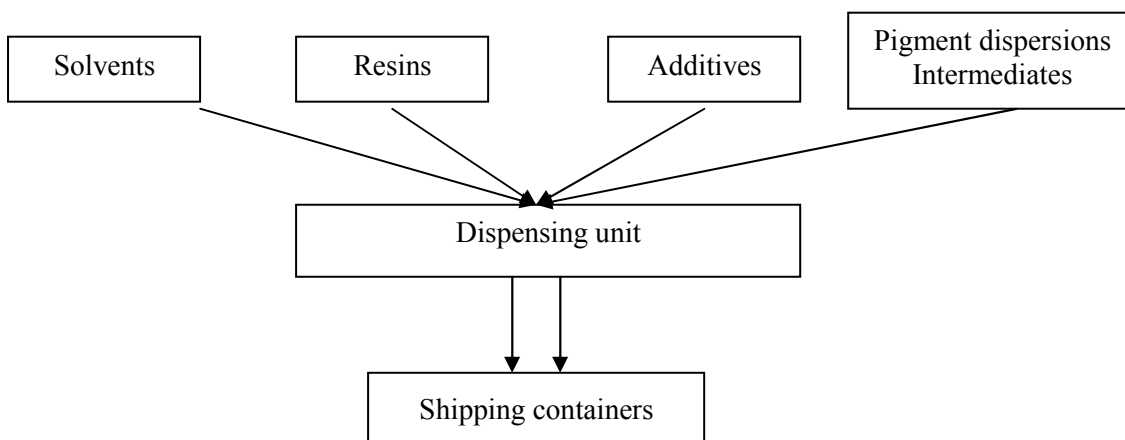


Figure 2.2: Dispense coatings manufacturing process (adapted from CEPE, 2003b)

In addition to the above steps there are many indirect processes critical to coating manufacture which includes:

- Delivery, unloading and storage of materials.
- Storage and dispatch of finished goods.
- Cleaning of manufacturing vessels.
- Disposal of raw material packaging, cleaning and other wastes.
- Containment and abatement of VOC emissions.

The following paragraphs (Sections 2.2.2.-2.2.5, Part II) provide a brief description of the stages comprising the traditional manufacturing method and also provide background information on Best Available Techniques (BAT) for each step of the manufacturing process.

2.2.2 *Dispersion*

2.2.2.1 Batch assembly

Bulk solvents and resins are normally delivered in road tankers and unloaded by pipes and pipelines into bulk storage tanks. Other liquid materials are delivered in 205 litre drums or 1 tonne Intermediate Bulk Containers (IBCs) and unloaded by forklift trucks.

Powder pigments and extenders are delivered in 25kg bags on 1 tonne pallets or in 1 tonne big bags or occasionally in bulk road tankers from which they are unloaded by compressed air into bulk silos. Note that bags for manual handling do not normally exceed 25 kg due to manual handling regulations in EU Member States (for example the Manual Handling Operations Regulations 1992 (SI 1992:2793) in the UK).

At the average manufacturing site, road tankers are discharged by pump or gravity into fixed bulk storage tanks. The top of the road tanker is normally open during this process and the head space of the receiving tank is normally vented to atmosphere. Small spills may occur during discharge and re-charge; 'drive away' incidents with hoses connected leading to damage and discharge are rare, but not unknown.

Occasionally, spills and emissions may also occur by discharging liquid material from a road tanker to 205 litre drums or when bulk tanks are overfilled. With regard to the use of IBCs and drums, their unloading is undertaken by forklift and any emissions are expected to occur only due to accidents.

To avoid such emissions, road tankers and bulk storage tanks could be fitted with return pipework, i.e. back-venting. Back-venting is only available to coatings manufacturers when tankers are appropriately equipped and when there are back-venting arrangements at the tanker loading point. According to CEPE, in most countries this infrastructure does not exist at present (CEPE, 2003b). Other BAT measures could include (CEPE, 2003b):

- Hose and pump discharge arrangements to assist draining of hoses into bulk storage.

- Specially designed ‘break away’ couplings with automatically closing iris valves on each side of the coupling to prevent solvent spills in the event of a ‘drive away’ incident.
- Prevention of discharging the road tanker contents into drums.
- Use of high-level alarms to prevent overfilling of storage tanks (preferably hard wire interlocked to site discharge pumps).

2.2.2.2 Storage

Liquid storage is normally in bulk tanks in tank farms. In some countries (for instance, Germany), regulations require these to be underground but elsewhere they usually are above ground. Drummed materials are normally stored on bunded impervious hardstandings, often outdoors. Pigments are stored on racking, undercover.

Tanks are normally vented direct to atmosphere and some solvent emissions are caused by daily temperature changes heating and cooling the tank and its contents. These emissions, however, are believed to be small by comparison with the displacement emissions arising from filling the tanks. Underground tanks, particularly old ‘single-skin’ tanks are prone to leakage resulting into emissions to the ground and to groundwater.

CEPE (CEPE, 2003b) indicates that the best option is to store materials in above ground bunded tanks (BAT). Moreover, pressure/vacuum valves that reduce or eliminate emissions from expansion may be included in new tanks or, where feasible, retro-fitted to old storage tanks. All underground tanks should be of the ‘double-skin’ type to avoid leakages.

Similarly, IBCs should best be fitted with pressure/vacuum valves to prevent air emissions and stored either indoors or under a roofed construction to avoid expansion/contraction of the contents and the subsequent fugitive emissions.

2.2.2.3 Pre-weigh

When small amounts of powder or liquid are required for a batch, they are often weighed out on scales in a specific area. This pre-weigh operation usually assembles all materials required in less than full pallet quantities. They are placed on pallets and transferred by forklift truck to the manufacturing area. The most widely used option is decanting the required amount out of a drum in the presence of local exhaust ventilation. For best control of emissions, pouring should be done from valves or ‘treacle taps’ and dispensing systems should be fitted with drum pumps to dispense fluids under maximum enclosure systems (systems often used with colourants) (CEPE, 2003b).

2.2.2.4 Transfer of bulk materials

Bulk liquids are normally transferred via piping either directly into closed vessels and open top vessels or by the use of petrol-type pumps to dispense liquids via a dispensing station. Pipework

may be made of flanged sections, bolted together or may be of screw thread construction. It may be underground or in the open air. Measurement may be by meter, dip stick, scale, load cell or mass flow meter. When common piping systems are used for the transfer of different liquids, some parts of pipelines may have to be drained and the drainings disposed of before the next operation takes place, but good design can avoid this.

Liquids are poured into a variety of vessels, usually either 205-litre drums or 5-20 litre pails. These may not be lidded, therefore, emissions may occur during transfer of materials.

BAT for transfer of materials include but are not limited to (CEPE, 2003b):

- Construction of pipework to national and international standards.
- Avoidance of underground pipework (to prevent undetected underground leakage) and painting of over ground pipework to prevent corrosion.
- Minimisation of the number of valves and manifolds and preferably use of ball valves rather than gate valves.
- Use of petrol-type pumps for open-end delivery pipes to minimise draining and loss.
- Fitting of resin piping with end-valves where possible. Dispensing from these pipes should be into vessels fitted with lids.
- Emptying of containers into vessels via a charging hatch. Best technique is to ensure the mouth of the container is as near as possible to the mouth of the hatch and that this is as small as possible; if air extraction is fitted, it should be around the mouth of the vessel and arranged to capture fugitive emissions.
- Lidding of manufacturing vessels and pre-weigh containers.
- Maximising the bulk storage of liquids and transfer by pipes to avoid emissions from frequent transfers from containers to manufacturing vessels.

2.2.2.5 The dispersion process

Dispersion essentially comprises the dispersion of powdered pigments in a resin/solvent blend. This is usually carried out using a high-speed rotating disk (a high-speed (1,000 rpm) saw-tooth blade) immersed in the powder/liquid mixture.

Vessels currently used may be divided into fixed and moveable. Fixed vessels may be:

- Totally enclosed, with liquid and pigment addition via piping and displaced air/vapour release via a vent system or powered air extraction.

- Enclosed with permanent dome tops, with piped liquid addition and a hole for charging powder and liquid from containers, or
- In the case of open topped large vessels with removable lids, permanently mounted through the first floor of a building or on a mezzanine platform.

On the other hand, moveable vessels are mobile pans and pots that are placed under freestanding dispersers and may have removable lids. The type of equipment to be used will depend upon the batch size and the type of paint that needs to be produced.

During dispersion, liquid raw materials are assembled and then mixed, with pigment and extenders added and held in suspension so as to enable the formation of a consistently mixed material. The pre-mix stage results in the formation of an intermediate product that is referred to as the base or mill base.

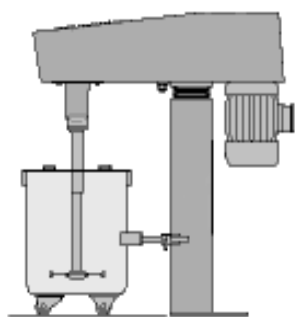
Typical raw materials for solvent-borne paints include:

- Polymers (resins).
- Organic solvents.
- Plasticisers.
- Pigment.
- Pigment extenders.

Raw materials used for water-borne paints include:

- Water.
- Ammonia or other amines.
- Dispersant.
- Pigment.
- Pigment extenders
- Polymers.

The most widely used dispersion method is the use of high-speed dispersers. Some paint blends may be manufactured entirely by using high-speed, disk type impellers.



High-speed disk dispersion may work well for some products such as undercoats and primers, however, it is less effective when preparing high gloss decorative coatings. It is, however, used for premix operations and when carried out efficiently will reduce the need for extensive milling.

Figure 2.3: Pre-mixer in the form of a high-speed disperser with a rotating disc, branched to a movable vessel (Netzsch, 2000, as shown in INERIS, 2000).

BAT for dispersion is based on the use of enclosed, lidded vessels that remain closed throughout the dispersion process (CEPE, 2003b).

2.2.3 Milling

Milling is required when the size of particles in the coating mixture needs to be reduced. It is common that the paste resulting from dispersion is diluted with resin and/or solvent and is then taken to a mill. This stage generally involves pumping the paste through a mill, which may be enclosed or open, though in ball mills (now uncommon) the whole charge is held in the mill chamber during grinding.

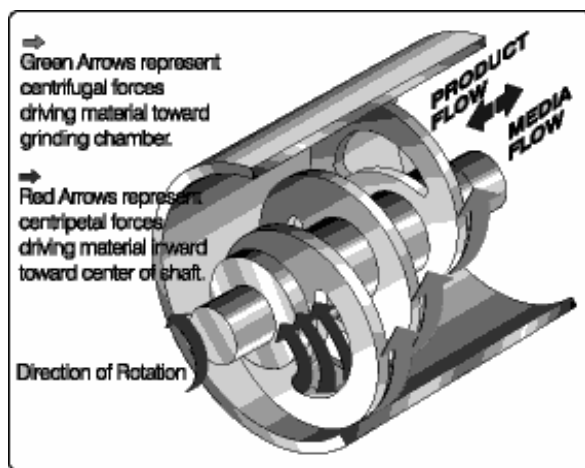


Figure 2.4: The cylinder of a horizontal bead mill with eccentric disc agitators (Netzsch, 2000, as shown in INERIS, 2000).

The main stages of milling are (CEPE, 2003b):

- **Wetting** (a surfactant wets the pigment particles by displacing air, moisture and gases that are adsorbed on the surface of the pigment particles).
- **Grinding** (mechanical break up and separation of pigment clusters into isolated particles by the use of media such as pebbles, balls or beads).
- **Dispersion** (the movement of wetted particles into the body of the liquid vehicle to produce a particle suspension).

The main milling tools currently used are (CEPE, 2003b):

- **Ball mills** (require transfer by intermediate vessel, or pump or gravity to the next stage mixing tank).
- **Triple or single roll mills** (open to atmosphere, although they usually have some form of air extraction fitted).

- **(Vertical) sand mills** (they have an open filter grid at the top of the grinding chamber which will give rise to solvent emissions which may or may not be captured by air extraction).
- **(Horizontal) bead mills** (normally totally enclosed).

It should be noted that roll and ball mills are somewhat outdated methods in current coatings manufacturing technology but are still in use. Roll mills are still in use for some small volume speciality materials such as aerospace sealants and high quality can coatings. This may vary across Europe as it is suggested that no UK company of any size uses roll mills in coatings manufacture (CEPE, 2003a). Beyond the coatings sector, roll mills (especially three-roll mills) are still used for very viscous formulations which are found in letterpress and offset inks and artist colours manufacture (CEPE, 2003a).

With regard to ball mills, they are not used for routine or typical coatings or ink manufacture, although there is a small (and falling) number of companies in the UK which are still using them, especially for the preparation of speciality materials such as additives. Industry considers that their use is not energy-efficient (CEPE, 2003a).

BAT would be to use a fully enclosed mill, usually a horizontal bead mill with a fully piped infeed from the pre-dispersion vessel and a piped outfeed to the mixing vessel (CEPE, 2003b). Additionally, many bead mills and sand mills have outlet collection hoppers prior to pump transfer. These should be lidded and fitted with high level cut-out devices to prevent overflow and spillage.

2.2.4 *Finishing*

2.2.4.1 Make up

The remaining ingredients are added to the mix once the required level of dispersion has been achieved. This could take place in the same vessel, if the batch size is small, or in a new vessel, if the batch size is large (over 1 tonne), into which the additional materials are added through hatches or by the use of pipes. Again, BAT essentially comprises the use of enclosed vessels and lidded containers (CEPE, 2003b).

2.2.4.2 Mixing

As well as addition of remaining polymer, the product finishing includes tinting and other additions to achieve the desired colour and viscosity. Tints and solvents are added and later small adjustments are made to achieve the final specifications.

Product finish activities for solvent-borne coatings involve the addition of (CEPE, 2003b):

- Various combinations of previously milled pigment pastes.
- Organic solvents.
- Polymers.

For water-borne paints the mixing stage involves the addition of (CEPE, 2003b):

- Preservative.
- Antifoaming agent.
- Polyvinyl acetate emulsion or other emulsion type resins such as acrylics or water soluble resins (acrylics or polyesters).
- Water.

2.2.4.3 Sampling

Samples are frequently taken to check the colour, viscosity and other characteristics of the mixture. These are normally taken by dipping a small container into the paint through the lid of a pan or hatchway of a tank. Emissions arise through the open hatch during sampling. To avoid such emissions, 'blind' sampling valves have been developed to assist the removal of samples. The samples are collected in a cup and the valve is cleaned from the outside. These devices are however rare, and the collection of representative samples and difficulties of cleaning remain barriers to their use. Alternatively (but not equally efficiently), hatches can be used as long as the length of time during which they remain open is kept to a minimum.

2.2.4.4 Tinting

Tinting is the adjustment of the colour of the mill base dispersion to the final product colour. It is often performed by skilled operators by eye and may require many additions and stirring for a long time between each addition. More modern systems rely on instrumental colour matching where predicted amounts of the pigment dispersions (known as 'tints' or 'stains') are added to the colour. The match is checked instrumentally and the quantity of any additional quantity of tint required is calculated.

2.2.4.5 Adjustment

Solvent (organic solvent or water) is added after tinting to adjust the viscosity of the end-product. Other properties may also be adjusted, such as conductivity for electrostatic spraying. BAT (CEPE, 2003b) consist of direct piping and accurate measurement of quantities of raw materials at the manufacturing stage, to give the maximum confidence of a product with the required properties. This ensures minimal intervention and adjustment that could result in emissions to the environment.

2.2.5 *Product filling*

2.2.5.1 Transfer

The coating is transferred from the finishing vessel to be filtered and filled. When this is a pan, it is usually pumped directly through the filter to the filling machine. When the finishing vessel is a

tank, transfer may be by fixed pipe, flexible pipe or the coating may be filled into mobile pans or IBCs for transfer.

BAT (CEPE, 2003b) include the installation and use of enclosed, usually stainless steel, pipework such as stainless steel that minimise losses and ‘pigging systems’ that require limited solvent cleaning of pipework.

2.2.5.2 Filtration

Filtration has the following aims:

- Removal of impurities (e.g. dust, gelled resin and pigment aggregates).
- Removal of particles of grinding media.
- Enhancement of the quality and uniformity of the product.

Filtration is currently achieved by:

- **Filter bags** on tank outlets (open to atmosphere or fitted with air extraction).
- **Filter bags** on the end of hose lines.
- **Vibratory sieves** (open or closed and with or without air extraction).
- **Enclosed filters** through which material is pumped (may have metal, fabric or non-woven fabric filters and may be of a flat, bag or cartridge form. For high quality automotive and industrial finishes, wound polypropylene or other resin cartridge filters are used).

Filtration is best carried out by fully enclosed filters that require a minimum of dismantling for cleaning or filter medium replacement (CEPE, 2003b). Those with semi-permanent filter mesh elements (which can be cleaned by scraper or back flushed *in situ*) are preferable to those where the element has to be replaced. Those that can be fitted directly in line without any inlet or outlet hopper are best for controlling emissions. It should be noted that not all systems can guarantee the same quality of filtering. Additionally, some highly viscous coatings are incompatible with some filtering systems (CEPE, 2003b).

2.2.5.3 Filling

Once the material has been filtered, it can be transferred into tins, pails, drums, totes, tank wagons, or other containers for shipment. Filling may be accomplished either manually or mechanically depending on the number and size of the containers to be filled (CEPE, 2003b).

Most filling is done by machine, where paint is fed from filtration to a reservoir or hopper and then via accurate displacement cylinders through filling heads into tins.

BAT for filling would include (CEPE, 2003b):

- Use of enclosed infeed hopper/break tank that only leaves a small emission gap between the fill/dispersing head and the container.
- Use of dip pipes to achieve ‘bottom filling’ of containers with solvents, and of 205 litre drums and IBCs (but not of small containers with pigmented products).
- Rapid lidding of containers after filling.

2.3 Other processes related to coatings manufacture

2.3.1 Cleaning of vessels

2.3.1.1 Cleaning of fixed vessels

Process equipment cleaning generates dirty cleaning solutions that have the potential to be recovered, re-used, recycled or disposed.

Cleaning of fixed vessels can be undertaken *in situ* or external to manufacturing operations depending on the equipment that has to be cleaned. Fixed process tanks and vessels and associated connecting pipes, pumps and filters need to be cleaned *in situ* in order to be re-used and consideration must be given to the cleaning procedure and type of equipment used. Parameters that will influence the type of cleaning include:

- The shape of the tank(s).
- The paint/resin formulation.
- The desired level of cleanliness.

Fixed tanks are often cleaned using static spray heads that are permanent or can be fixed into position over the top of the tank or through a cleaning port. The most common cleaning agents are solvents which are sprayed under low pressure into the top of the vessel. Alternatively, cleaning brushes may be used for manual cleaning of the exterior and/or the interior of the tank but this method finds more and more limited application nowadays (primarily due to worker safety concerns). Apart from solvents, other cleaning media are:

- Caustic soda.
- Water.
- Inert particles (such as grit or chalk for abrasive techniques).

High pressure water spray cleaners are used occasionally for water borne systems. They can use a lower volume of water (200 litres for a 20 tonne tank) and the washings may be re-used. This form of cleaning is expected to become more common as water borne coatings gain greater dominance.

The cleaning of pipework usually involves flushing the pipes with solvents which are compatible with the following batch to be passed through the pipework. Pigging is also a common method to

clean pipes by directly pushing out product residues from the line by sending a missile (pig or plug) through the pipe and is often used to recover product and minimise waste.

With regard to BAT, CEPE suggests that fixed open vessels are effectively impossible to clean without emissions, while the best technique for cleaning fixed closed vessels is the use of rotating or spray-ball washing heads through which solvent is pumped (usually recirculated) with the vessel fully closed. Droplets and vapour should be allowed to settle for as long as possible before inspection/starting to process the following batch (CEPE, 2003b).

2.3.1.2 Cleaning of mobile vessels

Portable tanks and IBCs or totes may be cleaned outside the manufacturing unit. Portable tank cleaning methods are typically carried out using fixed pan cleaning, automated or semi-automated equipment which uses spray heads or brushes and using one or a combination of solvents, water and caustic solutions as the cleaning media. Some manual cleaning will be carried out of non standard size pans and of the outside of pans and valves. A number of proprietary washing systems using spray balls/spray nozzles/brushes enclosed by lids are also employed. These are generally fitted with air extraction to clear the inside of the vessel or the enclosure in which it is washed of solvent vapour before it is released. Such systems are believed by CEPE to be part of BAT (CEPE, 2003b). To achieve best results, the cleaning should take place as soon as coatings manufacture is complete and by using solvents of as low a volatility as possible (some glycol ethers, for example).

Small parts and tools used during the manufacturing process are either cleaned *in situ* manually or in small baths which contain cleaning solution, typically solvent. These baths tend to be closed and interlocked with local exhaust ventilation and tools are left to soak and then cleaned manually with brushes.

Filters are cleaned in situ as part of the pipe flushing/pigging process or as an open manual process under local or general exhaust ventilation (e.g. gravity filters). The method of cleaning will depend on the type of filter. Filter cleaning can be avoided by using disposable filters.

Dry abrasive blasting that reduces both emissions and cleaning waste can also be used as BAT for some air-drying coatings.

2.3.2 *Production of waste*

2.3.2.1 Overview

Waste is generated from all the above manufacturing steps, including indirect processes such as material delivery, unloading, warehousing and process equipment cleaning. Examples of waste generated directly from the manufacturing processes include the following:

- Waste packaging (bags, drums, plastic wrap and pallets) from preassembly and dispersion.

- Waste liquid samples and waste in sample containers used for quality control, along with coating residues and cleaning liquids from the finishing process.
- Product filling will generate dirty filters and cleaning liquids.

Wastes generated from indirect activities include:

- Defective and obsolete raw materials.
- Intermediates and finished products.
- Other samples.
- Cleaning liquids.
- Liquid residues from water scrubbers.
- Collected filters and powders from particulate filter units.
- Spray booth wash.
- Storm water interceptors.
- Oils from forklift truck maintenance, etc.

With regard to spray booth wash, it should be noted that all coatings companies which carry out development of new products evaluate the performance in their laboratories and have to test each batch of product manufactured before it is supplied (CEPE, 2003a). Such activities involve determination of physical, application and film characteristics, during which products are applied using similar techniques to those used in practice. Coatings intended for spraying application by users are applied in small spray booths in development and in quality control laboratories. Spray booths can be of various types: water wash or dry back (see also Section 5.2.2, Part III). In the case of the former, the water used in the booth is regularly replaced and the old, contaminated water is disposed of as waste. In the case of the latter, the application of coatings results in residues on dry filter mats. CEPE indicates that emissions and wastes from such activities are very low. The booths and testing panels are generally small and their use is infrequent (CEPE, 2003a).

Another type of waste is the coating itself. Coating waste can be generated by several routes:

- By accident, during the manufacturing process, like the use of the wrong pigment or solvent which results in the rejection of the whole batch.
- Through over-making of a batch, or product in stock being no longer required by customers.

If the composition of the waste coating is suitable and it is of a light colour, it may be possible to tint it with a darker colour and recycle it (Baumann & Muth, 1995 in INERIS, 2000). However, if this is not possible the waste coating will need to be disposed of, usually as hazardous waste. Information collected from industry representatives in France and the UK indicates that such wastes are systematically incinerated. In France, for instance, liquid wastes have not been permitted in landfills since 1976. In the UK, landfill was the predominant disposal route, although incineration with energy recovery and recycling of wastes now are more important. In the past, coatings waste could be sold to small third party companies which would reprocess the

material and find outlets for a lower quality product; however, this ‘disposal’ route is no longer economic due to more stringent waste regulations and the loss of the UK’s manufacturing base (CEPE, 2003a).

2.3.2.2 Landfilling and incineration of coatings waste

As the provisions of the EC Landfill Directive (1999/31/EC) are applied across the whole of the EU, even solid wastes in the form of filter bags, vacuum cleaner bags, packaging waste, etc., which are classified as hazardous cannot be sent to landfill. Incineration in municipal incinerators will be the major disposal route (although such wastes will not be suitable for cement kilns, because of their variable calorific content and composition) (CEPE, 2003a).

In France and possibly other countries across the EU, incineration of coatings waste in cement plant is limited to solvent-containing waste where the calorific content of the combustible solvent is used as energy source. Solid wastes (filter bags, vacuum cleaner bags or empty packaging waste) are not normally incinerated but rather landfilled whenever possible (CEPE, 2003a).

In Sweden, all waste which is not recycled goes to either specialist chemical incineration or (e.g. packaging waste) to municipal incineration (CEPE, 2003a).

2.3.2.3 Process waste minimisation

When coatings manufacturing vessels are emptied some residue always remains in the vessel. This is particularly true if the paint is thick or thixotropic and if the vessel is flat bottomed or square. Traditionally, vessels were scraped using long handled scrapers and then they were solvent-washed using brushes, however, this would result in significant emissions. This is the reason for the use of dish- or cone-bottomed vessels often fitted with scraper blades. This should be considered as BAT; ‘traditional’ mixing vessels are still in use, particularly by small companies. Another BAT option is the use of pigging systems for the cleaning of pipework, as described above (CEPE, 2003b).

At present, most fixed vessels are dish- or cone-bottomed¹, however, a large number of vessels that are not fully enclosed are still used by the European industry (CEPE, 2003a). The majority of these not fully enclosed vessels are not fitted with integrated solvent or water wash systems. Scraper blades are normally only used for dispersion vessels/tanks for the manufacture of ‘thick’ coatings and are relatively rare. Mobile mixing vessels (1 tonne and below) are unlikely to have integral cleaning facilities. These are cleaned by use of either closed or enclosed cleaning equipment, to meet the relevant VOC emission standards set out in national legislation (such as PG6/10 in the UK). It should be noted that vessel lifetime in the industry is normally at least 20 years and is often greater than 40 years (CEPE, 2003a).

¹ In the UK, in part this is driven by occupational safety rules regarding entry into closed spaces, which would be required for fully closed vessels. Dish-/cone-bottomed vessels are widely used as they minimise production losses as well (CEPE, 2003a)

2.3.2.4 Disposal of liquid raw material containers

These containers may contain significant residual VOCs, however, in many countries, the containers are simply placed in skips and disposed of to a landfill along with the residual liquid (CEPE, 2003b). The collection and transfer of the containers gives rise to air emissions. Due to the cost of raw materials, containers are often drained (sometimes after heating to allow for viscous materials to be more easily removed) and, if they are the standard 205 litre drums, will be re-closed (Valspar, 2003; CEPE, 2003b). Crushing and shredding of containers may also sometimes take place before disposal (CEPE, 2003b). In other cases, used containers may be rinsed and the rinsate added to subsequent batches; this is more common for water-based coatings (US EPA, personal communication).

BAT for proper disposal of containers include (CEPE, 2003b):

- Draining the containers as far as practicable.
- Re-use of the collected solvent.
- Re-closing of containers after emptying.
- Recycling of containers (steel and aluminium containers can be recycled; before re-smelting, a number of processes could be undertaken such as crushing, shredding, solvent washing, caustic washing, burning or cryogenic treatment to clean the metal).
- Recovery of empty containers (return of containers to manufacturers of raw materials to be re-used or to drum reconditioners).

2.3.2.5 Disposal of washings

Re-use of equipment washing solvent has been a common measure for waste minimisation over the years and is usually achieved by distillation (on- or off-site) of the washing liquid to recover the cleaning solvent. As recovered solvent is usually a complex and variable mixture, its use is invariably restricted to equipment washing. On occasions its composition may make it suitable for incorporation into subsequent coating batches.

2.4 *Releases to the environment*

2.4.1 *Overview*

Emission sources identified for the coating manufacturing operations are:

- Process operations.
- Miscellaneous operations.
- Material storage.
- Equipment leaks.
- Spills.

In this document the last two points, which are of a more accidental nature, have not been taken into consideration. Due to a lack of available information, the same is true for material storage.

Emissions occurring during process operations can be classified into the following categories:

- Material loading emissions.
- Heat-up losses.
- Surface evaporation.
- Filling losses.

Emissions occurring during miscellaneous operations are mainly emissions due to all kinds of cleaning operations. Emissions can be of solid, liquid or gaseous nature. They can consist of a single substance, e.g. pigment dust, or of a combination of substances, e.g. the coating itself. Such emissions can end up in the air, water or soil. For the purposes of selecting appropriate emission factors in this ESD, substances are divided roughly into three types – volatile organic, non-volatile water soluble, and non-volatile non-water soluble. Substances are considered volatile if their vapour pressure is greater than 10 Pa at 23°C, and soluble if their solubility in water is above 1 g/l. It is recognised that the factors may not be appropriate for all possible substances; for example, the dust emission factors are not appropriate for a non-volatile non-water soluble substance which is a liquid. At present it is not possible to suggest factors for such substances.

The batch sizes have a considerable influence on the amount of process losses, that is both on the amount of waste and emissions generated during manufacture. As discussed in this document, larger batch sizes are generally associated with lower emission factors to the atmosphere (VOCs) and generation of smaller proportions as waste. The emission factors given in the following sections are related to the manufacture of small and medium-sized batches. Although batch sizes in the industry vary so that there is no standard size, for the purpose of the later calculations a “standard” batch of 1000 litres or 1000 kg is assumed. Large batch production is discussed separately.

2.4.2 *Emissions to air*

Main emissions to the air are expected to come from VOCs such as solvents. VOCs may be emitted during loading operations, or if the contents of mixers, dispersers or mills are exposed to the atmosphere. They may be emitted through the agitator shaft openings or around the edges of the vessel lids.

It is assumed that losses of VOCs to the atmosphere inside the manufacturing plant due to the elevated temperatures during coatings manufacture are negligible compared to emissions due to ventilation of vessels (FIPEC, 2003).

Ventilation of buildings and air extraction from manufacturing equipment results in the loss of solvents used in the coating formulation. Cleaning solvents also result in emissions as they evaporate, but they are not considered in the scenario, as they are not part of the coating formulation.

Raw materials in powder form, like pigments and fillers, can be emitted as dusts or particulates. These types of emissions may occur during weighing operations or during loading of the pre-mixer when a lid is open or from the chute through which ingredients are added.

Since the solid materials are dispersed or dissolved in a liquid matrix during the process, it can be considered that after pre-mixing no further air emissions of solids occur (until the application of the coating, as described in detail in Part III of this document).

2.4.3 *Emissions to water*

Water used in the manufacturing process of the coatings, remains in the coatings formulation. The only origin of releases to water are cleaning operations. Most of the equipment for cleaning operations contains residues of the final product. That means that the resulting wastewater stream contains all substances comprised in the coating formulation. On the other hand, if the cleaning involves the removal of dust deposited on the workshop floor, then the washing may include only some of the raw materials. It should be noted that most manufacturers are suggested to be using industrial vacuum cleaners to remove spillages from the workshop floor, therefore, only part of the deposited material will end up in wastewater stream (FIPEC, 2003).

2.4.4 *Releases to soil*

Several emission routes to soil are possible.

- **Deposition** of dust particles in the workshop or outside the facility, if they are emitted via the exhaust system.
- **Adsorption** of released substances onto particles in the air and following deposition.
- **Land spreading** of sludge from sewage treatment works handling discharges from industrial sources.
- **Incineration of waste** and deposition on soil of substances in flue gases.

No direct exposure of soil is to be expected during normal manufacturing operations and the release to soil is therefore not further considered in this document. It is, however, indicated whether the releases are in gaseous or particulate form, so that the atmospheric deposition can be adequately estimated.

3 PREVENTION AND ABATEMENT OF EMISSIONS

3.1 *Prevention of emissions*

3.1.1 *Vessel design*

Traditionally both fixed and mobile paint manufacturing vessels are open topped, fitted with loosely fitting light steel plate lids with a hole for the agitator which may be removed for raw material charging and cleaning. Significant emissions occur when the lids are removed and through the gaps in their fitting (CEPE, 2003b). The CEPE BAT document provides information on what could consist BAT with regard to vessel design (for instance, the use of fixed vessels of closed design with the domed top of the vessel being an integral fabricated part of it; extraction that takes place around the lip of the hatchway rather than ‘through’, etc.).

3.1.2 *Pipework design*

In the European coatings industry, at present, transfer between vessels is invariably achieved by pipe and pump or by free fall gravity discharge or even by bailing and pouring.

3.1.3 *Vessel extraction or Local Exhaust Ventilation (LEV)*

The main source of solvent emissions during manufacture is through extraction² of air containing the solvent from dispersion and mixing vessels. Air extraction currently takes place in a number of ways:

- By drawing air through a vessel hatchway, which passes over the surface of the coating and is directed to the extraction ducting at the rear of the vessel (known as ‘through extraction’).
- By systems being placed around the lip of the charging hatch and capturing vapours from solvents being added to the mixture (known as ‘lip extraction’).
- By a combination of the two methods above.

Extraction may be always on or used when required. According to the CEPE, traditional, permanent running through extraction on average emits around 1 mg of solvent per m³ of extraction volume to atmosphere (CEPE, 2003b).

The CEPE BAT Note provides information on BAT with regard to vessel extraction and this is generally focused on ‘lip’ extraction and the use of enclosed fixed and always-lidded vessels (CEPE, 2003b). It should be noted that lip extraction is not recommended when using highly flammable liquids or solvents above their flash point, as this can result in a build-up of vapours above the lower explosion limit, possibly resulting in fire or explosion (BCF 2003).

² Note that extraction here refers to the extraction of air from vessels or their immediate surroundings, and not to any liquid: liquid or liquid: solid solvent extractions.

3.1.4 *Extraction design: area ventilation*

Traditionally, many factories (UK, Southern Europe) have natural ventilation only. Others (Germany, Scandinavia) commonly have factory air extraction/ventilation systems, and emissions from these have to be measured (CEPE, 2003b).

3.1.5 *Condensers*

Emissions from vessels occur either due to forced extraction with fans or by displacement or breathing without any suction. The use of condensers to remove solvent vapours from forced extraction is impractical (the air flow is too fast for them to operate effectively). Condensers on breathing/displacement vents from closed vessels have been used in the past, especially in warmer countries, to condense out solvent vapour and return it to the batch, however, they require a significant temperature difference and this could mean that a flow of chilled water may be required (CEPE, 2003b).

3.1.6 *Other emission prevention measures*

The British Coatings Federation has produced guidance on best practice for environmental protection. This includes guidelines on BAT for handling of solid materials, liquid solvents and waste disposal (BCF, 2002).

3.2 *Abatement of emissions*

Abatement techniques find only limited application in the manufacture of coatings at present, especially with regard to VOCs emissions, the abatement of which entails a considerable capital investment and significant running costs. The abatement techniques currently known include:

Adsorption with carbon is an abatement technique with lower running costs than thermal incineration (described below); it appears to be a more environment-friendly option as it does not require the use of fossil fuel, does not emit CO₂ and the amount of carbon used may be regenerated and subsequently re-used. However, this technique requires expensive desorption equipment (or regeneration of the carbon charge off-site) and is of limited suitability for coatings manufacture since it cannot ensure removal of all VOCs. It also results in solvent-water mixtures (after regeneration of the adsorbed solvents with steam) that cannot be separated economically and, therefore, they need to be disposed of, while reaction (heat of absorption) with ketones may cause fires (this can be avoided by heat or CO detection systems and installation of nitrogen or water floods). CEPE reports that carbon adsorption has not been fitted to paint manufacturing vents except in recent years (CEPE, 2003b).

Condensation at low temperature and biological treatment with liquid media are not yet used widely in practice because of the low VOCs concentration and the variable composition of the emitted vapours that affect the efficiency of these techniques. Biofilters use bacteria to digest organic solvents and are designed for manufacturing processes other than coatings manufacture. For the bacteria to be effective, a constant composition of the

emitted vapour stream is required. A few examples of use of biofilters have been reported in recent years (CEPE, 2003b).

Thermal incineration is the most widely used choice and finds particularly extensive use in the abatement of emissions during cleaning operations. The air extraction stream is directed over heated sand or ceramic beds to oxidise all the organic material to CO₂ at a temperature of around 1000°C. The content of VOCs is not sufficient to fuel the beds and keep the temperature at the required level, therefore additional fuel needs to be added in the form of gas in the stream or as electric heating of the beds. Two or three beds are normally used. This technique may allow for low VOC emissions, however it is costly, is associated with hazards (possible ignition of the incoming gas stream) and results in the production of greenhouse gases (CO₂). The combination of thermal incineration and carbon adsorption has been tested but the results, as indicated by CEPE, have not been completely successful, although such 'end-of-pipe' techniques find increasing use in Europe (CEPE, 2003b; BCF, 2002).

Catalytic incineration is suitable for low VOCs concentrations, works on the same principle as a car exhaust catalyst and is designed to be more economic than thermal incineration. However, it suffers from high sensitivity to the presence of particulates in the air stream, in particular to 'poisoning' of the catalyst by heavy metals. Only trial examples are known in the coatings industry (CEPE, 2003b; BCF, 2002).

4 MANUFACTURE OF ORGANIC SOLVENT-BORNE COATINGS

4.1 *Organic solvent-borne coatings*

4.1.1 *General information*

Many 'conventional' coatings are organic solvent-borne coatings. Nearly every type of binder material can be used in formulating these coatings. By their nature, they contain significant amounts of VOCs with the quantity of solvent ranging between 30 and 80% of the total coating formulation.

Thermoplastic polymers with molecular masses over 20,000 g/mol are used as binders in physically-drying, solvent-borne coatings. They are also known as 'low solids coatings' due to their composition.

Chemically-drying solvent-borne coatings contain polymers with molecular weights between 800 and 10,000 g/mol. Cross-linking during film formation leads to much higher molecular weights in the dried coating film. Solvent content ranges between 30-60%. Most of these coatings are stoved, but systems that cure at ambient temperature using UV or IR radiation are also in use (as discussed in Part III of this document).

Oxidative-curing coatings are a special variety of chemically-drying coatings. The binders used contain double bonds that cross-link by reacting with oxygen from the air.

The following table shows the most important binders in organic solvent-borne coatings.

Table 4.1: Binders in organic solvent-borne coatings (Baumann & Muth, 1995)

Physical drying	Chemical drying	Oxidative drying
Cellulose ester, vinyl resins, thermoplastic alkyd resins, polyurethane, derivatives of rubber, hydrocarbon resins	Unsaturated polyester resins, epoxy resins, alkyd resins, polyester resins, vinyl resins, acrylate resins. Possible cross-linkers: phenol- and amino resins, polyisocyanates	Alkyd resins, drying oils, epoxy esters, modified phenol resins, urethane oils

4.1.2 High solids coatings

High solids coatings are part of the group of chemically-drying organic solvent-borne coatings. They have generally been designed to reduce VOC emissions. According to the definition of the German “Verband der Lackindustrie”, they contain less than 30% organic solvent (Baumann & Muth, 1995 in INERIS, 2000). The higher solid content influences the viscosity of the coating. In order to obtain a product with a sufficiently low viscosity, several techniques exist:

- Use of reactive solvents or thinners.
- Heating of the coating before application.
- Restriction of the molecular weight distribution of the binders.
- Use of metal compounds as cross-linkers.

High solids coatings exist as one-component and two-component systems. One-component systems give high-grade coatings with film thickness between 50 and 60 µm. They are used as stoved coatings on metal surfaces, for example for household appliances or metal furniture. Typical binders are alkyd, polyester and acrylate resins that are cross-linked with amino resins.

According to Baumann & Muth (1995), a typical one-component high solid coating can consist of:

- 42 % binder.
- 28 % pigment.
- 30 % solvent.

In two-component high solid systems, two types of binders are important: epoxy resins and polyester or acrylate resins. Film formation is based on poly-addition reactions.

Two-component high solids coatings based on **epoxy resins** have excellent adhesive properties on the substrate and are used as primers and surfacers on metal surfaces and as corrosion inhibitors. They are not suitable for use as finishing coatings for outdoor use.

Two-component high solids coatings based on polyester or acrylate resins reacted with polyisocyanates have good mechanical properties, good adhesion to the coated substrate and are suitable for outdoors use. They are used as finishing coatings in the automotive industry, on metal furniture, farming equipment and machines.

A typical two-component coating may consist of:

- 42 % binder.
- 28 % pigment.
- 30 % solvent.

4.2 *Manufacturing process*

The production of organic solvent-borne coating begins with mixing resins, dry pigment, organic solvents and fillers in a high-speed mixer and follows the general pattern of coatings manufacture, as described in Section 2.2, Part II above.

4.3 *Waste generation*

Due to the liquid form and the viscosity of the coating, the residues in the manufacturing equipment are quite important. The amount shall be estimated with $F_{equip_residue, waste} = 0.5\%$ by weight of the raw materials. This value is based on the following example calculation for a mixing vessel.

The vessel is supposed to be of a cylindrical shape. After emptying of the vessel, a thin layer of coating will remain on its inner surface. The volume V of the remaining substance can be calculated using Formula 2.1:

$$V = V_0 - V_1 = \pi * (r_0^2 * h_0 - r_1^2 * h_1) \quad \text{Formula 2.1}$$

Where:

- V : Volume of the residue (m^3)
- V_0 : Initial effective volume (m^3)
- V_1 : Effective volume of the uncleaned vessel (m^3)
- r_0 : Initial radius of the vessel (m)
- h_0 : Height of the vessel (m)
- r_1 : Radius of the vessel minus thickness of the coating layer (m)
- h_1 : Height of the vessel minus thickness of the coating layer (m)

For the calculation the following default values are assumed:

$$\begin{aligned} V_0 &= 1,000 \text{ litres (assumed average batch size)} \\ r_0 &= 0.5 \text{ m} \\ h_0 &= 1.274 \text{ m} \end{aligned}$$

A coating layer with a thickness of 1 mm is supposed to remain on the inner surface of the vessel. In consequence:

$$\begin{aligned} r_1 &= 0.499 \text{ m; and} \\ h_1 &= 1.273 \text{ m} \end{aligned}$$

With these values, the residue volume is $V = 4.8 \times 10^{-3} \text{ m}^3$ or 4.8 litres, representing 0.48% of the total vessel volume V_0 . Considering that the batch may be transferred into a second vessel and adding the residue in grinding equipment, the total residue has been estimated to be no more than **1%** of the total amount of used raw materials ($F_{equip_residue}$).

Note that the above calculation follows a simplified approach; the percentage of losses in the mixing equipment will depend on the physical characteristics of the coating. For instance, a thickness of 1 mm is realistic for high viscosity coatings, however, for coatings of lower viscosity the thickness of the remaining coating will be lower as the coating residues move towards the bottom of the vessel and can be more easily removed. For such low viscosity formulations, a thickness of 1 mm would inevitably lead to sagging of the coating on the vessel inner walls. Also note that modern mixing vessels are not necessarily cylindrical in shape; they could have a conical base for easier removal of the coating residues (FIPEC, 2003).

For the purposes of this document, we will assume that half of these losses ($F_{equip_residue, recyc} = \mathbf{0.5\%}$) are recovered and re-used at a later stage of manufacture (as long as the washings are compatible with the manufactured coatings). The remaining losses of **0.5%** ($F_{equip_residue, waste}$) compares with a figure of 0.4% that has been suggested by a UK manufacturer of low viscosity products (this figure was calculated from the difference in the weight of materials added in the vessel and compared to the weight of the batch transferred (BCF, 2001)).

After each batch, the whole equipment is usually rinsed and cleaned with organic solvent(s). These solvents are used several times. A first rinsing of the material will be made, using already contaminated solvents. Afterwards, the equipment is rinsed with clean solvent. Used rinsing liquids contain about 15% of solid matter, consisting of approximately 10% binders and 5% pigments, fillers and additives (Baumann & Muth, 1995 in INERIS, 2000). When there is no recycling, the used solvents are disposed of as hazardous waste. Due to its high calorific value, most of this waste may be incinerated (INERIS, 2000).

Waste due to residues of the raw materials in packaging material, as well as in used filters, is assumed to account for **0.5%** of total raw materials; this is an average figure ($F_{package_residue}$). The actual amount of residue will vary depending on the physical characteristics of the material (liquid, paste, powder, etc.) and the design and material from which the packaging is constructed. In the case of low viscosity solvents, it may be possible to drain a drum to 0.2%; in the case of a pasty material in an awkward shaped container, it may be as high as 5% (CEPE, 2003a). The same considerations have been taken into account in making the assumptions on the waste from

packaging materials for all types of coatings (organic solvent-borne, water-borne and powder coatings)³.

Depending on the substances, waste from residues is either disposed of as hazardous waste or landfilled. Therefore, the total fraction of waste generated for the purposes of the general scenario is $F_{equip_residue, waste} + F_{package_residue} = 1\%$ of total raw materials.

4.4 Releases to the environment

4.4.1 Emissions to air

The Emission Inventory Improvement Programme of the US EPA has published a document titled “Preferred and Alternative Methods for Estimating Air Emissions from Paint and Ink Manufacturing Facilities” (as referenced in CEPE, 2003b). According to the US EPA, a global emission factor for VOCs to the air of 3.4% can be assumed. CEPE has undertaken a review of the emission estimates models used by the US EPA and has made a series of estimates for the release of VOC during the manufacture of organic solvent-borne coatings. These estimates, given below as Table 4.2, provide an overview of VOCs emissions during each stage of the coatings manufacture. As can be seen from the table, the emissions will depend considerably on the type of solvents used (particularly their volatility) and on the speed of air.

Therefore, the emissions of VOCs can be assumed to be $F_{manuf. vol. air} = 0.13-3.6\%$ by weight of raw materials depending on the type of solvents used and the prevailing air speed.

Table 4.2: Emission factors (as percentages of raw materials used) for atmospheric releases of VOCs during organic solvent-borne coatings manufacture (CEPE, 2003b)

Air speed (m/s)	Type of Solvent					
	Low boiling point			High boiling point		
	0.5	2.5	10	0.5	2.5	10
Premix	0.038	0.540	1.595	0.032	0.111	0.327
Grinding	0.099	0.348	1.026	0.019	0.066	0.195
Finishing	0.442	0.442	0.442	0.049	0.049	0.049
	<i>0.044</i>	<i>0.044</i>	<i>0.044</i>	<i>0.005</i>	<i>0.005</i>	<i>0.005</i>
Filling	0.050	0.050	0.050	0.006	0.006	0.006
Cleaning	0.535	0.535	0.535	0.066	0.066	0.066
Total	1.164	1.915	3.648	0.172	0.298	0.643
	<i>0.766</i>	<i>1.517</i>	<i>3.250</i>	<i>0.128</i>	<i>0.254</i>	<i>0.599</i>

- Notes: 1. Figures in *italics* correspond to the use of vessels that are covered with lids.
 2. Note that a low boiling point solvent would be a mixture of: toluene 50%, methylethylketone 20%, methylisobutylketone 30%, while a high boiling point solvent would be a mixture of: xylene 50%, Solvesso 150 (solvent naphtha) 50%.

³ More detailed consideration of residues in bags, drums etc can be found in the ESD on transport and storage of chemicals (EA, 2007). Note that these residues are assumed not to be released to the environment at the coatings site.

With regard to the distinction between ‘high’ and ‘low’ boiling point, a general threshold value could be assumed to be 110-120°C, above which a solvent could be considered as being a ‘high’ boiling point solvent (CEPE, 2003a). The solvents mentioned above (Table 4.2) have the following boiling points (CEPE, 2003a):

- Toluene: 100°C (‘low’ boiling point solvent).
- Methyl ethyl ketone: 77°C (‘low’ boiling point solvent).
- Methyl isobutyl ketone: 107°C (‘low’ boiling point solvent).
- Xylene: 135°C (‘high’ boiling point solvent).
- Solvesso 150: 185°C (‘high’ boiling point solvent).

Dust emissions from handling of solid raw materials in powder form, particularly from pigments and fillers, are taken to be $F_{manuf_dust} = 0.5 - 1.0\%$ by weight of solid raw materials in powder form (US EPA, 1983). The higher figure of 1% is used here as a reasonable worst case. Of this 1%, 95-97% is estimated to be captured by local exhaust devices, according to industry sources (BCF, 2001). For the needs of this scenario, a capture efficiency μ_1 of **95%** will be assumed (on the basis of default estimates, as presented in INERIS, 2000). The remaining 5% (or **0.05%** ($F_{manuf_dust, dep}$) of the solid raw materials) is assumed to deposit on the surfaces inside the workshop.

According to industry (CEPE, 2003a), no direct dust emissions to air (for instance, due to escape from doors or windows) are expected to take place for any type of coatings manufacture (organic solvent-borne, water-borne or powder coatings). The general pattern of treatment of such emissions is the one used throughout this ESD: a significant part of the emitted dust is collected by air extraction systems and local exhaust ventilation systems with the remainder collected by industrial vacuum cleaners or washed off during wet cleaning of the workshop floors (CEPE, 2003a).

The scrubbing efficiency of the air extraction systems is taken as **99%** (η_1); this means that $F_{manuf_dust, air} = F_{manuf_dust} \times \mu_1 \times (1-\eta_1) = 1\% \times 0.95 \times 0.01 = \mathbf{0.0095\%}$ of solid raw materials will be emitted to the atmosphere outside the workshop area.

With regard to the solid material deposited on the workshop floor, industry has indicated (FIPEC, 2003) that European coatings manufacturers invariably use industrial vacuum cleaners for the removal of solid materials. For the purposes of this general scenario, a **90%** capture efficiency (μ_3) is assumed for vacuum cleaners used at the manufacturing sites. Therefore, $F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \times \mu_3 = 0.05\% \times 0.90 = \mathbf{0.045\%}$ of solid raw materials are assumed to be collected in vacuum cleaner bags and disposed of (either by landfilling or by incineration depending on the composition of the collected waste).

It should be noted that the capture efficiency of 90% for industrial vacuum cleaners is an assumption made on the basis of consultation with the European coatings industry (CEPE, 2003a; FIPEC, 2003).

4.4.2 Emissions to wastewater

Overall, the coatings manufacturing industry uses little process water disposed of as waste, although, clearly, quantities will be incorporated into water borne coatings. The only use of process water disposed of as waste of significance in this context is for cleaning of plant surfaces and the exterior of equipment. Note that the use of suction systems (industrial vacuum cleaners) is now widespread in the coatings manufacturing industry and should be taken into account in the estimation of emissions. As described above, for the general scenario we assume that **90%** of all deposited solid material will be removed by means of an industrial vacuum cleaner. The rest of solids ($0.05\% \times 0.10 = \mathbf{0.005\%}$) will be washed away during wet cleaning of the workshop. Some manufacturing sites have in place solid separators/traps on waste discharge lines that remove solids before they end up in the sewer, however their use is not universal. For a worst case scenario, we assume that this 0.005% ($F_{manuf_dust, water}$) will be released to the sewer.

Where water-borne products are manufactured, e.g. decorative coatings, more sophisticated controls may be in place, e.g. reverse osmosis and a de-ionising plant to remove particulate and water soluble materials from equipment wash waters, prior to discharge to sewers.

4.5 Onsite emission treatment techniques (treatment of VOCs emissions to air)

In general, there is limited uptake of VOC treatment techniques in the coatings manufacture industry at present (FIPEC, 2000 in INERIS, 2000). The abatement techniques described in Section 3.2.3. could make a difference in the quantities of VOCs emitted, however, for the purposes of this scenario we assume that no abatement currently takes place. In consequence, the **0.13-3.6%** by weight of total VOCs emitted during the process, are expected to be released to the air outside the facility without any treatment. To create special scenarios, for example a local risk assessment for a certain facility, it is possible to consider the presence of installations for the treatment of VOCs, by applying the capture device and the scrubbing efficiency. However, these capture and scrubbing efficiencies have not been used in the estimates of Table 4.4.

Limited information is available on the presence of on-site wastewater treatment facilities at coatings manufacture installations in Europe. The presence and sophistications of any such facilities may differ considerably across the continent. In France, for instance, it has been estimated by CEPE members that at least 80% of the manufacturing sites have wastewater treatment facilities due to regulations on industrial water emissions either in surface water (normally including a flocculation and filtration system) or to a collective sewage treatment plant (STP) which requires a minimal treatment before accepting waste water (French arrêté of 02/02/1998) (CEPE, 2003a).

In the UK instead, most companies have some form of interceptor or trap to control discharges of solids or organic solvents to sewers, to meet sewage discharge consents, in accordance with UK legislation. Where organic solvent-borne products are manufactured, the water discharged will not have been used directly in manufacture, but rather as cooling water, or it may be contaminated surface run-off water, and this level of control is, according to the UK coatings industry, sufficient to meet the legislative requirements (CEPE, 2003a).

In situations where there is a potential for local waters (streams, rivers, etc.) to be contaminated with discharges of water used to control a fire or in other incidental events, companies may install emergency interceptor facilities to prevent such contamination (CEPE, 2003a).

Note that this ESD does not examine the fate of emitted materials, therefore, no consideration is given to the fate of chemicals in a wastewater treatment plant. There are suitable models (e.g. SIMPLETREAT in EUSES) to predict such a fate according to their physicochemical properties and these may be used when conducting a risk assessment. An ESD is focused on the estimation of emission rather than the prediction of environmental fate.

4.6 Calculations and release table for standard batch manufacture of organic solvent-borne coatings

Table 4.3 provides an overview of the calculation of emissions of both VOCs and non volatile non water soluble raw materials during the manufacture of organic solvent-borne coatings. The derivations of the factors are included so that use can be made of more specific information if available.

On the basis of the calculations presented in Table 4.3, Tables 4.4 and 4.5 provide an overview of the percentages of used raw materials that are emitted to the environment during the manufacture of organic solvent-borne coatings and the assumptions made for the removal efficiencies of abatement techniques. The percentage emission factors in Table 4.4 are the sum of the relevant factors for each compartment from Table 4.3.

Table 4.3: Calculation of emissions of raw materials during the manufacture of organic-solvent borne coatings (standard size batch - 1,000 litres)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	1%	
of which (<i>all raw materials</i>): ($F_{equip\ residue, recyc}$)	0.5%	Recycled
and (<i>all raw materials</i>): ($F_{equip\ residue, waste}$)	0.5%	Waste
Packaging waste (<i>all raw materials</i>) ($F_{package_residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf\ VOC, air}$)	0.13 – 3.6%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing ($F_{manuf\ dust}$)	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_i$)	1.0% x 0.95 = 0.95%	

Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf_dust} \cdot \mu_1 \cdot \eta_1$)	$0.95\% \times 0.99 = 0.94\%$	Waste
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1-\eta_1)$)	$0.95\% \times 0.01 = 0.0095\%$	Air
Percentage of solid raw materials falling on the workshop floor ($F_{manuf_dust, dep} = F_{manuf_dust} \cdot (1-\mu_1)$)	$1.0\% \times 0.05 = 0.05\%$	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	$0.05\% \times 0.90 = 0.045\%$	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf_dust, water} = F_{manuf_dust, dep} \cdot (1-\mu_3)$)	$0.05\% \times 0.10 = 0.005\%$	Water

Table 4.4: Total emission factors for manufacture of organic-solvent borne coatings (standard batch - 1,000 litres)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	30-80%	-	20-70%
Air ($F_{manuf, air}$)	0.13-3.6%	-	0.0095%*
Water ($F_{manuf, water}$)	-	-	0.005%*
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	1%	-	1% (2%*)

* Valid for raw materials charged in powder form and released as dust.

Note that for the purposes of this ESD, we have assumed no direct emissions to industrial soil. The use of environmental fate models for chemicals may assist in the calculation of such emissions during the risk assessment of chemical substances.

Table 4.5: Assumed values for the efficiency of the different emission treatment techniques during manufacture of standard organic solvent-borne coatings (based on default estimates)

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
VOC treatment η_2	0	0
Vacuum cleaner η_3	0.90	(1)*

* - 100% efficiency assumed

4.7 Recycling of waste

Recycling techniques may target either the solvents or the coating sludge. The mix of solvents and coating that is generated during the cleaning of the equipment is heated in a distillation boiler (INERIS, 2000). The evaporated solvents are captured from the headspace of the boiler and they are subsequently condensed. The residue is a mix of coating sludge and solvent (see Figure 4.1). Starting from an initial solvent concentration of 85%, it is estimated that about 80% of the solvents can be recycled. It is in fact the rising concentration of coating sludge in the boiler that prevents any economical continuation of the process, as with increasing solid concentration the heat up losses rise. Moreover, the high temperatures during the process (130-200°C) lead to thermal destruction of the binder. The process is generally reserved for the recycling of the

solvents (Baumann & Muth, 1995 in INERIS, 2000). As shown in Section 4.3, half of the losses from cleaning of equipment are assumed to be recycled.

Figure 4.1 shows the composition of the residue of a re-distillation facility (Baumann & Muth, 1995).

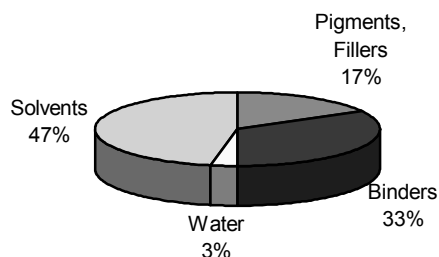


Figure 4.1: Composition of the distillation residue (INERIS, 2000)

The residue material is finally incinerated, for example in cement plants, hazardous waste incineration plants or it is dumped on specialised landfills (FIPEC, 2000 in INERIS, 2000).

The recycling of certain substances has no direct influence on the emission factors from the manufacturing process, as the substances concerned by these measures are first of all part of the generated waste stream. But as the recycling process itself will provoke emissions too, these have to be added to those that appear during the manufacturing process, in order to obtain the total of the emissions. Section 11 of Part III of this document provides an overview of emissions from recycling processes, although it should be kept in mind that the composition of the recyclable waste from coatings manufacture is not identical to the composition of the waste from coatings application.

4.8 *Manufacture of large batches*

4.8.1 *Overview*

The process is the same as described in the general part for organic solvent-borne coatings. The only difference is the size of the mixing tanks. This scales down the relative surface in contact with the air, and lessens the relative amount of product residues on the surface of the tank. The result is a lower percentage of VOC emissions. Moreover it can be assumed that the standards concerning the emission reduction measures in these facilities are better than in smaller ones. As discussed below, larger batches are also assumed to be associated with lower percentages of raw materials lost as residues in the manufacturing equipment. For the derivation of the release fractions in this section, see the preceding sections.

4.8.2. Emissions during large batch manufacture of organic solvent-borne coatings

For large batch manufacture we assume that the average batch size is 10,000 litres. The evaporation from the surface of the mixing vessel is assumed to be one of the main sources for VOC emissions. Comparing the relation of the surface of the vessel opening between a general 1,000 litre and a 10,000 litre vessel can provide information on the diminution of the emissions between small and large batch manufacture. The surface of the vessel opening can be calculated with the following formula:

$$A = \pi * r^2 \quad \text{Formula 2.2}$$

Where:

- A: Surface of the vessel opening (m²).
r: Radius of the vessel (m).

For an example, the radius of a 1,000 litre vessel is assumed to be 0.5 m. The radius of a 10,000 l vessel is estimated to be 1 m.

According to, Formula 2.2: $A_{1,000} = 0.785 \text{ m}^2$; $A_{10,000} = 3.14 \text{ m}^2$.

Building the ratio between surface of the opening and corresponding vessel volume according to the following Formula 2.3:

$$R = A/V \quad \text{Formula 2.3}$$

where:

- A: Surface of the vessel opening (m²).
V: Volume the vessel (m³).
R: Ratio.

and comparing the obtained values shows that the ratio between opening surface and volume of the large vessel is 2.5 times smaller than the one of the small vessel.

Taking into account that the other emissions from operations such as charging and filling are not affected by the batch size, the VOC emissions have been assumed to be 50% smaller than in the general scenario or $F_{manuf_VOC, air} = 0.07-1.8\%$ of total VOCs.

Residues in packages are assumed to remain unchanged since the size of bags used is the same irrespectively of the size of batches ($F_{package_residue} = 0.5\%$).

The application of Formula 2.1 allows the calculation of the residue in a large size batch vessel. When assuming that 1 mm of coating remains on the vessel surface⁴, the amount of coating that remains in the mixing vessel as residue is $2.3 \times 10^{-2} \text{ m}^3$ or 23 litres; this represents 0.23% of the total volume which is approximately half the fraction for a 1,000 litre vessel used for the general

⁴ Assuming a total volume of 10 m^3 and a radius of 1m, the height of the vessel is calculated as equal to 3.185 m.

scenario. Therefore, the amount of residues in processing equipment is assumed to be $F_{equip_residue} = 0.5\%$. Again, we assume that half of the residues will be used in the manufacture of coatings at a later stage of the process ($F_{equip_residue, recyc} = 0.25\%$), therefore, the actual waste ($F_{equip_residue, waste}$) will be **0.25%**.

Dust emissions during loading operations of solid materials in powder form are assumed to remain the same, because the batch size has no direct influence on this operation. The capturing efficiency of the exhaustion device is supposed to be slightly higher at $\mu_1 = 97\%$. This assumption has been made because it is assumed that facilities that produce large batches generally have better emission reduction techniques in place.

The assumptions for removal of solid material from the surfaces of the workshop are the same as for a standard size batch process (i.e. **90%** (μ_3) is removed with industrial vacuum cleaners whereas **10%** is washed off the workshop floor during wet cleaning of the working area).

As shown in Table 4.7 below, there is a general decrease of the emission percentages for both VOCs and insoluble raw materials for all relevant endpoints.

4.8.3. Calculations and release table for large batch manufacture of organic solvent-borne coatings

The calculation of the emissions of raw materials follows the same general pattern that is described in Table 4.3; the results are presented in Table 4.6 below.

Table 4.6: Calculation of emissions of raw materials during the manufacture of organic-solvent borne coatings (large size batch - 10,000 litres or greater)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip_residue}$)	0.5%	
of which (all raw materials): ($F_{equip_residue, recyc}$)	0.25%	Recycled
and (all raw materials): ($F_{equip_residue, waste}$)	0.25%	Waste
Packaging waste (all raw materials) ($F_{package_residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf_VOC, air}$)	0.07 – 1.8%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing (F_{manuf_dust})	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf_dust} \cdot \mu_1$)	$1.0\% \times 0.97 = 0.97\%$	
Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf_dust} \cdot \mu_1 \cdot \eta_1$)	$0.97\% \times 0.99 = 0.96\%$	Waste

Stage (description)	Calculated emissions	Endpoint
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1-\eta_1)$)	$0.97\% \times 0.01 = 0.0097\%$	Air
Percentage of solid raw materials falling on the workshop floor ($F_{manuf_dust, dep} = F_{manuf_dust} \cdot (1-\mu_1)$)	$1.0\% \times 0.03 = 0.03\%$	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	$0.03\% \times 0.90 = 0.027\%$	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf_dust, water} = F_{manuf_dust, dep} \cdot (1-\mu_3)$)	$0.03\% \times 0.10 = 0.003\%$	Water

Tables 4.7 and 4.8 provide an overview of the percentages of used raw materials that are emitted to the environment during the manufacture of organic solvent-borne coatings in large batches and the assumptions made for removal efficiencies of abatement techniques.

Table 4.7: Total emission factors for large scale batch manufacture of organic solvent-borne coatings (batch size of 10,000 litres or greater)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	30-80	-	20-70
Air ($F_{manuf, air}$)	0.07-1.8%	-	0.0097%*
Water ($F_{manuf, water}$)	-	-	0.003%*
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	0.75%	-	0.75% (1.74%*)

* Valid for raw materials charged in powder form.

Table 4.8: Assumed values for the efficiency of the different emission treatment techniques during the manufacture of organic solvent-borne coatings (batch size of 10,000 litres or greater)

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.97	0.99
VOC treatment η_2	0	0
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

Figure 4.2 provides a visual presentation of the emissions during the manufacture of organic solvent-borne coatings.

4.9 Example calculations

4.9.1 Pigment

A pigment produced for specialised coatings, used at a content of 10 %. Small production (only 5 tonnes per year). Assume average batch size of 1,000 litres (~1,000 kg) per day of coating produced.

For air emissions: $E_{manuf, air} = Q_{coating_manuf} \times Q_{subst_in_coating} \times F_{manuf, air}/100$

Explanation of symbols:

$E_{manuf, air}$	release of substance to air from coating manufacture	kg/d	
$Q_{coating_manuf}$	quantity of coating product produced per day	kg/d	specific information (here 1,000 kg), or TGD table B2.3
$Q_{subst_in_coating}$	quantity of substance per kg of coating	kg/kg	specific information (here 0.1 kg/kg)
$F_{manuf, air}$	fraction (%) of substance released to air	%	Table 4.4 (here 0.0095%)

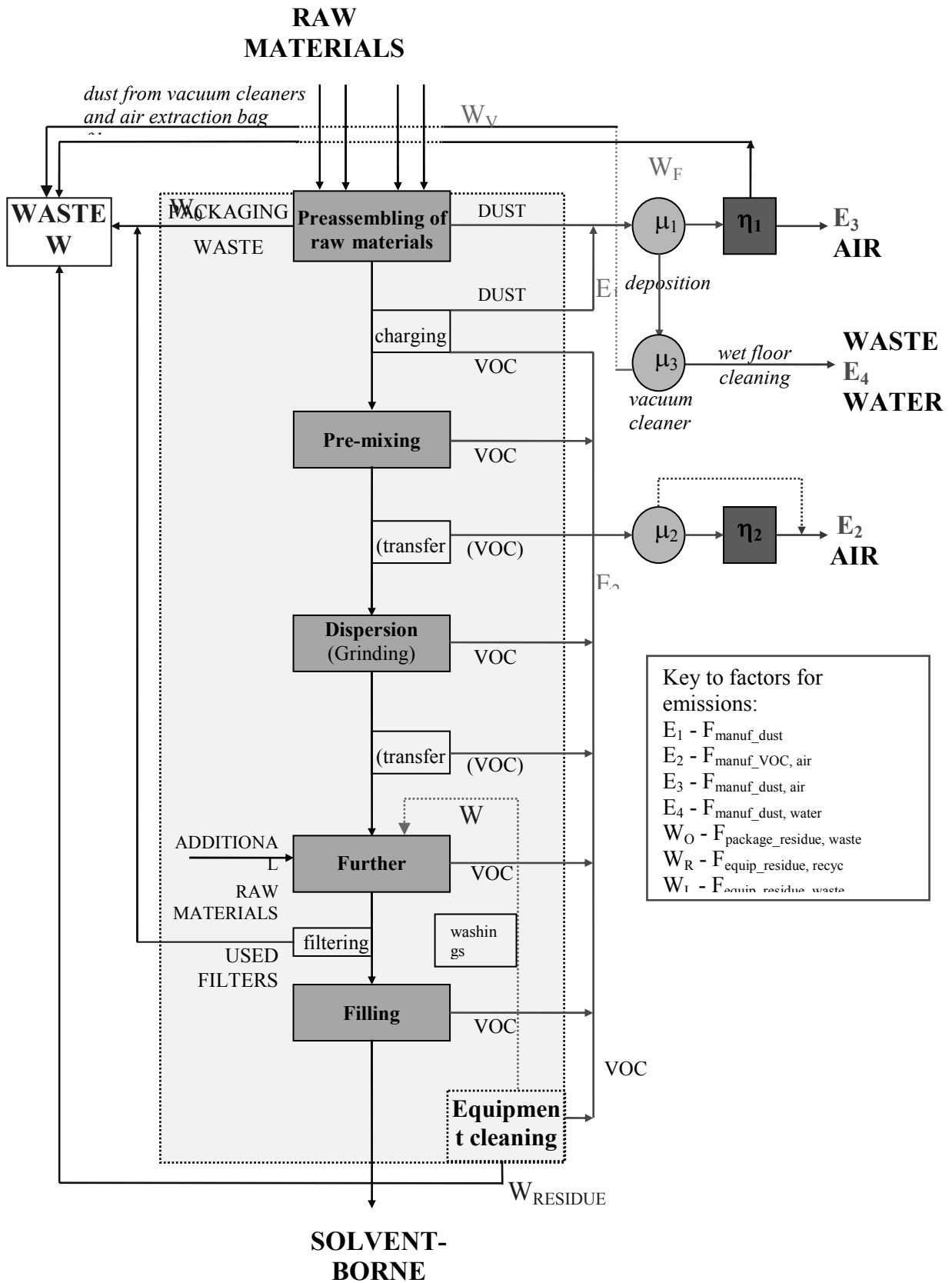


Figure 4.2: Flow diagram for the manufacture of organic solvent-borne

Similar equations apply to the other compartment, replacing the F value in each case. The resulting emissions are:

$$E_{manuf, air} = 9.5 \times 10^{-3} \text{ kg/day}$$

$$E_{manuf, water} = 5 \times 10^{-3} \text{ kg/day}$$

$$E_{manuf, waste} = 2 \text{ kg/day}$$

The calculations above are for a batch of 1000 kg of coating, which uses 100 kg of substance. The annual tonnage of 5 tonnes of the substance could produce 50 such batches, hence the annual emissions would be 50 times those above. In this example, all use (and hence emissions) is assumed to be at the one site. The total emissions can also be calculated by replacing ($Q_{coating_manuf} \times Q_{subst_in_coating}$) in the equation by the annual tonnage of the substance. The resulting annual emissions in this case are 0.48 kg to air, 0.25 kg to water and 100 kg to waste.

4.9.2 Solvent

Solvent used in high solids coatings, 10,000 tonnes used per year. Coatings contain 30% solvent, of which this specific solvent makes up 50%. Boiling point 90°C.

Equation is the same as that in Section 4.9.1. The content of the solvent in the coating is 50% x 30% = 15%, hence $Q_{subst_in_coating}$ is 0.15 kg/kg. No information provided on the amount of substance used at a site. For this example, the TGD table B2.3 is used. The amount of coating containing 10,000 tonnes of solvent is 67,000 tonnes. The fraction of main source is 0.4, hence the amount used on a site is 26,800 tonnes per year; 300 days of production are indicated, hence a daily production of 89 tonnes of coating ($Q_{coating_manuf} = 89,000 \text{ kg/day}$). This confirms that the factors for a larger site (batches over 10,000 litres) should be used. The boiling point indicates the substance is a low-boiling solvent; assume the emission factor corresponding to the highest air speed, so $F_{manuf, air}$ is 1.8% (upper end of range from Table 4.7). The factors for emission to other compartments should also be taken from Table 4.7.

The resulting emissions are:

$$E_{manuf, air} = 240 \text{ kg/day}$$

$$E_{manuf, waste} = 100 \text{ kg/day}$$

There are no emissions to water for volatile substances.

The total EU emissions can be estimated by replacing the quantity of coating made per day by the annual production of coating for the EU. As calculated above, the total amount of coating containing 10,000 tonnes of this solvent is 67,000 tonnes. (The same result is obtained by replacing ($Q_{coating_manuf} \times Q_{subst_in_coating}$) by the tonnage of the substance, 10,000 tonnes). The results are 180 tonnes per year to air and 75 tonnes per year to waste.

5 MANUFACTURE OF WATER-BORNE COATINGS

5.1 *Types of water-borne coatings*

5.1.1 *Overview*

The term ‘water-borne’ refers to coating systems that use water to some degree as the solvent (carrier phase). These types of coatings include aqueous dispersions, water-reducible (thinnable) coatings and colloidal dispersions.

5.1.2 *Aqueous dispersions*

Aqueous dispersions (or ‘latex’ coatings) consist of particles of a high molecular weight polymer dispersed in an aqueous medium. The size and distribution of these particles has a strong influence on the properties of the coating and can be used as a criterion for the classification of these coatings.

There exist mono-disperse dispersions with uniform distribution of the particle sizes, as well as hetero- and poly-disperse dispersions with a wide range of particle sizes. Classification according to the particle size is provided in Table 5.1.

Table 5.1: Classification of aqueous dispersion coatings according to the size of the polymer particles

Type of dispersion	Range of particle size (µm)
Fine	0.1 - 0.3
Middle	0.3 - 2
Coarse	2 - 5

Dispersion coatings are manufactured using a variety of polymeric resins such as styrene-butadiene copolymers, polyvinyl acetate, acrylics, alkyds, and polystyrene. The most important pigment used in this type of coating is titanium dioxide.

Table 5.2 provides an overview of the most prevalent fields of application for the various types of aqueous dispersion coatings.

5.1.3 *Water-reducible coatings*

Water-reducible coatings are coatings that contain a water miscible organic solvent or a mixture of such solvents and water, which are thinned (reduced) with water. In water-reducible coatings, chemical structures (polar groups) are incorporated into the binder polymer to make it soluble in water. The resins are generally produced via polycondensation or polymerization reactions in an organic medium (US EPA, 1998 in INERIS, 2000) and subsequently neutralised and inverted (dispersed) into water (Valspar, 2003).

Table 5.2: Types and fields of application for aqueous dispersion coatings (Baumann & Muth, 1995 in INERIS, 2000)

Type of aqueous dispersion	Field of application	Remarks
Dispersions for industrial uses	Various industrial applications	Pigment content is 15-20%; small content of filler but high proportion of titanium dioxide and coloured pigments
Dispersions for outdoors use	Wood and wall coatings	Pigment content is between 30% (wood) and 55% (concrete)
Dispersions for indoors use	Wall coatings	Pigment content is 50-80%
Synthetic-resin plaster	Plaster	Binder content is 6-8%; fillers are sand and other coarse grained matter
Dispersions used as primer	Indoors and outdoors applications	
Tint	Tinting of indoors and outdoors dispersion coatings	Contains binder, filler, surfactant, titanium dioxide, coloured pigments

The binders can be distinguished between non-ionic, anionic and cationic resins (INERIS, 2000):

Non-ionic resins are, for example, cellulose esters and ethers, polyglycol ethers, and polyacrylamides. They contain several functional (polar) groups that ensure their solubility. Their importance is relatively small and they are mainly used as thickener and to modify other types of resin (Baumann & Muth, 1995 in INERIS, 2000).

Cationic binders contain amino-groups and are neutralised with volatile organic acids. Cationic binders are for example amine-modified epoxy resins or amine-modified polybutadiene. They are cured through cross-linking when heated in an oven and are mainly used as primers in the automotive industry.

Anionic binders are the most important binders for water-reducible coatings. They contain carboxylic acid groups, and are neutralised using volatile amines or ammonia in order to obtain their solubility. These neutralising agents evaporate during film formation. A special category of anionic binders are silicates. After physical and chemical drying with atmospheric CO₂, they form an inorganic film. When applied to a mineral substrate, they might be able to react chemically and form a very adhesive film. Examples for anionic binders can be found in Table 5.3.

In water-reducible coatings, a high-boiling point, water-miscible organic solvent is required to aid the coalescence of the polymer after the water leaves the coating film. During the curing of the water-reducible coating, the water, co-solvent, and neutralising agent (ammonia, amines, carboxylic acids) evaporate, leaving a coating film that is no longer soluble in water. The concentration of neutralising agents in the mix may vary between 0.1 and 0.5%.

Table 5.3: Anionic water-soluble binders (Baumann & Muth, 1995)

Type of Binder	Film formation process	Field of application	Remarks
Silicates	Chemical cross-linking via silicate-bridges	Mineral substrates, typically on the inside or outside of buildings	Contains a maximum of 5% of organic resins
Alkyd resins	Oxidation	Industrial appliances like machine and vehicle coatings, corrosion protection primer, wood preservative coatings, surface sealing coatings	High quantities of co-solvents are recommended (neutralisation with amines)
Saturated polyesters	Cross-linking with amino-resins or polyisocyanates	Industrial flame drying coatings, coil coatings	Amine and solvent contents < 10%
Epoxy/acrylic resins	Cross-linking amino resins	Can coatings	
Phenolic resins	Thermal cross-linking (>160°C)	Flame-drying primers	Only in combination with other resins
Acidic polyacrylates	Physical or thermal cross-linking	Electro-dipping coatings	Can be used in combination with alkyd resins
Maleinised polybutadiene	Oxidation	Electro-dipping coatings in automotive or metal industry	Solvent contents <10 %

Co-solvents are used in a quantity usually around 10%. In some cases solvent contents can rise up to 25%. Typical co-solvents used in water-reducible coatings are presented in Table 5.4.

Table 5.4: Co-solvents used in water-reducible coatings (Baumann & Muth, 1995)

Solvent	Boiling point (°C)
Alcohol:	
Propanol	97
Butanol	118
iso-Butanol	117
sec-Butanol	99
Ethyl glycol ether:	
Propyl glycol	144
Butyl glycol	171
Ethyl diglycol	203
Butyl diglycol	233
Propylene glycol ether:	
Propylene glycol methyl ether	120
1-ethoxy-2-propanol	138
Propylene glycol methyl ether-1,2-acetate	146
Dipropylene glycol methyl ether	190

5.1.4 Colloidal dispersions

Colloidal dispersions are similar to water-reducible coatings. The binders are manufactured by poly-condensation and contain carboxylic groups. However, the number of polar groups is not sufficient for high water solubility, therefore, supplementary hydrophilic groups need to be added. This is achieved by the addition of polyglycols. These groups provoke the auto-emulsifying

properties of the resin and no supplementary emulsifier has to be added. The concentration of co-solvents and amines (preferably ammonia) is below 10%. Colloidal dispersions are used as ambient or oven-drying industrial coatings.

5.2 *Manufacture of aqueous dispersion coatings*

5.2.1 *Overview*

Aqueous dispersion coatings are manufactured using a variety of polymeric resins. The term 'latex coating' has become synonymous with dispersion coatings, but strictly speaking, latex refers to a dispersion of rubber particles. As the following descriptions are valid for different kinds of applied resins, the term 'latex coating' is not used.

5.2.2 *The manufacturing process*

The manufacturing process essentially follows the steps described in Section 2, Part II above. The average batch size is assumed to be 1,000 litres. Section 5.2.9, Part II provides the emission factors for large batch manufacture.

5.2.3 *Waste generation*

The principal sources of waste in the formulation of dispersion coatings are:

- Liquid paint from spills and off-specification paint.
- Raw materials not fully removed from bags and drums.
- Rinse liquid and sludge from equipment cleaning (US EPA, 1994a in INERIS, 2000).

We assume that the total fraction of raw materials lost to waste from the above sources is **1.5%**. This includes **1%** lost due to residues in the mixing vessels ($F_{equip_residue}$) and **0.5%** due to residues in bags, spills and product returns ($F_{package_residue}$)⁵. As for organic solvent-borne coatings, we assume that **half** of the residue material in the mixing vessels will be re-used in the manufacturing process (recycling, $F_{equip_residue, recyc} = 0.5\%$). For aqueous dispersion coatings the remaining equipment residue is assumed to be removed in water washings and hence to waste water, so $F_{equip_residue, water} = 0.5\%$.

As described in Sections 5.2.4.1.-5.2.4.2, Part II below, the total generated waste should also include raw materials in powder form which are collected either by air extraction systems or by industrial vacuum cleaners following dust emission to the air inside the workshop.

⁵ More detailed consideration of residues in bags, drums etc can be found in the ESD on transport and storage of chemicals (EA, 2007). Note that these residues are assumed not to be released to the environment at the coatings site.

5.2.4 Releases to the environment

The estimation of release factors follows a similar pattern to those for solvent-borne coatings, and the same terms are used here.

5.2.4.1 Releases to air

Air emissions during aqueous dispersion coating manufacture may have the following sources:

- **Dust emissions** during loading operations of solid raw materials.
- **Evaporation of VOCs** during different steps of the process, such as from open mixing vessels or during filling.
- **Evaporation of VOCs** due to drying from off-specification products, filters and packages.

With the exception of pigments and fillers, all raw materials are applied in liquid form.⁶ Dust emissions from weighing and filling operations are estimated to be $F_{manuf_dust} = 0.5-1.0\%$ by weight of the raw materials in powder form (US EPA, 1983 in INERIS, 2000). It is supposed, that **95%** of them will be removed by the ventilation system (μ_1). The remaining $1.0\% \times 0.05 = 0.05\%$ ($F_{manuf_dust, dep}$) is assumed to settle on the surfaces inside the workshop (see Section 5.2.4.2, Part II). The percentage captured by air extraction systems is $1.0\% \times 0.95 = 0.95\%$; with a scrubbing efficiency of **99%** (η_1) the percentage of solid raw materials released to the atmosphere is $0.95\% \times 0.01 = 0.0095\%$ ($F_{manuf_dust, air}$). The same percentage will apply to **both** non water soluble and non volatile water soluble raw materials if used in a powder form.

With regard to VOCs emissions to air, although only small amounts of VOCs are used in the formulation, VOCs emissions are generated during loading of the vessels, mixing, filling, cleaning and during drying of waste. The solvents used in dispersion coatings have a relatively low volatility. For the purposes of this document, the emission factors estimated by CEPE (CEPE, 2003b) will be taken forward. As shown in Table 5.5, the total percentage of VOCs emitted to the atmosphere during the manufacture of water-borne coatings ranges between **0.06-2.25%** ($F_{manuf_VOC, air}$) depending on the type of solvent used and the speed of air inside the workshop. The solvents mentioned in the table have the following boiling points (CEPE, 2003a):

- iso-Butanol: 100°C ('low' boiling point solvent).
- Butyl glycol: 171°C ('high' boiling point solvent).

⁶ It is assumed that the polymer particles are supplied in latex form, i.e. already dispersed in an aqueous medium, rather than added as a solid at this point.

Table 5.5: Emission factors (as percentages of raw materials used) for atmospheric releases of VOCs during water-soluble coatings manufacture (CEPE, 2003b)

Air speed (m/s)	Type of solvent					
	Low boiling point			High boiling point		
	0.5	2.5	10	0.5	2.5	10
Premix	0.129	0.453	1.336	0.023	0.082	0.243
Grinding	0.070	0.246	0.724	0.013	0.046	0.136
Finishing	0.126	0.126	0.126	0.025	0.025	0.025
	<i>0.013</i>	<i>0.013</i>	<i>0.013</i>	<i>0.013</i>	<i>0.013</i>	<i>0.013</i>
Filling	0.008	0.008	0.008	0.002	0.002	0.002
Cleaning	0.056	0.056	0.056	0.009	0.009	0.009
Total	0.389	0.889	2.250	0.072	0.164	0.415
	<i>0.276</i>	<i>0.776</i>	<i>2.137</i>	<i>0.060</i>	<i>0.152</i>	<i>0.403</i>

1. Figures in italics correspond to the use of vessels that are covered with lids.
2. Note that a low boiling point solvent would be iso-butanol and high boiling point solvent could be butyl glycol.

5.2.4.2 Emissions to wastewater

Water used for equipment cleaning operations (washing of residues) and cleaning of the workshop floor is assumed to be subsequently discharged into the wastewater stream of the facility, as noted in Section 5.2.3.

With regard to emissions of substances charged in powder form, an additional **0.005%** has to be added to the 0.5% which is released to wastewater in the form of residue material washings. This percentage corresponds to the amount of dust from raw materials in powder form, which was assumed to settle in the workshop and to be removed during wet cleaning operations (see Section 5.2.4.1, Part II). Of the initial 0.05% ($F_{manuf_dust, dep}$) settling inside the workshop, **90%** (μ_3) is vacuumed (i.e. $F_{manuf_dust, vac_waste} = 0.05\% \times 0.90 = \mathbf{0.045\%}$), while the remaining **10%** ($F_{manuf_dust, water} = 0.05\% \times 0.10 = \mathbf{0.005\%}$) is washed away during wet cleaning of the working area.

It should be noted these figures assume that no treatment of waste water effluent is undertaken on site. It is not unusual for sewage treatment companies to require adjustment of pH or for solids to be separated, prior to discharge. Separated solid material is sent to other disposal routes, such as landfill or incineration. Under such circumstances, the emission ratios are accordingly reduced.

5.2.4.3 Emissions to soil

Emissions to soil outside the facility are possible due to the atmospheric deposition of dust particles. By using distribution models, this fraction can be calculated on the basis of the air emissions.

5.2.5 On site emission treatment techniques (treatment of VOCs emissions to air)

Although they use only small quantities of VOCs, the dispersion coating manufacturing facilities generally have local or general exhaust systems (Baumann & Muth, 1995). However, due to the relatively low VOC concentrations in the exhaust air, further treatment is usually not applied.

5.2.6 Calculations and release table for the standard batch manufacture of aqueous dispersion coatings

Table 5.6 provides an overview of the calculation of emissions of both VOCs and non volatile non water soluble raw materials during the manufacture of standard batch aqueous dispersion coatings.

Table 5.6: Calculation of emissions of raw materials during the manufacture of aqueous dispersion coatings (standard batch size - 1,000 litres)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	1%	
of which (all raw materials): ($F_{equip\ residue, recvc}$)	0.5%	Recycled
and (all raw materials): ($F_{equip\ residue, water}$)	0.5%	Water
Packaging waste (all raw materials) ($F_{package_residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf\ VOC, air}$)	0.06 – 2.25%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing ($F_{manuf\ dust}$)	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_1$)	1.0% x 0.95 = 0.95%	
Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf\ dust} \cdot \mu_1 \cdot \eta_1$)	0.95% x 0.99 = 0.94%	Waste
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1-\eta_1)$)	0.95% x 0.01 = 0.0095%	Air
Percentage of solid raw materials falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.0% x 0.05 = 0.05%	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	0.05% x 0.90 = 0.045%	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf_dust, water} = F_{manuf_dust, dep} \cdot (1-\mu_3)$)	0.05% x 0.10 = 0.005%	Water

On the basis of the calculations presented above, Tables 5.7 and 5.8 show the percentages of used raw materials that are emitted to the environment during the manufacture of aqueous dispersion coatings and outline the assumptions made for removal efficiencies of abatement techniques.

Table 5.7: Total emission factors for standard batch manufacture of aqueous dispersion coatings (1,000 litres)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	1-5%	15-20%	70-80%
Air ($F_{manuf, air}$)	0.06-2.25%	0.0095%*	0.0095%*
Water ($F_{manuf, water}$)	-	0.5% (0.505%*)	0.5% (0.505%*)
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	0.5%	0.5% (1.49%*)	0.5% (1.49%*)

* Valid for raw materials used in powder form.

Table 5.8: Assumed values for the efficiency of the different emission treatment techniques during manufacture of standard batch aqueous dispersion coatings

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
VOC treatment η_2	0	0
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

5.2.7 Recycling of waste

A measure to reduce the generation of liquid waste from cleaning operations is to create production schedules. These allow the formulation of similar batches of paint, one after another. As a consequence, the production of several batches without intermediate cleaning is possible (US EPA, 1994a in INERIS, 2000).

Equipment is usually cleaned using water, which is used in the manufacture of the subsequent batch of coating. Under such circumstances, the emission of waste water is zero. Alternatively, the cleaning liquid can be used several times. Normally this will be discharged to sewer, as inevitable bacterial contamination would make it unsuitable to use in coatings manufacture. Assuming that these measures reduce the amount of waste generated during cleaning by about 50%, releases to wastewater from cleaning have to be reduced by this percentage: $F_{equip_residue, water} = 0.5\%$. This was taken into account in Section 5.2.3, Part II.

5.2.8 Manufacture of large batches of aqueous dispersion coatings

5.2.8.1 Overview

The main field of application for water-borne dispersion coatings is the architectural sector. They are used for decorative purposes on the inside and outside of buildings and account for a

significant portion of the coatings market. White is the major colour produced. The white basic colour can be tinted either by the manufacturer, the vendor or the user. Therefore, large scale production is very common in water-borne dispersion coatings manufacture.

5.2.8.2 Emissions during large batch manufacture of aqueous dispersion coatings

For an average batch size of 10,000 litres and following the assumptions presented in Section 4.7.2. for organic solvent-borne coatings, residues of raw materials in packages and containers and waste from used filters is assumed to remain the same at **0.5%** ($F_{package_residue}$), while the washings contain a total of **0.5%** ($F_{equip_residue}$) of raw materials (a decrease compared to the general scenario). Again, only **0.25%** ($F_{equip_residue, water}$) is assumed to end up in the wastewater stream, with the remaining $F_{equip_residue, recyc} = 0.25\%$ being recycled (re-used in a later stage of the manufacturing process).

VOCs emissions to air from manufacture ($F_{manuf_VOC, air}$) are assumed to be **halved** compared to the general scenario (**0.03-1.13%**) and the capturing efficiency of dust filters (μ_1) is increased to **97%** (although the scrubbing efficiency remains the same at 99%). The assumptions for removal of raw materials from the workshop floor remain the same.

5.2.8.3 Calculations and release table for large batch manufacture of aqueous dispersion coatings

The calculation of the emissions of raw materials follows the same general pattern which is described in Table 5.6; the results are presented in Table 5.9. Tables 5.10 and 5.11 provide an overview of the percentages of used raw materials that are emitted to the environment during the manufacture of aqueous dispersion coatings in large batches and the assumptions made for the removal efficiencies of abatement techniques.

Figure 5.1 provides a visual presentation of the manufacturing process for aqueous dispersion coatings.

Table 5.9: Calculation of emissions of raw materials during the manufacture of aqueous dispersion coatings (large size batch - 10,000 litres or greater)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	0.5%	
of which (all raw materials): ($F_{equip\ residue, recvc}$)	0.25%	Recycled
and (all raw materials): ($F_{equip\ residue, water}$)	0.25%	Water
Packaging waste (all raw materials) ($F_{package_residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf\ VOC, air}$)	0.03 – 1.13%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing ($F_{manuf\ dust}$)	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_1$)	1.0% x 0.97 = 0.97%	
Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf\ dust} \cdot \mu_1 \cdot \eta_1$)	0.97% x 0.99 = 0.96%	Waste
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1-\eta_1)$)	0.97 % x 0.01 = 0.0097%	Air
Percentage of solid raw materials falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.0% x 0.03 = 0.03%	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf\ dust, vac\ waste} = F_{manuf\ dust, dep} \cdot \mu_3$)	0.03% x 0.90 = 0.027%	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf\ dust, water} = F_{manuf\ dust, dep} \cdot (1-\mu_3)$)	0.03% x 0.10 = 0.003%	Water

Table 5.10: Total emission factors for large batch manufacture of aqueous dispersion coatings (batch size of 10,000 litres or greater)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	1-5%	15-20%	70-80%
Air ($F_{manuf, air}$)	0.03-1.13%	0.0097%*	0.0097%*
Water ($F_{manuf, water}$)	0.25%	0.25% (0.253%*)	0.25% (0.253%*)
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	0.5%	0.5% (1.49%*)	0.5% (1.49%*)

* Valid for raw materials in powder form.

Table 5.11: Assumed values for the efficiency of the different emission treatment techniques for large batch manufacture of aqueous dispersion coatings

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.97	0.99
VOC treatment η_2	0	0
Vacuum cleaner η_3	0.90	(1)*

* - 100% efficiency assumed

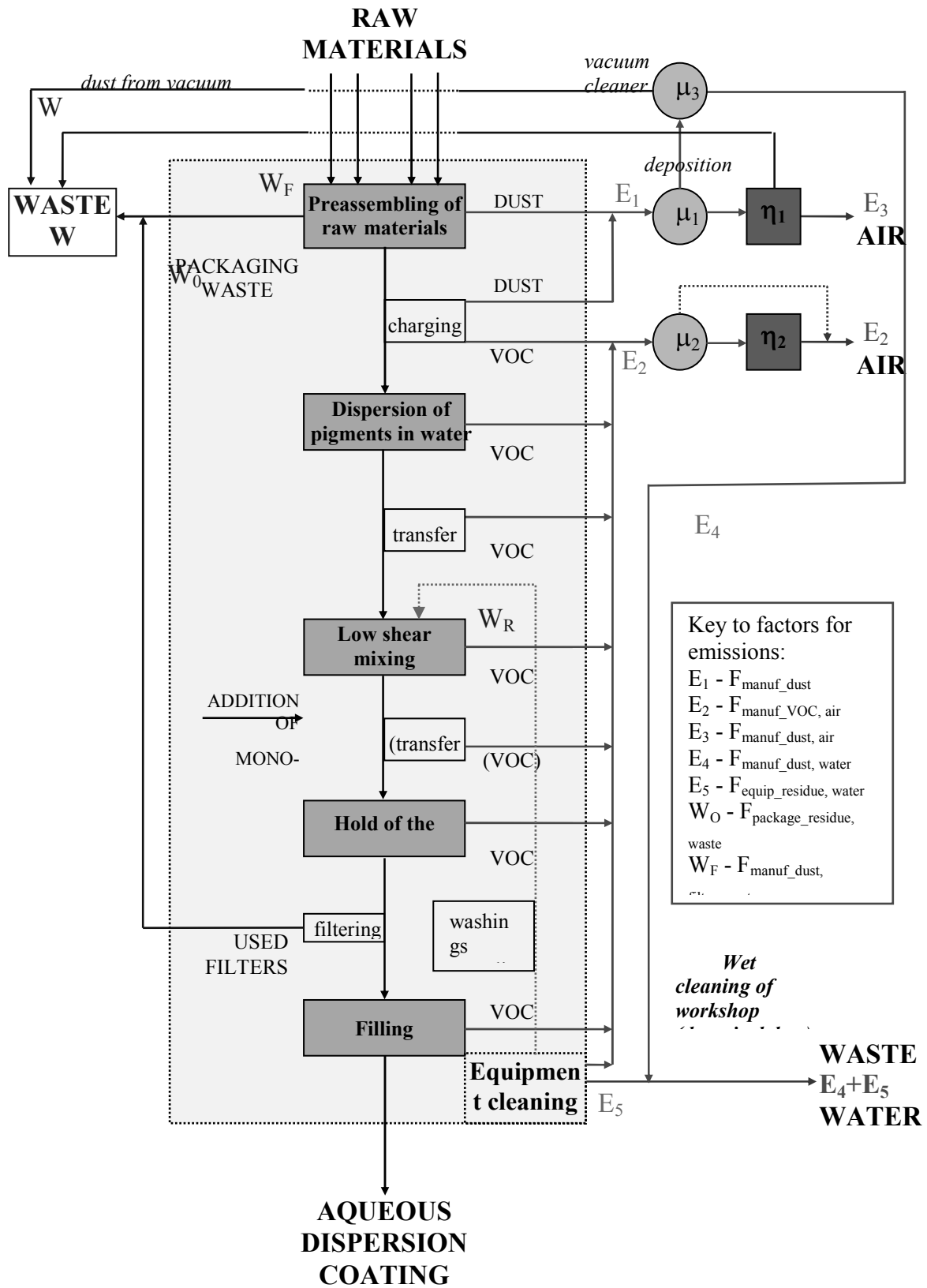


Figure 5.1: Flow diagram for the manufacture of aqueous dispersion

5.3 Manufacture of water-reducible coatings and colloidal dispersions

5.3.1 Overview

The manufacturing process of these two types of coatings is similar and does not need to be differentiated with regard to their environmental emissions. What distinguishes these coatings is the chemistry of the binder systems used, which allows the use of water instead of solvent.

Organic solvent contents in water-reducible coatings usually vary between 10 and 15%, but it may rise up to 25%, whereas in colloidal dispersions they are below 10%. The average (standard) batch size for the general scenario is assumed to be 1,000 litres.

5.3.2 Waste generation

The sources for the generated waste streams are the same as for aqueous dispersion coatings. The amount of residues in packages of raw materials as well as in used filters is estimated to be about $F_{package_residue} = 1.0\%$ of the raw materials. Residues in processing equipment ($F_{equip_residue}$) are estimated to be about **1%** by weight of raw materials, of which only **half** ($F_{equip_residue, water}$) is disposed of in the wastewater stream, while the remainder is re-used in the manufacturing process ($F_{equip_residue, recyc} = 0.5\%$).

In addition to the above, waste material collected in air extraction bag filters and industrial vacuum cleaners also needs to be disposed of (as Section 5.3.3.1, Part II below).

5.3.3 Emissions to the environment

5.3.3.1 Emissions to the air

As in the production of aqueous dispersion coatings, two types of sources for emissions to the air have been assumed:

- Dust emissions during loading operations of solid raw materials.
- Evaporation of VOCs during the various steps of the process, such as from open mixing vessels or during the filling of vessels.

The solvents used in water-reducible coatings and colloidal dispersions are oxygenated solvents such as alcohols and glycol ethers. They have boiling points of about 100°C. We assume that the VOCs emissions to air are similar to those indicated by CEPE (CEPE, 2003b) and presented in Table 5.5, therefore we take a VOC emission of $F_{manuf_VOC, air} = 0.06-2.25\%$ by weight of the raw materials.

Dust emissions from handling of raw materials in powder form are supposed to be $F_{manuf_dust} = 1.0\%$ of raw materials, if in powder form (US EPA, 1983 in INERIS, 2000); **95%** (μ_1) is

expected to be exhausted by the ventilation system (so $1.0\% \times 0.95 = \mathbf{0.95\%}$) and the remaining dust will subsequently deposit on the surfaces inside the workshop.

The air extraction system bag filters retain 99% of the captured solid material ($0.95\% \times 0.99 = \mathbf{0.94\%}$, $F_{manuf_dust, filter_waste}$), while the remaining $0.95\% \times 0.01 = \mathbf{0.0095\%}$ ($F_{manuf_dust, air}$) is emitted to the atmosphere outside the workshop.

Of the $1.0\% \times 0.05 = \mathbf{0.05\%}$ ($F_{manuf_dust, dep}$) that finds its way to the workshop floor, **90%** (μ_3) will be collected by means of an industrial vacuum cleaner ($0.05\% \times 0.90 = \mathbf{0.045\%}$, $F_{manuf_dust, vac_waste}$) and the remainder ($0.05\% \times 0.10\% = \mathbf{0.005\%}$, $F_{manuf_dust, water}$) will be washed away during wet cleaning of the workshop floor.

5.3.3.2 Emissions to wastewater

Cleaning operations are the major source for emissions to wastewater. Discharge of untreated wastewater containing water soluble solvents can lead to high levels of organic pollution. The COD of these waters can rise to 100,000 g/l with an average of about 10,000 to 20,000 g/l.

It is assumed that **0.5%** ($F_{equip_residue, water}$) by weight of the coating will be directed to the wastewater stream from cleaning of the mixing vessels and other equipment.

As indicated above, a further **0.005%** ($F_{manuf_dust, water}$) of raw materials in powder form should be added to the releases to wastewater due to wet cleaning of the workshop floor.

5.3.3.3 Emissions to soil

Emissions to soil are possible due to the deposition of pigment particles. If they are emitted to the exterior of the workshop via local exhaustion, they may deposit to soil in the area surrounding the site. This fraction can be calculated on the basis of the air emissions, using suitable distribution models.

5.3.4 Onsite emission treatment techniques (treatment of VOCs emissions to air)

The use of organic solvents can result in emissions of vapours into work areas. To meet occupational exposure limits, these vapours have to be extracted. A general extraction system of the workshop should therefore exist in every facility. Apart from this, there might be local extraction during some processing steps, helping to capture the vapours at their source.

However, the VOC concentration in the captured air streams is too low to allow for an economic and efficient treatment. For the purposes of this document, we do not assume any specific treatment of air emissions of VOCs. If abatement facilities do exist, the emissions need to be amended accordingly on a site-by-site basis.

5.3.5 Calculations and release table for standard batch manufacture of water-reducible coatings and colloidal dispersions

Table 5.12 provides an overview of the calculation of emissions of both VOCs and non volatile non water soluble raw materials during the manufacture of standard batch water-reducible coatings and colloidal dispersions.

Table 5.12: Calculation of emissions of raw materials during the manufacture of water-reducible coatings and colloidal dispersions (standard size batch - 1,000 litres)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	1%	
of which (all raw materials): ($F_{equip\ residue, recvc}$)	0.5%	Recycled
and (all raw materials): ($F_{equip\ residue, water}$)	0.5%	Water
Packaging waste (all raw materials) ($F_{package\ residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf\ VOC, air}$)	0.06 – 2.25%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing ($F_{manuf\ dust}$)	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_1$)	1.0% x 0.95 = 0.95%	
Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf\ dust, filter\ waste} = F_{manuf\ dust} \cdot \mu_1 \cdot \eta_1$)	0.95% x 0.99 = 0.94%	Waste
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf\ dust, air} = F_{manuf\ dust} \cdot \mu_1 \cdot (1-\eta_1)$)	0.95% x 0.01 = 0.0095%	Air
Percentage of solid raw materials falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.0% x 0.05 = 0.05%	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf\ dust, vac\ waste} = F_{manuf\ dust, dep} \cdot \mu_3$)	0.05% x 0.90 = 0.045%	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf\ dust, water} = F_{manuf\ dust, dep} \cdot (1-\mu_3)$)	0.05% x 0.10 = 0.005%	Water

On the basis of the calculations presented above, Tables 5.13 and 5.14 show the percentages of used raw materials that are emitted to the environment during the manufacture of water-reducible coatings and colloidal dispersions and outline the assumptions made for the removal efficiencies of abatement techniques.

Table 5.13: Total emission factors for standard batch manufacture of water-reducible coatings and colloidal dispersions (1,000 litres)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	5-25	45-70	20-30
Air ($F_{manuf, air}$)	0.06-2.25%	0.005%*	0.005%*
Water ($F_{manuf, water}$)	0.50%	0.50% (0.505%*)	0.50% (0.505%*)
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	0.50%	0.5% (1.49%*)	0.5% (1.49%*)

* Valid for pigments or raw materials charged in powder form

Table 5.14: Assumed values for the efficiency of the different emission treatment techniques during standard batch manufacture of water-reducible coatings and colloidal dispersions

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
VOC treatment η_2	0	0
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

5.3.6 Large batch manufacture of water-reducible coatings and colloidal dispersions

5.3.6.1 Overview

The market for water-reducible coatings and colloidal dispersions is increasing due to the introduction of relevant legislation aimed at the reduction of VOCs emissions. The technical progress and the development on these coatings allow for the replacement of the ordinary solvent-borne coating systems in many fields of application.

There is limited information on the extent to which large batch manufacture of water-borne coatings takes place in Europe. In the UK for example, industry indicates that the only large batch (e.g. 5,000 – 10,000 litres) water-borne manufacturing processes are of decorative coating emulsion paints and of water-borne internal can coatings (~10,000 litres). All industrial coating and printing ink manufacture is on a smaller scale (e.g. usually not more than 2,000, and typically a few hundred, litres) (CEPE, 2003a).

According to INERIS (INERIS, 2000), high quantities of water-reducible coatings and colloidal dispersions are currently being used by the automotive industry (as primers, surfacers (fillers), and finishes), the coil coatings and can coatings industries and in the coating of machines and trains (i.e. all kinds of metal surfaces). It should be noted that water borne technologies are not suitable for all applications and alternative low VOC technologies, such as solvent-free, high solids and coating powders, along with process controls which result in lower emissions of VOCs are also established and increasing in their use.

5.3.6.2 Emissions during large batch manufacture of water-reducible coatings and colloidal dispersions

For an average batch size of 10,000 litres and following the assumptions presented in Section 4.7.2, Part II for organic solvent-borne coatings, residues of raw materials in packages and containers and waste from used filters are assumed to remain the same at **0.5%** ($F_{package_residue}$), while the washings contain a further **0.5%** ($F_{equip_residue}$) of raw materials (a decrease compared to the general scenario for a standard batch size). Again, only **0.25%** ($F_{equip_residue, water}$) is assumed to end up in the wastewater stream, while **0.25%** ($F_{equip_residue, recyc}$) is re-used in a later stage of the manufacturing process.

VOCs emissions to air from manufacture are assumed to be **halved** compared to the general scenario ($F_{manuf_VOC, air}$, **0.06-1.13%**) and the capturing efficiency of air extraction bag filters (μ_1) is assumed to increase to **97%** (although their scrubbing efficiency is the same, **99%**).

5.3.7 Calculations and release table for large batch manufacture of water-reducible coatings and colloidal dispersions

The calculation of the emissions of raw materials follows the same general pattern which is described in Table 5.12; the results are presented in Table 5.15 below.

Table 5.15: Calculation of emissions of raw materials during the manufacture of water-reducible coatings and colloidal dispersions (large size batch - 10,000 litres or greater)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip_residue}$)	0.5%	
of which (all raw materials): ($F_{equip_residue, recyc}$)	0.25%	Recycled
and (all raw materials): ($F_{equip_residue, waste}$)	0.25%	Water
Packaging waste (all raw materials) ($F_{package_residue, waste}$)	0.5%	Waste
Volatilisation of VOCs		
VOCs emissions (CEPE, 2003b) ($F_{manuf_VOC, air}$)	0.03 – 1.13%	Air
Dust emissions		
Emissions of solid raw materials (particles) during mixing (F_{manuf_dust})	1.0%	(initially to air)
Percentage of solid raw materials captured by air extraction devices ($F_{manuf_dust} \cdot \mu_1$)	1.0% x 0.97 = 0.97%	
Percentage of solid raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf_dust} \cdot \mu_1 \cdot \eta_1$)	0.97% x 0.99 = 0.96%	Waste
Percentage of solid raw materials emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1-\eta_1)$)	0.97% x 0.01 = 0.0097%	Air

Stage (description)	Calculated emissions	Endpoint
Percentage of solid raw materials falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.0% x 0.03 = 0.03%	
Percentage of solid raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf\ dust, vac\ waste} = F_{manuf\ dust, dep} \cdot \mu_3$)	0.03% x 0.90 = 0.027%	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf\ dust, water} = F_{manuf\ dust, dep} \cdot (1-\mu_3)$)	0.03% x 0.10 = 0.003%	Water

Tables 5.16 and 5.17 provide an overview of the percentages of used raw materials that are emitted to the environment during the manufacture of water-reducible coatings and colloid dispersions in large batches and the assumptions made for the removal efficiencies of abatement techniques.

Table 5.16: Total emission factors for large batch manufacture of water-reducible coatings and colloidal dispersions (batch size of 10,000 litres or greater)

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	5-25	45-70	20-30
Air ($F_{manuf, air}$)	0.03-1.13%	0.0097%*	0.0097%*
Water ($F_{manuf, water}$)	0.25%	0.25% (0.253%*)	0.25% (0.253%*)
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	0.50%	0.5% (1.49%*)	0.5% (1.49%*)

* Valid for raw materials in powder form (note that when in powder form, the emissions of non volatile non water soluble raw materials to wastewater are slightly higher at 0.252%).

Table 5.17: Assumed values for the efficiency of the different emission treatment techniques during large batch manufacture of water-reducible coatings and colloidal dispersions

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.97	0.99
VOC treatment η_2	0	0
Vacuum cleaner η_3	0.90	(1)*

* - 100% efficiency assumed

Figure 5.2 provides a visual presentation of the manufacturing process for water-reducible coatings and colloidal dispersions.

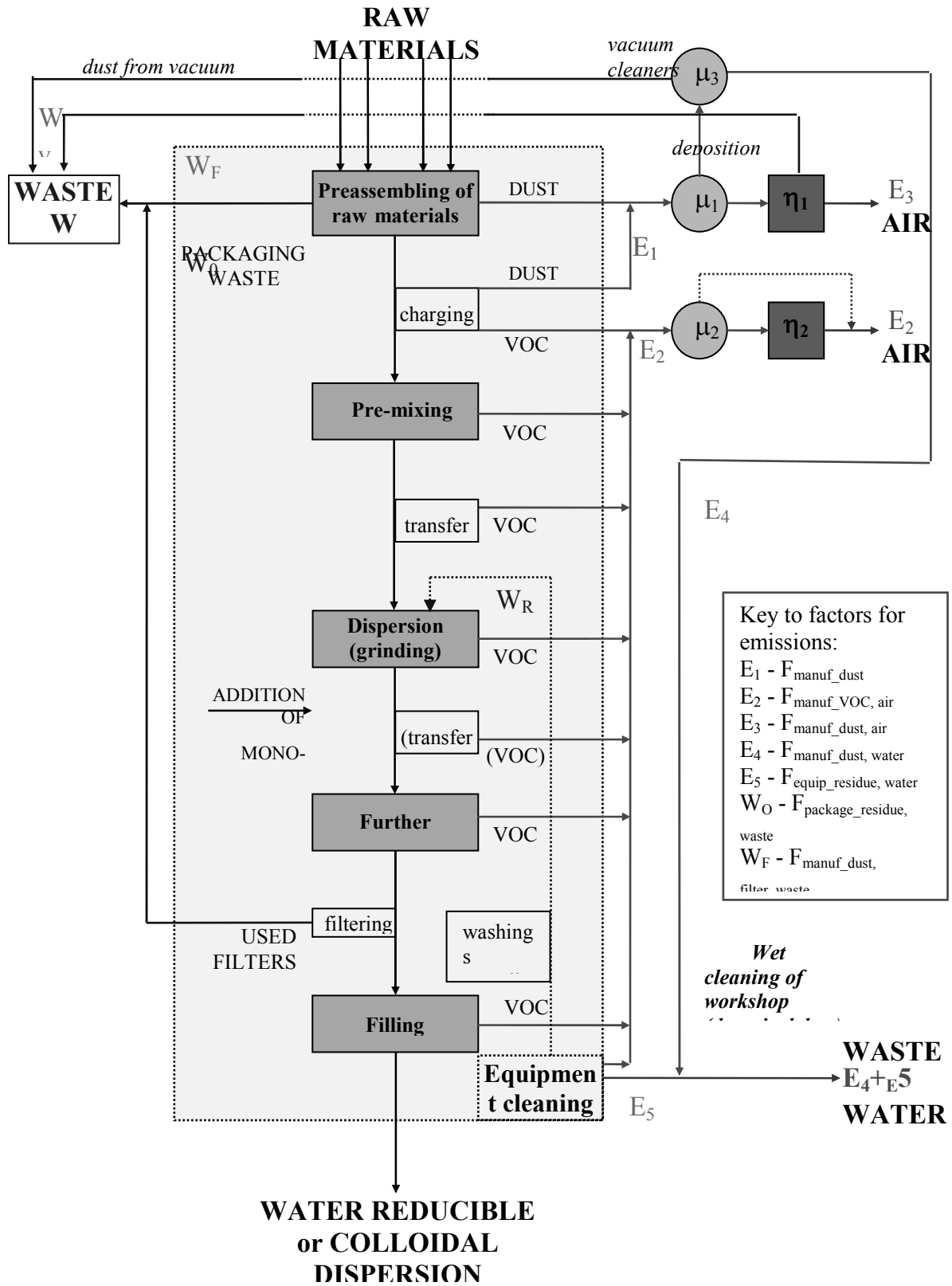


Figure 5.2: Flow diagram for the manufacture of water reducible or colloidal dispersion coatings

5.4 Example

The various types of water-borne coatings have similar releases, so only one example is included here. The calculation method is the same as for solvent-based coatings.

For this example, assume a pigment used in water-reducible coatings. The substance is considered to be non-volatile and non-water soluble. The production volume of the pigment is 1,000 tonnes per year, and it is used in the coatings at 3% by weight.

For air emissions:

$$E_{manuf, air} = Q_{coating_manuf} \times Q_{subst_in_coating} \times F_{manuf, air} / 100$$

Explanation of symbols:

$E_{manuf, air}$	release of substance to air from coating manufacture	kg/d	
$Q_{coating_manuf}$	quantity of coating product produced per day	kg/d	specific information or TGD table B2.3
$Q_{subst_in_coating}$	quantity of substance per kg of coating	kg/kg	specific information (here 0.03 kg/kg)
$F_{manuf, air}$	fraction (%) of substance released to air	%	Table 5.13 or 5.16 depending on batch size

There is no information on the amount used on sites or on the batch size. The amount of coating produced containing the substance at 3% is 33,000 tonnes per year. From the TGD B table the appropriate fraction of main source is 0.6 with a production over 300 days per year. Thus the amount of coating produced on site is 20,000 tonnes per year, 67 tonnes per day ($Q_{coating_manuf} = 6.7 \times 10^4$ kg/day). This suggests a large batch size of over 10,000 litres (10 tonnes) and so the factors from Table 5.16 are used. The fraction for release to air ($F_{manuf, air}$) is 0.0097%. Hence the emissions are:

$$E_{manuf, air} = 6.7 \times 10^4 \times 0.03 \times 0.0097 / 100 = 0.2 \text{ kg/day.}$$

The emissions to water and waste can be calculated in the same way using the appropriate factors, and the results are 5 kg/day to water and 30 kg/day to waste.

As in section 4.4, the total EU emissions can be calculated by replacing the daily production quantity of coating with the annual quantity of coating with this substance produced in the EU, or by replacing ($Q_{coating_manuf} \times Q_{subst_in_coating}$) with the total tonnage of substance used. The results are 100 kg to air per year, 2,500 kg to water and 14,900 kg to waste.

6 MANUFACTURE OF POWDER COATINGS

6.1 *Overview of manufacturing processes*

Two techniques exist for the manufacture of powder coatings:

- **Melt-blend** processing.
- **Dry-blend** processing.

About 100% of the thermoset powder coatings and 20% of the thermoplastic powder coatings (which are described in Sections 6.2.2. and 6.2.3, Part II below) are produced by melt-blend processing. Together they have a market share of about 90% of the entire volume of produced powder coatings (US EPA, 1994b in INERIS, 2000). The remaining 10% is believed to represent dry-blend powder coatings. These find only limited applications: they are believed to find some commercial success in Germany but only trial applications in France. In the UK they could be limited to artists' colours and children's paints (CEPE, 2003a).

As with any other type of coating, powder coatings are processed in batches. The quantity of coatings produced in a batch can vary between 100 kg and 50,000 kg. The volume of the batch influences not only the price, but also the amount of waste and emissions generated. In large powder coating production facilities, the average batch size is about 3,000 kg. For the purpose of this document an average (standard) batch size of 1,000 kg has been assumed.

6.2 *Types of powder coatings*

6.2.1 *Overview⁷*

Powder coatings are dry coatings. Instead of being dissolved or suspended in a liquid medium such as an organic solvent or water, powder is applied using electrostatic spray, fluidised bed or flame spray techniques. In all cases, the powder that adheres to the object being coated is melted using heat to provide a continuous film.

Powder coatings consist of a mix of different resins, pigment, filler, curing agents, flow control agents and other additives. They are 100% dry powders with typical particle sizes ranging between 10 and 100 µm.

Because they contain no solvents, they pose no risks to the environment from solvent emissions. However, powder coatings are accompanied by a number of disadvantages related to their application. Firstly, the substrate needs to be completely clean to ensure good adhesion of the powder. Secondly, the need for heating causes problems if the object is not heat-resistant or when the object to be coated is large or very heavy. Powder coating technology is rapidly developing and the number of products that can be coated using powder coatings is steadily increasing. Powder coatings are particularly suitable for the coating of metal substrates.

⁷ The comments in this section do not relate to the use of powder coatings in artists' materials or children's paints.

Powder coatings can be classified according to the applied resins into:

- **Thermoplastic** powder coatings.
- **Thermoset** powder coatings.

6.2.2 *Thermoplastic powder coatings*

Thermoplastic powder coatings can be deformed when heated. Binders used in thermoplastic powder coatings are nylon, polyvinyl chloride, fluoropolymers, and polyolefins. They are primarily applied on items that require a thick film (US EPA, 1995 in INERIS, 2000).

A typical thermoplastic PVC powder coating consists of:

- 51% PVC resin.
- 33% fillers and pigments.
- 15% plasticiser.
- 1% liquid stabilisers.

6.2.3 *Thermoset powder coatings*

Thermoset powder coatings are cured with heat and form a film that cannot be re-melted (Baumann & Muth, 1995 in INERIS, 2000). They have very good adhesion properties on metal surfaces and are applied as a single, relatively thin layer.

The majority of powder coating resins are thermoset coatings. These contain epoxy, polyester, polyurethane, and acrylic resins for thin-film applications.

A typical thermoset powder formulation consists of the following (INERIS, 2000):

- 60 to 70% resin and hardener (of which 80% is resin and 20% hardener).
- 26 to 38% fillers and pigments.
- 2 to 4% levellers and processing aids.
- 1% plasticisers and stabilisers.

6.3 *Melt-blend manufacture of powder coatings*

6.3.1 *Description of the process*

Melt-blend manufacture of powder coatings includes the following operations (US EPA, 1994b in INERIS, 2000):

- Weighing of the raw materials.
- Pre-mixing or dry blending of the raw materials into a homogeneous dry blend.

- Melt mixing of the dry blend into a single-phase continuous melt.
- Cooling and flaking of the melt-mixed extrudate.
- Grinding of the flaked extrudate into powder.
- Addition of metal powders for metallic effects and subsequent mixing (dry blending).
- Sieving and classification of the powder product.

At the weighing stage, the raw material components are weighed into a mobile container. Usually, the container is covered and loading is performed through a feed-tube. Subsequently, the container is moved to the blending station. Batches in containers up to 1,200 kg are branched to a mixing assembly, which dives directly into the container. The container remains covered during mixing. For the production of large batches, the contents of the container are emptied into a large, closed vessel with an integrated mixer (Karle, 2000 in INERIS, 2000).

All the ingredients of the powder coating formulation, such as resins, pigments, fillers, and additives, are fed into a vessel before pre-mixing starts (Baumann & Muth, 1995 in INERIS, 2000). Once the raw materials are sufficiently homogenised, they are directly transferred into the extruder hopper. A screw on the bottom of the hopper feeds the mix into the extruder, where it is kneaded and melted into a uniform melt (US EPA, 1994b in INERIS, 2000). The temperatures are above the softening point of the resins but below the curing point of the binder system (Baumann & Muth, 1995 in INERIS, 2000), generally between 90 to 120°C (Karle, 2000 in INERIS, 2000).

The emerging homogeneous stock is passed via a cooled chute onto the compact cooler. The cooled rolls of the compact cooler squeeze the stock to a thin band, that rapidly cools. At the end of the compact cooler, a crusher breaks the brittle band into flakes or chips, which are collected in a container. The chips container is then moved to the grinding station. There, the chips are fed into a mill which is connected to an air classifier. The air flow through the mill carries the desired size particles and the small amount of non-desired fine particles (smaller than 10 µm) over to a cyclone, which separates the powder coating particles. The still larger size particles are not carried over and stay in the grinding process, until their size is reduced to the carry-over dimensions. By gravity and via a rotary valve, the powder is discharged from the cyclone and passed onto the bagging station. The air passes through a bag filter, where the fine particles are removed. Subsequently, the air is discharged into the environment (Franz & Meier, 1998 in INERIS, 2000).

The average particle size of melt-blend processed powder coatings varies between 10 and 120 µm with an average density of about 1.6 g/cm³ (US EPA, 1994b in INERIS, 2000). Each discrete powder particle contains the entire coating formulation (Baumann & Muth, 1995 in INERIS, 2000).

Large facilities have modern processing installations, where the different operating steps are combined in a way that permits automation of tasks, especially for transportation and charging of the raw materials and the intermediate products. In smaller firms, the majority of the operations, for example the transport between the different processing units and charging, are performed manually.

6.3.2 Waste generation

Waste is generated during the classification of the powder particles, as well as during cleaning operations and the treatment of emissions.

Residues in bags, spills and product returns are considered to amount to 0.5% of all raw materials, as for other types of coating ($F_{\text{package_residue, waste}}$)⁸.

As in other coating manufacturing processes, the whole equipment is cleaned after each batch. Cleaning of the equipment, except the extruder, is performed by removal of the remaining dust with a vacuum cleaner or by rinsing with solutions. The amount of waste generated during equipment cleaning (with the exception of the extruder), is taken to be about **1%** by weight of the raw materials ($F_{\text{equip_residue}}$). We assume that $F_{\text{equip_residue, recyc}} = \mathbf{0.25\%}$ will be recovered and re-used when dry collection is performed, with **0.5%** ($F_{\text{equip_residue, water}}$) released into the wastewater. The remaining **0.25%** ($F_{\text{equip_residue, waste}}$) represents raw materials that are disposed of in filter bags or non aqueous solutions which are disposed of as hazardous waste. The assumption that only one quarter of the waste will be recycled is based on information from industry according to which collected dust cannot always be recycled in the manufacturing of coatings since its composition is a mixture in unknown proportions of pigments and fillers coming from various formulations (CEPE, 2003a).

The extruder is **dry-cleaned** using granular material like nutshells, maize or resins. The solid waste generated from extruder cleaning is estimated to be $F_{\text{extruder, waste}} = \mathbf{1\%}$ by weight of the raw materials (US EPA, 1994b in INERIS, 2000). This waste is also landfilled or incinerated.

Other types of waste include material collected by air extraction bag filters and vacuum cleaners and this is described in Section 6.3.3.1, Part II below.

6.3.3 Releases to the environment

6.3.3.1 Emissions to air

Releases to the air may be generated during the following operations:

- Transfer of raw materials into the weighing container.
- Transfer of the weighed raw materials into the pre-mixer.
- Pre-mixing of the raw materials (in general, the mixing vessel is a closed device, but there may be some dust emissions when the lid is open or through the chute during material loading (US EPA, 1994b in INERIS, 2000)).
- Charging of the extruder⁹.

⁸ More detailed consideration of residues in bags, drums etc can be found in the ESD on transport and storage of chemicals (EA, 2007). Note that these residues are assumed not to be released to the environment at the coatings site.

⁹ We have assumed that no losses of materials in non-powder form occur during these operations.

Similar to the manufacture of the other types of coating, a difference has to be made between raw materials applied in powder form and other raw materials. Usually, all raw materials are 100% dry solids, but the resins are typically in pellet form, to avoid the generation of dust. Other raw materials such as fillers, pigments and additives are applied in powder form and may lead to dust emissions (US EPA, 1994b in INERIS, 2000). They make up about 30 to 40% of the total raw materials. The amount of dust emissions from raw materials applied in **powder form** is assumed to be $F_{manuf_dust} = 1.5\%$. Again, $\mu_1 = 95\%$ of this fraction will be collected by local exhaust systems ($1.5\% \times 0.95 = 1.425\%$) with 99% (η_1) removed to filters and then to waste, and 1% of this fraction ($F_{manuf_dust, air} = 1.425\% \times 0.01 = 0.014\%$) lost to the atmosphere. The 5% not collected by local exhaust systems is assumed to deposit on floors. As before, 90% of this (μ_3) is removed by industrial vacuum cleaner ($F_{manuf_dust, vac_waste} = 0.075\% \times 0.9 = 0.067\%$) and the remainder ($F_{manuf_dust, water} = 0.075 \times 0.1 = 0.0075\%$) is washed to waste water.

The factors above apply to raw materials in powder form only. During the following steps, the emitted dust contains **all** of the substances that are used in the manufacture of the powder coating and hence the factors apply to all components. To distinguish the factors here, the format $F_{manuf_coat_dust}$ is used.

- **Melting** of the pre-mixed materials in the extruder. The heating of the mixed substances may favour the volatilisation of certain substances; these are mainly remaining water or solvents that have been used in the production of the raw materials. None of the principal ingredients is expected to evaporate, due to the relatively low temperatures and the short residence time in the extruder (Karle, 2000 in INERIS, 2000). No dust emissions are assumed to occur during this processing step, as the extruder is a closed system.
- **Flaking** of the rolled powder cake.
- **Crushing** of the powder cake into flakes.
- **Transfer** of the crushed powder flakes into the air classifier. In general, the flakes are stored in a container before being transferred to the mill. The filling of this container, its storage and the loading of the air classifier may result in dust emissions. For longer storage periods, the containers are usually covered, to avoid contamination of the product (Karle, 2000 in INERIS, 2000).
- To obtain powder coatings with metallic effects, **metal powder is added** at this stage of manufacture and blended with the powder coating to obtain a homogeneous mix (this step can be compared with dry-blend production of powder coatings (see Section 6.4, Part II)).
- **Filling** of the product into packages. During free fall of the product from the sieving device into the packages dust emissions may occur, especially during the filling of small-sized packages (Karle, 2000 in INERIS, 2000).

The emissions of coating materials to air inside the workshop from these sources, are assumed to be about **1.5%** ($F_{manuf_coat_dust}$) by weight of the raw materials (US EPA, 1994b in INERIS, 2000).

Of these emissions, **95%** ($1.5\% \times 0.95 = \mathbf{1.425\%}$) is assumed to be collected by local exhaust systems of which **1%** ($F_{manuf_coat_dust, air} = 1.425\% \times 0.01 = \mathbf{0.014\%}$) is released to the atmosphere; the rest is estimated to deposit on the surfaces inside the workshop, of which **90%** is subsequently removed by industrial vacuum cleaners ($F_{manuf_coat_dust, vac_waste} = 1.5\% \times 0.05 \times 0.90 = \mathbf{0.067\%}$).

With regard to the discharge of the air used for the air classifier, the cyclone only removes a certain fraction of powder particles from the air stream. All particles smaller than a certain diameter are not separated.

It can be assumed that the production of fine particles is about **5%** by weight of the raw materials ($F_{cyclone_fine}$). This fraction generally passes a bag filter which separates about $\eta_2 = \mathbf{99\%}$ of the fines (US EPA, 1994b in INERIS, 2000). In consequence, **4.95%** by weight is assumed to be held back by the filter. This fraction ($F_{cyclone_fine, recyc}$) is generally recycled. The remaining **0.05%** by weight ($F_{cyclone_fine, air}$) is emitted to the air outside the workshop. Dust collected in filters of vacuum cleaner bags are either landfilled or incinerated.

6.3.3.2 Emissions to wastewater

Emissions to wastewater will result from the cleaning of equipment and of the workshop floor. As shown above, **0.5%** ($F_{equip_residue, water}$) of all raw materials will end up in the wastewater stream from the cleaning of mixing equipment. Additionally, for the powdery raw materials lost during mixing and processing, the use of local exhaust ventilation and industrial vacuum cleaners mean that only $1.5\% \times 0.05 \times 0.10 = \mathbf{0.008\%}$ ($F_{manuf_dust, water} = F_{manuf_dust} \times (1-\mu_1) \times (1-\mu_3)$) of raw materials in powder form will end up in wastewater (as they are not collected by vacuum cleaners). In a similar way, only $1.5\% \times 0.05 \times 0.10 = \mathbf{0.008\%}$ ($F_{manuf_coat_dust, water} = F_{manuf_coat_dust} \times (1-\mu_1) \times (1-\mu_3)$) of raw materials not in powder form will end up in the wastewater stream.

6.3.3.3 Emissions to soil

Direct contamination of the industrial soil is possible due to the deposition of solid particles emitted to the air outside the workshop. But this is not considered further in this scenario.

6.3.4 *Calculations and release table for standard batch manufacture of melt-blend powder coatings*

Table 6.1 provides an overview of the calculation of emissions of raw materials during the manufacture of melt-blend coatings in standard size batches (1,000 kg).

Table 6.1: Calculation of emissions of raw materials during the manufacture of melt-blend powder coatings (standard batch size - 1,000 kg)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	1%	
of which (all raw materials): ($F_{equip\ residue, recyc}$)	0.25%	Recycled
and (all raw materials): ($F_{equip\ residue, water}$)	0.5%	Water
and (all raw materials) ($F_{equip_residue, waste}$)	0.25%	Waste
Packaging waste (all raw materials) ($F_{package_residue, waste}$)	0.5%	Waste
Cleaning of the extruder		
Raw materials losses ($F_{extruder, waste}$)	1%	Waste
Dust emissions during raw material transfer into pre-mixing vessel (only in powder form)		
Emissions of raw materials in powder form during mixing ($F_{manuf\ dust}$)	1.5%	(initially to air)
Percentage of raw materials in powder form captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_1$)	1.5% x 0.95 = 1.425%	
Percentage of raw materials in powder form retained by air bag filters and subsequently disposed of ($F_{manuf\ dust, filter\ waste} = F_{manuf\ dust} \cdot \mu_1 \cdot \eta_1$)	1.425% x 0.99 = 1.41%	Waste
Percentage of raw materials in powder form emitted to the atmosphere ($F_{manuf\ dust, air} = F_{manuf\ dust} \cdot \mu_1 \cdot (1-\eta_1)$)	1.425% x 0.01 = 0.014%	Air
Percentage of raw materials in powder form falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.5% x 0.05 = 0.075%	
Percentage of raw materials in powder form collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf\ dust, vac\ waste} = F_{manuf\ dust, dep} \cdot \mu_3$)	0.075% x 0.90 = 0.067%	Waste
Percentage of raw materials in powder form washed off the workshop floor ($F_{manuf\ dust, water} = F_{manuf\ dust, dep} \cdot (1-\mu_3)$)	0.075% x 0.10 = 0.008%	Water
Dust emissions during flaking, crushing and transfer of the final product (all raw materials)		
Emissions of all raw materials during mixing ($F_{manuf\ coat\ dust}$)	1.5%	(initially to air)
Percentage of all raw materials captured by air extraction devices ($F_{manuf\ coat\ dust} \cdot \mu_1$)	1.5% x 0.95 = 1.425%	
Percentage of all raw materials retained by air bag filters and subsequently disposed of ($F_{manuf\ coat\ dust, filter\ waste} = F_{manuf\ coat\ dust} \cdot \mu_1 \cdot \eta_1$)	1.425% x 0.99 = 1.41%	Waste
Percentage of all raw materials emitted to the atmosphere ($F_{manuf\ coat\ dust, air} = F_{manuf\ coat\ dust} \cdot \mu_1 \cdot (1-\eta_1)$)	1.425% x 0.01 = 0.014%	Air

Stage (description)	Calculated emissions	Endpoint
Percentage of all raw materials falling on the workshop floor ($F_{manuf_coat_dust, dep} = F_{manuf_coat_dust} \cdot (1-\mu_1)$)	1.5% x 0.05 = 0.075%	
Percentage of all raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	0.075% x 0.90 = 0.067%	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf_coat_dust, water} = F_{manuf_coat_dust, dep} \cdot (1-\mu_3)$)	0.075% x 0.10 = 0.008%	Water
Dust emissions during air classification of coating particles (cyclone emissions)		
Emissions of fine particles (all raw materials) ($F_{cyclone_fine}$)	5%	
Percentage of fine particles (all raw materials) captured by air extraction devices (bag filters) ($F_{cyclone_fine, recyc} = F_{cyclone_fine} \cdot \mu_2$)	5% x 0.99 = 4.95%	Recycled
Percentage of fine particles (all raw materials) released to the atmosphere outside the workshop ($F_{cyclone_fine, air} = F_{cyclone_fine} \cdot (1-\mu_2)$)	5% x 0.01 = 0.05%	Air

On the basis of the calculations presented above, Tables 6.2 and 6.3 show the percentages of used raw materials that are emitted to the environment during the manufacture of melt-blend powder coatings in standard batches (1,000 kg) and outline the assumptions made for the removal efficiencies of abatement techniques.

Table 6.2: Total emission factors for standard batch manufacture of melt-blend powder coatings (batch size of 1,000 kg)

	Properties of the substance			
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble	
			Raw materials in powder form	Other raw materials
% range present	-	-	30-40 %	60-70%
Air ($F_{manuf, air}$)	-	-	0.08%	0.06%
Water ($F_{manuf, water}$)	-	-	0.52%	0.51%
Soil ($F_{manuf, soil}$)	-	-	-	-
Waste ($F_{manuf, waste}$)	-	-	4.70%	3.23%

Table 6.3: Assumed values for the efficiency of the different emission treatment techniques during melt-blend manufacture of powder coatings (standard batch size)

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
Cyclone bag filter η_2	0.99	(1)*
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

The above figures, particularly those for raw materials ending up in the waste stream, indicate a scenario where solid material collected in filter bags of the local exhaust systems is generally not recycled. As indicated in Section 6.3.2. above, the recycling of the collected mixture of raw materials is not always feasible or economically desirable.

On the other hand, a member of CEPE that manufactures powder coatings indicated that powder extracted from the air is “normally re-processed”. Under this condition, a maximum of **3.8%** total losses for a standard batch size production has been calculated by the company, with this including warehouse losses, pre-mixing, extrusion, grinding, classification and cleaning processes at all stations (CEPE, 2003a).

On the basis of the emission estimates in Table 6.1, we may calculate the total losses of all raw materials during the manufacture of melt-blend powder coatings in standard size batches taking into account the composition of the raw materials in Table 6.1 (powder raw materials: 30-40%; non-powder raw materials: 60-70%) and assuming that all material collected in air filter bags is recycled. Table 6.4 presents the calculations of total losses for two different ratios powder/non-powder raw materials: 40:60 and 30:70.

Table 6.4: Calculation of total losses of raw materials during the manufacture of melt-blend powder coatings (standard batch size - 1,000 kg).

Endpoint of emissions		Calculated losses of total raw materials
Raw materials in powder form: other raw materials = 40:60		
For raw materials in powder form	Air	$40\% \times 0.08\% = 0.03\%$
	Water	$40\% \times 0.52\% = 0.21\%$
	Waste	$40\% \times 4.70\% = 1.88\%$
	“Recyclable” fraction (material collected in air bag filters)	$40\% \times (1.41\% + 1.41\%) = 1.13\%$
	Total loss of raw materials after recycling of collected matter	$(0.03\% + 0.21\% + 1.88\%) - 1.13\% = 0.99\%$
Raw materials in other raw materials form: other raw materials = 60:40		
For other raw materials	Air	$60\% \times 0.06\% = 0.04\%$
	Water	$60\% \times 0.51\% = 0.31\%$
	Waste	$60\% \times 3.23\% = 1.94\%$
	“Recyclable” fraction (material collected in air bag filters)	$60\% \times 1.41\% = 0.85\%$
	Total loss of raw materials after recycling of collected matter	$(0.04\% + 0.31\% + 1.94\%) - 0.85\% = 1.44\%$

Endpoint of emissions		Calculated losses of total raw materials
Totals	Total losses from melt-blend powder coatings manufacture	$0.99\% + 1.44\% = 2.43\%$
	Total losses from melt-blend powder coatings manufacture (standard batch size) when no recycling of materials collected in air filter bags takes place	$(0.03\% + 0.21\% + 1.88\%) + (0.04\% + 0.31\% + 1.94\%) = 4.41\%$
Raw materials in powder form: other raw materials = 30:70		
For raw materials in powder form	Air	$30\% \times 0.08\% = 0.02\%$
	Water	$30\% \times 0.52\% = 0.16\%$
	Waste	$30\% \times 4.70\% = 1.41\%$
	“Recyclable” fraction (material collected in air bag filters)	$30\% \times (1.41\% + 1.41\%) = 0.85\%$
	Total loss of raw materials after recycling of collected matter	$(0.02\% + 0.16\% + 1.41\%) - 0.85\% = 0.74\%$
For other raw materials	Air	$70\% \times 0.06\% = 0.04\%$
	Water	$70\% \times 0.51\% = 0.36\%$
	Waste	$70\% \times 3.23\% = 2.26\%$
	“Recyclable” fraction (material collected in air bag filters)	$70\% \times 1.41\% = 0.99\%$
	Total loss of raw materials after recycling of collected matter	$(0.04\% + 0.36\% + 2.26\%) - 0.99\% = 1.67\%$
Totals	Total losses from melt-blend powder coatings manufacture (standard batch size)	$0.74\% + 1.67\% = 2.41\%$
	Total losses from melt-blend powder coatings manufacture (standard batch size) when no recycling of materials collected in air filter bags takes place	$(0.02\% + 0.16\% + 1.41\%) + (0.04\% + 0.36\% + 2.26\%) = 4.25\%$

According to Table 6.4, for both compositions of the total raw materials, the total loss of raw materials after recycling of the material collected in air filter bags is around 1.9%. This is below the figure of 3.8% maximum total loss given by the company in question. However, it should be noted that the company’s figure includes some losses that are not directly related to the manufacturing process, such as warehouse losses, which are not considered for the purposes of this document.

Recycling of collected raw material does not necessarily occur. Where this does happen, the total losses of raw materials after recycling are expected to be around 1.9 % of the total raw materials.

6.3.5 Recycling techniques

The most suitable material for recycling in powder coating manufacture is the fine particles. These are in fact separated, because they affect the application process. This fraction of very

small coating particles can be re-used in different ways. When there are no high demands on the quality of the coating, the producer may re-mix the fine particles into the fraction of normal sized coating particles. Another possibility is to collect and sort the fine particles according to their colour. They are then re-injected into the manufacturing process before extrusion.

Re-injection of the fines into the manufacturing process is a common technique and considered as default setting for this scenario. As shown in Section 6.3.2, Part II, **0.25%** of raw materials is assumed to be recycled and a further **4.95%** of the fine captured from the air classifier is also believed to be recycled.

6.3.6 Melt-blend manufacture of powder coatings in large batches

For the purpose of this chapter, the average batch size is assumed to be 3,000 kg (Akzo Nobel, 2000 in INERIS, 2000). The following modifications are made in comparison to the standard scenario.

During transferring and charging, the levels of dust emissions for raw materials **in powder form** (F_{manuf_dust}) are believed to be as low as **0.5%** by weight of these raw materials. Similarly, the emissions for **all** raw materials during the processing of the coating ($F_{manuf_coat_dust}$) is **0.5%**. The capture and scrubbing efficiency of air extraction systems as well as the collection efficiency of industrial vacuum cleaners are the same as for the manufacture of standard size batches.

We assume that residues in mixing equipment are **reduced by half**. Therefore, $F_{equip_residue, recyc} =$ **0.125%** of raw materials will be recovered (and re-used) from equipment cleaning, with **0.25%** ($F_{equip_residue, water}$) released into the wastewater. Another **0.125%** ($F_{equip_residue, waste}$) is disposed of in filter bags or non aqueous solutions as hazardous waste. The solid waste generated from extruder cleaning is estimated to be $F_{extruder, waste} =$ **1%** by weight of all raw materials. This waste is also landfilled or incinerated.

Modern grinding equipment increases the yield of good sized powder particles. The amount of fines ($F_{cyclone_fine}$) is estimated to amount to **2%**. The capture rate of the fine particles (μ_2) is still assumed to be **99%**.

6.3.7 Calculations and release table for large batch manufacture of melt-blend powder coatings

The calculation of the emissions of raw materials follows the same general pattern which is described in Table 6.1; the results are presented in Table 6.5.

Table 6.5: Calculation of emissions of raw materials during the manufacture of melt-blend powder coatings (large batch size - 3,000 kg or greater)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip_residue}$)	0.5%	

Stage (description)	Calculated emissions	Endpoint
of which (<i>all raw materials</i>): ($F_{equip_residue, recyc}$)	0.125%	Recycled
and (<i>all raw materials</i>): ($F_{equip_residue, water}$)	0.25%	Water
and (<i>all raw materials</i>) ($F_{equip_residue, waste}$)	0.125%	Waste
Packaging residue (all raw materials) ($F_{package_residue, waste}$)	0.5	Waste
Cleaning of the extruder		
Raw materials losses ($F_{extruder, waste}$)	1%	Waste
Dust emissions during raw material transfer into pre-mixing vessel (only in powder form)		
Emissions of raw materials in powder form during mixing (F_{manuf_dust})	0.5%	(initially to air)
Percentage of raw materials in powder form captured by air extraction devices ($F_{manuf_dust} \cdot \mu_1$)	0.5% x 0.95 = 0.475%	
Percentage of raw materials in powder form retained by air bag filters and subsequently disposed of ($F_{manuf_dust, filter\ waste} = F_{manuf_dust} \cdot \mu_1 \cdot \eta_1$)	0.475% x 0.99 = 0.47%	Waste
Percentage of raw materials in powder form emitted to the atmosphere ($F_{manuf_dust, air} = F_{manuf_dust} \cdot \mu_1 \cdot (1 - \eta_1)$)	0.475% x 0.01 = 0.005%	Air
Percentage of raw materials in powder form falling on the workshop floor ($F_{manuf_dust, dep} = F_{manuf_dust} \cdot (1 - \mu_1)$)	0.5% x 0.05 = 0.025%	
Percentage of raw materials in powder form collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	0.025% x 0.90 = 0.022%	Waste
Percentage of raw materials in powder form washed off the workshop floor ($F_{manuf_dust, water} = F_{manuf_dust, dep} \cdot (1 - \mu_3)$)	0.025% x 0.10 = 0.003%	Water
Dust emissions during flaking, crushing and transfer of the final product (all raw materials)		
Emissions of all raw materials during mixing ($F_{manuf_coat_dust}$)	0.5%	(initially to air)
Percentage of all raw materials captured by air extraction devices ($F_{manuf_coat_dust} \cdot \mu_1$)	0.5% x 0.95 = 0.475%	
Percentage of all raw materials retained by air bag filters and subsequently disposed of ($F_{manuf_coat_dust, filter\ waste} = F_{manuf_coat_dust} \cdot \mu_1 \cdot \eta_1$)	0.475% x 0.99 = 0.47%	Waste
Percentage of all raw materials emitted to the atmosphere ($F_{manuf_coat_dust, air} = F_{manuf_coat_dust} \cdot \mu_1 \cdot (1 - \eta_1)$)	0.475% x 0.01 = 0.005%	Air
Percentage of all raw materials falling on the workshop floor ($F_{manuf_coat_dust, dep} = F_{manuf_coat_dust} \cdot (1 - \mu_1)$)	0.5% x 0.05 = 0.025%	

Stage (description)	Calculated emissions	Endpoint
Percentage of all raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf_dust, vac\ waste} = F_{manuf_dust, dep} \cdot \mu_3$)	$0.025\% \times 0.90 = 0.022\%$	Waste
Percentage of solid raw materials washed off the workshop floor ($F_{manuf_coat_dust, water} = F_{manuf_coat_dust, dep} \cdot (1-\mu_3)$)	$0.025\% \times 0.10 = 0.003\%$	Water
Dust emissions during air classification of coating particles (cyclone emissions)		
Emissions of fine particles (all raw materials) ($F_{cyclone_fine}$)	2%	
Percentage of fine particles (all raw materials) captured by air extraction devices (bag filters) ($F_{cyclone_fine, recyc} = F_{cyclone_fine} \cdot \mu_2$)	$2\% \times 0.99 = 1.98\%$	Recycled
Percentage of fine particles (all raw materials) released to the atmosphere outside the workshop ($F_{cyclone_fine, air} = F_{cyclone_fine} \cdot (1-\mu_2)$)	$2\% \times 0.01 = 0.02\%$	Air

Tables 6.6 and 6.7 provide an overview of the percentages of used raw materials that are emitted to the environment during the manufacture of melt-blend powder coatings in large batches and the assumptions made for the removal efficiencies of abatement techniques.

Table 6.6: Total emission factors for large batch manufacture of melt-blend powder coatings (batch size of 3,000 kg or greater)

	Properties of the substance			
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble	
			Raw materials in powder form	Other raw materials
% range present	-	-	30-40 %	60-70%
Air ($F_{manuf, air}$)	-	-	0.03%	0.025%
Water ($F_{manuf, water}$)	-	-	0.26%	0.25%
Soil ($F_{manuf, soil}$)	-	-	-	-
Waste ($F_{manuf, waste}$)	-	-	2.61%	2.12%

Table 6.7: Assumed values for the efficiency of the different emission treatment techniques during large batch manufacture of melt-blend powder coatings

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
Cyclone bag filter η_2	0.99	(1)*
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

Similarly to Section 6.3.4, Part II, a powder coatings manufacturer has calculated a maximum total loss of **2.5%** of raw materials during large batch manufacture of powder coatings when the materials collected in air filter bags is re-processed rather than disposed of (although, as the company noted, some production managers in the European powder coatings industry base their calculations on a maximum of 2% loss of all raw materials). On the basis of the emission estimates in Table 6.5, we may calculate the total losses of all raw materials during the manufacture of melt-blend powder coatings in large size batches taking into account the composition of the raw materials in Table 6.1 (powder raw materials: 30-40%; non-powder raw materials: 60-70%) and assuming that all material collected in air filter bags is recycled. Table 6.8 presents the calculations of total losses for two different ratios powder/non-powder raw materials: 40:60 and 30:70.

Table 6.8: Calculation of total losses of raw materials during the manufacture of melt-blend powder coatings (large batch size - 3,000 or greater).

Endpoint of emissions		Calculated losses of raw materials
Raw materials in powder form: other raw materials = 40:60		
For raw materials in powder form	Air	$40\% \times 0.03\% = 0.01\%$
	Water	$40\% \times 0.26\% = 0.10\%$
	Waste	$40\% \times 2.61\% = 1.04\%$
	“Recyclable” fraction (material collected in air bag filters)	$40\% \times (0.47\% + 0.47\%) = 0.38\%$
	Total loss of raw materials after recycling of collected matter	$(0.01\% + 0.10\% + 1.04\%) - 0.38\% = 0.77\%$

Endpoint of emissions		Calculated losses of raw materials
For other raw materials	Air	$60\% \times 0.025\% = 0.02\%$
	Water	$60\% \times 0.25\% = 0.15\%$
	Waste	$60\% \times 2.12\% = 1.27\%$
	“Recyclable” fraction (material collected in air bag filters)	$60\% \times 0.47\% = 0.28\%$
	Total loss of raw materials after recycling of collected matter	$(0.02\% + 0.15\% + 1.27\%) - 0.28\% = 1.16\%$
Totals	Total losses from melt-blend powder coatings manufacture (large batch size)	$0.77\% + 1.16\% = 1.43\%$
	Total losses from melt-blend powder coatings manufacture (large batch size) when no recycling of materials collected in air filter bags takes place	$(0.01\% + 0.10\% + 1.04\%) + (0.02\% + 0.15\% + 1.27\%) = 2.59\%$
Raw materials in powder form: other raw materials = 30:70		
For raw materials in powder form	Air	$30\% \times 0.03\% = 0.01\%$
	Water	$30\% \times 0.26\% = 0.08\%$
	Waste	$30\% \times 2.61\% = 0.78\%$
	“Recyclable” fraction (material collected in air bag filters)	$30\% \times (0.47\% + 0.47\%) = 0.28\%$
	Total loss of raw materials after recycling of collected matter	$(0.01\% + 0.08\% + 0.78\%) - 0.28\% = 0.59\%$
For other raw materials	Air	$70\% \times 0.025\% = 0.02\%$
	Water	$70\% \times 0.25\% = 0.18\%$
	Waste	$70\% \times 2.12\% = 1.48\%$
	“Recyclable” fraction (material collected in air bag filters)	$70\% \times 0.47\% = 0.33\%$
	Total loss of raw materials after recycling of collected matter	$(0.02\% + 0.18\% + 1.48\%) - 0.33\% = 1.35\%$
Totals	Total losses from melt-blend powder coatings manufacture (large batch size)	$0.59\% + 1.35\% = 1.94\%$
	Total losses from melt-blend powder coatings manufacture (large batch size) when no recycling of materials collected in air filter bags takes place	$(0.01\% + 0.08\% + 0.78\%) + (0.02\% + 0.18\% + 1.48\%) = 2.55\%$

According to Table 6.8, for both compositions of the total raw materials, the total loss of raw materials after recycling of the material collected in air filter bags is just above **1.4%**. This is below the figure of 2.5% maximum total loss given by the company in question. However, it

should be noted that the company's figure includes some losses that are not directly related to the manufacturing process, such as warehouse losses, which are not considered for the purposes of this document.

Recycling of collected raw material does not necessarily occur. Where this does happen, the total losses of raw materials after recycling are expected to be around 1.4 % of the total raw materials.

Figure 6.1 provides a visual presentation of melt-blend processing of powder coatings. The emissions in Figure 6.1 are related to the factors estimated above as in Table 6.9.

Table 6.9: Factors related to emissions/flows in Figure 6.1

<i>Emission/flow</i>	<i>Factors</i>	<i>Notes</i>
E ₁	F_{manuf_dust} and $F_{manuf_coat_dust}$	Combines E _{IRM} and E _{IC} ; includes both powder raw material and coating contributions
E ₂	$F_{cyclone_fine}$	Relates to coating
E ₃	$F_{manuf_dust,air}$ and $F_{manuf_coat_dust,air}$	Includes both powder raw material and coating contributions
E ₄	$F_{equip_residue,water}$	Relates to all raw materials
E ₅	$F_{manuf_dust,water}$ and $F_{manuf_coat_dust,water}$	Includes both powder raw material and coating contributions
E ₆	$F_{cyclone_fine,air}$	Relates to coating
W ₀	$F_{package_residue,waste}$	Relates to all raw materials
W _E	$F_{extruder,waste}$	Relates to all raw materials
W _F	$F_{manuf_dust,filter_waste}$ and $F_{manuf_coat_dust,filter_waste}$	Includes both powder raw material and coating contributions
W _V	F_{manuf_dust,vac_waste} and $F_{manuf_coat_dust,vac_waste}$	Includes both powder raw material and coating contributions
W _R	$F_{equip_residue,recyc}$	Relates to all raw materials
W _{RF}	$F_{cyclone_fine,recyc}$	Relates to coating

6.4 Dry-blend manufacture of powder coatings

6.4.1 Description of the process

This process is much simpler than melt-blend processing. It encompasses the following operations (US EPA, 1994c in INERIS, 2000):

- Weighing of the raw materials.
- Dry-blending of the raw materials (mixing into a homogeneous dry mix).
- Sieving of the powder product.

All raw materials with the exception of liquid stabilisers are dry powders. After weighing, they are transported into a mechanical mixer for blending. In about 80% of the cases, small amounts

of stabilisers or plasticisers are added and they are rapidly absorbed by the powder materials. After intensive mixing for 2-20 minutes, the product is passed through a coarse screen and fed into containers. The batch sizes vary between 100 and 500 kg. Typical size of the powder particles is about 40 to 200 μm . The average density of the powder product is 1.3 g/m^3 (US EPA, 1994c in INERIS, 2000).

6.4.2 *Production losses*

The manufacturing installation is reduced to a weighing installation, a mixer and a filling device. Compared to melt-blending, no materials are lost in the extruder or the air classification installation. Therefore production losses are considered to be smaller than in melt-blend manufacture of powder coatings (US EPA, 1994c in INERIS, 2000).

6.4.3 *Waste generation*

The main source of waste is the cleaning of the equipment. Residues in bags, spills and product returns are considered to amount to 0.5% of all raw materials, as for other types of coating ($F_{\text{package_residue, waste}}$)¹⁰. Waste generated during cleaning of the equipment of any residue ($F_{\text{equip_residue}}$) is estimated to be **0.5%** by weight of the raw materials. A fraction of **0.25%** ($F_{\text{equip_residue, recyc}}$) is assumed to be recycled, with the remaining ($F_{\text{equip_residue, water}}$) being disposed of in the wastewater stream (due to wet cleaning of the mixing equipment).

¹⁰ More detailed consideration of residues in bags, drums etc can be found in the ESD on transport and storage of chemicals (EA, 2007). Note that these residues are assumed not to be released to the environment at the coatings site.

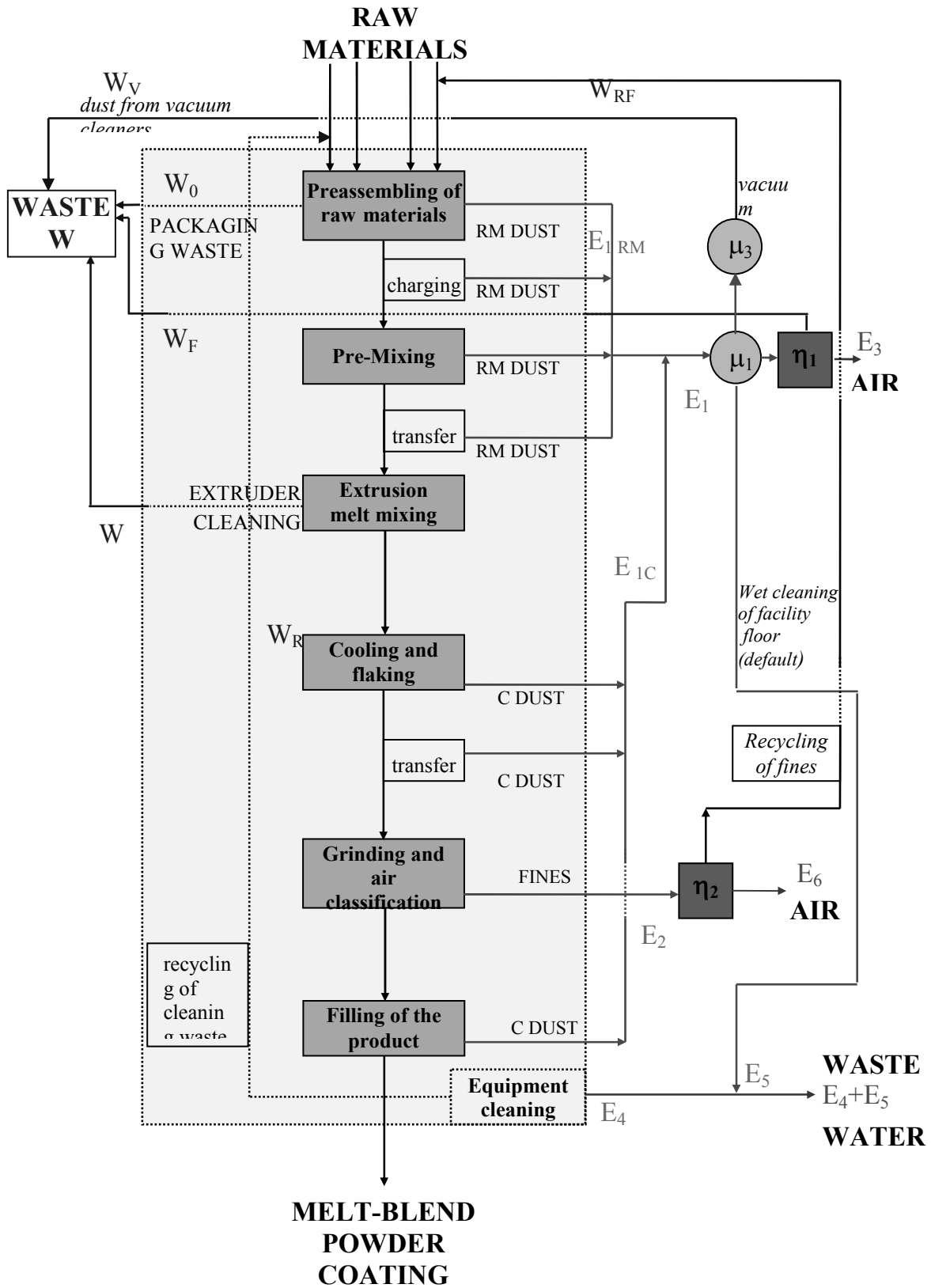


Figure 6.1: Flow diagram for melt-blend manufacture of powder coatings

As indicated in Section 6.4.4.1, Part II, a part of the dust emitted to air is also collected in air extraction bag filters and in vacuum cleaners and is subsequently disposed of as waste.

6.4.4 Releases to the environment

6.4.4.1 Emissions to air

Releases to the air may be generated during the following operations:

- Transfer of raw materials into the weighing container.
- Transfer of the weighed raw materials into the mixer.

Handling of the raw materials in powder form (e.g. loading operations) provokes dust emissions. Their level depends on the kind of installation used and the way the operations are carried out by workers.

- **Blending of the raw materials:** in general, the mixing vessel is a closed device, but there may be dust emissions when a lid is open or through the chute for material loading (US EPA, 1994c in INERIS, 2000).
- **Filling and packaging:** free fall of the powder coating into the container may provoke dust emissions.

Overall emissions to air in the workshop during these operations are estimated to be **1.5%** by weight of the raw materials (F_{manuf_dust}). Of this, **95%** (μ_1) are assumed to be extracted by ventilation ($1.5\% \times 0.95 = \mathbf{1.425\%}$) of which **1%** ($1-\eta_1$) is eventually released to the atmosphere outside the workshop (so $F_{manuf_dust, air} = 1.425\% \times 0.01 = \mathbf{0.01425\%}$). The amount of raw materials that is collected in the bag filters ($F_{manuf_dust, filter_waste} = 1.425\% \times 0.99 = \mathbf{1.41\%}$) is disposed of as waste (by landfill or incineration).

Of the dust that is not captured by air extraction systems ($F_{manuf_dust, dep}$), **90%** (μ_3) is removed by means of an industrial vacuum cleaner (hence $F_{manuf_dust, vac_waste} = 1.5\% \times 0.05 \times 0.90 = \mathbf{0.067\%}$) and is subsequently disposed of as waste. The remaining **10%** is washed into the wastewater stream during wet cleaning operations (i.e. $F_{manuf_dust, water} = 1.5\% \times 0.05 \times 0.1 = 0.0075\%$).

6.4.4.2 Emissions to wastewater

There are two sources of emissions to wastewater:

- **0.25%** is lost to wastewater as residues in equipment ($F_{equip_residue, water}$, see Section 6.4.3. above).
- $1.5\% \times 0.05 \times 0.10 = \mathbf{0.0075\%}$ is not collected by vacuum cleaners from the workshop floor and is subsequently washed off during wet cleaning of the manufacturing area ($F_{manuf_dust, water}$, see Section 6.4.4.1. above).

6.4.4.3 Emissions to soil

Similarly to melt-blend processing, the route for direct contamination of industrial soil is theoretically possible, due to the deposition of emitted solid particles (see Section 6.3.3.3. above).

6.4.5 Calculations and release table for the manufacture of dry-blend powder coatings

Table 6.10 provides an overview of the calculation of emissions of raw materials during the manufacture of dry-blend coatings in standard size batches (up to 500 kg).

Table 6.10: Calculation of emissions of raw materials during the manufacture of dry-blend powder coatings (standard batch size - up to 500 kg)

Stage (description)	Calculated emissions	Endpoint
Waste generation		
Equipment residues ($F_{equip\ residue}$)	0.5%	
of which (all raw materials): ($F_{equip\ residue, recvc}$)	0.25%	Recycled
and (all raw materials): ($F_{equip\ residue, water}$)	0.25%	Water
Packaging residues (all raw materials) ($F_{package\ residue, waste}$)	0.5%	Waste
Dust emissions during blending and filling		
Emissions of raw materials in powder form during mixing ($F_{manuf\ dust}$)	1.5%	(initially to air)
Percentage of raw materials captured by air extraction devices ($F_{manuf\ dust} \cdot \mu_1$)	1.5% x 0.95 = 1.425%	
Percentage of raw materials retained by air bag filters and subsequently disposed of ($F_{manuf\ dust, filter\ waste} = F_{manuf\ dust} \cdot \mu_1 \cdot \eta_1$)	1.425% x 0.99 = 1.41%	Waste
Percentage of raw materials emitted to the atmosphere ($F_{manuf\ dust, air} = F_{manuf\ dust} \cdot \mu_1 \cdot (1-\eta_1)$)	1.425% x 0.01 = 0.014%	Air
Percentage of raw materials falling on the workshop floor ($F_{manuf\ dust, dep} = F_{manuf\ dust} \cdot (1-\mu_1)$)	1.5% x 0.05 = 0.075%	
Percentage of raw materials collected by industrial vacuum cleaners and subsequently disposed of ($F_{manuf\ dust, vac\ waste} = F_{manuf\ dust, dep} \cdot \mu_3$)	0.075% x 0.90 = 0.067%	Waste
Percentage of raw materials washed off the workshop floor ($F_{manuf\ dust, water} = F_{manuf\ dust, dep} \cdot (1-\mu_3)$)	0.075% x 0.10 = 0.0075%	Water

On the basis of the calculations presented above, Tables 6.11 and 6.12 show the percentages of used raw materials that are emitted to the environment during the manufacture of dry-blend powder coatings in standard batches (up to 500 kg) and outline the assumptions made for the removal efficiencies of abatement techniques.

Table 6.11: Total emission factors for dry-blend manufacture of powder coatings

	Properties of the substance		
	Volatile organic compounds	Non volatile water soluble	Non volatile non water soluble
% range present	-	-	100
Air ($F_{manuf, air}$)	-	-	0.014%
Water ($F_{manuf, water}$)	-	-	0.26%
Soil ($F_{manuf, soil}$)	-	-	-
Waste ($F_{manuf, waste}$)	-	-	1.98%

Table 6.12: Assumed values for the efficiency of the different emission treatment techniques during dry-blend manufacture of powder coatings

Treatment	Efficiency of the capture device μ	Scrubbing efficiency η
Dust filter η_1	0.95	0.99
Vacuum cleaners η_3	0.90	(1)*

* - 100% efficiency assumed

6.4.6 Recycling techniques

No fine particles are generated during dry-blend processing. There are no other waste streams of the used substances that lend themselves to recycling.

Figure 6.2 provides a visual presentation of dry-blend processing of powder coatings.

6.5 Example

A processing aid is used at 4% in melt-blend thermoset coatings. Production is 750 tonnes per year. Substance is in powder form.

The calculation method is the same as in the examples in Sections 4 and 5. For air emissions:

$$E_{manuf, air} = Q_{coating_manuf} \times Q_{subst_in_coating} \times F_{manuf, air} / 100$$

Explanation of symbols:

$E_{manuf, air}$	release of substance to air from coating manufacture	kg/d	
$Q_{coating_manuf}$	quantity of coating product produced per day	kg/d	specific information or TGD table B2.3
$Q_{subst_in_coating}$	quantity of substance per kg of coating	kg/kg	specific information (here 0.04 kg/kg)
$F_{manuf, air}$	fraction (%) of substance released to air	%	Table 6.2 or 6.6 depending on batch size

There is no information on the amounts used on sites. The amount of coating produced using 750 tonnes of the substance is 18,750 tonnes. From the TGD Table B2.3, the fraction of main source is

0.7, with 300 days production. The amount of coating produced on site is therefore 13,125 tonnes per year, or 44 tones per day ($Q_{coating_manif} = 4.4 \times 10^4$ kg/day). This suggests the larger size of batches (3,000 kg per day or greater), so the factors from Table 6.6 are appropriate. For air, $F_{manuf.air} = 0.03\%$ for a substance in powder form. The emission to air is therefore

$$E_{manuf,air} = 4.4 \times 10^4 \times 0.04 \times 0.03/100 = 0.53 \text{ kg/day.}$$

The emissions to other compartments can be calculated in the same way. The results are 4.6 kg/day to water and 46 kg/day to waste. As in previous examples, the total EU emissions can be calculated using the total coating production value (18,750 tonnes) in place of the daily production quantity, or by replacing ($Q_{coating_manif} \times Q_{subst_in_coating}$) with the tonnage of the substance (750 tonnes). The results here are 25 kg/year to air, 1,950 kg/year to water and 19,575 kg/year to waste.

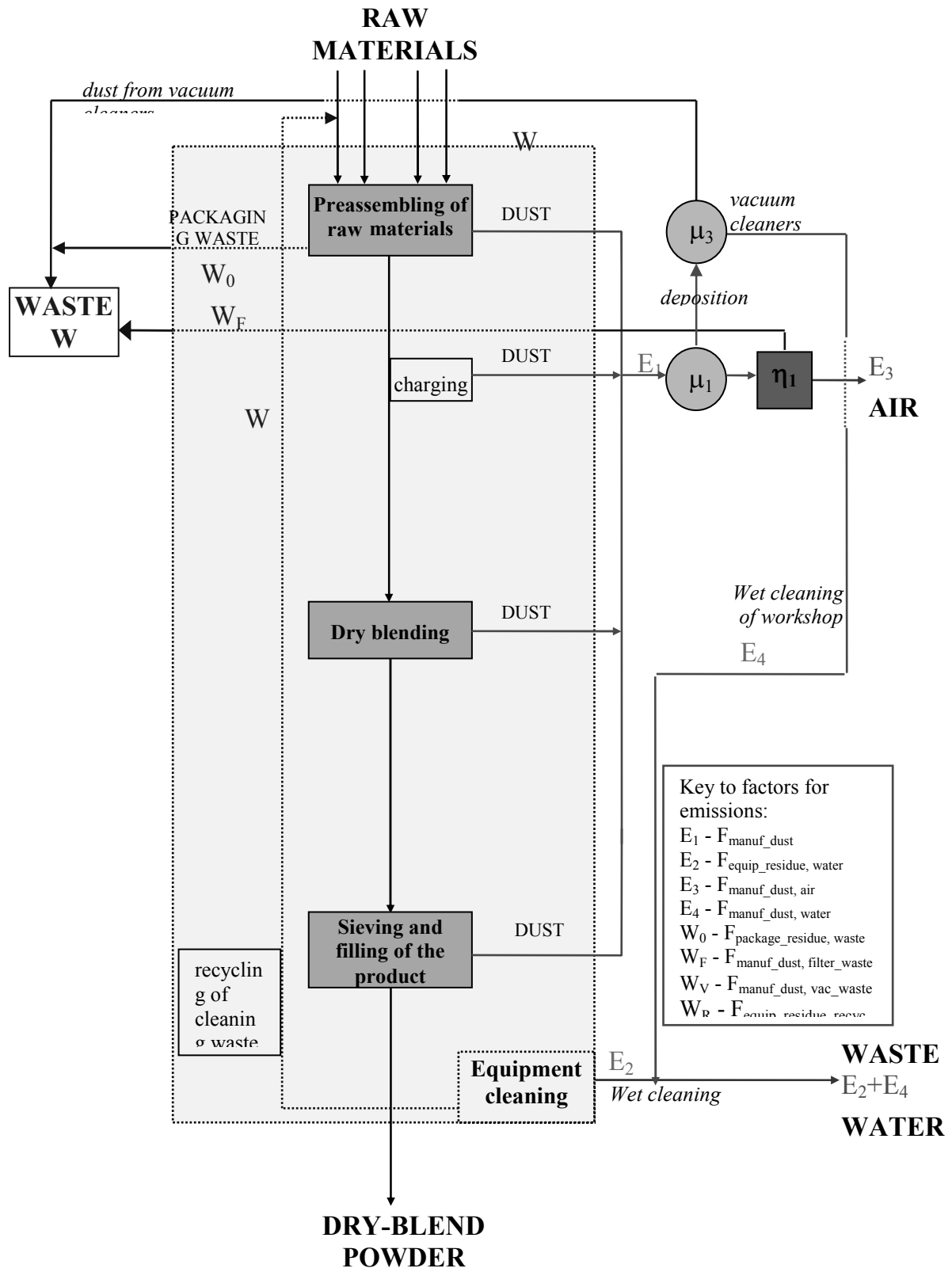


Figure 6.2: Flow diagram for dry-blend manufacture of powder coatings

7. EMISSION ESTIMATES ASSUMPTIONS

Table 7.1 provides a summary of the assumptions on which the above emission estimates for coatings manufacture are based.

Table 7.1: Assumptions for the development of emissions estimates for coatings manufacture

Parameter	Value
Organic solvent-borne coatings	
Size of standard batch	1,000 litres
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	1% of which 0.5% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.5% ($F_{equip_residue, waste}$) is sent for disposal (landfilling or incineration)
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.13-3.6%
Emissions of solid raw materials during loading and mixing (F_{manuf_dust})	1.0%
Capture efficiency of exhaust ventilation (μ_1)	95%
Scrubbing efficiency of air extraction bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
<i>Large batch manufacture</i>	
Size of large batch	10,000 litres (or more)
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	0.5% of which 0.25% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.25% ($F_{equip_residue, waste}$) is sent for disposal (landfilling or incineration)
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.07-1.8%
Emissions of solid raw materials during loading and mixing (F_{manuf_dust})	1.0%
Capture efficiency of exhaust ventilation (μ_1)	97%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
Water-borne coatings	
<i>Aqueous dispersions</i>	
Size of standard batch	1,000 litres
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	1% of which 0.5% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.5% ($F_{equip_residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)

Parameter	Value
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.06-2.25%
Emissions of solid raw materials during loading and mixing (F_{manuf_dust})	1.0%
Capture efficiency of exhaust ventilation (μ_1)	95%
Scrubbing efficiency of air extraction bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
<i>Large batch manufacture</i>	
Size of large batch	10,000 litres (or more)
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	0.5% of which 0.25% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.25% ($F_{equip_residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.03-1.13%
Emissions of solid raw materials during loading and mixing (F_{manuf_dust})	1.0%
Capture efficiency of exhaust ventilation (μ_1)	97%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
<i>Water-reducible coatings and colloidal dispersions</i>	
Size of standard batch	1,000 litres
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	1% of which 0.5% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.5% ($F_{equip_residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.06-2.25%
Emissions of solid raw materials during loading and mixing (F_{manuf_dust})	1.0%
Capture efficiency of exhaust ventilation (μ_1)	95%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
<i>Large batch manufacture</i>	
Size of large batch	10,000 litres (or more)
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	0.5% of which 0.25% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.25% ($F_{equip_residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Emissions of VOCs to air ($F_{manuf_VOC, air}$)	0.03-1.13%

Parameter	Value
Emissions of solid raw materials during loading and mixing ($F_{manuf\ dust}$)	1.0%
Capture efficiency of exhaust ventilation (μ_1)	97%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
Powder coatings	
Melt-blend powder coatings	
Size of standard batch	1,000 kg
Raw materials lost as residues to equipment (washings) ($F_{equip\ residue}$)	1% of which 0.25% ($F_{equip\ residue, recyc}$) is recycled at a later stage of the manufacturing process, 0.25% ($F_{equip\ residue, waste}$) is sent for disposal (landfilling or incineration) and 0.5% ($F_{equip\ residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package\ residue}$)	0.5% (sent for disposal)
Raw materials lost at the extruder (all raw materials) ($F_{extruder, waste}$)	1% (sent for disposal)
Emissions of raw materials in powder form during transfer and pre-mixing ($F_{manuf\ dust}$)	1.5%
Emissions of all raw materials during flaking, crushing and packaging ($F_{manuf\ coat\ dust}$)	1.5%
Dust emissions from air classifier (all raw materials) ($F_{cyclone\ fine}$)	5%
Capture efficiency of exhaust ventilation (μ_1)	95%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of cyclone bag filter (air classification) (μ_2)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
Large batch manufacture	
Size of large batch	3,000 kg (or greater)
Raw materials lost as residues to equipment ($F_{equip\ residue}$)	0.5% of which 0.125% ($F_{equip\ residue, recyc}$) is recycled at a later stage of the manufacturing process, 0.125% ($F_{equip\ residue, waste}$) is sent for disposal (landfilling or incineration) and 0.25% ($F_{equip\ residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package\ residue}$)	0.5% (sent for disposal)
Raw materials lost at the extruder (all raw materials) ($F_{extruder, waste}$)	1% (sent for disposal)
Emissions of raw materials in powder form during transfer and pre-mixing ($F_{manuf\ dust}$)	0.5%
Emissions of all raw materials during flaking, crushing and packaging ($F_{manuf\ coat\ dust}$)	0.5%
Dust emissions from air classifier (all raw materials) ($F_{cyclone\ fine}$)	2%
Capture efficiency of exhaust ventilation (μ_1)	95%

Parameter	Value
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of cyclone bag filter (air classification) (μ_2)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%
<i>Dry-blend powder coatings</i>	
Size of standard batch	Up to 500 kg
Raw materials lost as residues to equipment (washings) ($F_{equip_residue}$)	0.5% of which 0.25% ($F_{equip_residue, recyc}$) is recycled at a later stage of the manufacturing process and 0.25% ($F_{equip_residue, water}$) is lost to wastewater
Raw materials lost as residues in packaging ($F_{package_residue}$)	0.5% (sent for disposal)
Dust emissions from operations (blending, filling and packaging) (F_{manuf_dust})	1.5%
Capture efficiency of exhaust ventilation (μ_1)	95%
Scrubbing efficiency of bag filters (η_1)	99%
Capture efficiency of industrial vacuum cleaners (μ_3)	90%

8. DATA GAPS/LIMITATIONS/IMPROVEMENTS

There are a number of areas where data which would be useful in the ESD are not available. There are also areas where the estimation methods could be improved. These are noted in the main text, this section summarises the main points.

The majority of the emission factors are based on expert judgement, and only a few are derived statistically. The collection and inclusion of such statistically-based information would make this a more versatile tool for estimating emissions in a variety of different situations.

The factors included in the document are either applied to all chemicals, or to broad ranges of chemicals (such as volatiles or non-volatiles). A possible area for development would be to investigate the extent to which the properties of the substance affect these emissions. In the case of emissions as dust, the choice is between powders (producing dust) and others (producing no dust). A more detailed treatment related to the size of dust particles may be possible. There is also no information on emissions of substances which do not produce dusts, such as liquid additives.

The ESD assumes two sizes for the production of coatings, a medium size and a large site. There is little or no information on the actual distribution of the sizes of sites producing coatings. The user of this document may have this information when using the document for a specific substance assessment, but it would be useful to include information on actual sizes for different activities.

At present the document contains only a few examples of compositions of coatings. Further examples could be added, although it will always be better to have specific information on the substance of interest and the specific coatings in which it is used.

PART III: APPLICATION AND DISPOSAL OF COATINGS

1 PRESENTATION OF EMISSIONS ESTIMATES

Throughout this part of the Emission Scenario Document, emissions from each type of coating process are described using flowcharts. Figure 1.1 provides an example of such a flowchart (in this case for spray application of a coating). These charts indicate the percentage losses of solid (S) and volatile (V) coating components at each lifecycle stage and the routes by which emissions occur. There are four compartments to which solid and volatile components may be lost, with those being air, water, soil (industrial soil in the terminology of the EU TGD (CEC, 1996), referred to as “land” in the figures) and disposal. In terms of the latter, the ‘disposal’ route will vary and may include, for example, incineration, landfilling or solvent recovery (depending upon the industry sector, country, waste type and companies involved).

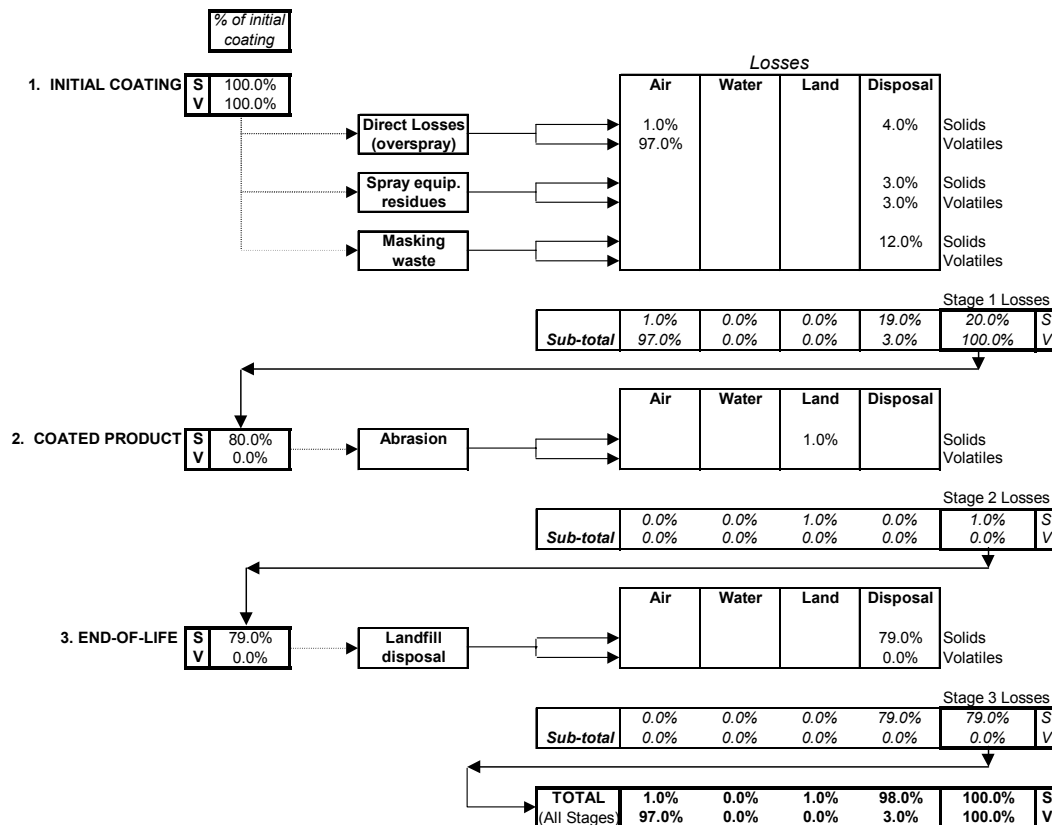


Figure 1.1: Example of flowcharts used for emissions estimates for coatings application

The chart begins with the initial coating which contains 100% of the *starting* amounts of solids and volatiles. During application of the coating (Stage 1), proportions of these initial amounts are lost to the various compartments. For example, ‘direct losses’ to disposal during spray application comprise 4% of the starting amount of solids (which, for example, may be collected on filters drawing air from the spraying area). Direct losses to air comprise 97% volatiles and 1% solids (lost by passing through the filters, for example). In this example, during the application stage, losses of both solids (3%) and volatiles (3%) also occur through washing out of residues in the spray equipment, as well as loss of solids (12%) onto masking waste.

Subtotals for losses to each compartment are provided and, at the end of this stage, 20% of solids and 100% of volatiles have been lost (indicated under ‘Stage 1 losses’). Thus, 80% of solids and 0% volatiles remain on the coated product, as indicated in the box at the start of Stage 2.

Stage 2 involves losses during the life of the coated product. In this case, 1% of the initial solids are lost from the product (to land) via abrasion, with this being the only loss during stage 2, as shown in the subtotal. Therefore, total loss during stage 2 is 1% for solids and 0% for volatiles. When these feed into Stage 3, 79% of solids remain at the end of the coated product’s life.

At the end-of-life stage (Stage 3), all of the remaining coating will be disposed of, either by removal from the coated product and subsequent disposal or through disposal along with the coated product. In this example, all of the remaining coating (79%) is disposed of to landfill.

Total losses throughout the whole of the lifecycle are also indicated in the flowcharts, calculated by adding together all of the subtotals.

It should be noted that the estimates of emissions are intended to represent a reasonable worst case. If there is specific information that particular controls are implemented, as may be the case in the initial coating stage, then this should be taken into account when using this ESD.

1.1 Calculation of emissions

The general equation to use in calculating emissions for the scenarios is

$$E_{step, comp} = Q_{step} \times Q_{subst_in_coating} \times F_{process, comp} / 100$$

Explanation of symbols:

$E_{step, comp}$	release of substance to compartment comp from life cycle step	kg/d or kg/year
Q_{step}	quantity of coating product relevant for life cycle step (local or larger scale)	kg/d or kg/year
$Q_{subst\ in\ coating}$	quantity of substance per kg of coating	kg/kg
$F_{process, comp}$	fraction (%) of substance released to comp from process	%

Each of the coating application methods has its own flow chart and the individual processes included there may differ between methods. This general approach is presented rather than develop separate equations for each case.

Emissions may be calculated on a daily or annual basis. For larger scale emissions (such as the regional and continental scales in the EU), the value for Q_{step} will relate to the total amount of the coating used in the relevant scale, and annual emissions will probably be the most useful. For the initial coating step, emissions may be required on a daily as well as an annual basis. Estimates may also be required for a local site. This document does not contain information on the appropriate sizes of site to use for such local estimates. It is suggested that in the absence of more specific information the relevant B tables from the EU TGD be used to estimate the value of Q_{step} if a local site is being considered. The examples contain some specific information on this.

Where the coating is used on a product that has a substantial lifetime in use, the values for losses during use of coated products take this into account, and hence they can be applied to the annual tonnages used to obtain annual emission estimates (this effectively assumes that the level of use remains at the current level over the lifetime) .

Emission factors are presented for solids and volatiles for some processes and life cycle steps, and an appropriate choice of factor will need to be made. The factors as presented in the flowcharts apply to the amount of coating initially applied (the amount corresponding to 100% in the initial coating step). Thus in the example chart above, the release of 1% to land through abrasion from the coated product is 1% of the initial amount, and not 1% of the 80% of solids which reaches this life cycle step.

Examples are included at the end of each section for the different areas of coating use. It has not been possible to cover all of the potential combinations of information which might be available in each of the examples, but most aspects are covered in at least one of the examples. Therefore it is recommended that all examples are reviewed before making new calculations.

2 GENERAL OVERVIEW OF COATINGS APPLICATION

2.1 *Coatings application, drying and curing methods*

There are various methods of applying a coating to a surface, the most common being the spraying of a liquid preparation. There are numerous other methods for transforming the initial coating material into a thin layer, adhering to a surface of a product, such as:

- ‘Traditional’ **manual application** with roller and/or brush.
- **Air spray systems**, including low volume/high pressure (LVHP), high volume/low pressure (HVLP), and low pressure/low volume coating applications (LPLV).
- **Airless and air-assisted airless spray** coating systems.
- **Electrostatic spray** systems.
- **Electrodeposition/electrocoating and autodeposition.**
- **Dip coating and flow and curtain coating** systems.

- **Roll coating** systems.
- **Supercritical carbon dioxide** coating systems (where the use of supercritical carbon dioxide assists the dilution of the binder and the reduction of viscosity; generally, it falls within the coatings spray systems).

After a coating film has been applied on the surface, it undergoes a curing or drying process for the coating procedure to be completed. The terms ‘drying’ and ‘curing’ are commonly used in the paint industry, sometimes without distinction, although they refer to different processes. In ‘curing’, the resin forms a solid film through chemical reaction, whereas ‘drying’ refers to the mere loss of the solvent whilst the resin remains the same (GLRPPR, not dated). To meet production schedules, these mechanisms (essentially evaporation and polymerisation) can be accelerated by applying energy in the form of heat, ultraviolet light, electron beam radiation or infrared radiation. For powder coatings especially, elevated temperatures are necessary in order for the coating to melt, fuse and/or cure (Izzo, 2000).

The main methods used include:

- Air drying.
- Baking or elevated temperature curing, relying on the use of conduction, convection or radiation (such as infrared radiation).
- Radiation curing using mainly ultraviolet (UV), electron beam (EB) electromagnetic radiation.

Curing ovens are frequently used, in which solvents evaporate, powder coatings fuse and cure, and paint films dry and cure under controlled conditions. Residence times vary from a few seconds for ultraviolet (UV), electron beam (EB) and high-intensity infrared (IR) to up to 45 minutes for thermal ovens, depending on the chemistry of the coating, oven temperature, and configuration of the coating and curing equipment (Izzo, 2000).

2.2 Trends and technology in coatings application

During the 1990s there was a general trend towards the abandonment of ‘conventional’ paint systems. There follows a brief discussion of conventional paints and of new technologies that have started to evolve as a result of technological advancement and/or legislative requirements.

Conventional paint systems consist of a surface coating material (usually a pigment with a binder resin) dissolved in an organic solvent. Typically they contain 60-80% solvent (720-920g of VOC per litre of coating), and thus 20-40% solids by weight. The solvent evaporates during and following application and the dry coating film forms in ambient air, sometimes aided by airflow to assist solvent evaporation. In stoved systems, curing occurs through heating of the applied coating, promoting the chemical elimination reaction that results in cross-linking of the paint resin.

Two-pack paints are essentially comprised of two separate components which, when mixed, react to form the final coating (such as polyisocyanate and alcohol in polyurethane coatings). **Three-pack systems** also exist, the third component usually being a pigment.

Two-pack paints have a solvent content of 0-50% depending on their composition and their thinning requirements. In general, they have lower VOC content than conventional paints, produce less waste during application and have lower curing requirements in terms of energy consumed.

High solid paints have a solids content of 50-80% and thus a relatively low solvent content and low VOC emission potential. When used for coating, they have the advantage of greater dry coating per unit volume and, hence, smaller quantities of paint are needed to perform a particular coating operation. In certain cases, their relatively high viscosity requires the use of a heated spray system. Nevertheless, they have wide areas of application on metal, plastic, and wooden surfaces.

Attempts to reduce VOC emissions through legislation at an EU and national level have promoted the development and use of low-VOC **water-borne coatings**. These systems contain 20-40% solids (about as much as conventional paints), however, the majority of solvent used is water. The use of water, rather than an organic solvent, helps to ensure compliance with legislation but also leads to prolonged drying times and to a potential increase in corrosion on equipment and pipelines in large paint-handling systems (these findings mainly apply to industrial and heavy-duty coating materials rather than decorative coatings). In the UK, water-borne coatings represent almost 70% of total sales of decorative paints (PRA, 2000b).

Powder coatings are totally solvent-free since they consist of a thermosetting or thermoplastic plastic or resin material. Their greatest advantage is a transfer efficiency as high as 99%, since the capture and reuse of oversprayed powder is a relatively easy task. They frequently do not require priming and take less time to process, although they provide thicker films than wet applied coatings. Tinting and colour mixing is not feasible with powder coatings and the finish quality can only be determined following the curing stage. Powder coatings are generally suitable for thin gauge metals and have limited applicability on plastics or wood. The main areas of use are in steel furniture, exterior and interior construction applications, domestic appliances, radiators, automotive parts and machinery.

Electrodeposited paints are used in medium to high volume coatings operations. When an electric current is passed through components being dipped in electrophoretic paints, the coating becomes bound to the surface of the component in a similar way to electroplating. They are used for coating objects of complex shape and there are no losses due to overspraying result from these operations (under the common definition of overspray that accompanies traditional coating technologies). Coating formulations can be used repeatedly and when the coating process is over the bath contents need to be disposed of under controlled processes.

Autodeposited paints are used in the coating of ferrous substrates using a mixture of rubber latex and carbon black in a dilute solution of hydrofluoric acid. Their main application is drum and can coatings. They need stoving temperatures lower than electrodeposited paints and they are suitable for applications where very hard coatings are required. Complex shapes or tubes made of composites of steel with rubber or plastic can be easily coated using this technique.

Another recent development is the replacement of some volatile components in paints with **supercritical carbon dioxide**. This technique can reduce VOC content to around 280 g/litre as compared to 480 g/litre of a typical high solids coating. When such paints are sprayed, the carbon dioxide expands, aiding atomisation (ETBPP, 1997).

Table 2.1 provides an overview of the main characteristics of the most common coating application method

Table 2.1: Overview of most common coating application techniques

Abbreviations: LVHP→ Low Volume/High Pressure; HVLP→ High Volume/Low Pressure; LVLP→ Low Volume/Low Pressure; VOC→ Volatile Organic Compounds

Parameter	LVHP	HVLP	LVLP	Airless	Air-assisted airless	Electrostatic	Electro-/Auto-deposition	Dip coating	Roll coating	Flow & curtain coating
<i>Speed</i>	High	Moderate	Moderate	Moderate/low	Moderate/low	High	High	High	Moderate	High
<i>Finish quality</i>	Good, smooth finish	Moderate	Unproven track record	Low	Low	Variable	Low/moderate	Poor	Good/Moderate	Poor
<i>Cost</i>	Low	Low	Low	Moderate/high	Moderate/high	Moderate/high	Moderate/high	Low	Low	Low
<i>Atomisation</i>	Very good	Good, ideal for low viscosity paints	Good	Moderate/good for thick coats	Moderate (better when heat is used)	Variable (moderate)	Not applicable	Not applicable	Not applicable	Not applicable
<i>Recess coating</i>	Good	Good	Good	Good	Good	Poor	Good	Good	Poor	Moderate/Poor
<i>Transfer efficiency</i>	30-60%	65-75%	60-80%	65-70%	60-65%	65-90%	90-99%	80-90%	85-95%	70-95%
<i>Waste production</i>	Significant amounts of waste (masking, cleaning equipment, unwanted materials)	Masking, drums, filters, overalls in large quantities	Similar to LVHP and HVLP	Disposal of used respirator filters and gun nozzles; coat sagging results in extra waste; handling of guns is hazardous	Increased waste production; handling of guns is hazardous	Waste paint in spraying lines in large quantities, fire hazards present	Rinsing required after coating; sanding and stripping are problematic	Limited waste generated	Limited waste, one drum usually is emptied into another; limited masking	Significant amounts of waste paint unless recycling is used
<i>VOC/toxic emissions</i>	High emissions due to poor transfer efficiency	Significant but lower than LVHP	Lower than LVHP and HVLP but still high	Lower than air systems; less bounce-back of paint	Low use of solvents; bounce-back and overspray are low	Lower than conventional but still significant	Very low VOC and toxic emissions, curing at low temperatures	Intense VOC and toxic emissions with older systems (Trifix); fumes create hazardous environment	Significant VOC emissions; booth use is necessary	Increased VOC emissions from coating conveyor systems

ENV/JM/MONO(2009)24

Parameter	LVHP	HVLP	LVLP	Airless	Air-assisted airless	Electrostatic	Electro-/Auto- deposition	Dip coating	Roll coating	Flow & curtain coating
<i>Cleaning/ Maintenance requirements</i>	Poor transfer efficiency demands extensive cleaning of sprayers and booths	Easier cleaning of booths and equipment	Low filter replacement costs, cleaner booths	Smooth, less turbulent flow reduces overspray, gun tips often clog; maintenance is costly	Lower maintenance than airless systems, savings in used materials and solvents	Overspray covers areas adjacent to the substrate and spraying guns (Faraday cage effect)	Limited cleaning and maintenance requirements	Overflow of tank can cause problems, air dryers only used (limited maintenance)	Extensive cleaning only when accident occurs, or a batch needs to be disposed of	Moderate cleaning; limited maintenance required

2.3 Abatement technologies in coating application

2.3.1 *Applicability of abatement options to different coating processes*

Of the sectors presented below, the following coating processes lend themselves to abatement:

- Furniture coating.
- Automotive original equipment manufacturer.
- Metal packaging coating.
- Coil coating.
- Small scale aerospace coating (e.g. not airliners).
- Rail vehicle coating.
- Coating waste management.

These sectors involve processes that do not readily lend themselves to abatement are:

Decorative coating (it is virtually impossible to capture the emissions from decorative coating applications).

Vehicle refinishing (abatement is not a cost effective option. A body shop with an annual turnover of £1 million would need to invest £300,000 for an incinerator).

Marine coating (due to the large size of the operations).

Large scale aerospace coating (again, due to the size of operations usually carried out in hangars).

2.3.2 *Abatement options available to the coatings application sectors*

There are several abatement options available and each is mainly intended to remove VOCs from the waste gas streams. The main types are essentially the same as those that could potentially be used for abatement of emissions during coatings manufacture as indicated in Section 3.2.1, Part II). In theory, combinations of the available methods (i.e. adsorption, condensation, incineration or biological treatment) could also be used.

3 WOODEN FURNITURE COATINGS

3.1 *General overview of the sector*

This section concerns the application of coatings to wooden furniture products. There is a wide range of products under this category, including household and office furniture, and other wooden

items (e.g. doors, coffins, pencils, joinery, etc.)¹¹. Furniture production accounts for 10% of the total supply of industrial coatings in the EU with some 7,000 jobs linked to the supply of coatings for this sector alone (UEA, 2000). As indicated in Table 2.2, Part I of this ESD, wood coatings represent 6% of the domestic sales volume (or 330,000 tonnes in 2001 including Norway and Switzerland) and 7% of the domestic sales value (or €1.1 billion) in the EU.

The information on emissions provided by industry and presented in this Section is based on information submissions from the UK furniture industry.

3.2 *Process description and coating products used*

3.2.1 *Coating types and trends*

Table 3.1 provides a breakdown of the types of wood coatings used in the UK in 1980 and then in 1998, providing an indication of the changes that have taken place within the industry with regard to coating types. There is a general trend away from the use of traditional solvent-borne coatings towards use of low solvent/high solids coatings and is expected that a similar trend has emerged in the EU as a whole. According to expert opinion and relevant internal research from the UK furniture industry, it is expected that the latter will account for 80% of the market by 2008. This figure is a projection based on 1980 and 1998 factual data and knowledge of the UK industry.

Table 3.1: Breakdown of UK furniture coatings use in 1980 and 1998

Coating Type	Consumption in 1980	Consumption in 1998
Nitrocellulose	70%	53%
Acid-catalysed	20%	25%
Polyester/UV polyester	5%	4%
Polyurethane	5%	6%
Water-borne	-	5%
Acrylic UV	-	7%

Table 3.2 provides an overview of the typical compositions of the main types of coatings in terms of the fractions of solids, volatiles and water. A more detailed description of each type is provided below.

It should be noted that the emissions below do not apply to wood preservatives for which a separate ESD on biocides should be consulted.

Nitrocellulose coatings are the ‘traditional’ type of coating used on wooden furniture. They consist of cellulose nitrate, plasticiser, modifying resin and various other

¹¹ Note that although some furniture will include metal components, the relevant coating activities are covered under other sectors. External furniture coatings (benches, shed, fences) are covered in the decorative coatings section.

additives in a mix of solvents. Typical solvents used include acetone and ethyl acetate, often in combination with slower evaporating solvents such as glycol ethers.

Table 3.2: Breakdown of coatings compositions (ETBPP, 1999)

Coating Type	Solids	Organic Solvent	Water
Nitrocellulose ¹	25%	75%	-
Acid catalysed	40 - 55%	45 - 60%	-
PU 2-pack	30 - 40%	60 - 70%	-
Water-borne	30%	10%	60%
UV cured acrylic	90 - 100%	0 - 10%	-
Water-borne UV cured acrylic	30 - 35%	5%	60 - 65%

Note: ¹Nitrocellulose stains are also used (containing only around 5% solids).

Acid catalysed two-pack coatings consist of a blend of amino resin, alkyd resin and modifying agents in a mixture of solvents, to which an acid catalyst is added before use. ‘Compliant’ acid catalysed coatings have become more common in the UK due to the requirements of the LAPC regime. These have a solids content at the higher end of the range in Table 3.2.

Polyurethane two-pack coatings are solvent-borne coatings (again a mixture of solvents is used) based on polyester resins which are mixed prior to use with polyisocyanate to form a urethane. Other additives are also included within the polyester component.

Water-borne coatings are one-pack acrylic based coatings which incorporate a small amount of solvent (coalescent agent) as with many other water-borne coatings. They have become more common recently due to requirements on reductions in solvent use¹².

UV cured acrylic coatings are based on resin modified acrylates carried in an acrylic monomer (which is liquid) and employing a UV photo-initiator to promote reaction to UV light. The products may contain pigments and may also contain up to 10% solvents for use in automatic spraying. They are most suitable for application to flat panels by roller application (where a specialist curing plant is required).

Water-borne UV cured acrylic coatings are of the same nature as the previous coating type but contain water, as well as a small amount of organic solvent. They are mainly used as clear lacquers but may also contain pigments. They may be applied by automated spraying and overspray may be recovered.

¹² These types of coatings represent a reduction in solvent use per weight of solids applied of around 75 to 90%.

3.2.2 Coating processes

There are two main methods for the application of coatings to wooden furniture. These are spray application and flatline finishing. The great majority of furniture coating in the UK takes place using hand sprayers although there is an increasing use of automated coating lines. In terms of flatline finishing, the two main application techniques are roll coating and curtain coating.

The main stages in application of coatings to wooden furniture are as follows (ETBPP, 1999):

- Staining, which adds some initial colour and evens out existing colour.
- Spray application of fillers to smooth the surface and reduce penetration of later layers.
- Sealing with a basecoat (e.g. with nitrocellulose lacquer) to seal the wood and enhance adhesion. This will generally be followed by sanding.
- Applying a colour coat if required and then a topcoat (lacquer).

Spray coating generally takes place within a spray booth (although this is unlikely to be the case with all smaller companies). Both wet and dry spray booths may be used, with the latter employing filters to remove particulates from the extraction system.

In terms of roll and curtain coating, the coating materials are fed to the coating equipment using feed lines. In roll coating, a 'pickup' roller is used to pick up coating from a tray (in which the roller is partially submerged); this is then transferred to an 'applicator' roller. Excess coating is diverted back to the feed tray, for recycling.

3.3 Emissions estimates

Table 3.3 details the typical transfer efficiencies (TEs) of spray techniques used in wooden furniture coating.

Table 3.3: Use levels and transfer efficiencies for furniture coating (ETBPP, 1999 and ETBPP, 1998)

Application Technique	Usage ¹	Transfer Efficiency
Conventional spraying	27%	30 - 50%
Airless	2% ²	55 - 60%
Air-assisted airless	56%	40 - 70%
High volume low pressure (HVLP)	15%	55 - 80%

Notes: ¹Based on a survey of companies in ETBPP (1998).

²ETBPP (1998) lists 2% of usage as relating to 'other' application techniques.

Based on the data in Table 3.3, an average transfer efficiency for spray application is taken as being about 50%. Using this assumption, Figure 3.1 details the estimated losses during spray painting of furniture in a dry spray booth, during use and through disposal.

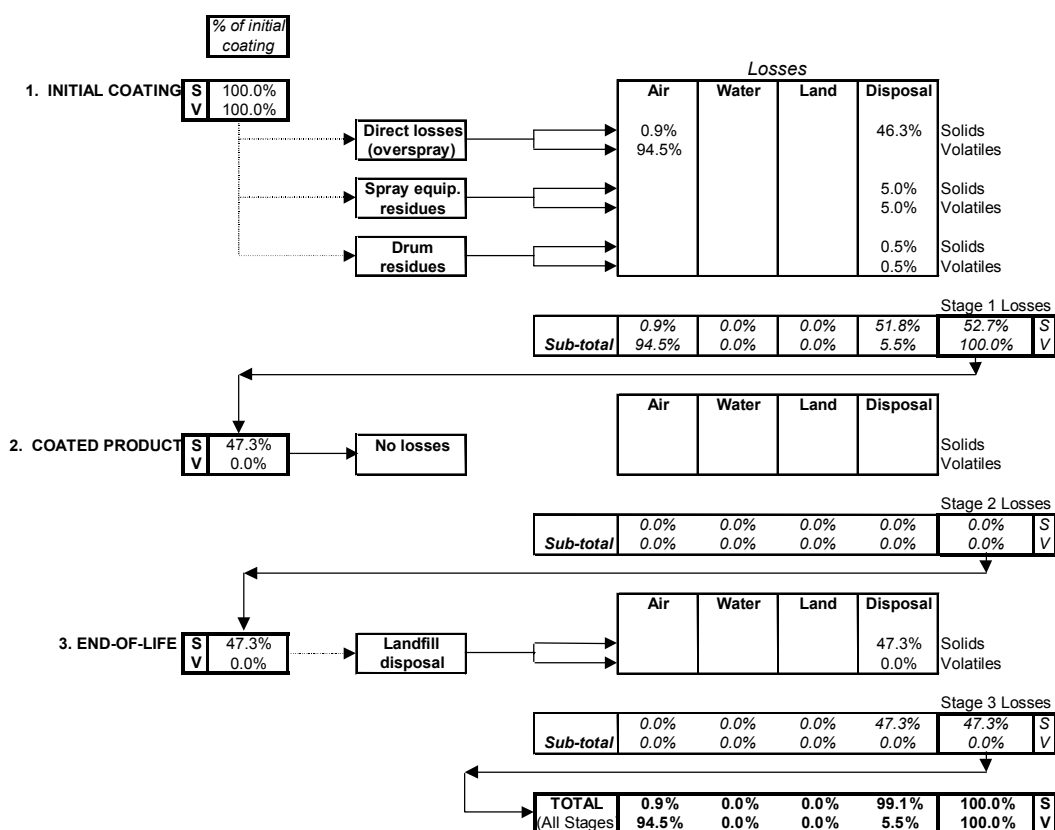


Figure 3.1: Emissions estimates for spray application of furniture coatings (dry booth at 50% TE)

In interpreting the data in Figure 3.1, the following points should be taken into account:

- An estimated 5% of paint is assumed to remain in the spray equipment which will later be cleaned using solvent and the waste will then be disposed of (or recovered).
- Around 0.5%¹³ is estimated to remain in drums which should then be disposed of as special waste, although this may not always be the case.
- From the initial 100% of solids and volatiles, a total of 5.5% solids and 5.5% volatiles are deducted (see above). At the remaining percentage of solids (94.5%) a transfer efficiency of 50% is applied, while the entire remaining volatile fraction is emitted to the air. Hence, ~47.2% of the initial solids are lost as overspray. A fraction of 2% of this overspray is lost to air (0.9%), while the remaining 46.3% of the initial quantity is captured on masking equipment (or the interior of the booth) and eventually is disposed of. Emission estimates should be revised if more detailed information on application techniques is available and the average transfer efficiency of 50% does not apply.

¹³ ETBPP 1999 indicates a percentage of higher than 0.1%.

For water-backed spray booths, essentially all of the overspray will be captured in water (47.2% of initial solid components). It is estimated that, on average, 15% of such water (containing about 7.1% of initial solids) will be disposed of to water (i.e. sewer) and the remainder will be disposed of as special waste through a specialist operator. Some solvent will also be present in this wastewater; its amount will be greatly dependent on the types of solvents used.

Roll coating and curtain coating have a transfer efficiency of around 99%. The remaining 1% relates to coating which is left on rollers or in feed lines (and is removed using organic solvent or water for recycling or disposal). For UV cured coatings, essentially all of the coating is reactive and thus volatile emissions will be negligible. For other types of coatings, their volatile content will be emitted to air. Figure 3.2 details the estimated emissions for flatline coating.

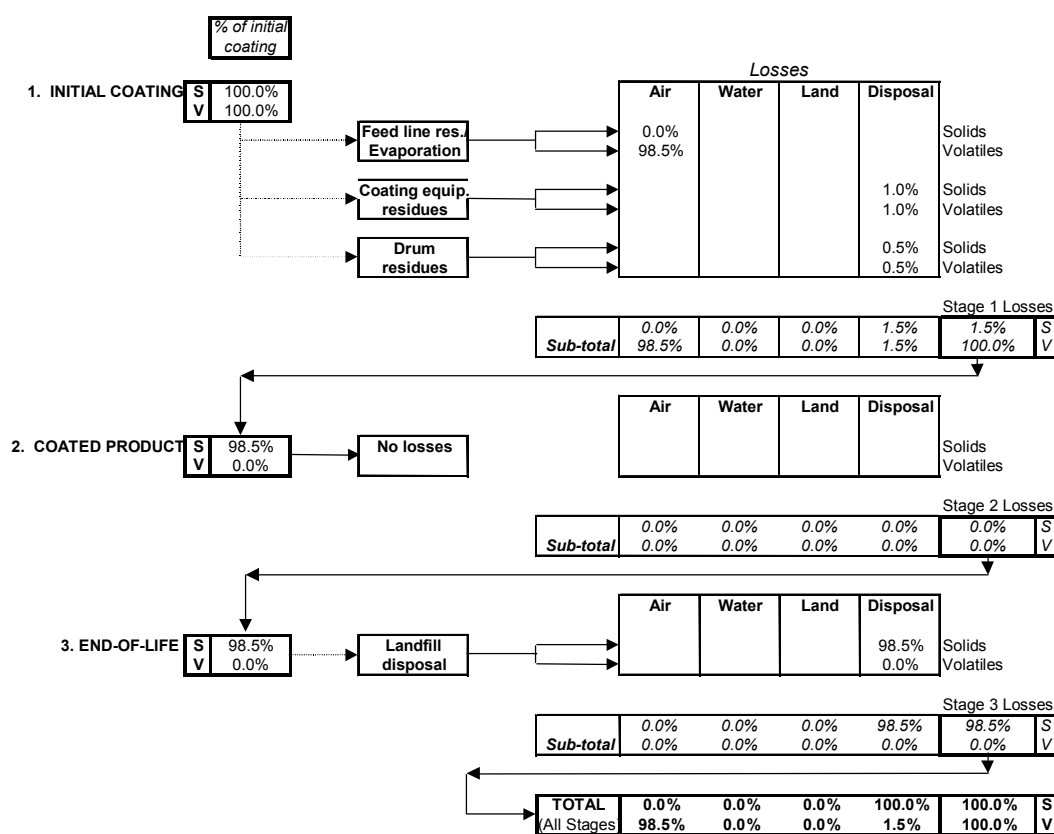


Figure 3.2: Emissions estimates for flatline application of furniture coatings

A specific percentage of losses to the environment from secondary processes such as sanding cannot be provided. Such emissions are considered to be incorporated in the losses outlined in the flowcharts.

Actual emissions may vary considerably from these estimates due to differences in equipment used (e.g. equipment used by small as compared to larger operators) and due to housekeeping practices. Differences are expected to exist between operators of different size as well as operators of similar size.

The choice of flow diagrams to be used in site-specific emissions estimations will depend on knowledge of the type of application method employed at a given site. This is necessary given the considerably different profile of emissions when different coating application methods are used. Given that spray application is more widely used, the emissions profile of Figure 3.1 should be adopted as a worst case scenario approach when the type of application is unknown.

For further details of the basis for the emission estimates, please refer to Environment Agency R & D Technical Summary P2-203/TS1 (Environment Agency, 2002).

3.4 Example calculations

A company that manufactures wooden furniture consumes 3 tonnes of a particular acid catalysed coating per year. Coating application takes place in a dry booth with air-assisted airless spraying guns having an average transfer efficiency of 50%.

The mixture of solvents in this coating contains solvent X (VOC) at a percentage of 63%. The total solvent content of the paint is 52%. The following calculations are based on Figure 3.1 and give the quantities of X emitted to the different environmental compartments during a coatings lifecycle in a year.

Total quantity of paint used ($Q_{init_coat_ann}$): **3 tpa**
 Content of solvent X ($Q_{subst_in_coat}$): $52\% \times 63\% = 0.328$
 Total quantity of solvent X used: $3 \text{ tpa} \times 0.328 = \mathbf{0.983 \text{ tpa}}$
 Fraction loss to air ($F_{init_coat, direct_loss, air}$): **94.5%**
 Loss of X to air during application: $0.983 \text{ tpa} \times 94.5\% = \mathbf{0.929 \text{ tpa}}$
 Loss of X to disposal (or recycling/recovery)
 from spray equipment residues
 (factor is $F_{init_coat, equip_res, waste, 5\%}$): $0.983 \text{ tpa} \times 5\% = \mathbf{0.049 \text{ tpa}}$
 Loss of X to disposal (or recycling/recovery)
 from drum residues
 (factor is $F_{init_coat, drum_res, waste, 0.5\%}$): $0.983 \text{ tpa} \times 0.5\% = \mathbf{0.005 \text{ tpa}}$
 Amount left on product after application: **0 tpa**
 Amount sent to disposal at end-of-life: **0 tpa**

For the use of 3 tonnes of coating, the B table in the TGD indicates use over 55 days per year (the fraction of main source would be 0.9, but the information here on the amount used per year is used in preference). Hence the daily emissions for a site would be 17 kg/day to air, and 1 kg/day to disposal.

4 DECORATIVE PAINTS

4.1 *General overview of the sector*

This section covers the use of paints applied to buildings, their trim and fittings and for decorative and protective purposes by both professionals and the general public.

Total annual sales of decorative coatings in the EU are estimated at around 3,465 kilotonnes (as shown in Table 2.2, Part I), while the value of the decorative market stands at around €7.2 billion (data for 2001). According to Chemiewinkel *et al.* (2000), around 90% of this total market for paint is used in the following key applications:

- Interior wall and ceiling paints for plaster, etc.
- Exterior wall paints for masonry, brick, etc.
- Interior/exterior wood/metal primers, undercoats and finish paints.
- Interior/exterior stains and varnishes for wood.

There are an estimated 1,300 ‘significant’ paint manufacturers in the EU, with this figure increasing to over 3,000 when small localised family businesses are included. However, roughly 50% of total production is accounted for by the largest 10 manufacturers. The total number of employees in the sector is around 122,000 (data for 1996) with an average number of employees per company ranging from 179 (for Finland) to 25 (for Luxembourg). The market in countries in the North and West are generally dominated by a small number of large firms, however, in countries in the South of Europe, there is a considerable presence of small-scale producers (Chemiewinkel *et al.*, 2000).

The difference between the percentages of decorative paints used in professional and ‘do-it yourself’ (DIY) applications varies across the EU. The split between these two types of uses ranges from around 30% in Greece to around 70% in Sweden. The costs of using professionals and a growing interest in DIY are major factors affecting this split. Table 4.1 shows the percentages of the main types of paints used for both professional and DIY purposes in Western Europe in 1996. Most DIY painting relates to the use of interior emulsions, while professional activity is more evenly spread.

Table 4.1: Consumption of paints by application (Chemiewinkel *et al.*, 2000)

	Professional (%)	DIY (%)
Interior emulsions	30.6	54.0
Interior glosses	20.0	14.8
Exterior paints	10.3	7.4
Undercoats & primers	12.9	8.2
Wood care products	11.8	8.9
Masonry paints	8.9	4.2
All other	5.5	2.6
Total	100	100

Note that the discussion that follows is based on consultation primarily with the UK coatings industry.

4.2 Process description and coating products used

4.2.1 Coating products

Decorative paints and varnishes are made from varying blends of raw materials that are formulated so as to provide a range of different properties, including ease of application, drying times, durability, compatibility (with other coatings), protection and decorative effects. All decorative coatings are supplied as liquid materials, which undergo a number of physical and chemical transformations after their application to produce the end serviceable coating. These transformations essentially involve the loss, during drying and curing processes, of some components. For solvent-borne paints, these losses will be comprised of volatiles, mainly VOCs, while for water-borne paints the losses will be comprised of both water and VOCs, with water being predominant.

Most decorative coatings are based on either solvent-borne alkyd and latex or water-borne emulsion technology. Alkyd resins have dominated trim and joinery applications due to their competitive cost and superior application and appearance characteristics. In contrast, wall and ceiling paints are dominated by the use of latex-based systems.

The market share for water-borne paints across the EU is about 70%. The greatest level of use of water-borne coatings is for wall and ceiling paints, with these coatings accounting for up to 100% of such paints in some countries. However, the level of use of water-borne trims and varnishes is considerably lower (5-40%). In addition, use of water-borne paints tends to be lower amongst professional painters than for the DIY sector.

The market share of water-borne decorative paints varies across the EU countries. For a total of 10 European countries (9 EU Member States plus Norway), CEPE has indicated that the market share for water-borne paints in the different applications is as follows (Chemiewinkel *et al.*, 2000):

- Interior walls and ceilings: 90%.

- Exterior walls: 82%.
- Pigmented trim - wood and metal: 20%.
- Clear coatings, stains and varnishes: 38%.

Differences across Member States exist; the most striking differences relate to the Swedish market share for water-borne coatings for exterior walls (only 2%) and the UK market share for water-borne coatings for clear coatings, stains and varnishes (68%, possibly due to the effect of large consumption volumes for products used for treatment of sheds and fences).

Table 4.2 provides indications of the typical compositions of decorative paints on the market at present.

With regard to the VOC content of decorative paints and varnishes, Directive 2004/42/CE (as described in Section 1.5.6, Part I) provides a detailed list of limit values for the various products falling under the description of “paints and varnishes”. These limit values are provided as Table 4.3.

Table 4.2: Typical compositions of decorative paints (by weight)

Coating type	Volatile	Non-volatile water soluble	Non-volatile non-water soluble
Vinyl matt emulsion	0 - 5%	3 - 5%	40 - 54%
Standard alkyd gloss finish	30 - 60%	-	40 - 70%
Water-borne exterior woodstain (or paint)	0 - 10%	1 - 3%	25 - 50%
Solvent-borne interior/exterior woodstain	55 - 70%	-	30 - 45%
High solids gloss paints	<30 - 50%	-	50 - >70%

Note: Based on Tables 3.17 to 3.20 of the existing Technical Guidance Document and revised through consultation (Environment Agency, 2002).

Table 4.3: Maximum VOC content limit values for decorative paints and varnishes (proposed Products Directive, CEC, 2002)

Product subcategory	Type	Phase I, from 01/01/2007 (g/l ready to use)	Phase II, from 01/01/2010 (g/l ready to use)
Interior matt walls and ceilings (gloss <25@60°C)	WB	75	30
	SB	400	30
Interior glossy walls and ceilings (gloss >25@60°C)	WB	150	100
	SB	400	100
Exterior walls of mineral substrate	WB	75	40
	SB	400	430
Interior/exterior trim and cladding paints for wood and metal	WB	250	130
	SB	300	*
Interior/exterior trim varnishes and woodstains, including opaque woodstains	WB	150	100
	SB	500	400
Interior and exterior minimal build woodstains	WB	150	130
	SB	700	700
Primers	WB	50	30

Product subcategory	Type	Phase I, from 01/01/2007 (g/l ready to use)	Phase II, from 01/01/2010 (g/l ready to use)
	SB	450	350
Building primers	WB	50	30
	SB	750	750
One-pack performance coatings	WB	140	140
	SB	600	500
Two-pack reactive performance coatings for specific end use such as floors	WB	140	140
	SB	550	500
Multi-coloured coatings	WB	150	100
	SB	400	100
Decorative effects coatings	WB	300	200
	SB	500	200

WB: water-borne coatings; SB: solvent-borne coatings.

* According to Article 9 of the proposed Directive, by the end of 2006, the European Commission shall review the technical and economic feasibility of applying from 2010 a content limit value to the solvent-borne coatings of this category and shall make a proposal to the European Parliament and Council for the value to be applied by 2010. At the moment, technical and economic considerations do not make the balance between advantages and disadvantages in setting a more stringent limit in 2010 for the category sufficiently clear; further studying is required.

4.2.2 Coating processes

Two principal processes are used to apply decorative coatings by the general public and professionals. These are brush application and roller application. A small amount of these coatings will be applied using spray application (conventional spraying or airless spraying application). However, spray application usually relates to products such as furniture or project-based professional painting of large-surface substrates.

4.3 Emissions estimates

Emissions estimates are separated into professional use and DIY use. Figures 4.1 and 4.2 describe the estimated emissions during application, in-service use and disposal of decorative coatings.

For use by the general public, we assume that:

- An estimated 25% of the initial coating will be left unused in paint cans. Only one quarter of the volatiles of this residue will eventually remain in the can and will be disposed of. The other three quarters (19% of the initial volatile fraction) will be emitted to the air.
- Of the remaining 75% of the initial coating, solids and volatiles have different fates. 2% of these solids (i.e. 1.5% of the initial solid fraction) will be lost as brush residues and then end up in the sewer with the remaining 98% (i.e. 73.5% of the initial solid fraction) will be deposited on the coated product. On the other hand, 1% of the volatile fraction (i.e. ~1% of the initial volatile fraction) will be lost as brush residues,

while the rest 99% (i.e. 74% of the initial volatile fraction) will be emitted to air. Hence during application, 19+74=93% of the initial volatile fraction will be lost to the atmosphere.

- We assume that 3% of the coating will be lost to industrial soil (land in the figure) during the useful life of the coating product. That accounts for 2% of the initial solid fraction.
- The entirety of the coating remaining on the product at the end of its life (essentially 71.5% of the initial solid fraction) will be disposed of, usually to landfill¹⁴.

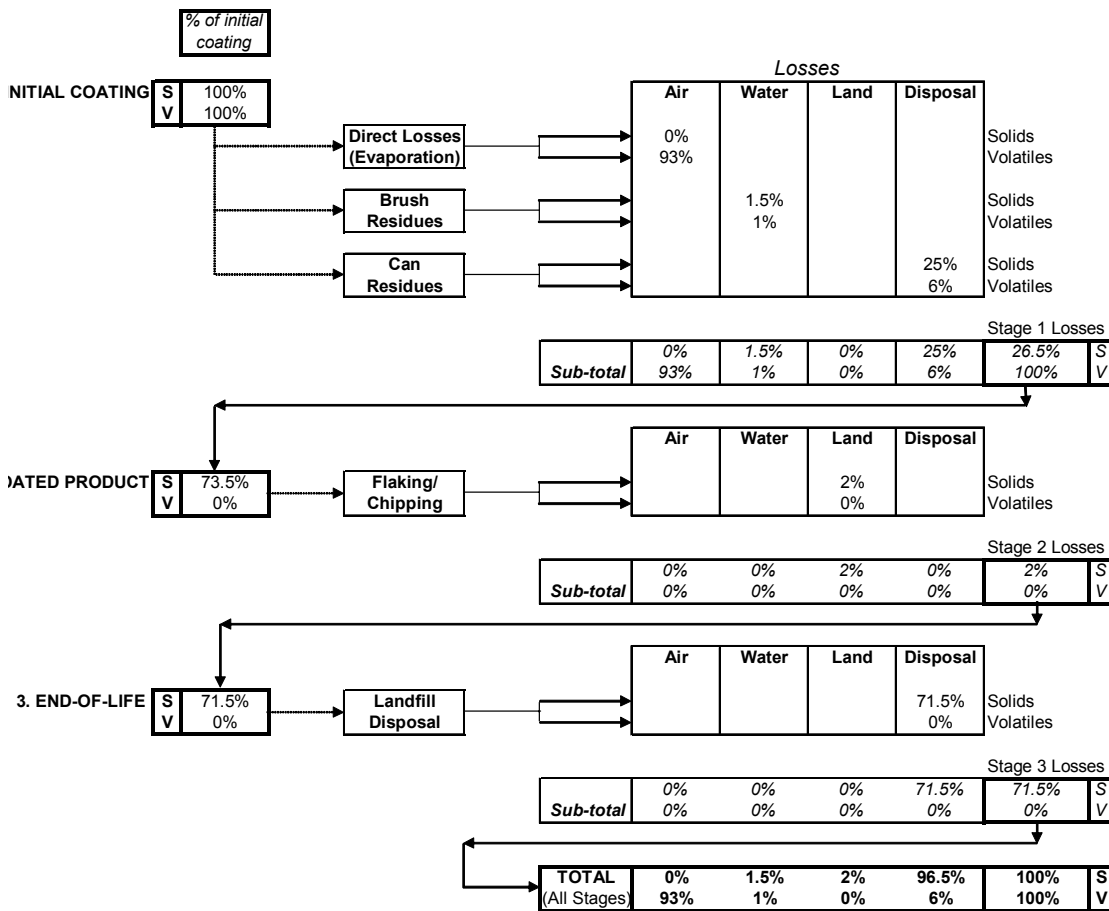


Figure 4.1: Emissions estimates for general public use of decorative paints

By comparison, for professional painters we assume that:

¹⁴ Typically, the general public will dispose of used paint cans to the domestic waste stream (where they will be landfilled or incinerated). However, in order to reduce the amount of wasted paints - 25% of total paint is typically wasted - industry has been encouraging schemes for collection and redistribution of unwanted paint.

- An estimated 3% of the initial coating will be left unused in paint cans. Again, only one quarter of the volatiles of this residue will eventually remain in the can and will be disposed of. The other three quarters (2% of the initial volatile fraction) will be emitted to the air.
- Of the remaining 97% of the initial coating, solids and volatiles have different emission patterns. 1% of these solids (i.e. ~1% of the initial solid fraction) will be lost as brush residues and then will be properly disposed of by the painter, while the remaining 99% (i.e. 96% of the initial solid fraction) will be deposited on the coated product. On the other hand, 1% of the volatile fraction (i.e. ~1% of the initial volatile fraction) will be lost as brush residues into a disposal route, while the rest 99% (i.e. 96% of the initial volatile fraction) will be emitted to air. Hence during application, 2+96=98% of the initial volatile fraction will be lost to the atmosphere.

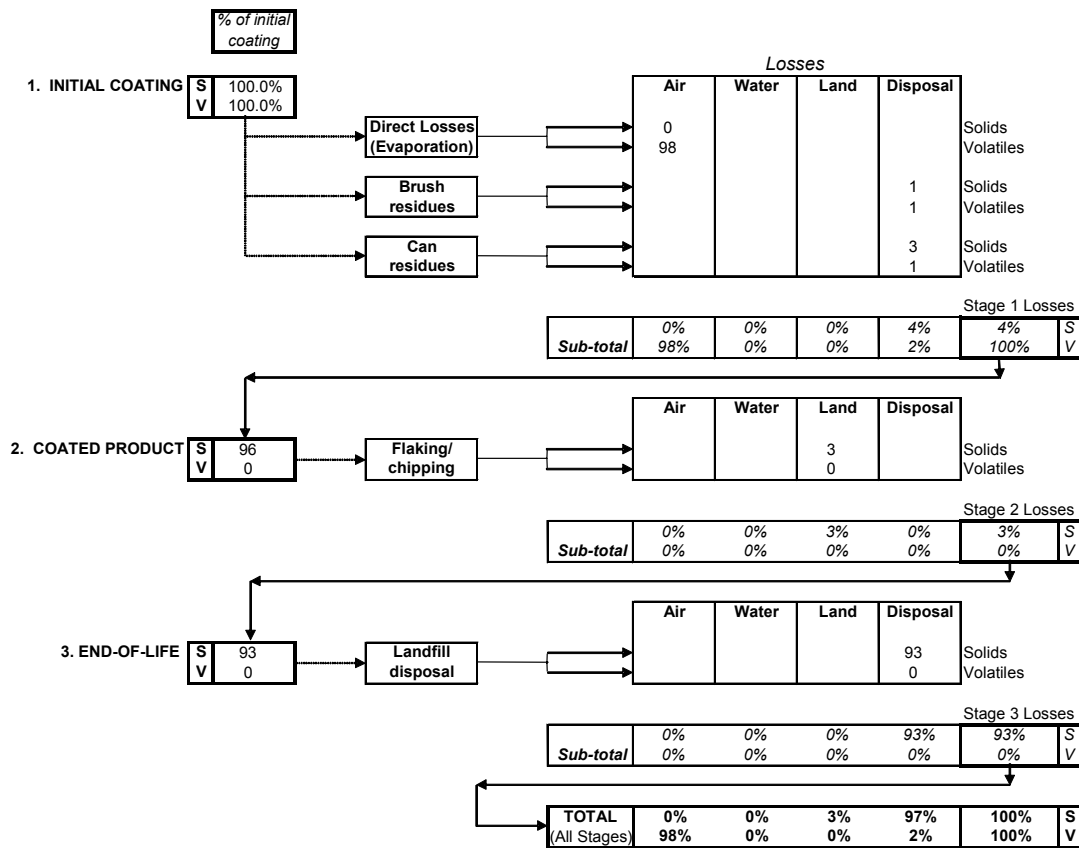


Figure 4.2 Emissions estimates for professional use of decorative paints

- We assume that 3% of the coating will be lost to industrial soil (land in the figure) during the useful life of the coating product. That accounts for 3% of the initial solid fraction.

- The entirety of the coating remaining on the product at the end of its life (essentially 93% of the initial solid fraction) will be disposed of.

Note that the above estimates take into account input received from experts-members of CEPE.

4.4 Example calculations

A pigment is used at 5% in paints as formulated; 750 tonnes of the pigment are used each year in the EU. There is no specific information as to whether the paints are used by professionals or by the public.

The amount of paint containing 750 tonnes of pigment at 5% is 15,000 tonnes/year ($Q_{init_coat_ann} = 1.5 \times 10^7$ kg/year). $Q_{subst_in_coat}$ is 0.05 kg/kg. If the paints were used only by professionals:

From Figure 4.2, $F_{init_coat, brush_resid, waste} = 1\%$, and $F_{init_coat, can_resid, waste} = 3\%$

Hence $E_{init_coat, waste} = 1.5 \times 10^7 \times 0.05 \times (1+3)/100 = 30,000$ kg/year.

If the paints were used only by the public:

From Figure 4.1 $F_{init_coat, brush_resid, water} = 1.5\%$, and $F_{init_coat, can_resid, waste} = 25\%$

Hence: $E_{init_coat, water} = 1.5 \times 10^7 \times 0.05 \times 1.5/100 = 1.125 \times 10^4$ kg/year $E_{init_coat, waste}$
 $= 1.5 \times 10^7 \times 0.05 \times 25/100 = 1.875 \times 10^5$ kg/year.

If information on the distribution between professional and public use is available then this could be used to generate a combined estimate.

For local emissions, the TGD B table indicates a fraction of main source of 0.002 for public use. It is assumed that the distribution of professional use for these types of paints is the same as for the public use (the difference being, for example, whether the home owner paints the house or employs a professional to do so). Hence a fraction of main source of 0.002 is suggested for professional use too. This should be applied to the regional tonnage, i.e. to 10% of the total, and for 300 days. Hence the daily emission to water from public use would be 7.5×10^{-3} kg/day.

5 AUTOMOTIVE COATING AND REFINISHING

5.1 General overview of the sectors

This section covers the use of paints used in the manufacture of original automotive equipment (OEM) and also in the refinishing of automobiles (vehicle refinishing, VR). Separate emissions estimates are provided for other types of vehicles in Sections 8, 9 and 10 (Part II) on marine, aerospace and rail vehicle coatings respectively.

The total quantity of coatings used in OEM and VR operations represented 7% of the total volume of the EU coatings market in 2001 (see Table 2.2, Part I). In that year, 275,000 tonnes of coatings were used for automotive coating purposes and 110,000 tonnes for vehicle refinishing. The value of the two markets was €1.1 billion and €1.6 billion respectively.

In the last decade, the EU vehicle refinishing industry has made a transition from a sector based on small individual companies to medium to large integrated organisations offering complete solutions to their customers, mainly as a result of constant changes in the insurance business.

The 2000 Entec report to the European Commission provided an overview of the vehicle refinishing sector in the EU. Table 5.1 shows the breakdown into small medium and large bodyshops in the EU. The figures correspond to data from 1999 and projections for the year 2007.

Table 5.1: Summary of current and future bodyshop numbers in the UK and the EU (Entec, 2000)

Region	Number of bodyshops in 1999 (number of employees)				Number of bodyshops in 2007 (number of employees)			
	Small (1-5)	Medium (6-10)	Large (>10)	Total	Small (1-5)	Medium (6-10)	Large (>10)	Total
EU	53,220	15,855	6,315	75,390	30,600	23,320	9,410	60,330

For the purposes of the Entec report, the number of bodyshops included the vehicle refinishing workshops with paintshop facilities. Bodyshops may either have on-site paint spraying facilities or may have specialised paint shops. Therefore, those bodyshops that do not undertake painting activities have been excluded. For the UK in particular, the Entec reports notes a significant decrease in the overall number of bodyshops since the beginning of the 1990s: from 10,000 bodyshops in 1990, the total number fell to 5,890 in 1999. The number of people employed in the industry in 1999 was around 317,000 for the whole of the EU (Entec, 2000).

Data on commercial vehicles bodyshops for three EU countries in 1999 are given in Table 5.2.

Table 5.2: Numbers of commercial vehicle bodyshops in Finland, Germany and the UK (Entec, 2000)

Country	Number of commercial vehicle bodyshops (1999)				Number of commercial vehicle bodyshops (projections for 2007)			
	Small (1-5 empl)	Medium (6-10 empl)	Large (>10 empl)	Total	Small (1-5 empl)	Medium (6-10 empl)	Large (>10 empl)	Total
Finland	80	0	0	80	80	0	0	80
Germany	300	80	20	400	350	90	25	465
UK	6	22	511	539	NA	NA	NA	NA

NA: Not available data. Similar data for the whole of the EU were not made available.

Large facilities may deal with more than 50 jobs per week, while medium-size bodyshops are undertaking 10-49 jobs in the same period of time. Small-size businesses are expected to work on less than 10 jobs per week (Entec, 2000).

The information provided below is based on UK data but is expected to apply also to the EU, since the vehicle manufacture and refinishing industry shows similarities across the EU Member-States.

5.2 Processes description and coating products used

5.2.1 Automotive OEM

Figure 5.1 provides an overview of the processes involved in automotive original equipment manufacture (OEM) coating operations.

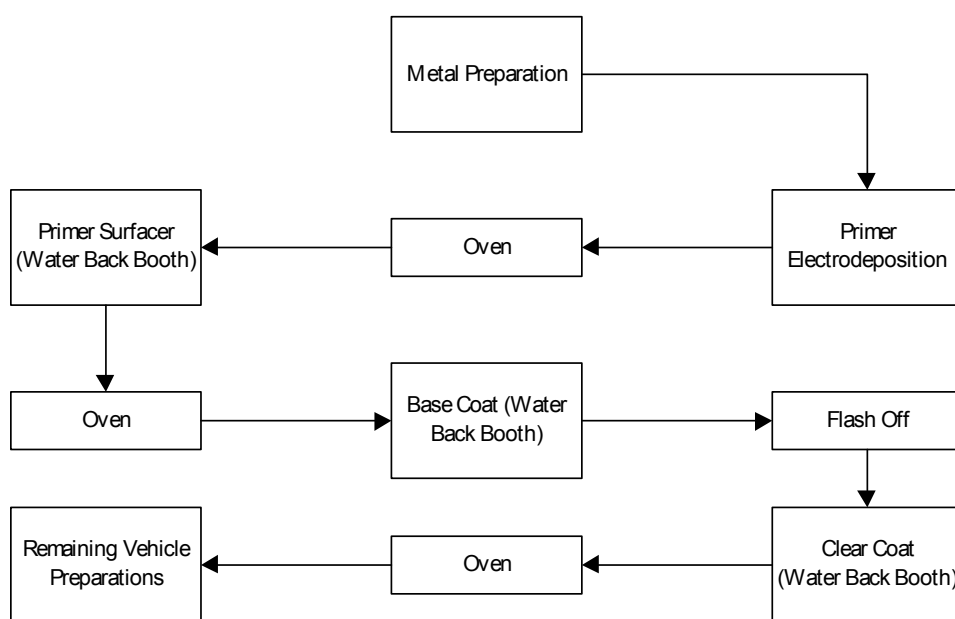


Figure 5.1: Main coating related activities in automotive OEM

In relation to preparation of the metal before painting, activities include cleaning, degreasing and use of chemical treatment (phosphating) baths. These activities are described further in an Emission Scenario Document on metal finishing (OECD, 2004a).

A primer is then applied by immersion of the assembled body in an electrodeposition bath. This involves submersion of a negatively charged vehicle in a positively charged bath of primer (around 80 to 85% water with a small amount - less than 3% - of solvent). The electrodeposition medium also contains pigments, additives and a resin, such as acrylic, polyester or epoxy (epoxy resins have limited stability against UV radiation but this can be overcome by primer surfacers and by UV absorbers in clearcoats). Solids content is typically around 14 to 18% (DuPont, 2003; Environment Agency, 1997).

The primer is baked on in an oven and weld points on the body are filled with a sealant (sealants serve as sound deadeners for the seams and as underbody protection; according to industry, apart from weld points, adhesives are also used to improve the stability of the carbody). The vehicle then enters a water backed booth¹⁵ for spray application of an anti-chip primer surfacer (urethane- or polyester melamine formaldehyde or epoxy ester-based), which may include some pigment (DuPont, 2003).

Following further baking, a basecoat is applied which contains the pigments and other additives which dictate the appearance (colour, etc.) of the vehicle. The basecoat may be either solvent-borne or water-borne, although there is a growing trend towards the latter. The basecoat is typically allowed to cure by flashing off of the solvent without additional heat.

¹⁵ These are typically very long booths through which the car body moves, with a downdraft to capture overspray which is passed to the water.

Finally, the solvent-borne clear coat is applied in another spray booth and further heating takes place. Typical clear coats include acrylic urethanes and acrylic melamine formaldehyde. Today, the vast majority of car bodies have clear overbase topcoats but some still have monocoats for solid colours.

Note that, where ovens are used, this is undertaken at relatively high temperatures for relatively short periods of time. Electro-coats require a baking temperature of up to 180°C; primer surface require a temperature of 160°C and topcoats a temperature of 140°C (DuPont, 2003).

5.2.2 *Automotive refinishing*¹⁶

5.2.2.1 Basic steps and coatings used

The basic steps involved in vehicle refinishing (VR) are as follows:

- Cleaning and degreasing of the body, including removal of the old coating (or some of it) using abrasive rubbing or blasting.
- Repairs to the body.
- Masking of the areas that are not to be painted and application of primers.
- Application of a filler/surfacer to provide a flat surface.
- Application of the topcoat(s)¹⁷.

Typical coatings used in vehicle refinishing are polyurethane-acrylic or epoxy-based. Primer/surfacers are usually solvent-borne, as are clearcoats. However, there is a growing trend towards use of water-borne products in basecoat products, accounting for around 50% of all basecoats and around 8% of the total coating (around 16% of the total coating is accounted for by basecoats). This trend is expected to continue following implementation of the Solvent Emissions Directive (SED) and will extend to primers and clearcoats under new legislation (see below).

The Entec report (Entec, 2000) provides an overview of the quantities of ready-to-use coatings that are applied to different types of vehicles. It is assumed that these quantities do not differ significantly across bodyshops of different sizes but rather that they vary depending on the types of coatings and equipment used. The information is presented in Table 5.3.

¹⁶ Further information on automotive refinishing can be found in the OECD ESD on Coating Application via Spray-Painting in the Automotive Refinish Industry (OECD, 2004b)

¹⁷ In most cases, this involves application of base (colour) coat followed by clear coat. However, in some cases, a single layer topcoat may be used whereas in others a three layer system is used, including a ground coat, pearl effect coat and then clear coat.

Table 5.3: Typical consumption of coating components in the UK vehicle refinishing industry

Refinishing repair	Year	Area to be coated (m ²)	Total cleaner/degreaser and thinner (l)	Total single layer solid (primer and colour layer) (l)	Total clear and basecoats (l)
Small vehicles	1998 ¹	< 0.39	0.75	0.62	1.07
	1999 ¹		0.75	0.63	0.78
Medium vehicles	1998	0.4 – 0.79	0.75	0.89	1.49
	1999		0.75	0.81	1.24
Large vehicles	1998	0.8 – 1.59	0.75	1.21	1.96
	1999		0.75	1.05	1.6
Extra large vehicles	1998	> 1.60	0.75	1.53	2.43
	1999		0.75	1.34	2.03
Front/rear corner	1998		0.75	2.49	3.69
	1999		0.75	1.82	2.79
Full front/rear or side	1998		0.75	3.2	4.85
	1999		0.75	2.55	3.92
Whole body	1998		0.75	4.5	9.0
	1999		0.75	3.64	7.51

Note: ¹The data were provided by the UK motor insurers Thatcham Research Centre. Values for 1998 correspond to the use of HVLP guns and medium solids materials, while 1999 values correspond to the use of high solids and water-borne materials.

5.2.2.2 Implications of European legislation on VOCs

The key features of the SED for vehicle refinishing are shown in Table 5.4. The figures refer to all the products used in the painting process, from surface cleaning to final finishing and polishing.

‘Vehicle refinishing’ is defined as all ‘repair, conservation or decoration outside of manufacturing installations’, and this covers all repainting of vehicles. Original coating of vehicles with refinishing-type materials - for example, coach building on commercial vehicles - is also covered, where either

- This is carried out ‘away from the original manufacturing line’, or
- The vehicle is a trailer, or
- The solvent use is less than 15 tonnes per annum.

The Directive does not specify a list of VOC limits of products used in vehicle refinishing, instead it uses a model to establish a target maximum solvent content. These calculations do not take into consideration any reductions in VOCs emissions from the use of more sophisticated

spraying equipment. For vehicle refinishing, there is also a limit of 500 kg of solvent used per annum per bodyshop, therefore small enterprises are not covered by the requirements of the Directive. Table 5.4 provides an overview of the targets of the Directive.

Table 5.4: The SED: Key targets for vehicle refinishing (CEPE, 1999)

Key targets	Interim stage	Final stage
Maximum average solvent content (excluding water)	64.3%	54.5%
Corresponding emissions reduction	40%	60%
Implementation deadline for new installations	October 2001	October 2004
Implementation deadline for existing installations	October 2005	October 2007
Threshold solvent use per year	500 kg	500 kg

Table 5.5 presents the CEPE standards for low solvent content coatings that can be used by professionals in order to comply with the requirements of the SED. These proposals have been adopted by the European Commission and appear in Annex II to the proposed Products Directive on the regulation of VOCs emissions from coating products used in the decorative and vehicle refinishing sectors (see also Section 1.5.6, Part II and CEC, 2002).

Table 5.5: CEPE standards for low solvent coating products used in the vehicle refinishing sector (CEPE, 1999)

Product	VOC content (g/l)	
	Actual values in 1992 (from CEPE, 1994)	Proposed limits
Gunwash	850	850
Precleaner	850	200
Stopper and body filler	250	250
Wash primer	780	780
Precoat, primer, primer surfacer, surfacer, filler	600-720	540
One coat topcoat	600-720	420
Basecoat	800	420
Clearcoat	600	420
Special coatings	840	840
Average solvent percentage	~75%	~50%

Wash primers need to have a high solvent content to ensure adhesion of subsequent coats on difficult, bare metal surfaces such as aluminium, zinc plated, or galvanised metals. For other substrates, an adhesion primer or precoat is sufficient. It should be noted that, according to CEPE (CEPE, 1999), some new products that have a low solvent content cannot fulfil the requirements

of all end uses, therefore, they cannot act as direct replacement of existing products at present. CEPE is working to achieve a solvent content of 250 g/l for all primers and surfacers by 2010 (CEPE, 1999).

The use of advanced application technologies (with higher transfer efficiencies) could also result in solvent emission reductions, although CEPE calculations have shown that the effect of the use of such technologies is much smaller than that produced by the use of low solvent coatings (CEPE, 1999).

The most common application method is the use of spray guns and, partly, brushes. More sophisticated application systems could include:

- High volume low pressure (HVLP) spray.
- Airless spray.
- Air assisted airless spray.

Electrostatic assistance could, in theory, increase considerably the transfer efficiency in many production line spraying processes. However, its use is not practicable, as the necessary static electrical charge could damage the vehicle's engine management system and other electronic components (CEPE, 1999).

Table 5.6 describes the potential reduction in solvent emissions from the vehicle refinishing sector if the standards developed by CEPE are implemented in full. It has been assumed that there will be no change in the quantity of the solid paint required, although the use of more advanced application systems is assumed to potentially result in a 20% reduction in the usage of paint, which in turn results in solvent emissions reductions.

In addition to the above, CEPE also assumes that full enclosure could result in an 80% reduction of emissions from spray gun washing. The combined effect of these measures is an overall estimated saving of 69% of emissions (CEPE, 1999).

Table 5.6: Estimated solvent emission reductions for the vehicle refinishing sector under the CEPE guidelines on the solvent content of coating products (CEPE, 1999)

	Annual status for 1992	CEPE proposed limits
Overall process solvent content	~75%	~50%
Emission reduction due to:		
• Reduced solvent content in coating products		56%
• Use of enclosed spray gun wash		6%
• Use of advanced application systems (HVLP)		7%
Total VOC emission reduction		69%

5.2.2.3 Types of spray booths used in vehicle refinishing

Spray application of paints in the VR sector is undertaken in either dry back or wet back spray booths. Paint application is undertaken mainly using air-atomised spray guns, due to the small amounts of paint applied to vehicles. However, due to the low transfer efficiency of this technique, regulatory requirements in some countries (e.g. the Netherlands and the UK) are stimulating greater use of 'compliant' low pressure guns, with a transfer efficiency of around 65% as compared to the 30 to 40% achievable with conventional spray guns.

The types of spray booths used in the VR sector are (HSE, 2000):

- **Cross-draught booths** in which airflow is horizontal, being passed through filters at the intake points (to remove particulates that might contaminate the paintwork).
- **Down-draught booths** in which airflow is vertical (downwards). Around 10% more air is supplied than extracted with the excess leaking out through gaps (and carrying some vapour and overspray).
- **Semi-down-draught** booths where air enters at the roof and is extracted at one end.
- **Spray-bake booths** where paint is baked within the booth after spraying.

In terms of filtration, the two principal methods are dry filters and water wash. The former (in dry back booths) utilise either pleated paper or fibre matting. Water back booths are either of the pumped type, in which a water curtain is formed by spraying water onto a deflector plate near the rear of the booth (this collects the overspray) or of the non-pumped type, in which a high static-pressure fan extracts air from the booth under a plate at a water reservoir's surface.

As compared to automotive OEM, temperatures used in baking the coatings are much lower (around 70°C for VR as compared to up to 180°C for OEM). This is mainly due to the fact that OEM painting is undertaken before installation of components to the vehicle (such as dashboards and seats), whereas VR is undertaken afterwards (DuPont, 2003).

The spraying technologies used by vehicle refinishing bodyshops are to a certain extent dependent on their size. Small bodyshops are not always capable of meeting the costs of highly efficient spray guns (although, these may give a very short payback (Giordan, 2003)) and booth systems. According to the Entec report on the vehicle refinishing sector (2000), small companies often rely on second hand equipment. Sophisticated techniques, such as electrostatic application systems whose use may result in 30% reduction of the amount of paint used, are not used mainly because they cause damage to electronic components, such as the engine management system (CEPE, 1999). Additionally, recycling of spent solvents is a practice traditionally pursued by companies that can afford it; the economics of solvent recovery depend on solvent use, hence only medium to large bodyshops may benefit from such practices. However, the introduction of the SED has meant that even small companies are interested in solvent recycling if that helps them keep below the 0.5 tonne threshold of the SED. The Entec report also notes that recovery/recycling is more widely used in the northern countries of the EU.

Under the light of such imbalance among companies of different sizes, we assume an average transfer efficiency in the vehicle refinishing operations of around 40%, as explained further below. In cases where the existing technology allows for better performance, the emission estimates should be amended accordingly.

5.3 Emissions estimates

5.3.1 Automotive OEM

The majority of automotive OEM companies have incineration equipment for abatement of emissions, particularly VOCs. Spray booths are generally of the water backed type. The majority of solids that are oversprayed, therefore, will be captured in the water, which is almost exclusively sent for licensed disposal when contaminated with paint wastes.

Figure 5.2 describes typical emissions during automotive OEM coating activities. Note that emissions relating to the application stage relate only to spraying: electrodeposition is essentially assumed to have a 100% transfer efficiency, although a small amount of solvent used will be lost to incineration and a small amount of coating will be disposed of after the coating of vehicle parts has been concluded. The available information does not allow for an estimation of the percentage of coating that needs to be eventually disposed of but it is expected to be very low.

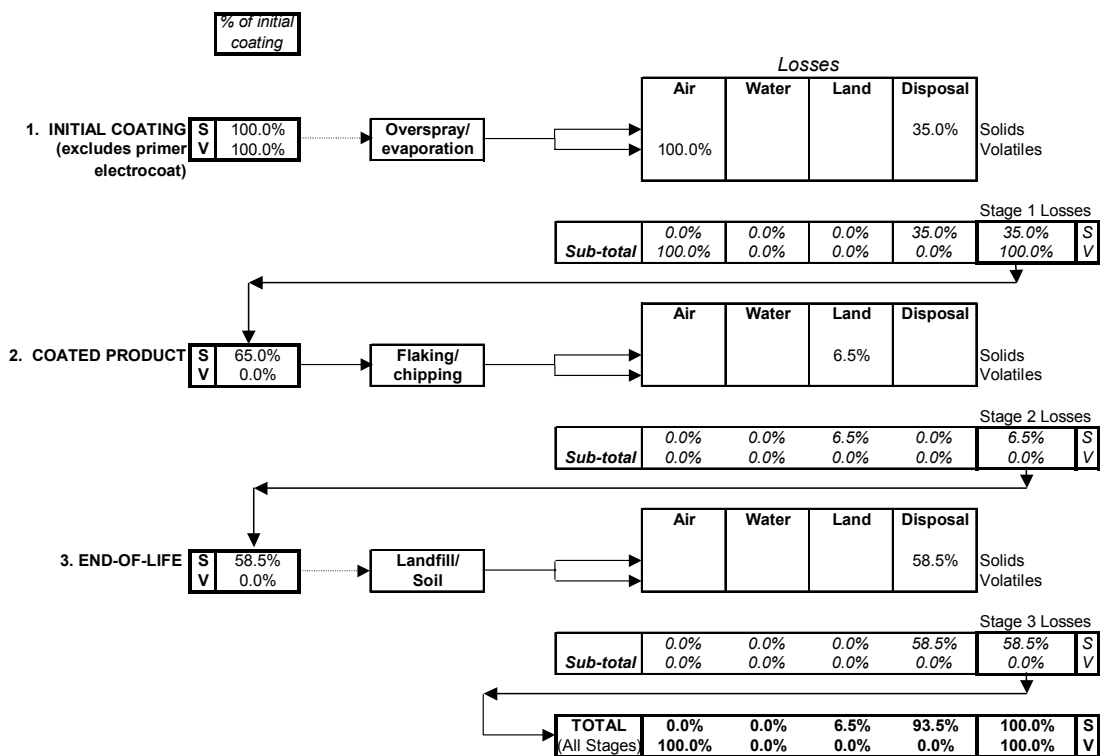


Figure 5.2: Emissions estimates for coating use in Original automotive Equipment Manufacture (OEM)

All of the solvent in a paint product will be lost to air during the various application and baking stages. Note that incineration is typically used for oven air and not for exhaust air from spray booths. Oven air may contain up to 30% of the organic solvents emissions; if incineration is extended to the flash off area (which is not a common practice), the solvent emissions to be incinerated may account for up to 50%, with the remaining 50% being untreated (PPG, 2003). Because of such an approach, the average VOCs emissions from UK OEM plants are still in the range of 60 g/m³ or 5 kg per unit (DuPont, 2003).

It has been assumed that about 10% of the coating is being lost during the vehicles useful life due to flaking and chipping. This is considered to be to industrial soil (land in the figure). The remaining 58.5% of the coating (essentially solids) will be disposed of at the end-of-life of the vehicle (dumping of vehicles has not been considered under the light of recent EU legislation on end-of-life vehicles).

A transfer efficiency of 65% has been assumed for the spraying processes. The theoretical transfer efficiency when using electrostatic spray (high rotation devices) is 80%, however, internal parts are still sprayed pneumatically (with traditional spraying techniques) with a transfer efficiency that does not exceed 40%. Moreover, the second application step of metallic basecoats is also applied pneumatically with a transfer efficiency of up to 50%. Therefore, the average transfer efficiency for the entire process is assumed to be around 65%. It should be noted that additional losses may occur due to colour change for tinted coatings (DuPont, 2003).

It should be borne in mind that some cars will undergo additional coating during their life cycle. In this case, the emissions estimates relating to VR would apply. However, the estimates are not combined for the purposes of this document.

5.3.2 *Automotive refinishing*

As mentioned above, both dry back and wet backed booths are used in automotive refinishing. Figures 5.3 and 5.4 describe the emissions estimates for these coating processes. In relation to wet back booths (Figure 5.4), the final compartments for emissions will be very similar and the only change required is that 3% of the 39% of total paint solvent that is lost to air will be lost to water instead (making the respective losses of volatiles to air and water for this stage 36% and 3%).

In relation to the estimates in both figures, the following should be taken into account:

- Cleaning solvent is used for equipment cleaning after mixing and paint application. A proportion of this will be recycled, assumed to contain 3% of the solvent that was initially present in the paint.
- On average, solvent will constitute around 64% of the paints used with solids comprising the remaining 36% (water is not considered) - around half this amount of solvent again is used for cleaning purposes. As shown above, regulatory requirements will gradually alter this ratio towards 50:50.

- A transfer efficiency of 40% is used in estimating overspray during paint application (with this calculated as 51.1% of total solids applied after accounting for equipment residues). 50% is the average transfer efficiency of pneumatic application on large external surface areas. Vehicle refinishing is usually done on small surface areas including fuel lids, mirror houses, bumpers, etc. Therefore, the average transfer efficiency is assumed to be around 40% (or slightly better at 45% when using HVLP guns) (DuPont, 2003).
- Oversprayed paint solids will generally be landfilled/incinerated.
- We assume that about 10% of the coating is being lost during the vehicles useful life due to flaking and chipping. This is considered to be to industrial soil (land in the figure). The remaining 30.6% of the coating (essentially solids) will be disposed of at the end-of-life of the vehicle (dumping of vehicles has not been considered under the light of recent EU legislation on end-of-life vehicles).

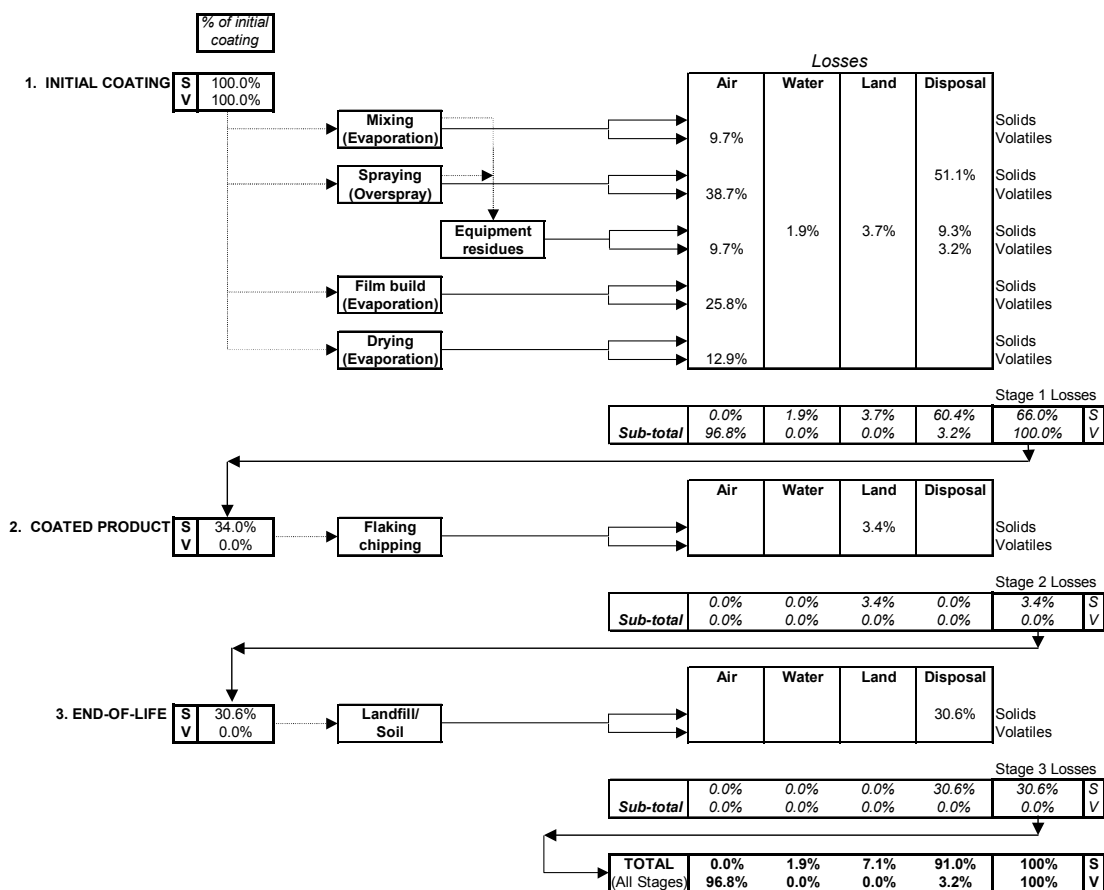


Figure 5.3: Emissions estimates for automotive refinishing (for dry back booth)

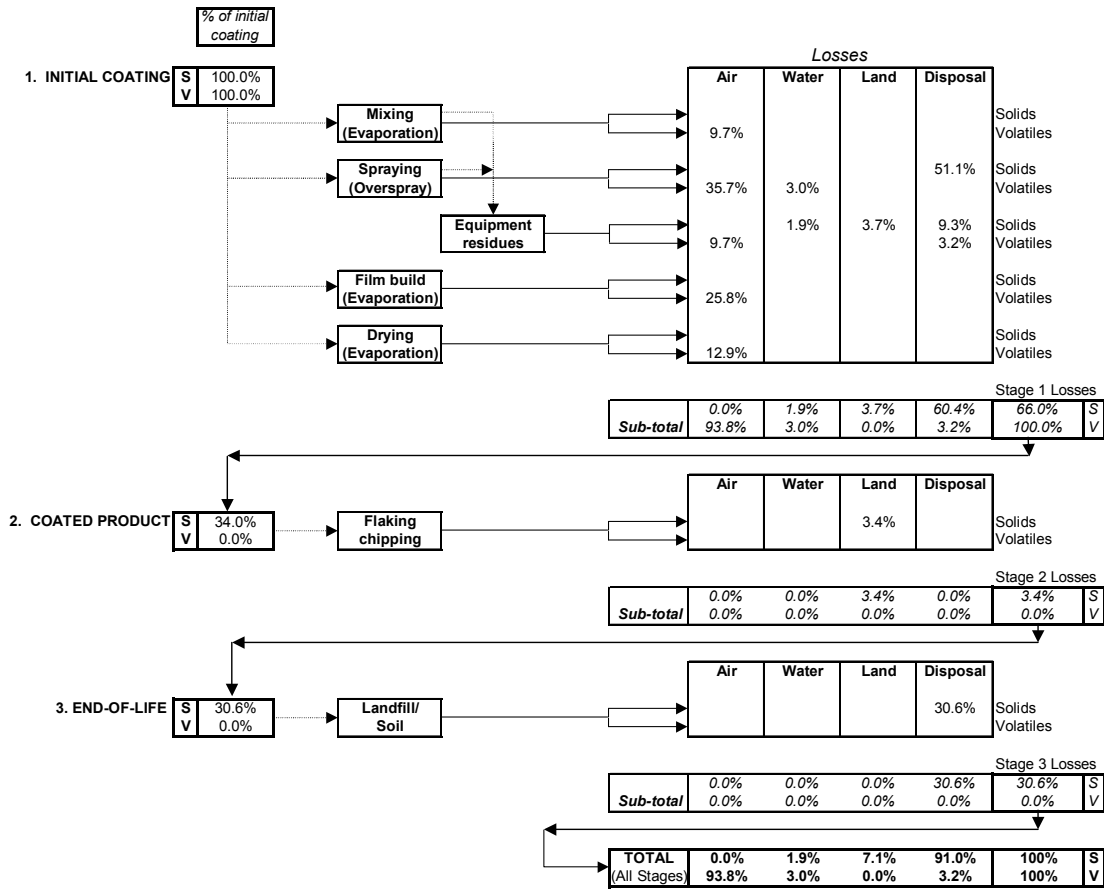


Figure 5.4: Emissions estimates for automotive refinishing (for wet back booth)

5.4 Notes on the revisions to existing estimates

Use of a combination of electrostatic spray and pneumatic spray application has been taken into account in developing estimates for losses during coating application in OEM, having an average transfer efficiency of around 65%. This represents an increase in emissions as compared to the existing emissions estimates (those in the TGD). However, the following should be borne in mind:

- Losses to water from the water backed booths will be treated either on-site using wastewater treatment plant or will be passed to a licensed disposal operator.
- The estimates in Figure 5.2 do not take into account electrodeposition of the primer, which is essentially assumed to have a 100% transfer efficiency.

Estimates for losses from VR represent average emissions, taking into account both good and bad practice. Where good practice is followed, there should not be any emissions to water or land (see Figures 5.3 & 5.4).

The two figures provided in this section may be used for both solvent- and water-borne coatings alike, although the percentage of solids and volatiles will be different in coatings belonging to these two categories. Solvent-borne products are still more widely used than water-borne ones, as mentioned in Section 5.2.2. There is, however, a growing trend towards a wider uptake of the latter.

5.5 Example calculations

Insoluble substance X is produced at 2 tonnes per year and is used as a drying catalyst agent in solvent-borne coatings (in clearcoats and basecoats) for automotive refinishing. The concentration of X in these coatings is 5 g/l on average.

It is assumed that the coatings can be used in all sizes of body shop, and may be used on all sizes of vehicles. For a reasonable worst case, a large body shop is assumed (so at least 50 jobs per week from Section 5.1). For this calculation, 50 jobs per week are assumed, with half on large vehicles and half on medium vehicles. The application of these paints typically takes place in wet back booths with a transfer efficiency of 40% (as assumed in Figure 5.4).

From Table 5.3, the volume of clearcoat and basecoat for a large vehicle is 1.6 litres, so the volume used per week is 40 litres. Similarly, the volume for a medium vehicle is 1.24 litres, and the weekly volume is 31 litres. Hence the total use per week is 71 litres; assuming operation over six days per week the daily use of coatings is 11.8 litres per day. This value is used as $Q_{init_coat_day}$; note that the units here are litres rather than kg per day, but these match the information on the content of the substance in the coating ($Q_{subst_in_coat}$ is 5 g/litre, or 0.005 kg/litre).

From Figure 5.4:

$F_{init_coat, overspray, waste} = 51.1\%$; $F_{init_coat, equip_res, water} = 1.9\%$; $F_{init_coat, equip_res, land} = 3.7\%$; $F_{init_coat, equip_res, waste} = 9.3\%$.

Hence:

$$E_{init_coat, waste} = 11.8 \times 0.005 \times (51.1+9.3)/100 = 0.0356 \text{ kg/day}$$

$$E_{init_coat, water} = 11.8 \times 0.005 \times 1.9/100 = 1.1 \times 10^{-3} \text{ kg/day}$$

$$E_{init_coat, land} = 11.8 \times 0.005 \times 3.7/100 = 2.2 \times 10^{-3} \text{ kg/day}$$

To estimate the total emissions for the substance from this use, the amount used per day is $11.8 \times 0.005 = 0.059$ kg. The total used is 2 tonnes, which is 33,900x the daily use. Hence multiplying the daily releases by this factor gives overall emissions for the EU of 1207 kg/year to waste, 37 kg/year to water and 75 kg/year to land.

The release factor for the use of coated products in this case is 3.4%. The total quantity $Q_{init_coat_ann} \times Q_{subst_in_coat}$ is 2 tonnes (as given); this is the quantity to which the factor should be applied (i.e. to the whole, not to the 34% actually on the vehicles, as the factor in the figure takes this into account). Hence the emissions from the use of the product (service life) are $2,000 \text{ kg} \times 3.4\% = 68 \text{ kg/year}$.

6 METAL PACKAGING COATINGS

6.1 *General overview of the sector*

This section concerns the application of coatings to metal packaging, particularly coating of cans. The sector can be divided into three main types of cans: beer and beverage cans, food cans and general line cans. The former two categories are fairly uniform in type, whereas the latter (general line cans) includes hundreds of different sizes and shapes of cans. Table 6.1 provides a breakdown of the number of sites involved in the coating of cans in the UK and the associated numbers of cans produced. The metal packaging manufacture industry employs around 10,000 people in the UK.

Table 6.1: Overview of metal packaging operations in the UK (year 2000 figures)

Sector	No. of Sites	No. Cans Per Year	1990-2000 Change in Production Volume
Beer & beverage	8	7.4 billion	Static
Food	8	5.7 billion	Slight decrease
General line¹	8	0.8 billion	Slight increase
Aerosols	4	0.7 billion	Moderate increase
Metal closures²	5	1.4 billion	Slight increase
Total	33	16 billion	-

Notes: ¹Includes aerosol cans and other miscellaneous cans.

²Closures made for non-metallic packaging, e.g. glass and plastic bottles and jars.

The processes used in production of metal packaging are fairly uniform across the EU, as indicated by the UK manufacturers. The following process descriptions and emissions estimates for the UK are, therefore, considered to apply equally to other EU Member States.

6.2 *Process description and coating products used*

6.2.1 *Introduction*

Discussion in this section is divided into the coating processes and products used in beer and beverage can manufacture and those used for food cans and general line cans (the processes for the latter two being essentially the same).

In general, though not without exception, beer and beverage cans are two-piece cans (i.e. they are assembled from two pieces of sheet metal). Food cans and general line cans are, on the whole, three-piece cans.

6.2.2 Beer and beverage cans

Figure 6.1 describes the processes involved in beer and beverage can manufacture. A typical production facility may manufacture up to 2000 cans per minute.

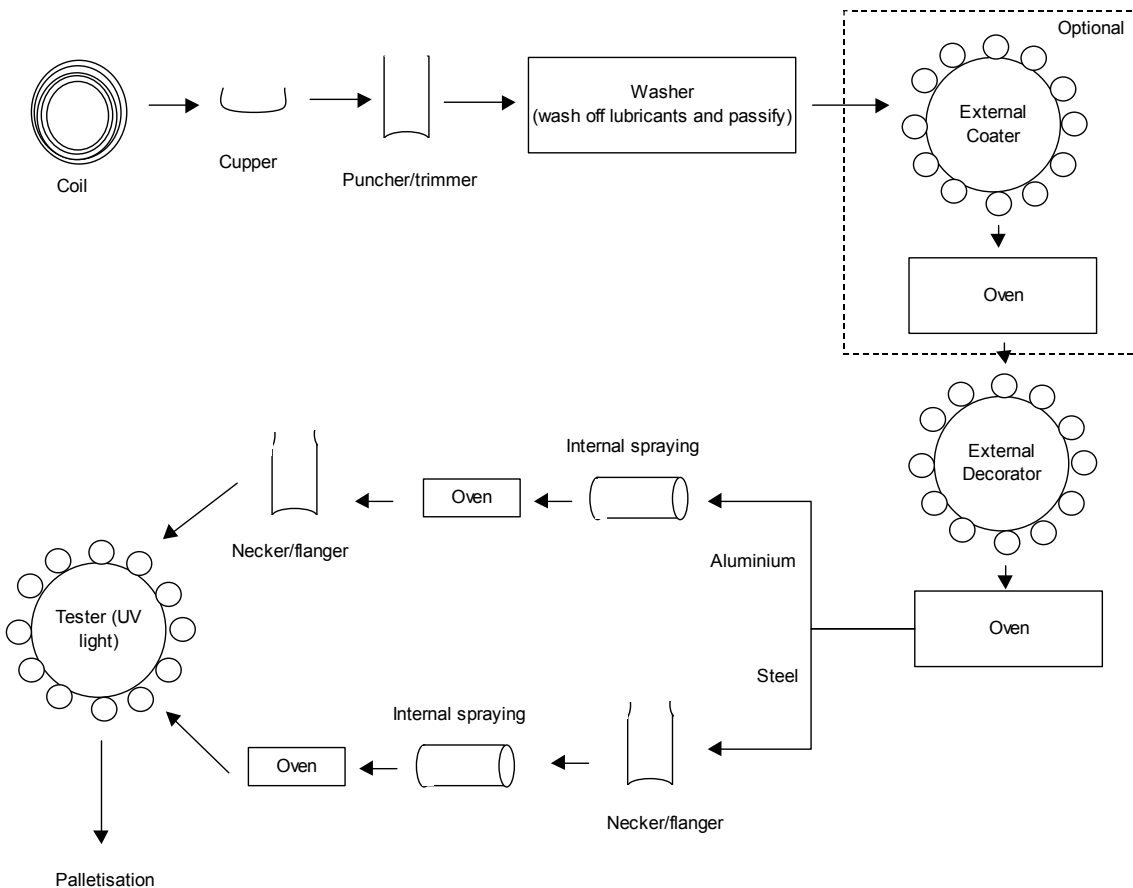


Figure 6.1: Process description for beer and beverage can manufacture

As mentioned above, beer and beverage cans are generally made in two pieces. The main coating processes apply to the body of the can (with this being the production process represented in Figure 6.1)¹⁸. There are two key coating processes, which are as follows:

1. **External coating of the can using roll coating.** This occurs following punching of a metal ‘cup’ into shape and washing of the metal. It may be undertaken in two stages (where first the coater applies a clear or pigmented basecoat and then the decorator applies up to six additional colours and a varnish) or alternatively in just one stage (only a decorator is used).
2. **Internal coating (lacquering) of the can using spray application.** It is common for two sprayers to be used simultaneously for internal coating. In the case of aluminium

¹⁸ The ‘easy open’ ends are produced separately using coil coating processes.

cans, internal coating occurs before the can is shaped to give the ‘neck’ whilst for steel cans, this coating occurs afterwards.

Following each of the coating stages, the metal cans are placed in an oven, during which the coating cures and solvents (including water) are evaporated. In general, emissions from beer and beverage can coatings application are not treated at either the coating stage or from the ovens.

Due to recent legislative changes in the EU and in Member States (Solvents Emissions Directive, LAPC Regulations in the UK, etc.) there has been a widespread shift in *external* coatings to water-borne products, although some solvent-borne products are still in use. The *internal* lacquers are generally water-borne products. Table 6.2 provides details of ‘typical’ coating products used internally and externally. Table 6.3 presents estimates of the amounts of total coatings used per can and per site for the three types of cans.

Table 6.2: Coatings used in beer and beverage can manufacture

	External Water-Borne	External Solvent-Borne	Internal Lacquer
Resin used	Acrylic/polyester	Acrylic/polyester	Epoxy
Organic solvent	20 %	50 %	15 - 20 %
Solids	50 %	50 %	20 - 25 %
Water	30 %	-	55 - 65 %

Table 6.3: Use of coatings at can manufacturers in the UK

	Beer & beverage	Food	General line
Total cans (billions)	7.4	5.7	2.9 ^a
Total sites	8	8	17
Total solvent use (tpa)	2831	3953	2754
Solvent %	30%	64%	54%
Total coating use (tpa)	9437	6177	5100
Average coating per site (tpa)	1180	772	300
Coating per can (g)	1.3	1.1	5.1

Note: a – includes aerosols and metal closures from Table 6.1

6.2.3 Food cans and general line cans

Figure 6.2 describes the processes employed in coating food cans and general line cans. As mentioned above, these are usually three-piece cans although some two-piece food and general line cans are also produced.

The coatings used are generally solvent-borne, in contrast to the beer and beverage can sector. Food cans are generally coated on the inside only. Some general line cans are also coated on the outside.

In this case, the sheet metal (generally steel) is cut into large sheets. Coatings (lacquers) are applied to these sheets before they are cut further into 'body blanks'. Since the body of a can is formed from a 'blank' (i.e. a sheet of metal), it requires joining into a cylinder. Once joined, a further stage of coating takes place. This is undertaken by spraying on a 'sidestripe' to the inside of the join, utilising a solvent-borne coating, similar to the internal food can coatings. After the coating/lacquer is applied, incineration of the exhaust fumes is generally undertaken in order to reduce solvent emissions.

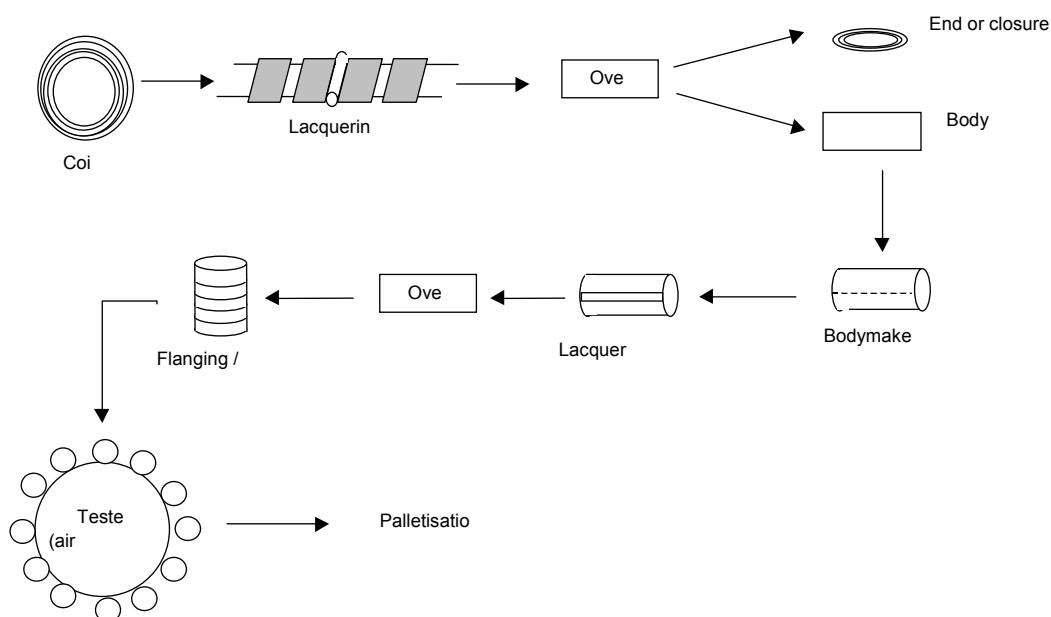


Figure 6.2: Process description for three-piece food can/general line can coating

The coatings used internally in food cans are generally epoxy phenolic lacquers (containing around 35% solids). For general line cans, there is a wide variety of different (generally solvent-borne) coatings used, with single facilities using up to 80 different specifications of coating materials in one year.

6.3 Emissions estimates

6.3.1 Beer and beverage cans

Figure 6.3 describes the key emission points for external coating of beer and beverage cans and subsequent lifecycle stages. The figure also indicates the estimated level of emissions at each of these points. Figure 6.4 provides estimates for internal lacquering. The emissions estimates included in Figures 6.3 and 6.4 can be characterised as follows:

- 1.5% is an average value for the percentage of coating left in containers. The value is lower than, for example, consumer paints because the majority of containers will not

end up in the waste stream, since internal lacquers are generally supplied in bulk and external coatings are usually supplied in returnable containers.

- Of the external coating that is transferred from the roller, all of the solvent (and water) will be lost to air (exhaust from coating process and ovens). Additionally, 1% of the solids will be contained upon process scrap, which is generally recycled.
- For internal lacquering, all of the solvent contained in the lacquer is again assumed to be lost direct to air. Additionally, there will be overspray of 3% solids with these being lost. 1% of this will be lost through the exhaust to air, with the remainder (2%) being deposited on the ground within the facility (and assumed to pass eventually to landfill).
- There are assumed to be no environmental emissions during in-service use.

When considering possible emissions at the end-of-life stage, it is important to consider the disposal route. At present, recycling rates for steel and aluminium packaging in the UK are 42% and 24% respectively, for example. These values are taken into consideration in the example calculations below. The recycling rates of other EU countries should be taken into account where appropriate.

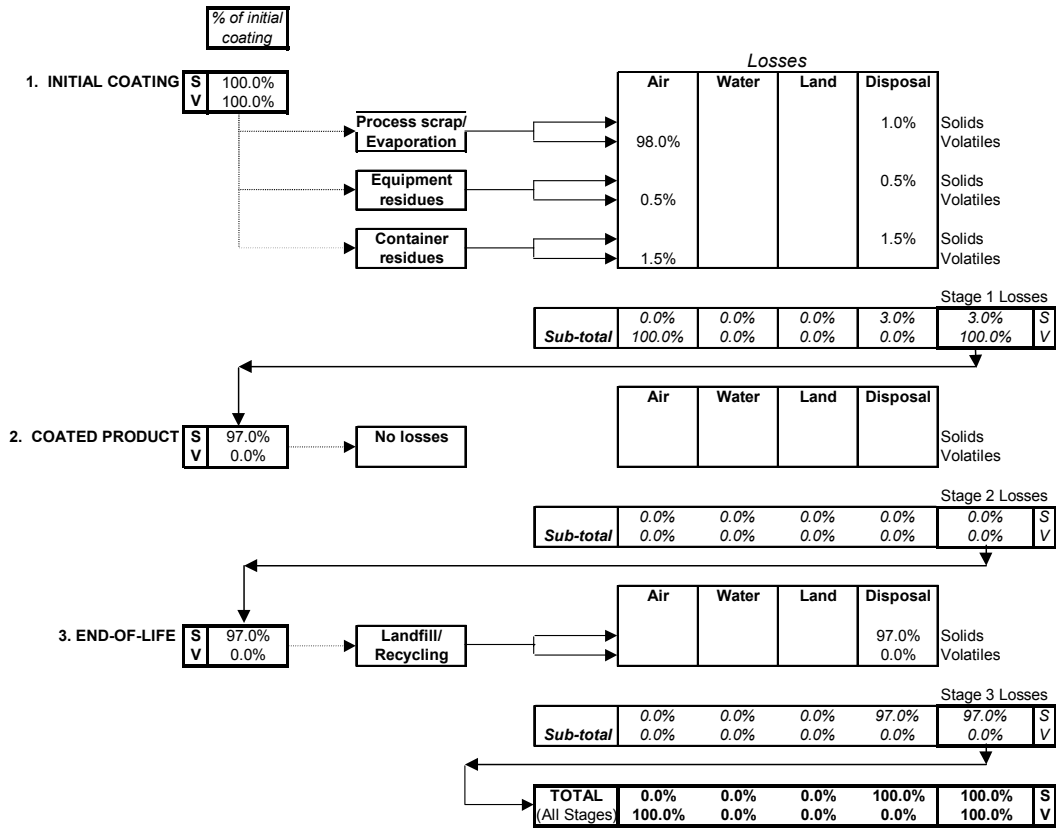


Figure 6.3: Emissions estimates for external coating of 2-piece beer/beverage cans

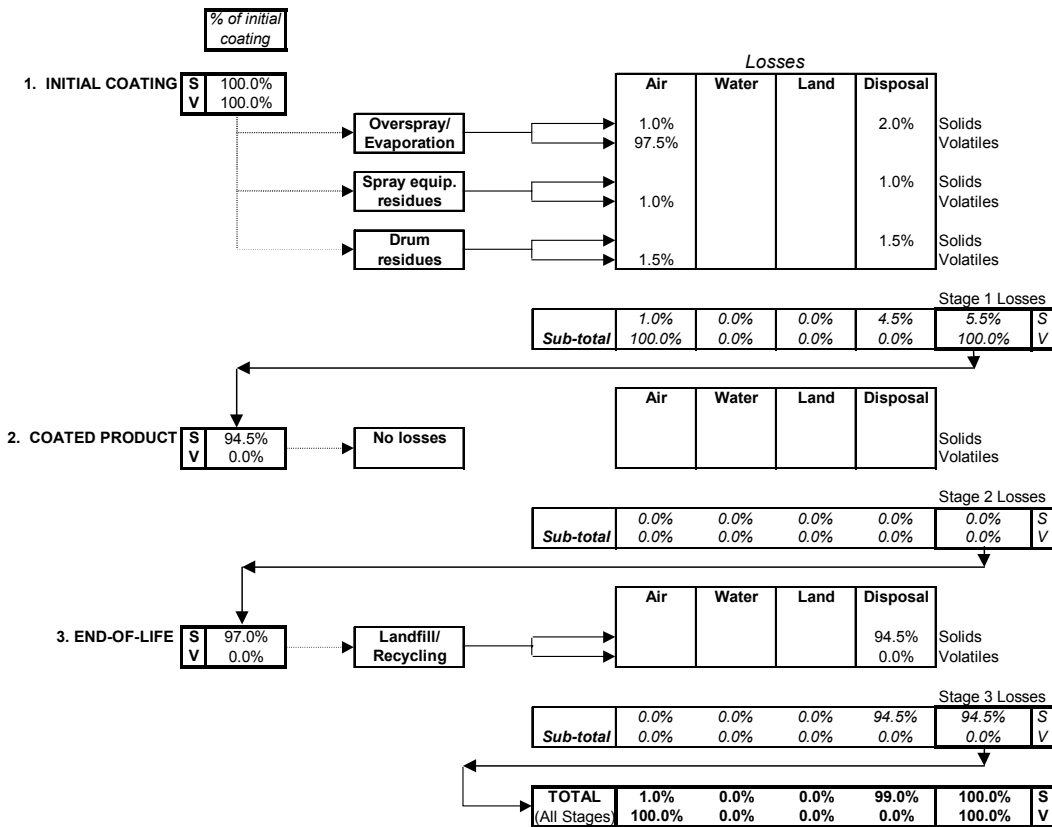


Figure 6.4: Estimates for internal lacquering of 2-piece beer/beverage cans

In terms of disposal from the facility (coatings containers, other wastes relating to overspray, etc.), these are generally required to be treated as special waste (and would thus be landfilled as such). However, in practice, the wastes may not always be treated as being special wastes.

6.3.2 Food cans and general line cans

Figure 6.5 provides emission estimates for coatings used on food cans and general line cans. As stated above, emissions from the coating process and oven are abated using incineration. Emissions to air, therefore, are provided in terms of total loss (100%, representing all of the solvent) and loss after abatement (assumed to reduce losses by about 37% leaving about 63% of treated volatiles being emitted to air, according to information obtained from industry sources). Abatement approaches used in the flowchart above are based on data for UK manufacturers of food cans and general line cans. The extensive use of abatement techniques for these has been reported to be the result of the non-availability of coatings compliant to the relevant PG6/7 LAPC Guidance by these manufacturers.

For further details of the basis for the emission estimates, please refer to Environment Agency R & D Technical Summary P2-203/TS1 (Environment Agency, 2002).

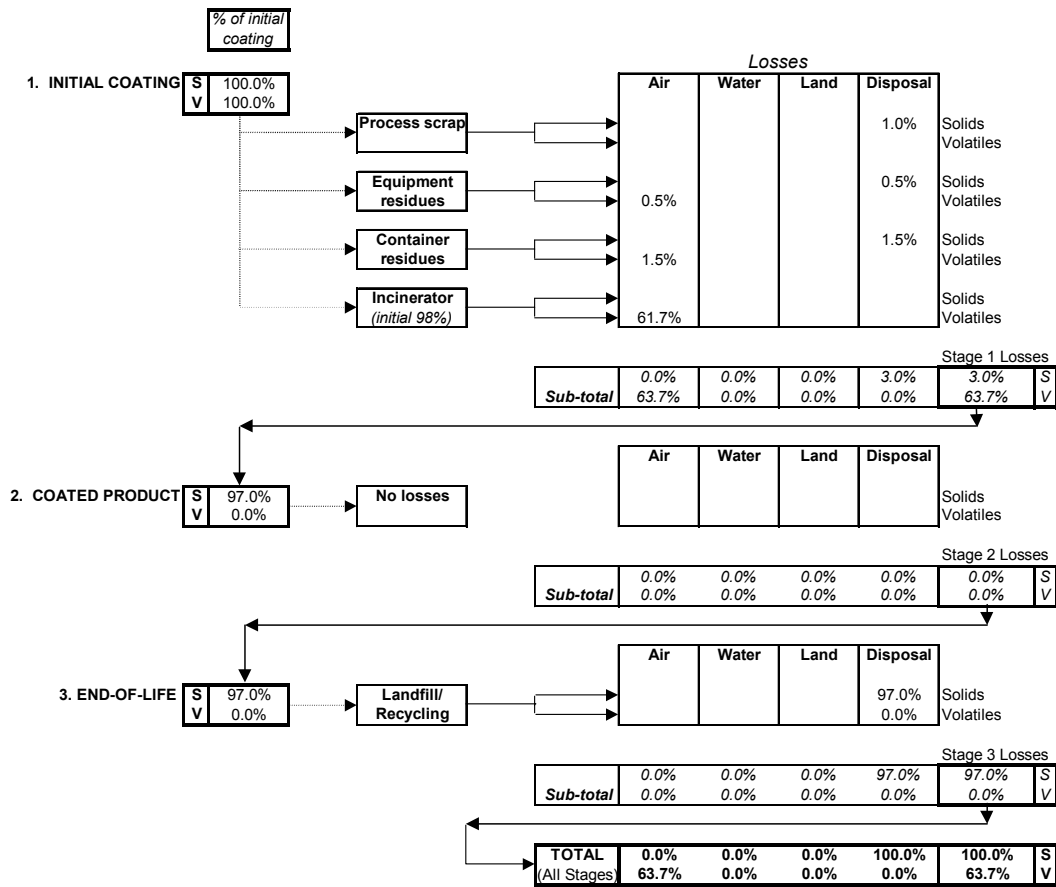


Figure 6.5: Emissions estimates for three-piece food/general line can coating

6.4 Example calculations

Insoluble substance X is used as a stabiliser in general line coating by a UK coater. It is used in the coatings at a typical concentration of 3.5% by weight. It is assumed that X is used in 10% of all three-piece general line can manufacture.

In order to estimate emissions of X from a single facility in a year, the average amount of coating per site from Table 6.3 (300 tonnes per year) is used. It is also assumed that the site operates for 300 days per year. The substance is used in 10% of the coatings at the site; it is assumed that when coatings containing the substance are in use they are used for the whole production at that time; hence use of coatings containing the substance takes place on 30 days per year.

The daily use of coating $Q_{init_coat_day}$ is 1 tonne. The content of the substance $Q_{subst_in_coat}$ is 0.035 kg/kg (3.5%).

From Figure 6.5 (general line coating), $F_{init_coat, process_scrap, waste} = 1.0\%$, $F_{init_coat, equip_res, waste} = 0.5\%$ and $F_{init_coat, contain_res, waste} = 1.5\%$. Hence:

$$E_{init_coat, waste} = 1000 \times 0.035 \times (1+0.5+1.5)/100 = 1.05 \text{ kg/day.}$$

It should be noted that the use of special waste landfills may not always be the endpoint for wastes generated during the aforementioned stages.

Assuming a similar level of use at all general line coating plants in the UK, the total amount of coating used containing the substance would be 17 plants x 30 days x 1 tonne/day, or 510 tonnes per year. Of this, 97% is on the cans after application. The recycling rates from Section 6.3.1 are assumed to apply, so 42% is recycled and 58% disposed of. Hence the amounts of substance involved are:

$$E_{end_of_life, recyc} = 510,000 \times 0.97 \times 0.035 \times 42/100 = 7,300 \text{ kg/year}$$

$$E_{end_of_life, waste} = 510,000 \times 0.97 \times 0.035 \times 58/100 = 10,000 \text{ kg/year}$$

Note that at this stage, the fractions for amounts recycled and to waste are not adjusted to apply to the amount originally applied, hence the total amount of coating is adjusted by the fraction of coating actually on the cans. Other countries or regions may have different recycling rates, so the calculations would need to be adjusted in such cases.

More specific information on the total amount of substance used or the total amount of coating containing the substance could be used to estimate overall emissions at each stage, as described in other examples.

7 COIL COATINGS

7.1 *General overview of the sector*

Coil coating is the process of applying a coating to sheet metal in order to provide a pre-coated material for use in a wide range of downstream sectors. The coated sheet metal can then be formed using processes such as stamping, drawing or bending for use in the finished article.

Application of a coating to flat sheet metal is more efficient than application to shaped products (the transfer efficiency is greater). Further, where companies use pre-coated metal, they will not be subject to the regulatory provisions relating to coating that would otherwise apply.

The most common types of industries using coated coil are as follows:

- Building and construction.
- Automotive and other road transport.
- Domestic appliances (e.g. washing machines).
- Electrical and electronics.
- Recreational vehicles (such as caravans).
- Signs.

Coil coating can be applied to both steel and aluminium sheet metal. The total area of metal coated in the UK in 2002 was reported to be around 100 million m². Of that 90% represented coating of steel, with the remaining representing coating of aluminium. With regard to the total of the EU, data exist for the year 1999. According to the European Coil Coatings Association (ECCA), in EU the total area coated was just over 1 billion m². Of this:

- 828 million m² were coated steel, and
- 241 million m² were coated aluminium (ECCA, 2003).

There are four companies involved in coil coating throughout the UK. Three of these companies operate one coating line each with the fourth operating six lines. Only one line is for coating of aluminium and the rest are for steel (hot-dipped-galvanised, electrozinc, cold rolled steel or aluminium coated steel). Information presented in this section was provided by UK representatives of ECCA and is believed to reflect the EU situation as well the UK one. As can be derived from Tables 2.1 and 2.2, Part I, coil coatings consumption accounts for 110,000 tonnes with a total value of €0.5 billion in 2001.

7.2 Process description and coating products used

7.2.1 Coating types and quantities

According to the ECCA (ECCA, 2003), the majority of paints applied during coil coating are of the polyester and PVC plastisol types. Note that when a liquid plastisol film is heated, it changes from a liquid to a solid. During this process, only around 5% of the diluent evaporates. The plasticiser is absorbed into the resin particles and they subsequently fuse, so the plasticiser is present in the cured (solid) film. The various coating types used are detailed in Table 7.1.

Table 7.1: Coating types used in coil coating applications

Coating Type	Solvents ¹ Used	Solids	Solvent
PVC plastisol	Hydrocarbon	60% ¹ (around 90% after curing)	< 10%
Polyester	Hydrocarbon, ester, glycol ether	50 - 70%	30 - 50%
Backing coat			
Silicone polyester			
Polyurethane			
Poly(vinylidene fluoride)	Hydrocarbon, ester, glycol ether, ketone	50 - 60%	40 - 50%
Epoxy primer	Hydrocarbon, ester, glycol ether, alcohol	45 - 55%	45 - 55%
Polyester primer		50 - 60%	40 - 50%

Note: ¹In a plastisol, the hydrocarbon used does not dissolve the PVC resin; it is rather used to modify the viscosity of the paint (contrary to the use of solvents in solvent-borne coatings). Therefore, the term 'solvent' used in the table should be assumed to mean 'diluent' in the case of plastisol coatings (ECCA, 2003).

Table 7.2 provides details of the breakdown of coatings used in the EU coil coating industry for 1999. The total quantity of these coating products amounted for around 140 million kilograms in 1999.

Table 7.2 Breakdown of coatings use for the EU (1999 figures from ECCA, 2003)

Coating Product	Proportion Used
Total solvent-borne topcoaters, of which	65.1%
• Polyester	57.9%
• PVC plastisol ¹	27.7%
• Polyurethane polyester	6.4%
• Silicone modified polyester	1.0%
• PVdF	3.8%
• Acrylic	~0.0%
• Others	3.2%
Primers	18.3%
Backing coats	16.4%

Note: ¹As indicated in Table 7.1, PVC plastisol cannot be strictly considered a 'solvent-borne' coating.

7.2.2 Coating process

Figure 7.1 provides an overview of the key stages involved in coil coating. These can be further described as follows:

- At the entry section, uncoated coil enters the coating line and is joined to coil already in the process to ensure constant material flow through the process.

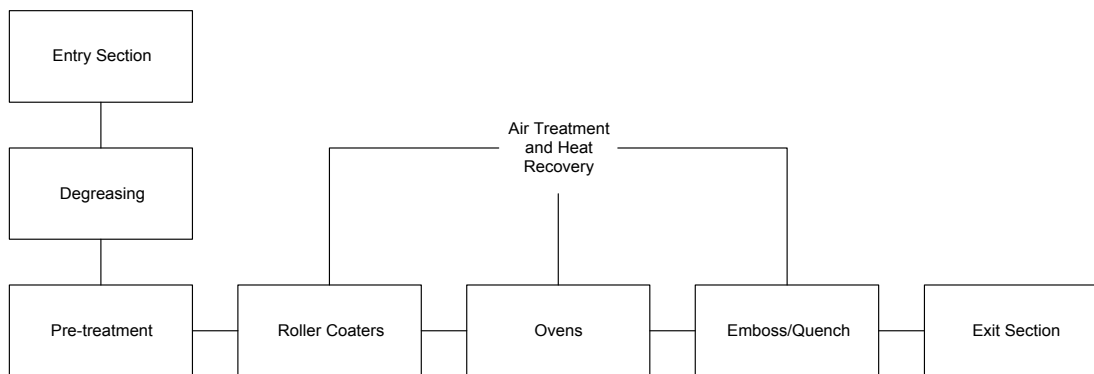


Figure 7.1: Stages involved in the coil coating process

- Dirt and oils are removed using an alkaline cleaning process and then a chromate conversion coating is applied to improve corrosion resistance and increase paint adhesion.
- The painting process involves passing the coil through a roll coating machine, which first applies a primer to both sides of the strip. The primer is then cured in an oven before returning to the coating house for application of topcoats, followed by further curing in the oven.
- Curing takes place using conductive air technology with solvents and other fumes extracted using fans (fumes are incinerated and some of the heat recovered).
- The coated strip is then quenched using water spraying and dried with an air blower¹⁹.
- The coated coil is packaged for shipment to the customers.

Larger coating lines can hold up to 32 tonnes of metal, with widths up to 1.90 metres and thickness from 0.15 to 2 mm. Coil can pass through the process at up to 120 metres per minute or even 150 meters per minute depending on the width of the strip (e.g. 600-700 cm) (ECCA, 2003).

7.3 Emissions Estimates

The emissions estimates of concern here do not relate to any pre-treatments that might be applied but rather to the paints themselves. Emissions of pre-treatments, such as chromates that are applied to the metal coil, are considered in another document (Environment Agency, 1997).

Coatings are shipped to a site in sealed tanks or drums (usually 205 litre barrels) and are stored in heated and ventilated areas. They are supplied ready-for-use (RFU) and thus do not generally require the addition of thinners. They do, however, require mixing which is undertaken in a dedicated (ventilated) mixing room.

¹⁹ For PVC plastisols, an embossing roll is used to imprint a pattern to the paint surface before quenching takes place.

Coating machines are almost exclusively enclosed in order to minimise losses of solvents to the wider factory atmosphere, while coating houses are ventilated using fans. There are two main situations in the UK regarding extraction and treatment of air:

1. Fans vent air from the coating houses to atmosphere. Localised extraction is used to remove solvent fumes from close to the coil surface and coating equipment, with these then incinerated.
2. Alternatively, all air from the coating room can be extracted and passed through the oven system and then incinerated²⁰.

Application of coatings using roll coating is very efficient with the main process wastes relating to paint residues remaining in barrels. These account for between 0.5% and 3% of the coating used.

A circulation system pumps the coating directly onto the roller coater (or in some cases, the applicator roller picks up paint direct from a tray). Following a production run, unused paints will generally be pumped back into drums from circulation pipes and trays. Less than 1% of the paint used is lost through cleaning of equipment.

Pipes and trays are then cleaned using solvents such as methyl ethyl ketone, xylene, aromatic hydrocarbons and esters (or mixtures of these solvents).

In the curing ovens, solvents and other organic fumes are extracted in order to maintain a mass flow and pressure balance, which prevents the escape of fumes and ensures that organic vapour concentrations do not reach potentially explosive levels²¹. These fumes are then incinerated at over 650°C and the remaining air is vented to atmosphere. Heat exchangers are often employed during this incineration process, in order to feed pre-heated air to the curing ovens or to heat process water. Efficiencies of the incinerators (oxidisers) range from 99.45% to 99.8%, according to the UK coil coating industry.

Water is used in the quenching process and overflow is then passed to sewer. However, coating constituents in this water are not monitored and concentrations are assumed to be negligible (since the coating will have cured by the time the coated coil is quenched). For the purposes of this document (as a worst case estimate), it is estimated that 0.25% of the coating's solid constituents will be lost to water during quenching. These estimates were agreed collectively by all four coil manufacturers in the UK.

Wash wastes from rollers, paint trays and pipes will contain large amounts of solvent and are sent to drums for solvent recovery. This is also true of unused paint wastes, which are combined within drums and also sent for chemical recovery (as described in Section 11). Return rates for solvent-borne wastes shipped for chemical recovery are generally in the order of 65 to 80%.

²⁰ It is expected that all UK sites will have incineration facilities by the end of 2001.

²¹ Concentrations are kept to below 25% of the lower explosive limit.

In terms of in-service losses, emissions are assumed to be essentially zero. For most coil coated products, the coating is designed to last longer than the finished product (with build guarantees from 20 to 50 years). In some cases, there may be limited chalking of (or to a smaller extent leaching of constituents from) products during use, but these will be dependent upon the application in question.

The estimated emissions for coil coating are provided in Figure 7.2. In interpreting these estimates, the following should be taken into account:

- Loss of solvent during the coating process will occur during mixing, coating and curing but is assumed here to occur during curing (for simplicity).
- The estimates assume that incineration of emissions from the curing ovens (and wider factory atmosphere) takes place. For sites with no incineration, all volatiles not contained as residues or waste paints will be lost to atmosphere.
- As indicated above, wastes from equipment washing and drums are sent for chemical recovery.

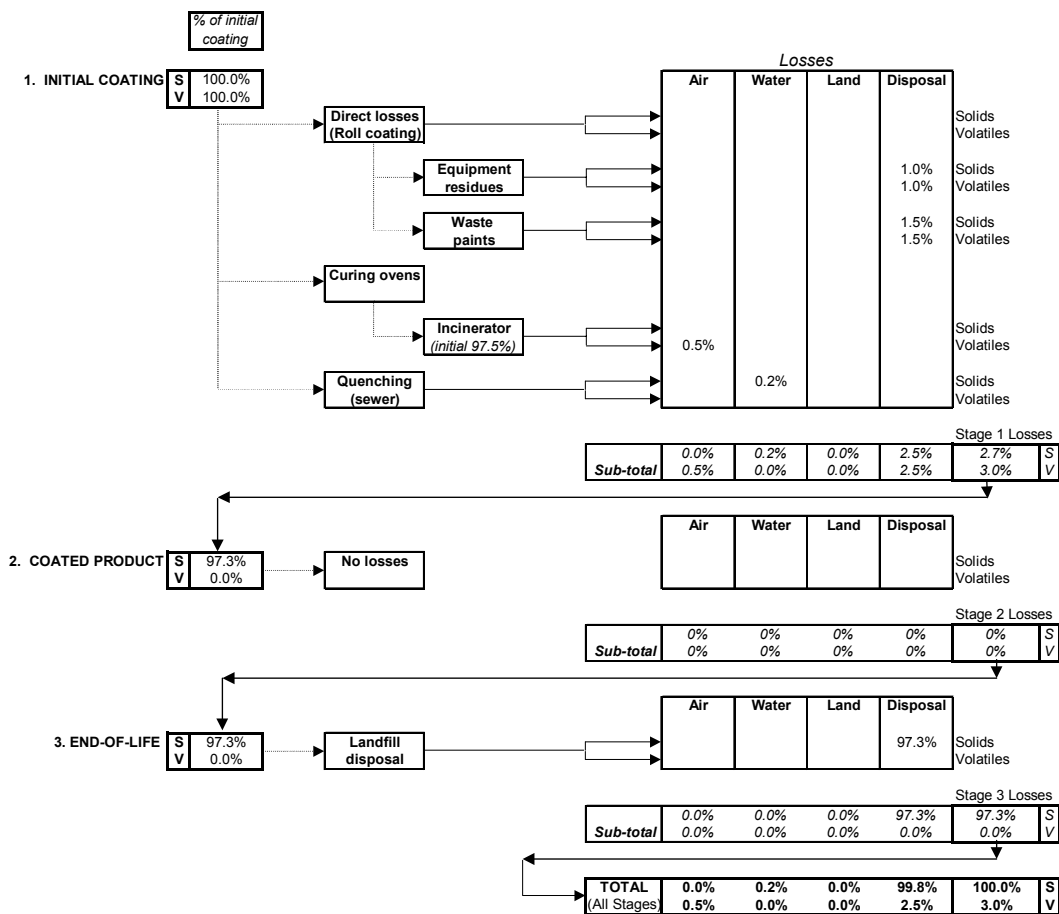


Figure 7.2: Emissions estimates for coil coatings application

For further details of the basis for the emission estimates, please refer to Environment Agency, 2002.

7.4 Example calculations

Tripropylene glycol ether X is used as the main solvent in polyurethane coatings used in a coil coating manufacturing company. The percentage of X in the volatile fraction of the coatings is estimated to be 76% with an average solvent content of the coatings equal to 48% of total coating weight.

From Section 7.1, there are four companies involved in coil coating, operating a total of nine lines between them. Total production is ~100 million m². Assuming that each line produces roughly the same amount of material, a single line produces around 10 million m² per year. Assuming continuous operation for 365 days, the daily production is 2.7x10⁴ m²/day.

The total production in the EU is ~10⁹ m², hence the daily production for one line is 2.7x10⁻³% of this. The total amount of coating used in this area in the EU is 110,000 tonnes (Section 7.1). Hence the approximate coating use per day is 2.7x10⁻³% of this, or ~3 tonnes. Coil coating operations are run to minimise changes, so it is assumed that the coatings containing the substance will be used for a continuous period, so that use over a whole day can be considered. Hence $Q_{init_coat_day}$ is 3 tonnes, or 3,000 kg.

The solvent content of the coating is 48% and the substance makes up 75% of the solvent. Hence the content of the substance in the coating ($Q_{subst_in_coat}$) is 48% x 75% or 0.36 kg/kg.

From Figure 7.2, the emission/transfer factors are: $F_{init_coat, equip_res, waste} = 1.0\%$; $F_{init_coat, waste_paint, waste} = 1.5\%$; $F_{init_coat, incin, air} = 0.5\%$. Hence the emissions are:

$$E_{init_coat, waste} = 3000 \times 0.36 \times (1+1.5)/100 = 27 \text{ kg/day}$$

$$E_{init_coat, air} = 3000 \times 0.36 \times 0.5/100 = 5.4 \text{ kg/day}$$

The remaining 97% is destroyed in the incinerator, so there are no losses from products. Emissions could be scaled up to the UK by multiplying by 10; however, this would need to be checked against the total amount of substance used.

8 MARINE COATINGS

8.1 General overview of the sector

This section covers the coating operations involved in the building of new vessels and maintenance and repair activities. Around 110,000 tonnes of coatings are used per annum with a value of around €0.3 billion, according to 2001 data for the EU (see Table 2.2, Part I).

Painting is reported to be feasibly carried out at almost every location within the shipyard, with several types of paints serving a range of applications. There are six key areas where shipboard paints are required (NPI, 1999):

- Underwater (hull bottom).
- Waterline.
- Topside superstructures.
- Internal spaces and tanks.
- Weather decks.
- Loose equipment.

This section examines emissions associated with the use of coatings in the marine industry by professional users. Consumer application has not been included due to the fact that no documented or other data were found and because it is very difficult to develop site-specific emission estimates for the at-large, uncontrollable use of such products by the public.

However, a considerable part of the data provided below has been derived from internationally available sources of information and therefore they are likely to reflect practices in the wider EU marine coating sector.

8.2 *Process description and coating products used*

8.2.1 Overview

Surface coating is necessary in the shipbuilding and repair industry so as to prevent corrosion and deterioration of the structure and components of the ship. Coating activities vary from the initial priming of the steel to the final paint decoration of the ship. The key activities that may lead to environmental releases are surface pre-treatment, coating application and equipment cleaning.

8.2.2 Surface pre-treatment

A ship's surface needs to be prepared prior to any new coatings being applied, with this being particularly important with regard to the re-coating of ships.

Raw steel sheets and parts first receive a pre-construction prime coat, which is important for maintaining the condition of the part throughout the construction process. Steel plates, shapes, sections of piping and ventilation ducting receive this pre-construction coat. Most pre-construction primers are zinc-rich with organic or inorganic binders and these coatings offer protection similar (but not identical) to galvanising, with zinc oxide forming a water-impermeable layer (NPI, 1999).

Abrasive blasting is the most common method for removal of existing paint layers, utilising abrasives such as copper slag, coal slag, steel grit, steel shot and glass. There are three basic types of abrasive blasting used in shipyards (NPI, 1999):

Centrifugal blasting, which has the advantage of easy recovery of abrasive materials for reuse and recycling, leading to significant savings in purchasing and disposal costs.

Air nozzle blasting, which can be performed manually either in blast booths or in the open air depending on the application.

Wet abrasive blasting and **hydro-blasting**, which are used for the removal of chipping paint, marine growth (including organisms), mud, and salt water from the ship's hull while it is in a floating dry dock, graving dock or other building or repair positions.

8.2.3 *Coating application*

Coating application methods vary according to the area of the vessel that is being painted, for example:

- Paint may be mixed manually or automatically.
- Coating may take place either indoors or outdoors.
- Shrouding fences may be used to block release of overspray from the painting area.

Spraying is usually undertaken using airless sprayers, which have a transfer efficiency of around 90%. Air-assisted systems can achieve a transfer efficiency as high as 80% (although the actual TE is usually below this threshold) (NPI, 1999).

Hull painting is usually performed when the vessel is fully dry-docked. Airless spray guns are most often used and, for the hard to reach areas, lifts or scaffolding facilitate the coating of the entire hull surface. Superstructure painting (decks, deck houses and structures above the main deck) is undertaken on scaffolds and shrouding is generally used to prevent paint from falling into adjacent waters. Detachable parts, such as doors, are coated before fitting in spray booths (either dry filter booths or water wash booths) (see other Sections for estimating emissions from wet and dry booths, e.g. Section 5, Part III).

The two main types of paints used in the industry are:

- Anticorrosive paints, including vinyl, lacquer, urethane, or epoxy-based coating systems.
- Antifouling paints, used to prevent the growth of marine organisms by releasing small quantities of toxins, which discourage marine life from growing on the hull (NPI, 1999).

Typical primers used on boats are one- and two-pack epoxy coatings. Typical finishes include one and two-pack polyurethanes. Varnishes used on boats are often also polyurethane-based. Antifoulant coatings are not examined in this report (for this see the OECD ESD ENV/JM/MONO(2005)8).

As with other industry sectors, legislative pressures have stimulated a move towards coatings with lower solvent emissions. Greater use of high solids coatings and water-borne coatings is becoming more prevalent. For example, the existing ESD indicates that the amounts of volatiles and solids in marine coatings are 45% and 55% respectively. Since many of the coating operations are carried out outdoors, companies have tended to follow the route of using compliant coatings in relation to the requirements of national legislation, such as the LAPC Regulations in the UK (emissions control is obviously more problematic outdoors). Typical compliant coatings have between 220 and 520 g/litre of solvent, or around 20% to 45% solvents (with some of these coatings containing water).

8.3 Emissions estimates

8.3.1 Surface preparation

The materials used and the emissions from blasting depend on the blasting method implemented. The choice of method depends on the condition of the surface in question (e.g. presence of old paint, rust, scale, dirt, grease, etc.), the type of coating to be applied, the size, shape and location of the surface and the type of metal.

Particulate matter from abrasive blasting will contain blasting abrasive and paint chips in proportions that are dependent upon the amount of abrasive used, the efficiency of the blasting method and the type of coating being removed. This particulate matter may be emitted both to the immediate area surrounding the work and to surrounding surface waters (depending upon containment methods²²).

8.3.2 Coating application

Painting/coating operations are the main source of solvent emissions and account for over half of the hazardous waste generated by processes undertaken at shipyards. The volatilisation of paint solvent during coating applications results in significant amounts of VOCs being released. Overspray of coatings is another source of air emissions, with solvents rapidly volatilising and the remaining dry paint particles drifting off site or into nearby surface waters (NPI, 1999).

Wastewater from spray booths is generally treated on-site using filtration, activated carbon adsorption or centrifugation. The resulting liquid is then reused rather than discharged (NPI, 1999).

8.3.3 Equipment cleaning and other residuals

Wastes from the coating process account for a significant proportion of total losses of paint components in shipyard operations and include the following (NPI, 1999):

²² Emissions of particulate matter are typically controlled by preparing surfaces indoors or by surrounding the work area with shrouding fences made of steel, plastic or fabric.

- Residue paint.
- Waste paint containers.
- Spent equipment.
- Masking paper, rags and other materials contaminated with paint.
- Spent solvents.
- Still bottoms from recycled cleaning solvents.
- Sludge from the sumps of water wash spray booths.

Wastewater contaminated with paint residues is produced as a result of equipment cleaning activities when water is used for cleaning purposes (i.e. when water-borne coatings are being used).

8.3.4 *Summary of emissions estimates*

The following assumptions underlie the emissions estimates presented in Figure 8.1:

- A transfer efficiency of 65% is assumed for application of non-antifoulant coatings.
- Of the remaining 35% solids that are oversprayed, 90% will be captured for disposal, with the remainder being spread evenly between water and land (industrial soil), working to the basis that vessels may be coated at berth, drydocked or indoors.
- All solvents are assumed to be lost to air during paint application.
- 1% of the coated (solids) material will be lost into the water during in-service use.
- At the end-of-life stage, coatings are removed by blasting and 90% of the remaining coating is assumed to be captured for disposal, with the remainder being lost to the environment, spread evenly between water and land (using the same assumptions as for the application stage).

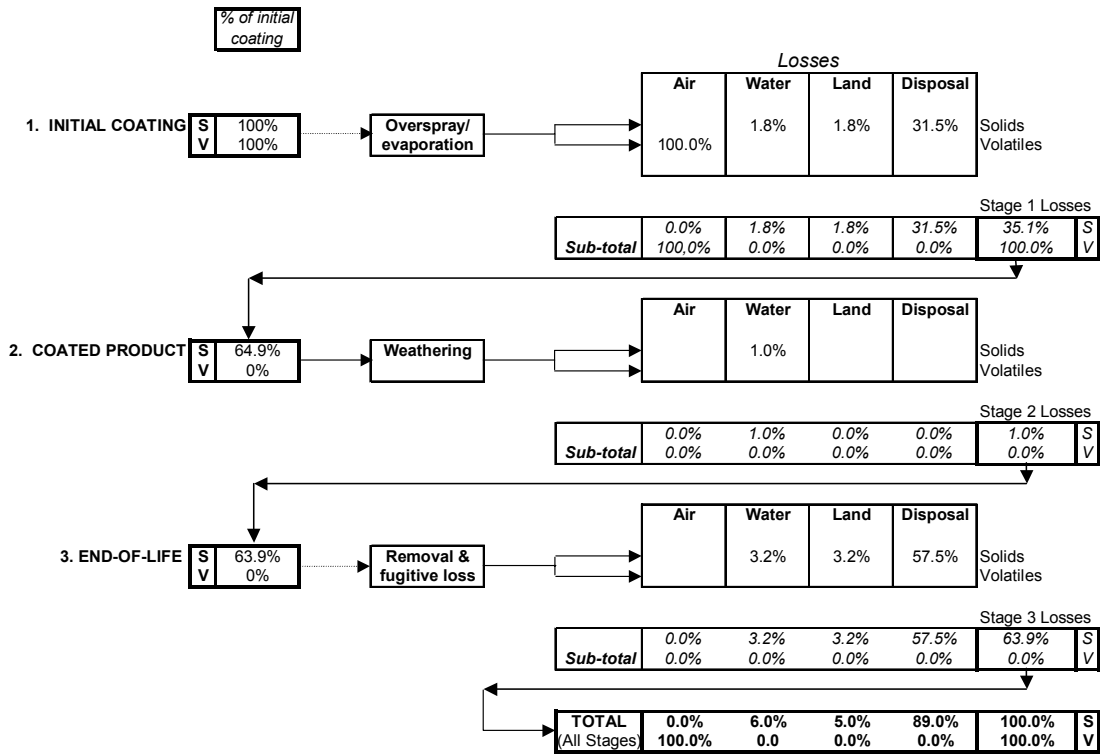


Figure 8.1: Emissions estimates for marine coatings application (non-antifoulant)

8.4 Example calculations

Solid insoluble plasticiser X is used in a two-pack epoxy non-antifoulant coating for marine vessels. One tonne is used in coatings at a typical concentration of 0.2% by weight (hence the total amount of coating is 500 tonnes).

There is no information on the amount used at a site. Using Table B3.13 in the TGD, for 500 tonnes of coating a fraction on main source of 0.15 is indicated, so the amount of coating at a site would be 75 tonnes per year. The number of days is 300, hence the amount used per day ($Q_{init_coat_day}$) is 250 kg. The content of the substance in the coating is 0.2%, hence $Q_{subst_in_coat}$ is 0.002 kg/kg.

From Figure 8.1, the emission factors are: $F_{init_coat, overspray, water} = 1.8\%$; $F_{init_coat, overspray, land} = 1.8\%$; $F_{init_coat, overspray, waste} = 31.5\%$. The resulting emissions are:

$$E_{init_coat, water} = 250 \times 0.002 \times 1.8/100 = 0.009 \text{ kg/day}$$

$$E_{init_coat, land} = 250 \times 0.002 \times 1.8/100 = 0.009 \text{ kg/day}$$

$$E_{init_coat, waste} = 250 \times 0.002 \times 31.5/100 = 0.16 \text{ kg/day}$$

Total releases can be estimated from the total tonnage of the substance used, i.e. 1 tonne ($\equiv Q_{init_coat_ann} \times Q_{subst_in_coat}$). For losses from coated products in use, the factor from Figure 8.1 is 1.0% ($F_{coated_prod, water}$) and hence the emissions are 1 tonne \times 1/100 = 10 kg/year.

9 COATINGS IN THE AEROSPACE INDUSTRY

9.1 *General overview of the sector*

This section covers the use of coatings in the aerospace industry, including both civilian and military aircraft. The industry comprises a wide range of companies, from very large ones manufacturing aircraft themselves (which they subsequently coat) down to the small and medium sized operators that specialise in the production of a single component. The number of coating facilities in the EU is uncertain, however, there were reported to be 15 facilities authorised for aircraft coating under the UK LAPC regime in 1999 (Entec 1999).

9.2 *Process description and coating products used*

9.2.1 *Overview*

There are three principal operations in the coating of aircraft, which may give rise to environmental emissions. These are:

- Surface preparation.
- Aircraft painting operations.
- Equipment cleaning.

For the purposes of this report, a process which involves both removal of existing coatings and replacement of these with new coatings is presented. The aim has been to ensure that all relevant stages in the lifecycle are addressed.

9.2.2 *Surface preparation*

There are two types of surface preparation, depending on the owner's requirements:

- Stripping and repainting (provides a good quality finish).
- Rubbing and repainting (no stripping or sealing involved but the surface is still re-primed and solvent-washed).

If a new coating is necessary for only a short period of time (e.g. for promotional or commercial reasons), then the second option is usually chosen by the owner of the aircraft. In such circumstances, coatings may be removed within a few months. However, an average lifetime for coatings in the industry is about 5 years.

For removal of existing paint, abrasive products and strippers (solvents) are used. After removal, the aeroplane is washed with solvent (manually from buckets) and resealed. No significant losses to the floor or the drainage systems are expected.

9.2.3 *Coating application*

9.2.3.1 Types of coatings

Coatings used in this sector tend to be specialist in nature due to the following requirements:

- They must be able to expand or contract with the aircraft during changes in temperature and pressure.
- They need to withstand the extreme conditions (e.g. temperature, erosion, corrosion) to which an aircraft's exterior is subjected during flight.
- They must comply with the relevant safety requirements.

There is a growing trend within the industry away from traditional ultraviolet resistant (UVR) paints that contain a significant amount of solvent to high solids coatings. UVR paints are generally two-pack polyurethane coatings that are mixed with hardener and thinner in a 2:2:1 ratio²³. By comparison, high solids paints tend to require smaller quantities of coating to achieve a finish of equivalent quality and do not require addition of thinner (besides that already contained in the paint).

For primers, there is also a trend towards the use of high solids coatings, although this change is occurring at a slower rate. Therefore, the quantities of thinner used with primers are greater than those used for topcoats.

9.2.3.2 Spraying

The majority of spraying is undertaken using electrostatic guns. The primer is added first and then either two or three topcoats, depending upon the type of paint used. Spray guns receive the coating material through long lines (e.g. 25 metres).

Around 10% of a typical plane will also be coated using conventional spraying. This occurs where, for example, a particular pattern is required, the small size of which makes use of electrostatic spraying unfeasible (since the paint must fill the 25 metre lines before it can be sprayed). Spray booths may also be used for coating smaller components.

Table 9.1 indicates the typical quantities of coatings used in painting of an aeroplane's fuselage (in this case an Airbus A320).

²³ As with several other sectors, aircraft painters generally apply a primer, followed by a base (colour) coat and then a clearcoat.

Table 9.1: Products used in high solids coating of an aeroplane

Layer	Coating	Quantity Used
Primers ¹	External primer	15 litres
	Internal primer	35 litres
Topcoats	Colour coats	82.5 litres

Notes ¹Thinners are added to primers in approximately a 1:1 ratio (no thinners added to topcoats).

²Around 95 litres of solvent will also be used for cleaning of spray guns and other equipment.

9.2.4 *Equipment cleaning*

After the coating procedure has been completed, solvent is passed through the paint lines to remove any paint residue (as indicated in Table 9.1). Some solvent may be reclaimed on-site (using solvent distillation equipment) with other solvent wastes being generally collected in an interceptor tank for controlled disposal or collected in drums for solvent reclamation by specialist companies (see also Section 11, Part III).

9.3 *Emissions estimates*

9.3.1 *Overview*

Painting of aircraft takes place in a hangar, which is sealed during spraying and which has extraction systems for removal of solvents and particulates from the workplace atmosphere.

The main emissions to air include solvent losses and overspray. Electrostatic guns have a transfer efficiency ranging from 60 to 95%, with 70% considered most realistic for this sector. In contrast, conventional spray guns have a lower transfer efficiency (30 to 60%) and, hence, have significant losses due to overspray. Both of these techniques will be used in spraying a typical aircraft.

Emissions to air are controlled using air extraction units during the coating operation (these are moved closer to the aeroplane when coating takes place). The air extraction units are fitted with filters that remove particulate matter, with solvents passing to atmosphere. During spraying, the air in the hangar is replaced around twice per hour.

An aircraft is masked before spraying takes place and a significant quantity of the coating will be lost via overspray to this masking. There will also be losses to overalls, facemasks and gloves, as well as to the floor (floors are washed regularly to remove oversprayed material). Both toxic and non-toxic waste skips are used²⁴ for such wastes, with the ratio of wastes between the two types being around 1:8.

²⁴ Toxic waste skips receive polyethylene masking material, stripper, drums which have contained phenolic products, paint tins, etc.

Hangars are fitted with drainage systems that remove the washings from the coating area and then take them to (interceptor) tanks. The tanks generally have a capacity of several thousand tonnes and are emptied around once every three or four months.

Waste collected from the interceptor tank is treated as special waste, with disposal at controlled landfills or through incineration.

Aerospace coatings are designed to withstand extreme conditions and are thus more resistant than coatings used in other sectors. However, given the abrasive conditions in flight, it is estimated that around 1% of the coating is lost during use, related to areas such as the turbines and high erosion areas (e.g. bolts).

9.3.2 *Summary of emissions estimates*

Figure 9.1 provides a summary of the estimated emissions for aircraft coating. It includes emissions occurring as a result of removal of existing coatings as well as application of the new paint and losses during use of the aircraft.

The estimates in Figure 9.1 are based on the following assumptions:

- 5% of paint product is assumed to be left in the spray equipment (lines, etc.), which is then removed by solvent and passes to disposal or recovery.
- Transfer efficiency is 68% with 80% of overspray being transferred to masking, clothes or the hangar floor. These wastes will be disposed of either in skips or will be washed to an interceptor tank.
- Of the remaining 20% overspray (6.1% of solids, after losses to equipment), three quarters is captured by fibreglass filters in the air extraction units (which are landfilled when saturated) and the remaining quarter is lost to air.
- 1% of the remaining coating solids on the aircraft is lost during use.

The estimates in Figure 9.1 do not include emissions from coating of small components of aircraft. Such coating is usually undertaken in a spray booth (see, for example, Section 5, Part III for estimates of emissions from spray booths in automotive coating). Emissions from such spray booths are usually vented to the extraction system used for removal of emissions from the hangar when spraying the fuselage. In some cases, however, emissions from spray booths are controlled in such way that there are essentially zero emissions to atmosphere. These figures were developed after consulting (and visiting) with UK organisations that perform coating operations on both passenger and military aircraft.

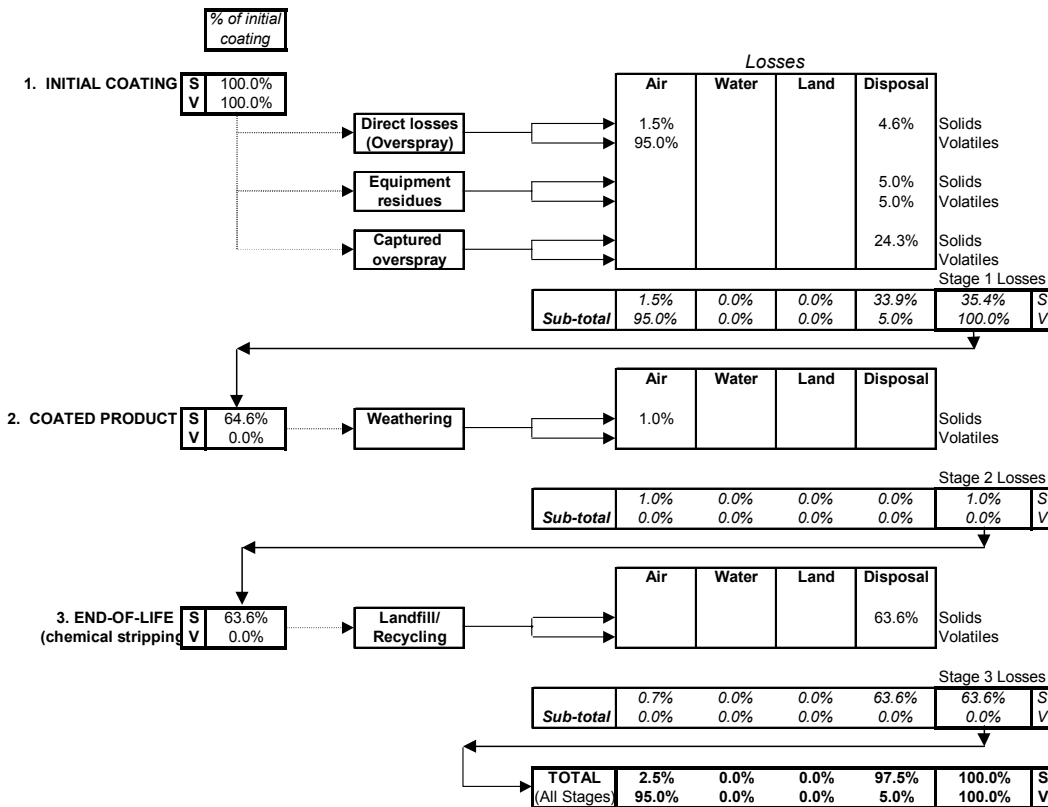


Figure 9.1: Emissions estimates for aircraft painting

9.4 Example calculations

Solid insoluble substance X is used as a rheology modifier in polyurethane top coatings for the aerospace industry. The average use concentration is 1%. There is no specific information on the amount used at a site per day; for the purpose of this calculation it is assumed that a site applies the equivalent of a single coat to an Airbus A320 each day. From Table 9.1, the amount of topcoat applied to an Airbus is 82.5 litres; Section 9.2.3.2 indicates that this would be for two or three coats, so half of this is taken as the use per day, i.e. 41 litres. This is equivalent to $Q_{init_coat_day}$ with different units. In this example the concentration given for the substance is by mass, so the density of the coating is assumed to be 1, hence $Q_{init_coat_day}$ is 41 kg/day. The content is 1%, hence $Q_{subst_in_coat}$ is 0.01.

From Figure 9.1, the emission factors are: $F_{init_coat, direct_loss, air} = 1.5\%$; $F_{init_coat, direct_loss, waste} = 4.6\%$; $F_{init_coat, equip_res, waste} = 5\%$; $F_{init_coat, capt_spray, waste} = 24.3\%$. Hence the emissions are:

$$E_{init_coat, air} = 41 \times 0.01 \times 1.5/100 = 6.2 \times 10^{-3} \text{ kg/day}$$

$$E_{init_coat, waste} = 41 \times 0.01 \times (4.6+5+24.3)/100 = 0.14 \text{ kg/day.}$$

10 RAIL VEHICLE COATINGS

10.1 *General overview of the sector*

No EU-specific information is available. There are three main companies in the UK that undertake coating of both new and existing rail vehicles. There is at least one further company undertaking large-scale recoating of rail vehicles. Furthermore, there are several smaller companies that undertake small scale recoating. In total, there are at least 10 companies involved in rail coating which are subject to control under the UK LAPC regime.

The sector is currently undergoing significant consolidation in the UK and it is expected that there will only be two principal companies involved in coating operations within the near future (although the number of sites is expected to remain the same).

Companies involved in the manufacture of new rail vehicles (and also trams, which are coated using similar methods) tend to have their state of the art facilities in other EU countries (such as Belgium and Italy). It is expected, therefore, that the majority of new coating activities will occur outside the UK in the near future, with repainting becoming relatively much more prevalent.

No specific data on the consumption of coatings and the number of vehicles coated per year were made available for UK companies. Data that were obtained from consultees and a site visit may not be representative of the entire industry sector and could also be misleading given the envisaged changes in the rail industry. Generally, the number of vehicles being refinished each year may well be up to several hundred, while the consumption of ready for use coatings per vehicle was given as an indicative value of 80 litres.

10.2 *Process description and coating products used*

10.2.1 *Overview*

There are three principal activities during coating of rail vehicles that may lead to environmental releases:

- Surface preparation (particularly removal of existing coatings).
- Coating of the rail vehicle.
- Equipment cleaning.

Figure 10.1 provides an overview of the coating processes of relevance in rail vehicle coating. For the purposes of this report, a process that both removes and replaces coatings is considered appropriate because this represents all of the relevant stages in the lifecycle. In general, rail vehicles are prepared for coating by shot blasting and then coated with paint by spray application. However, a small proportion (around 10%) are prepared by mechanical sanding and then painted using brush application.

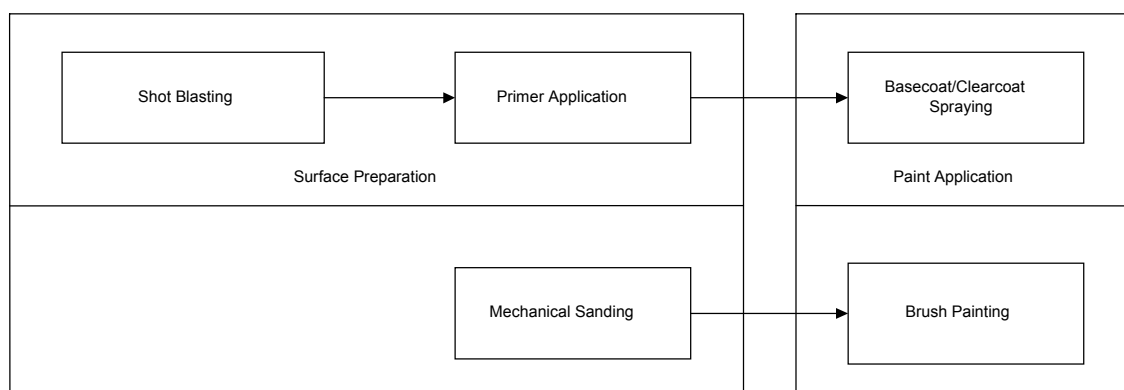


Figure 10.1: Coating processes for rail vehicles

A rail coating facility will also undertake various other activities, such as maintenance and repair of interiors, bogies, wheels and underframes. These are not considered in detail here since they either do not relate specifically to coating activities or are relatively minor as compared to coating of the main rail vehicles.

10.2.2 *Surface preparation*

The most common method of preparing (existing) rail vehicles for coating is through shot blasting of the exterior to remove the existing paint. This is undertaken in a dedicated building in which both shot blasting and application of the first primer layer takes place²⁵.

Aluminium oxide is used as the shot blast medium. Around 0.25 tonnes per vehicle are used in the removal of all of the existing paint. The paint, mixed with the shot blast medium, is removed from the room using dust extractors and is collected in bags which are sent for disposal in controlled landfills. During application of the primer, the dust extractor is switched off and air extraction to atmosphere (via a filtration medium) is switched on instead.

An alternative, lower budget option for surface preparation is to remove a portion of the existing paint using mechanical sanding. This generally produces a lower quality finish than when surfaces are prepared using shot blasting.

Primers used on rail vehicles are typically solvent-borne one- or two-part polyurethane coatings²⁶, containing around 50% solids by weight. In the UK, the coatings being used have a maximum VOC content as dictated by the relevant UK LAPC Process Guidance Note (PG6/41).

²⁵ The primer must be applied soon after shot blasting since the exposed metal is prone to rapid corrosion.

²⁶ Despite being commonly referred to as two-part products, these coatings actually commonly contain three parts: the paint, the thinner and a hardener.

10.2.3 *Painting*

Following application of the initial primer, sanding and additional filling will be undertaken to create a smooth surface²⁷. Additional primer will also be applied.

A basecoat (colours) and clearcoat are then applied to the vehicle. This generally occurs within a dedicated spray/bake booth. Spraying is undertaken using low pressure 'compliant guns' which have a transfer efficiency of at least 65% (see further below).

In terms of the basecoat, up to ten different colours may be applied to a vehicle. Areas that are not to be sprayed must be masked off with paper and tape. Basecoat application is then followed by application of the clear topcoat.

Spraying takes around 48 hours per vehicle (working 24 hours per day in eight hour shifts). Significantly less time than this (around a quarter to a third) will be spent actually spraying, with the remaining time spent preparing for spraying (especially masking). Air is extracted from the spray/bake booth and passed through filters before being passed to atmosphere. Filters trap a significant quantity of paint solids that are emitted (as particulates). Waste materials that contain paints will be passed to landfill (e.g. masking paper).

Typical basecoats are acrylic urethane coatings. These are solvent-borne and generally have around 50% to 60% solids (i.e. they are high solids coatings). They are generally mixed with a thinner and hardener before application. Typical topcoats (clearcoats) are essentially the same as the basecoats, without containing pigments. It is assumed that the solids content of these coatings is 50%.

Generally, around 150 kg of paint will be applied to one rail vehicle. However, only around 50 kg of solids will be applied since paints are diluted at a ratio of around 2:1 for spray application. Thus, the ready for use paint will comprise around two thirds volatile component and thus one third solids.

The thickness of the various coatings applied to rail vehicles (indicating the relative proportions of products used) is approximately as follows²⁸:

- Around 35 μm of primer is applied.
- Multi-colour basecoats are around 12 to 15 μm thick.
- The clear coat is around 40 μm thick.

Total coating thickness is around 90 μm thick.

²⁷ There will be dents from e.g. welding of the vehicle, which are revealed during shot blasting.

²⁸ The data are based on car refinishing thicknesses but are thought to be a reasonable approximation for rail vehicle painting.

10.2.4 Equipment cleaning

Spray guns are cleaned using solvents. Cleaning is frequently undertaken using equipment that utilises clean solvent and then collects the contaminated solvent for later reclamation/disposal by specialist waste companies (see Section 11, Part III).

Rail coating companies may also have their own solvent distillation equipment which removes paint solids; the cleaned solvents are then being reused in gun cleaning operations.

10.3 Emissions estimates

10.3.1 Shot blasting

This process represents both the start and the end of the coating's lifecycle. As paint is removed from a rail vehicle by shot blasting, it becomes mixed with the shot blast medium, which is extracted from the facility. The efficiency of such extraction systems is typically 99% (i.e. 99% of the blast medium will be collected in bags which are sent to landfill). Thus, 99% of the paint that is removed from a vehicle will pass to landfill. The remainder is assumed to be lost to air, although much of this can be expected to be deposited within relatively close proximity.

10.3.2 Spray painting

The transfer efficiency of the sprayers used is up to 90% on flat surfaces (which will be the case for the majority of a vehicle). The transfer efficiency will be less for areas around windows and the edges of a vehicle. Overall, the transfer efficiency will be around 75%. Of the 25% of paint solids that are not transferred to the vehicle, around four fifths are deposited on the masking paper and the remaining fifth remains airborne and passes through the extraction system.

Of the paint solids that pass through the extraction system, around 75% to 80% is trapped on the filters (based upon calculated throughputs and emissions). This compares with standard values for fibreglass filters trapping paint solids of around 80% (although in some cases it may be as high as 95%). The remaining paint solids pass through the filter to atmosphere²⁹. The emission concentration limit for particulates under the relevant process guidance note is 50 mg/m³ (in the UK).

²⁹ Emissions through the vents have been calculated from estimated particulate emissions of 2 mg/m³ during painting (12 hours for one vehicle). In order to estimate capture efficiency of the filters, the total quantity that passes through the filters is estimated using the aforementioned emission factors and assuming an air flow through the booth of 50,000 m³ per hour and total coating application of 125 litres (156 kg) per vehicle, of which two thirds is volatile components.

10.3.3 *Equipment cleaning*

After spraying, it is estimated that around 5% of the paint remains in the spray equipment and is then cleaned out using solvents. These are then shipped to waste companies for recovery/disposal³⁰.

10.3.4 *Summary of emissions estimates*

Figure 10.2 provides an overview of the estimated emissions during rail vehicle painting activities (including paint removal and equipment cleaning).

We have assumed that 2% of the total coating solids (in fact the initial primer) is being lost due to sanding. Of that, 75% (1.5% of total coating solids) will be filtered and disposed of while the remainder (0.5% of total coating solids) will be lost to air. Additionally, 5% of the solids and volatiles are lost as equipment residues.

Only 69.7% of the coating solids will end up on the vehicle. While the entirety of volatiles is lost to air during spraying, a transfer efficiency of 25% means that 23.3% of total coating solids is lost during spraying (note that with regard to solids, the transfer efficiency applies to the 93% of the initial quantity that is left after 2% is lost due to sanding and a further 5% due to spraying equipment residue). Of this 23.3%, four fifths will be retained by masking equipment and disposed of (18.6% of the initial solids) with the rest split between filter/disposal and air at a ratio of 3:1.

Losses during in-service use are not assumed to occur. When the rail vehicle is repainted, all of the paint is removed (69.7% of the initial solids). Of this, the majority will be sent to landfill, contained in the shot blast medium, with a small fraction being emitted initially to air. It is evident that the shot blast medium will also be disposed of along with the removed coating; as mentioned above the consumption of blast medium is usually 0.25 tonnes per vehicle.

Note that no estimates were provided in the TGD for this sector. These new estimates were based on extensive consultation including a site visit, as mentioned in Section 10.1. During that visit, monitoring and inventory data from the consultees were made available to the study team. Additionally, and particularly with regard to the application methods used in the rail coating industry, knowledge of automotive original manufacture and refinishing was taken into account given the similarities between the two sectors.

10.4 *Example calculations*

A pigment (X) is contained in basecoats used in painting of rail vehicles by a certain rail coating operator. The concentration of X in undiluted basecoats is 6.5 g/l. The average coating consumption is 80 l/vehicle. Larger sites can deal with several hundred vehicles per year; for this

³⁰ The value of 5% has been calculated by using the value for the quantity of such wastes produced combined with the typical paint solids concentrations sent to waste companies.

calculation a value of 300 per year is assumed. Operation over 300 days is also assumed, so that an average of 1 vehicle per day is treated. It is also assumed that this basecoat is used for the whole vehicle, so that all of the basecoat used on a day will contain the substance.

Here the amount of coating per day is in terms of a volume, and the content of the substance is also in volume terms. Hence these can be used directly as $Q_{init_coat_day}$ (80 litres) and $Q_{subst_in_coat}$ (6.5 g/litre). Note that the calculations here use g/day rather than kg/day in contrast to the other calculations in this document.

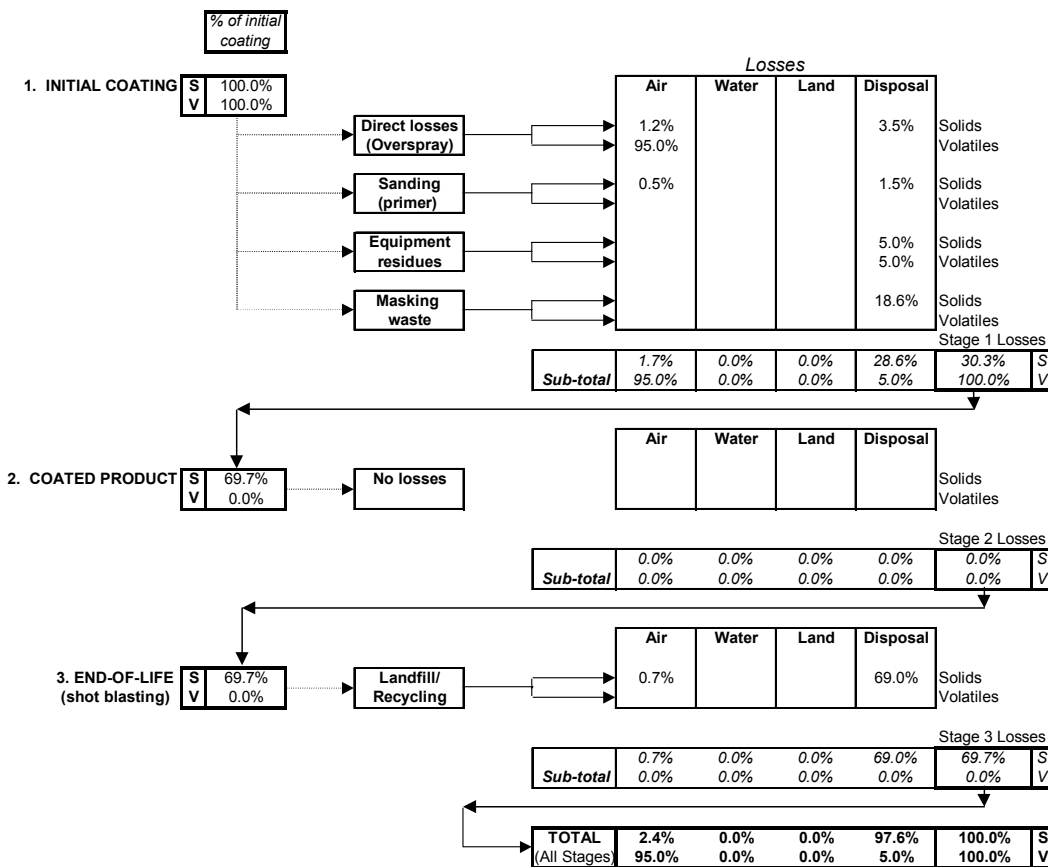


Figure 10.2: Emissions estimates for rail vehicle coating

From Figure 10.2 the emission factors are: $F_{init_coat, direct_loss, air} = 1.2\%$; $F_{init_coat, direct_loss, waste} = 3.5\%$; $F_{init_coat, sanding, air} = 0.5\%$; $F_{init_coat, sanding, waste} = 1.5\%$; $F_{init_coat, equip_res, waste} = 5\%$; $F_{init_coat, masking, waste} = 18.6\%$. Hence the emissions are:

$$E_{init_coat, air} = 80 \times 6.5 \times (1.2+0.5)/100 = 8.8 \text{ g/day}$$

$$E_{init_coat, waste} = 80 \times 6.5 \times (3.5+1.5+5+18.6)/100 = 149 \text{ g/day.}$$

Annual emissions from the site would be 300 times those above. Information on the total amount of the substance used in these coatings would be needed in order to estimate overall emissions.

11 TREATMENT OF COATINGS WASTES

11.1 *General overview*

There are various points at which coating wastes may arise given the activities undertaken in the various sectors (as described in Sections 3 to 10, Part III). For many products, the coating is disposed of in the same way as the product to which it is applied (for example, beverage cans³¹). In other cases, the coating may be removed during the service life of a product. This is the case, for example, with rail vehicle coatings as described in Section 10, Part III. This refers to intentional removal of the coatings; as shown in Section 9, Part III, unintentional removal of coatings could also take place (e.g. weathering of coatings used in the aerospace industry).

This section is concerned with wastes that arise as a result of coatings operations. Such wastes may be created, for example, through the cleaning of equipment used for mixing or for application of coatings, through collection of paint still bottoms or as paint wastes created as a result of overspray.

Due to increased legislative requirements for control of environmental emissions of VOCs and other substances found in coatings³², there has been an increased trend towards collection of wastes from coating activities. These emissions may be passed on to a specialist waste treatment company or may be treated (to an extent) on-site. Where solvents are passed on, these can be deducted from a company's solvent inventory, and count as an input to the waste company's inventory. In relation to treatment on-site, many companies will have solvent distillation equipment which is used to separate solvent from the other components of paint wastes. The solvent can then be reused, for example, in equipment cleaning. The focus of this section, however, is the treatment of paint wastes by dedicated waste companies.

11.2 *Process description*

Companies involved in the application of coatings may collect, for instance, still bottoms by combining wastes from several batches, which are then sent for solvent recycling. In other circumstances, companies will have equipment for cleaning spray guns. Cleaning solvent will be used and then collected together with the paint wastes for collection by the waste company.

Wastes created from coating processes will vary considerably, according to the types of coatings used, amounts of solvents required for cleaning and the stage at which wastes are collected. However, *on average*, the paint wastes collected have the composition indicated in Table 11.1. The data provided in the following table are based on expert opinion and monitoring data provided by industry representatives within the UK waste recycling sector. They reflect

³¹ Although the metal may of course be recycled.

³² As well as through increased recognition of related financial benefits.

current practices at the time of writing the present report. No indication was provided on the timeframe for the data collection which led to the following estimates.

Table 11.1: Average composition of paint wastes sent for recycling/disposal

Component	Average concentration (% w/w)
Solvents (with examples)	
Ketones (acetone, MEK, methylisobutylketone)	< 20%
Esters	< 17%
Aromatics	< 35%
Alcohols	< 10%
Chlorinated solvents (methylene chloride)	< 0.2%
Other hydrocarbons	< 20%
Water	10%
Paint solids (pigments, clays, fillers)	10%

Paint wastes enter the facility in drums. These may be mainly solvent-borne, where the wastes originate primarily from processes such as equipment cleaning, or may contain a high proportion of solids, for example, where various still bottoms have been combined with a drum.

Figure 11.1 provides an overview of the processes involved in the reclamation of solvents from paint wastes. Paint wastes that are unsuitable for recycling of VOCs are treated separately, being blended for use as a liquid fuel. A substantial proportion of this liquid fuel is used in cement works.

In terms of paint thinners (which will also contain paint solids and water), these are first placed into an evaporator. The volatile fraction will pass from this into a distiller, along with some of the less volatile fractions. Solids, including some paint residues but also paint cans in some cases, are removed from the bottom of the evaporator and are sent for disposal to landfill (they are analysed first for heavy metals content, etc. to determine whether special waste landfill is required).

Solvents are then removed using the distiller, with some residues remaining at the bottom. These are also disposed of to landfill (or in some cases incineration).

In terms of high solids paint waste, solvents are removed using suction and are then sent for storage, along with the solvents from the paint thinner residues. Solids are removed by augering out of the drums. Where the properties allow, a liquid fuel is then created which is used in cement kilns; otherwise the wastes are disposed of to a landfill.

11.3 Emissions estimates

Emissions estimates for the treatment of collected paint wastes are provided in Figure 11.2. The estimates relate both to emissions from recovery of solvents from thinners and also emissions from the other paint waste streams.

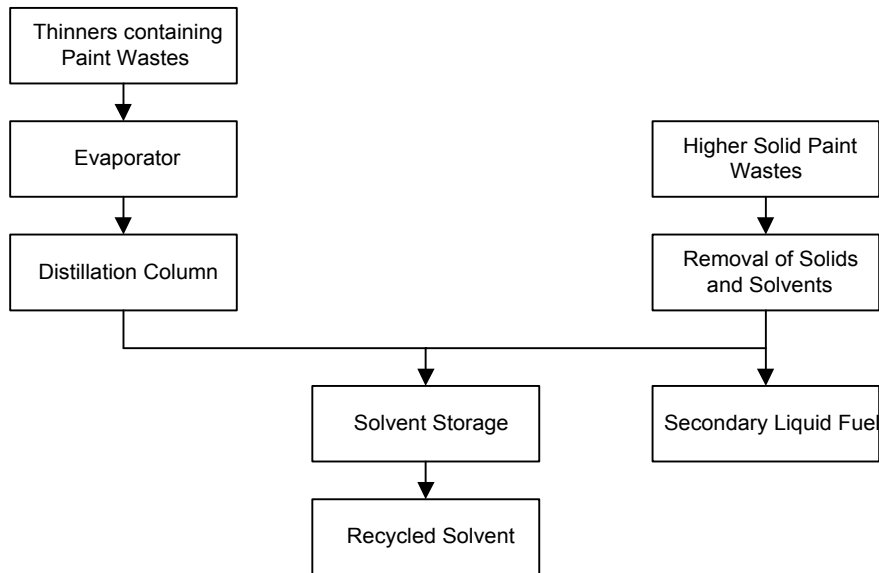


Figure 11.1: Overview of recovery process for paint wastes

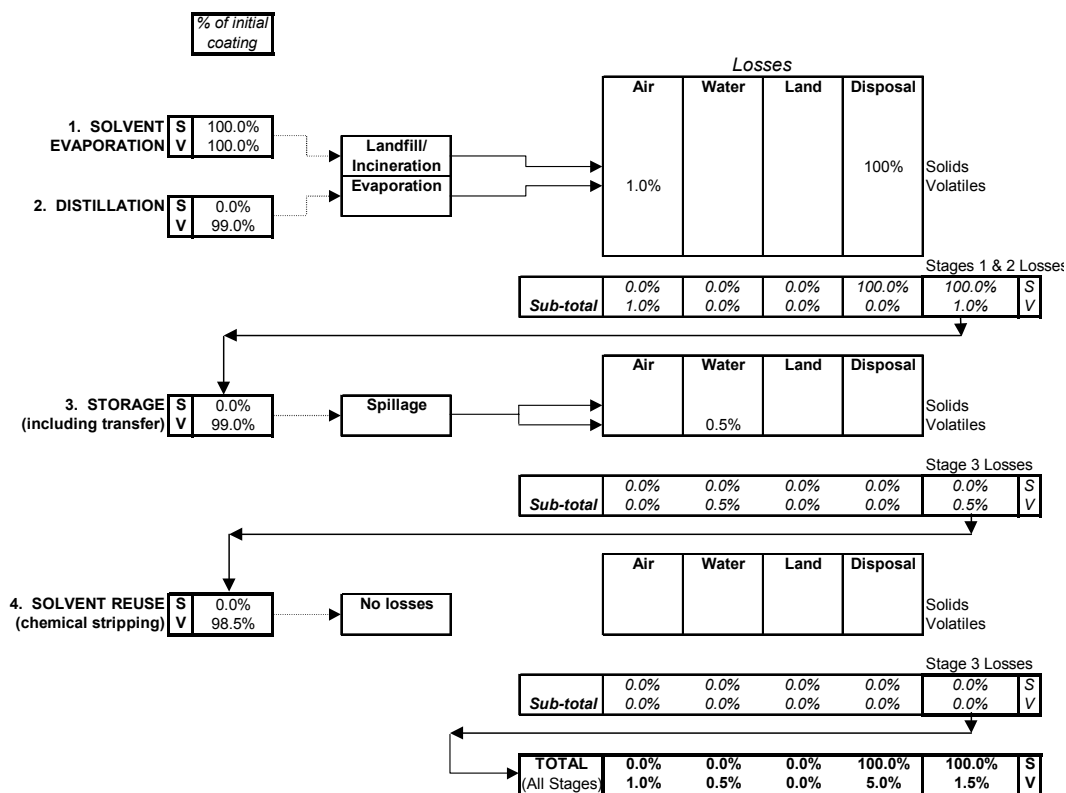


Figure 11.2: Emissions estimates for treatment of coatings wastes

The following should be taken into account in interpreting these data:

- All of the paint solids are lost to ‘disposal’ in the figure. This disposal route relates partly to disposal to landfill but also includes creation of the fuel for cement kilns.
- Solvent evaporation and distillation are estimated by industry experts to be responsible for loss of 1% of the solvent fraction, with this being lost to air. This has been estimated based on emissions monitoring data from a site and confirmed using data for inputs and outputs at the site.
- The data for total volatile losses at the bottom of the figure do not add up to 100% because much of the solvent is recovered for use by coating companies (amongst others).

The above estimates are the result of consultation and a site visit that yielded documented monitoring data which formed the basis for Figure 11.2. The data reflect current practices in this industry sector.

11.4 Example calculations

As noted in Section 11.2, the wastes from coating operations can vary considerably. Waste treatment companies may collect wastes from a range of different operations, and hence it is difficult to devise a meaningful scenario for waste treatment. The scale of operations may also vary, and will not necessarily be related to the coating operations. The calculation below shows how estimates could be made of the amount of volatile substances released from the treatment of a specific waste. This may be useful in considering the overall fate of a specific substance (they could be adapted to consider all of the waste coating containing a substance from a particular use). It should be borne in mind, however, that the substance may be present in other wastes from other coating uses. No specific information on the size of waste treatment sites is available, and so the emissions are based on an annual tonnage of waste (information on sizes might allow estimates to be made of the number of days waste containing a specific substance would be received).

A company involved in the coil coating business sends on average 35 tpa to a specialised contractor for solvent reclamation. On average the ratio of solids to volatiles in this type of waste has been calculated to be 1.5:1, and the substance of interest represents 22% of the entire volatile fraction.

The volatile components of the waste make up $(1/(1+1.5))$ of the total, or 40%. The substance makes up 22% of this, so 22% of 40% is 8.8% of the waste. For this scenario, the waste is considered to be equivalent to the coating. Hence $Q_{subst_in_coat}$ here is 0.088 kg/kg. The amount of coating is 35 tonnes per year, $Q_{init_coat_ann}$.

From Figure 11.2, the factors are: $F_{evap+dist, air} = 1\%$; $F_{storage_spill, water} = 0.5\%$. The emissions are:

$$E_{waste_treat, air} = 35,000 \times 0.088 \times 1/100 = 30.8 \text{ kg/year.}$$

$$E_{waste_treat, water} = 35,000 \times 0.088 \times 0.5/100 = 15.4 \text{ kg/year}$$

12. DATA GAPS/LIMITATIONS/IMPROVEMENTS

There are a number of areas where data which would be useful in the ESD are not available. There are also areas where the estimation methods could be improved. These are noted in the main text, this section summarises the main points.

The main area which could be improved in this part of the document is the information on amounts used at individual locations. In the absence of this, the use of the default approaches in the EU Technical Guidance Document is suggested. For some areas of paint use this may be the most appropriate, for example use by the general public. For other, more industrial areas, it would be useful to have information on the likely amounts to be used at representative locations.

Single values are used for factors such as the transfer efficiency of paint sprays. It would be useful to include information on the ranges of values for such properties, to allow the user to select a value which is appropriate to the application of the substance of interest. Such information can be included in the calculations as presented, but at present the user has to provide this information.

The comments in Section 8, Part II, relating to the emission factors and chemical properties are also relevant here.

PART IV: GLOSSARY AND REFERENCES

1 GLOSSARY

Abrasive blasting material: The material used in abrasive blasting to remove surface contaminants. Examples of abrasive media are sand, iron shot, crushed iron slag, glass beads or ground nut shells.

Acrylic (also acrylate) resin: A generic term for resin technologies based on acrylate chemistry and available in organic solvent borne, water reducible, emulsion and radiation curable systems for both decorative and industrial applications. Acrylic emulsion decorative coatings may be thinned and cleaned up with water. Interior and exterior latex paints in flat, eggshell and semi-gloss can be based on pure acrylic emulsions.

Additive: Any one of a number of special chemicals added to paint to bring about special effects. Examples are plasticisers, dryers, and anti-setting agents, etc.

Air-assisted airless spraying: Spraying systems, a variation of airless spraying, where air jets are used to help the atomisation of paint.

Airless spraying: A spraying system in which paint is atomised using high hydraulic pressure rather than compressed air. In such a system, paint under high pressure is passed through a nozzle and broken down into droplets, or "atomised", when it enters the lower pressure region outside the gun tip (less air is used than in conventional air spraying so that the problems of dry spray and paint bounce-back are reduced).

Alkyd resins: Resins prepared by reacting alcohols and fatty acids. The basis of solvent borne decorative coatings for wood and metal substrates and widely used as the basis of many air dried and stoved industrial coatings. Alkyd based decorative coatings are thinned and cleaned up with organic solvents and thinners. In the context of decorative coatings, the terms alkyd paint and oil-based paint are generally used interchangeably.

Anti-skinning agents: Chemicals added to a paint to help prevent the formation of a surface film.

Autodeposition: A six-step coating process used with solvent-borne coatings and metal substrates (iron-, steel-, zinc- and zinc alloy-plated ones).

Backing coat: A coat of paint which is applied to the back of woodwork and exterior siding to prevent moisture from entering the wood and causing the grain to swell.

Baking: Process of drying a coating in a heated oven.

Ballast tank: Tank that is placed in the hold of a ship to enhance stability.

Basecoat: In the case of the automotive OEM sector, a highly pigmented colour coat applied prior to a clear coating that gives the system the desired colour (primer). In other industrial coating sectors, it has other meanings.

Bilge: The rounded portion of a ship's hull, forming a transition between the bottom and the sides.

Binder: The non-volatile portion of the vehicle of a coating that holds together the pigment particles.

Blast cleaning: The cleaning and roughing of a surface by the use of sand, artificial grit or fine metal shot which is projected at a surface by compressed air or mechanical means.

Bleeder gun: Spray gun with no air valve - the trigger controls the fluid flow only.

Bleeding: The diffusion of colour matter through a coating from underlying surfaces causing colour change.

Blistering: The formation of blisters in paint films by the local loss of adhesion and lifting of the film from the underlying substrate. Blistering is usually caused by the expansion of air, solvent vapour, or moisture trapped beneath the film.

Bodyshop: Premises of a business specialising in vehicle refinishing.

Bogie: A railroad car or locomotive undercarriage having pairs of wheels that swivel so that curves can be negotiated.

Bounce-back effect: The rebound of atomised paint, especially when applied by conventional air spray methods.

Build: Thickness or depth of paint film.

Carrier phase: Coating component which evaporates after application and allows solid materials to immobilise and form the thin protective film. It can be an organic solvent or water or mixture of those.

Chalking: The formation of a friable powdery coating on the surface of a paint film, generally caused by exposure to ultraviolet radiation resulting in a loss of gloss. Chalking promotes self-cleaning of white paint but causes fading in coloured paints.

Chipping: Small pieces of paint removed from the surface, typically a sign of physical damage incurred in shipping or handling. Use of a surface tolerant primer for touch up followed by the same finish coat generally solves the problem.

Clear coating: A transparent protective and/or decorative film.

Coalescing: The settling or drying of an emulsion paint as the water evaporates.

Coating: A general term referring to any type of paint, stain, lacquer, varnish etc.

Coating system: A number of coats separately applied, in a predetermined order, at suitable intervals to allow for drying and curing, resulting in a completed job.

Cold rolled steel: Low carbon, cold-reduced, sheet steel. Differs from hot rolled steel by the absence of mill scale.

Colourant: A substance that imparts colour to a coating. It can be either a pigment or a dye. Also used to describe a concentrated pigment dispersion that is used to tint and adjust the colour of bases.

Colour retention: The ability to retain the original colour during weathering or chemical exposure.

Conduction: The transmission or conveying of something through a medium or passage, especially the transmission of electric charge or heat through a conducting medium without perceptible motion of the medium itself.

Convection: A process of transfer or transmission, as of heat or electricity, by means of currents in liquids or gases, resulting from changes of temperature and other causes.

Corrosion: Oxidation or deterioration due to interaction with the environment.

Cross-draught booth: A booth in which the airflow is horizontal, being passed through filters at the intake points (to remove particulates that might contaminate the paintwork).

Cross-linking: The formation of chemical links between molecular chains to form a three dimensional network of connected molecules.

Cupper: Machinery used to shape metal sheets like a cup.

Curing: Process by which paint is converted from a liquid to a solid state and results in the change of the physical properties of a material through chemical reaction by means of free radical condensation or addition polymerisation.

Curing agent: A hardener or activator added to a synthetic resin to develop the proper film forming properties.

Curing oven: Heated chamber for the purpose of solidifying paint by either chemical cross-linking or drying.

Curtain coating: Application process, in which a conveyorised substrate is passed through a vertical curtain of coating.

Dip coating: Coating by immersing the object in a tank of coating and then withdrawing the object.

Dispersant: Additive that increases the stability of a suspension of pigments in a liquid medium.

Down-draught booth: Spray booth in which air movement is from ceiling to floor.

Electrodeposition/Electrocoating: Process by which electrically charged coating is "plated" on conductive surfaces of an opposite charge.

Electron Beam radiation system: System of curing coatings using the energy of an electron beam, i.e. the high-energy radiation of the beam cross-links the polymers.

Electrostatic spraying: A system of applying coating in which the paint droplets or powder particles are given an electrical surface charge resulting in their attraction to a grounded workpiece.

Electrozinc plated steel: Steel whose surface is meticulously cleaned by electrochemical and electrolytic means, then activated chemically to allow a good 'take' on the surface during the zinc coating process. Actual coating is achieved when the strip passes between zinc plates (or anodes) suspended in vertical plating cells through which the plating solution of zinc sulphate - known as the 'electrolyte' - is pumped. The thickness of the zinc coating is controlled by the strength of the current and the speed at which the coil passes through the cell assembly, and on exiting, it is thoroughly rinsed and a protective treatment is applied before the strip is rewound into coil form, now ready for packing and despatch.

Emulsion paint: A usually decorative coating, which is based on an aqueous emulsion polymer..

Epoxy: A generic term used to describe a class of synthetic resins containing epoxide groups.

Erosion: Wearing away of paint films to expose the substrate and undercoat.

Extender/Filler: White or light-coloured inorganic substances. Supplement expensive prime pigments in building up the pigment volume concentration.

Faraday cage effect: Phenomenon by which charged particles are prevented from entering recessed areas. Faraday Cage Effect is due to the curvature of electric force lines to the nearest grounded surface.

Film: A layer of coating or paint applied to the surface (the layer remaining after the coating has dried is often called the dried film).

Flash-off time: Time which must be allowed after the application of a paint film before baking to prevent entrapment of solvents and other volatile materials, which could affect the appearance or technical performance of the film.

Flattening agent: The ingredient used in lacquers and varnishes to give a flat or hand-rubbed effect. Calcium, aluminium or zinc stearate are used. Silicate flattening pigments give better products than these metallic soaps.

Flow coating: A coating system which uses 10 to 80 separate streams of paint in order to coat all surfaces of an object as it is carried through the flow coater on a conveyor.

Fugitive emissions: Emissions which are not captured by a ventilation or extraction system.

Fuselage: The central body of an aircraft, to which the wings and tail assembly are attached and which accommodates the crew, passengers, and cargo.

Galvanised steel: Cold rolled steel which has been coated with a thin layer of metallic zinc by hot dipping or electroplating.

Gloss: The lustre or shininess of coatings.

Gravity feed gun: A spraying system which involves a cup positioned above the nozzle and the liquid gradually enters the air stream due to gravity.

Grit: An abrasive blasting medium obtained from slag and various other materials.

Grit blasting: Abrasive blasting using grit as the blasting medium.

Ground coat: The basecoat in an antiquing system. It is applied before the graining colours, glazing or other finish coat.

Hangar: A shelter especially for housing or repairing aircraft.

Hardener: An activator curing agent, catalyst or cross-linking agent.

Hiding power: The ability of a coating to hide or obscure a surface, colour or stain over which it has been uniformly applied. Hiding power is provided by the coating's pigment.

High solids coating: Coating that has a solid content of 60-90% and thus a relatively low solvent content and low VOC emission potential.

High Volume-Low Pressure (HVLV) spraying system: A system where the spraying and atomisation of paint is achieved by utilising a high volume of paint with low air pressure.

Hydrocarbon: Organic compound consisting of hydrogen and carbon only (term has been incorrectly used to denote any organic compound).

Infrared radiation: Light energy having a wavelength of 2.5-50 millimicrons. Such energy can be absorbed by organic molecules and provides an energy source for curing coatings used in appropriate industrial applications.

Lacquer: Traditionally, a clear or coloured coating, based on non-convertible (thermoplastic) binders in organic solvents, which forms a film by solvent evaporation. Can also be used to describe clear (transparent) industrial coatings applied to wood or metal substrates.

Latex-based paint: General (although incorrect) term used for water-borne emulsion paints (the preferred term) made with synthetic binders such as 100% acrylic, vinyl acrylic, terpolymer or styrene acrylic. A stable emulsion of polymers and pigment in water.

Levelling: The ability of a coating to form a smooth film without brush marks appearing. Higher quality latex paint has superior levelling ability.

Low Pressure/High Volume (LPHV) spraying system: System with special spray guns that utilise low pressure/high volume air sources to atomise and spray the coating.

Masking: Temporary covering of areas not required to be coated.

MEK: Methyl ethyl ketone.

Nitrocellulose: Cellulose nitrate cotton. Also used to describe coatings, lacquers and varnishes based on this polymer, which were widely used in finishing automobiles and furniture during the 1920's through the 1940's, and which still find uses today in a number of industrial coating systems for wood and metal substrates.

Non-bleeder gun: Spraying gun that has an air valve controlling the air flow, which is synchronised with the trigger release.

Oblation: See "hiding power".

Opacification: The action of hiding the previous surface or colour.

Overspray: Sprayed coating which did not hit, or adhere to, the target, i.e. waste.

Oxygenated solvents: An organic solvent containing oxygen as part of its molecular structure (i.e. alcohols, ketones, etc.).

Pearlescent coating: A translucent coating with a finely ground material that has the distinctively soft and luminescent visual quality of a pearl. These coatings can be tinted in shades other than pearl white.

Peeling: The failure of a film to adhere to its substrate. Peeling results when contaminated surfaces are painted or when there is an excessive difference between coating and surface polarity or in the thermal expansion characteristics of the substrate and the coating.

Phosphating: A pre-treatment of steel by a chemical solution containing metal phosphates and phosphoric acid to temporarily inhibit corrosion.

Photoinitiator: Chemical that initiates polymerisation by the action of radiation.

Pigging: the use of devices that are inserted into a travel throughout the length of a pipeline driven by a product flow. Originally developed to remove deposits which could obstruct or retard the flow through a pipeline, today pigs are used during all phases in the life of a pipeline for a variety of reasons: (a) to batch or separate dissimilar products; (b) for displacement purposes; or (c) for internal inspection.

Pigment: Finely ground, natural or synthetic, inorganic or organic insoluble dispersed particles which, when dispersed in a liquid vehicle to make coating, may provide, in addition to colour and opacity, other essential properties such as hardness, durability and corrosion resistance.

Plasticiser: A low molecular weight substance added to polymeric materials such as paints, plastics or adhesives to improve their flexibility.

Plastisol: Coatings based on thermoplastic polymers and plasticisers, which produce highly flexible and durable films on metal substrates.

Polyester: Describes a wide range of binders that contain the chemical group $(RCOOCR)_x$. Resin formed by the reaction between a dibasic acid and a dihydroxy alcohol - both organic.

Polyurethane: A generic term for a range of coating films that are produced by the reaction of polyisocyanates with polyols, such as polyester and acrylate resins. Polyurethanes have good application and excellent film performance, durability and resistance characteristics.

Polyvinyl acetate (PVCA): Synthetic resin produced by the polymerisation of vinyl acetate (once used extensively in decorative coatings).

Polyvinyl chloride (PVC): Synthetic resin used in organic solvent borne coatings; produced by polymerisation of vinyl chloride.

Powder coating: Protective and/or decorative films formed by application of a coating powder to a substrate, after which the powder is fused into a continuous film by the application of heat or radiant energy. Coating powders are finely divided particles of organic polymer generally containing pigments, fillers, and additives which remain finely divided during storage under suitable conditions.

Primer: The initial coat of a multilayer system, which is applied to a surface. Such coatings are designed to provide adequate adhesion to new surfaces and are formulated to meet the special requirements of the surfaces.

Primer surfacer: Coating used to prime a surface as well as fill irregularities in the substrate.

Puncher/trimmer: Mechanical equipment used by the can coating industry for shaping metal sheets into cans before the coating operation begins.

Quench: To rapidly cool by means of liquid immersion - usually water or forced air cooling.

Radiation curing: Curing or drying a coating by means of exposure to electromagnetic waves or particles such as infrared, ultraviolet, or electron beam.

Reclaimed solvent: Solvent which has been recovered through absorption or condensation from an application process or exhaust steam, or by distillation on- or off-site.

Resin: Synthetic or natural material used as the binder in coatings. Can be translucent or transparent, solid or semisolid. Examples: acrylic, alkyd, epoxy, polyurethane, polyvinyl chloride, silicone.

Roller coating: Industrial coating process, in which a coating is applied to a continuous web or sheets of metal, using a roller or series of rollers **or** the coating applied by roller coating.

Sandblast: Blast cleaning of a surface prior to coating using sand as an abrasive.

Sealing: Application of a coating that prevents excessive absorption of subsequent coats into a porous surface or increases the compatibility of a primer coat for a topcoat.

Semi-down-draught booth: A booth where air enters at the roof and is extracted at one end.

Sheen: The degree of lustre of a dried film.

Shop primer: An inexpensive, rust inhibiting primer designed to protect steel from corrosion immediately after fabrication and before final coating, which occurs on the construction site.

Shot blasting: Abrasive blasting with usually iron shot, or any material which retains its spherical shape.

Siphon feed gun: Spraying equipment consisting of a cup containing the coating which is positioned below the nozzle of the gun. The coating spray exits due to the creation of low pressure as the air stream passes above.

Solvent-borne: Coating containing only organic solvents (non-water-borne).

Spray bake booth: A booth where the applied coating is baked within the booth after spraying.

Spray pattern: The configuration of coating sprayed on the surface.

Stain: A solution or suspension of colouring matter in a vehicle designed primarily to be applied to create colour effects rather than to form a protective coating. A transparent or semiopaque coating that colours without completely obscuring the grain of the surface.

Stripping: Removal of old finishes with paint remover.

Supercritical carbon dioxide (CO₂): Supercritical carbon dioxide is highly compressed CO₂ that combine the properties of gas and liquid. Supercritical CO₂ may find uses as an environmentally acceptable alternative to organic solvents, although it is a greenhouse gas and leads to global warming .

Surfacer: Pigmented composition for filling depressions in order to obtain a smooth, uniform surface before applying the finish coat.

Surfactants: Contracted from surface-active agents, these are additives which reduce surface tension and may form micelles and thereby improve wetting (wetting agents); help disperse pigments (dispersants); inhibit foam (defoamers); or emulsify (emulsifiers). Conventionally, they are classified as to their charge: anionic (negative); cationic (positive); nonionic (no charge); or amphoteric (both positive or negative).

Thermoplastic resin: A resin which does not chemically cure and which softens when exposed to heat and/or redissolves or softens in its carrier solvents.

Thermosetting resin: A resin which chemically cures under the application of heat or radiation.

Thinner: A generic term describing the liquid materials used to reduce the viscosity or composition of a coating, prior to its application. Thinners can be water, single organic solvents or mixtures, depending on the particular coating composition.

Three-pack system: Coating essentially comprised of three separate components. One of them is pigment; the other two, when mixed, react to form the final coating.

Three-piece can: Can made from a top, bottom, and body.

Tint base: In a custom colour system, the basic paint to which colorants are added, i.e. white or accent base.

Tinting: The final adjustment of the colour of a coating to the exact shade required. Tinting is achieved by adding small portions of colorant to a tint base of prepared paint.

Topcoat: A coating designed to provide a "finish" capable of providing protection and colour. Previous coatings may be referred to as primers and undercoats.

Transfer efficiency: Ratio of the liquid paint or coating powder actually deposited on a substrate as compared to the amount directed at the part to be coated.

Two-pack coating: A coating which is supplied in two parts (a base and an activator) which must be mixed in the correct proportions before use in order to cure.

Two-piece can: A can fabricated from a top and a body made from a single piece of metal.

Ultraviolet (UV) radiation: Light energy having a wavelength of about 0.4 to 80 millimicrons. Such energy can break certain chemical bonds and thus contribute to the degradation of exterior

films when exposed to such radiation. UV energy is also used in the curing of certain industrial coating systems.

Undercoat: In the decorative coating sector and for unpainted surfaces, the coat between the primer and the topcoat. For previously coated surfaces, the undercoat can be applied directly to the previous topcoat.

Varnish: An unpigmented coating consisting of binder in a solvent solution which is applied to protect or decorate a surface.

Vinyl: (1) The unsaturated, univalent radical $\text{CH}_2=\text{CH}-$ derived from ethylene; (2) any of the various compounds containing this group, typically highly reactive, easily polymerised and used as a basic material for coatings.

Viscosity: The property of a liquid which enables it to resist flow.

Volatile Organic Compounds (VOC): Any organic compound that is volatile under the conditions of use, and which is emitted to atmosphere. In the coatings sector, organic solvents represent the major proportion of VOCs, together with low molecular weight components and products produced during film formation. Different definitions are used in relation to different regulatory control regimes.

Washability: The ability of a film to be easily cleaned without wearing away during cleaning.

Water-borne coatings: Coatings in which water is the sole or major component of the liquid phase.

Water blasting: Blast cleaning using high velocity water.

Water-borne emulsion coating: A coating based on an emulsion resin

Waterwash spray booth: Spray booth in which vapour from overspray particulate is vented through a waterwash to be recovered as sludge.

Wraparound: A characteristic of liquid or powder coatings in an electrostatic application to seek out and adhere to parts of the substrate not in direct line of sight of the delivery system end point.

The glossary preparation was based on the following references: Armstrong Steel, 2000; Spectra Paint Co., 2000; University of Nottingham, 1999; Carboline Co., 1997; FSTC, 1978; General Paint Co., not dated; PPG, not dated; PPSA, 2001; US Paint Corp., not dated.

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Note on Web references

A number of the references in this section are to web addresses. Since the original reports, some of these have changed and some have disappeared. A check on the web addresses was made in October 2006, and where possible changed addresses have been updated. Others are marked where they could not longer be located.

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