Guidance on VOC Substitution and Reduction for Activities Covered by the VOC Solvents Emissions Directive (Directive 1999/13/EC)

Guidance 8 – Part 1:

Other metal coating

European Commission - DG Environment

Contract ENV/C.4/FRA/2007/001

Content

1 Introduction

This guidance addresses metal coating other than for vehicle, presenting options to substitute or reduce the use of VOC and its resulting emissions. Vehicle coating and vehicle refinishing[1] are addressed in separate guidance documents: for vehicle coating of small series and for vehicle refinishing see guidance no. 6 part 1, for large series vehicle coating see guidance no. 6 part 2.

Table 1: Scope definition of the VOC Solvent Emission Directive (SE Directive)

SE Directive – Scope definitions (Annex I)
Coating of other metal parts is defined by the SE Directive as 'any activity in which a single or multiple application of a continuous film of a coating is applied to metallic surfaces including surfaces of airplanes, ships, trains, etc.'

Emission limit values for other metal coating activities are listed in Annex II A of the SE Directive under activity no. 8, which also includes the coating of other materials like plastics, textile, fabric, film and paper. These activities are adressed in guidance document no. 8 part 2 ('other coating').

THE SE DIRECTIVE APPLIES TO "OTHER" METAL COATING IF A SOLVENT CONSUMPTION THRESHOLD OF 5 TONNES IS EXCEEDED

Table 2: Emission limit values (ELVs) of the SE Directive

SE Directive - Emission limit values (ELVs) (Annex II A – activity No. 8 – metal coating)			
Activity	**Solvent consumption threshold [tonnes/year]**	**ELVs in waste gases [mg C/Nm³]**	**Fugitive emission values [% of solvent input]**
Other metal coating	> 5 - 15	100 (1) (2)	25 (2)
	> 15	50/75 (2) (3)	20 (2)
Special provisions: (1) ELV applies to coating application and drying processes operated under contained conditions. (2) Coating activities which cannot be applied under contained conditions (such as shipbuilding, aircraft painting) may be exempted from these values, in accordance with Article 5(3)(b)[2]. (3) The first emission limit value applies to drying processes, the second to coating application processes.			

1 Vehicle finishing covered by the scope of the SE Directive is 'the original coating of road vehicles as defined in Directive 70/156/EEC or part of them with refinishing-type materials, where is carried out away from the original manufacturing line, or the coating of trailers including semi-trailers (Category O)'

2 Art. 5(3)(b): 'The reduction scheme of Annex II(B) is then to be used, unless it is demonstrated to the satisfaction of the competent authority that this option is not technically and economically feasible.
In this case, the operator must demonstrate to the satisfaction of the competent authority that the best available technique is being used.'

Instead of complying with the above ELVs, operators may choose to use a reduction scheme, following the specifications of Annex II (B) of the SE Directive.

Specific requirements apply for VOCs classified as CMR substances[3] as well as for halogenated VOCs which are assigned the risk phrases R40 or R68[4]. There is a general obligation to replace CMR substances– as far as possible – by less harmful substances or preparations within the shortest possible time. In the case of a mass flow ≥10 g/h for VOC classified as CMR substances or ≥100 g/h for halogenated[5] VOC with R40/R68 the ELVs in waste gases are 2 and 20 mg/Nm³ respectively, and these also apply when a reduction scheme is being used.

National legislation may define lower thresholds for solvent consumption, stricter ELVs or additional requirements.

2 Summary of VOC substitution/reduction

For 'other metal coating', the solvent related VOC emissions mainly depend on the coating products used and their solvent content.

VOC emissions can be reduced by using high efficiency application techniques (e.g. by reducing overspray).

Lower emissions may also be achieved by reducing the solvent content in the coatings and fillers/primers (by using 'high-solids' products) or by a change of the coating system (e.g. from conventional coatings with a solvent content of about 70 % to water based products with a solvent content of about 4 – 15 %).

In some cases, the substitution of solvent-based application techniques by powder coating may be possible.

If primary measures cannot be applied then VOC emissions may be abated by efficient waste gas treatment, eventually pre-concentrating effluents with adsorption technique to achieve autothermic combustion.

VOC REDUCTION CAN BE ACHIEVED BY USING MORE EFFECTIVE APPLICATION TECHNIQUES OR BY SUBSTITUTING SOLVENT-BASED COATINGS WITH WATER BASED COATING SYSTEMS OR POWDER COATINGS

3 CMR substances-carcinogenic(R45, R49), mutagenic(R46), or toxic to reproduction (R60,R61)

4 After the implementation of the SE Directive a revision of the R-phrase R40 took place. The original wording of R40 was: 'Possible risk of irreversible effects'. The new wording is: 'Limited evidence of a carcinogenic effect'. In the 'old' version mutagenity (cat 3) was included. This mutagenic effect is now covered separately under R68: 'Possible risk of irreversible effects'. This new risk phrase does not include carcinogenicity. The 'new' version of R40 is obviously less restrictive than the old version. Until the SE Directive is adapted to this change, a final decision on which version applies can only be given by the European Court

5 Halogenated organic solvents are hydrocarbons with one or more of the following halogens: fluorine, chlorine (e.g. trichloroethylene), bromine (e.g. n-propyl bromide) or iodine.

3 Description of the activity and related industry sectors

Metal coating, other than for road vehicles, is used in all countries of Europe in a wide range of different industries. For 2004, the EU 15 Member States reported about 5000 existing and 300 new installations falling under the SE Directive[6], carrying out activities under the scope of number 8 activity of Annex II A. These figures do not only cover metal coating, as the activity also comprises activities for coating of plastics, textile, fabric, film and paper. [Implementation 2006].
In general, two types of activities can be distinguished: coating that can be applied under contained conditions (e.g. machinery, construction materials, household appliances, metal furniture) and coating that cannot be applied under those conditions (such as shipbuilding or aircraft painting).
The following sections describe examples of metal coating activities.

Coating of mechanical engineering equipment

Surfaces of machines need to have a resistance to oils, cooling agents and other liquids. Coatings therefore need to produce both a high quality surface finish and provide corrosion protection.
Typically a water-based base coat is applied first to the surface via electrostatic dipping or spray coating. This is usually followed by two top coat layers, either a 2-component coating system based on acryl, polyurethane (PUR) or epoxides as coloured base coat - followed by a clear coat, or a 2-layer colour base coat. The coatings are usually applied via spray techniques but depending on the application, casting, rolling, dipping and flooding or powder coating may be used as well.
[DFIU 2003] [EGTEI 2004]

Coating of agricultural machinery

The visual surface quality of agricultural vehicles is not as critical as that of passenger cars but its importance is increasing. Agricultural machinery is produced throughout the year but usually sold in spring. Therefore, most of the machinery needs to have an attractive coating following a period of outside-storage during both winter and summer conditions pending sale. [DuPont 2008]
The main task of the coating, nevertheless, is corrosion protection. The varnish has to sustain heavy mechanical and chemical stress. Chemical corrosion may occur due to aggressive plant residues and moisture and the coating usually cannot last the vehicle service life.
The base coating is often applied manually, via spray coating with solvent based coatings, but water-based electrophoretic dip coating is progressively displacing this technique.
The topcoat may be manually sprayed with solvent- or water-based coatings though powder coatings are increasingly being used.
In the pursuit of greater automation, manufacturers tend to apply base coat and top coats before assembly takes place. [DFIU 2003]

6 No data of Italy and Sweden.

Coating of special-purpose vehicles

Special-purpose vehicles[7] include town council vehicles - like street sweepers or dustcarts, vehicles for road making like asphalt-rolling or mowing and construction vehicles.

They are usually spray coated using 'serial' or 'refinishing' coatings, depending on the costumer's finishing requirements and the nature of the individual parts to be coated. [Ökopol 2008]

Coating of bikes and motorbike frames

Bicycle and motorbike coatings consist of one to three layers: a ground coat, a colour-bearing base coat and a clear topcoat. Whether a single-layer or multi-layer coating is used depends on the individual product requirements, the product size, and the equipment of coating installation.
Powder coatings are increasingly replacing the traditional solvent-based base and clear coats. Problems may be encountered, however, if the adhesive bonding of the frames weakens at temperatures of greater than 180°C, the temperature needed to fuse the powder coating. [DFIU 2003]

Coating of heating elements

For the coating of heating elements, powder coating systems are most commonly used. [DFIU 2003]

Coating of metal furniture

For the coating of metal furniture, conventional solvent-based systems, water-based systems and powder coatings are used.
Application techniques comprise spray coating (conventional/ electrostatic, manual/automatic), electrophoretic dip coating and powder coating.
Metal hospital furniture is typically coated with polyester powder coating that guarantees higher resistance to hot water and scratching as well as to disinfectants and superheated steam-sterilization.
Shelves are produced in a wide variety of colours and shapes and so conventional solvent based paint systems, water based systems and powder coating systems tend to be used.
The final coating, for standard colours, may be applied by spraying techniques or by dip coating; in some cases powder coatings can be used.

High voltage switch cabinets are usually base coated via electric dipping. Top coats are conventional 2-component systems, water-based systems or powder coatings. [DFIU 2003]

7 All vehicles not being road vehicles as defined by Directive 70/156/EEC

Coating of aircrafts

Coating materials on aircrafts need special permission according to international aviation rules for each type of airplane and for exterior as well as interior parts. Aircraft coating comprises two subsectors: OEM (Original Equipment Manufacturer) and MRO (Maintenance, Repair and Overhaul). Permitted coating systems for OEM may differ from those allowed for MRO. New coating systems are usually introduced first for the OEM sector and similar systems can only be used for existing airplanes after specific additional development, testing and permitting procedures for the MRO sector.
[BREF STS 2007] [Ökopol 2008]

Coating of ships

Coating systems for ships consist of one or more layers of solvent-based, low solvent or non-solvent coatings. Predominant binders are epoxy resins (usually 2-component), polyurethane, acrylates, alkyd resins and chlorinated rubber.

Layers of 200 and 1000 µm thickness are applied. A thicker layer of special top coatings is usually applied to ramps and working areas.

Coating materials are usually applied by means of airless spraying processes, which enable the processing of low solvent and non-solvent products. Roller and brush application is widely used in coating yachts. Rollers are also used for pre-delivery coating of passenger ships.

[BREF STS 2007]

4 Technical process description

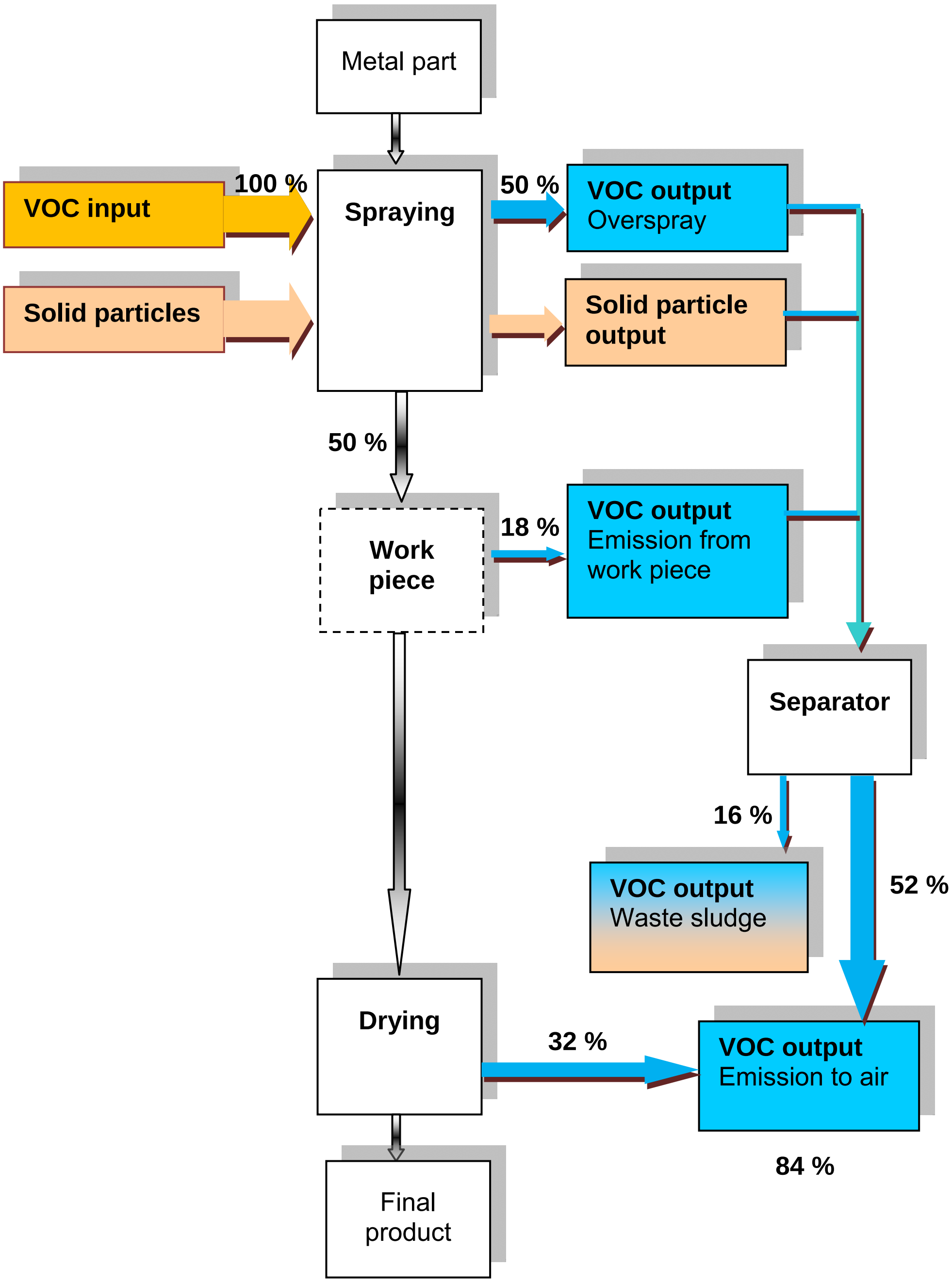
4.1 Process flow and relevant associated VOC emissions

The flow chart in Figure 1 gives an overview of the typical process steps, and the VOC emissions that can occur, assuming the use of conventional spray coating techniques with 50% overspray.

COATING EFFICIENCY HIGHLY DEPENDS ON THE GEOMETRY OF THE WORK PIECE

In practice, conventional spray coating may have a coating efficiency between 5% and 60%, depending on the geometry of the work piece (plane surface or lattice-like) and the skill of the sprayer.

A change of the coating efficiency (e.g. due to a change of spraying technique) or the solvent content of the coating would have a corresponding impact on the VOC flows shown in the chart.



Based on [DFIU 2003]

Figure 1: VOC emissions from spray application with conventional technology assuming 50% overspray

4.2 Process description

Coating processes can differ significantly due to the fact that a wide range of different products with different requirements are coated. Typical process steps and coating application techniques are described below.

4.2.1 Degreasing

In most cases where special purpose vehicles are given original coatings they (or the parts of them to be coated) are sandblasted and further degreasing is not necessary. In cases of local contamination e.g. with oil from final drilling or cutting activities, these areas of the work piece are usually cleaned manually by brushing or wiping. Degreasers used for this type of application usually have a high VOC content, from about 50 % up to 100 %.

Small metal parts are pre-cleaned either with a water-based cleaner using a pressure washer or with solvent containing cleaners applied by spraying.

For further details of degreasing see guidance document no. 4/5 (‘surface cleaning’).

4.2.2 Coating systems

Coating systems for metal coating activities in most cases consist of at least two layers, a primer and one or more top-coat layers.

The primer is used as first coating of the metal surface, having an anticorrosive function and helping to increase bonding of the subsequent coating.

A typical conventional primer for metal coating is based on polyvinylbutyral resin. These primers have a total solvent content of 55- 65 % w/w. More modern systems are either epoxy based (with a solvent content of about 40 % w/w) or polyester based (solvent content of about 20 % w/w).

In most cases top-coating is performed with a single layer system. This single layer coating has to provide both the colour/appearance and protection against chemical or other attack (sunlight, mechanical impact, etc).

The single layer top-coating may either be a 1-component system with a typical solvent content of about 45 – 55 % w/w or a 2-component system with solvent content of about 25 – 35 % w/w. As an alternative, water based systems may be used with a VOC content of about 10 – 15 % w/w.

WATER-BASED TOPCOAT SYSTEMS HAVE 10-15% VOC CONTENT COMPARED WITH 25 – 55 % IN SOLVENT-BASED TOPCOATS

In cases where specific colour effects need to be achieved two- or multi-layer systems are used. The two coat system consists of a basecoat providing colour, followed by sealing with a clear topcoat. For multi-layer systems, an additional colour-coat is applied (intermediate coat).

4.2.3 Application techniques

The application techniques used differ depending on the coated product. For efficiencies of different application systems see table 3 on page 29.

The choice of coating system depends not only on the requirements of the work piece (e.g. the corrosion resistance to be achieved) but also on the size, available equipment and core business of the paint shop or company performing the coating.

Electrophoretic dipping is a major technique for applying the primer systems. Various types of spray coating are then used for subsequent coating layers in the case of small scale production, whereas for large scale production powder coatings are typically used.

Conventional high and low pressure spraying

Coating material is ejected from the nozzle of a spray gun using compressed air. The air transports the particles of the coating material onto the surface of the work piece.

The higher the pressure of the air the finer are the particles of the coating material. Fine particles increase the quality and the smoothness of the coated surface. On the other hand, the finer the particles, the greater the ease with which they are deflected by the airflow from the coated surface leading to increased coating waste (overspray). Conversely, if the pressure is too low, the coated surface is of poor quality (e.g. an 'orange peel' effect is created).

The coating efficiency varies between 5 % (for lattice-like work pieces) up to 30 – 60 % (for work pieces with large and plane surfaces).

Conventional spray coating is applicable for any surface and is used in particular for topcoats because of its ability to achieve high quality finishes and special surface effects (e.g. metallic or pearl look).

[DFIU 2003] [BREF STS 2007]

High volume low pressure spraying (HVLP)

For high volume low-pressure spraying (HVLP), the atomising pressure is decreased from the conventional 3 – 6 bar down to 0.7 bar. Compared to high-pressure spray coating, up to 20 % overspray can be avoided and the coating efficiency is about 40 - 80 %.

HVLP SYSTEMS ACHIEVE HIGH MATERIAL EFFICIENCIES OF UP TO 80 %

Due to the larger particles of coating material created by HVLP sprays, the quality of the finish may not match that achieved with conventional high pressure air guns. However, improvements in HVLP gun design are such that the most modern designs are able to match the quality of finish achieved by high-pressure guns. [DFIU 2003] [BREF STS 2007]

Airless spraying

In airless spray coating, the paint is forced through very small metal nozzles (< 2 mm) with a pressure of 80 to 250 bar. The paint jet strikes the stationary air outside the nozzle and is broken up in fine particles due to the force of this impact.

The paint is delivered to the nozzle using high-pressure pumps and this prevents quick colour changes. However, a high throughput of coating is possible. Airless spray coating is cheap and fast and can be used for 1-component and 2-component paint.

Airless spray coating gives a rough finish that needs to be sanded before finer coatings can be applied. This introduces an additional process stage compared with the use of high pressure air spraying. However, optimisation of the spraying can improve finish quality to close to that achieved with HVLP guns, especially with primer coatings. Operator training is essential in order to maximise the performance of airless spraying systems.

AIRLESS SYSTEMS ARE ONLY EFFICIENT ON LARGE SURFACES

This spraying technique may be used either manually or automatically. Material efficiency for airless spray coating is about 5 % (lattice-like work pieces) up to 40 – 75 % (large surfaces). [DFIU 2003] [BREF STS 2007]

Electrostatic spray coating

An electric field is created between the work piece and the coating material, these having opposite polarity. Coating material is atomised and sprayed and the particles are attracted to the work piece. The process halts when the film thickness is nearly equal on all surfaces and edges. Cathodic coating is the most widely used technique as anodic work pieces tend to corrode.

ELECTROSTATIC SPRAY COATING CAN ACHIEVE VERY HIGH MATERIAL EFFICIENCY OF 95 – 100 %.

In general, the efficiency of electrostatic spray coating is from 95 % up to 100 %. Compared to conventional spray coating, electrostatic spray coating is more time and material efficient and easier to automate. Less waste residues are generated and spray booths require less cleaning.

For electrostatic spraying to work, the work piece has to be conductive. This limits the substrates and coatings that can use the technique (e.g. it is not possible to recoat existing coatings). In addition geometries that act as Faraday cages have to be avoided because the coating is applied to them unevenly.

Electrostatically assisted compressed air, airless and air assisted spraying

These techniques combine regular compressed air or airless spraying with the electrostatic charging of paint particles.

For compressed air, the material flow is up to 1000 ml/min, for airless or assisted airless techniques the material flow can be up to 3000 ml/min. The material efficiency is up to 85 %.

Compared to conventional spraying, less overspray is generated and spray booths are less polluted. Therefore, less cleaning agents are needed.

With electrostatically assisted spraying more complex geometries can be coated than with electrostatic spray coating.

[BREF STS 2007]

Conventional dipping

Work pieces are either dipped manually or transported and dipped via conveyor systems. Dipping into water-based paints might produce foam. Water-based paints are only stable over a small range of pH levels and, therefore, very sensitive to contamination that might be introduced from the pre-treatment processes.

DIPPING ALSO ACHIEVES VERY HIGH MATERIAL EFFICIENCY OF UP TO 100 %.

This technique is quite cost effective and can achieve a material efficiency of up to 100% [BREF STS 2007]. The finish quality is relatively low. The technique is not applicable for coating of open-cell surface structures. [VDI 2008]

Electrophoretic dipping

Electrophoretic dipping is mainly used for pre-coating. In the process, a direct electric current is made to flow between the work piece and the electrodes of opposite polarity installed in a tank.

Cathodic (work piece loading) systems are commonly used, because they offer better resistance against corrosion than do anodic systems.

Electrophoretic dipping is only used with water-based coatings having a solvent content between 1 – 4 %.

Electrophoretic dipping is an efficient application technique that produces high quality coatings. However, it is a cost intensive system (investment and material costs), and requires a high level of maintenance of the paint tanks for quality assurance. [BREF STS 2007].

The work piece has to be conductive. Primer base coats applied by electrophoretic dipping are often followed by a powder coated topcoat.

Application of powder coatings

Powder coatings achieve high efficiencies up to 100 % as overspray material can be re-used. They are applied and then melted and cured by heating the work piece at 200°-250°C [BREF STS 2007].

WITH POWDER COATING, HIGH EFFICIENCY OF UP TO 100 % IS ACHIEVED.

Powder coating – electrostatically assisted spraying: The powder particles are electrostatically charged and sprayed onto the work piece using compressed air. Spray booth and application tools can be cleaned by vacuum cleaning or by blowing with compressed air. There are no solvent emissions associated with this spraying process.

Powder sintering: The work piece is heated above the melting temperature of the powder coating before coatings are applied. As soon as the powder is in contact with the surface, sintering and merging takes place.

[BREF STS 2007]

4.2.4 Drying

After the application, the coating has to dry. The drying time can be reduced by the use of additional drying units (ovens). Spray booths may also function as ovens.

The drying time depends on the object or substrate, the type of coating and the coating thickness, and varies from a few seconds to one hour.

Dehumidified air is used for the drying of water-based coatings or a pre-drying step of wet-on-wet layers (second coating taking place before first coating has dried completely). Due to the removal of water in this manner, the drying times can be significantly reduced. [BREF STS 2007]

In contained conditions drying air can be captured and routed to treatment, eventually concentrating low VOC loaded air in activated carbon or zeolite before treatment. If drying cannot be done under contained conditions, influence of weather conditions has to be kept as low as possible (e.g.

reduction of dust sources, reduction of direct sunlight exposure during coating, if possible).

4.2.5 Cleaning

Cleaning needs to be undertaken in all application techniques: for work pieces (see also guidance document 4/5 on ‘surface cleaning’), for work place environment, coating equipment and parts thereof.

A range of cleaning techniques can be used, from manual cleaning to automatic cleaning using closed systems with solvent recovery (e.g. for spray guns and parts, see figure 3). Solvent cleaners are used (and sometimes heated for higher efficiency) as well as water. Cleaning with water is possible when water-based coating systems are used and when the cleaning is performed before paints have fully dried.

Cleaning needs to be effective and fast. Cleaning intensity varies according to the nature of colour changes and is also dependent on whether the contamination is semi-dry or dry.

[BREF STS 2007]

Spray booths are usually cleaned with cleaners with a low VOC content. An alternative approach is the use of a film or a strippable varnish, applied to the walls of the booth.

[VDI 2008]

5 Solvent use, emissions and environmental impact

5.1 Solvents used

Conventional solvent-based coatings

Conventional solvent-based coatings contain about 30 - 80 vol.-% solvents. Solvents used are mainly mixtures of hydrocarbons (xylene, toluene and white spirit), although alcohols, esters and ketones are also used.
They are classified as coatings based on polycondensation (e.g. phenol/urea/melamin resin), polymerisation (e.g. polyesters, acrylate resins, alkyd resins) or polyaddition (e.g. epoxy or polyurethane resins).

[DFIU 2003]

Solvent based high-solid coatings

High-solid coatings contain < 35 % solvents.

The following solvents are used: xylene, white spirit, aromatic hydrocarbon mixtures, butyl acetate, alcohols, and glycol ethers. Ketones and toluene do not play a significant role in Europe.

Binders of high-solid coatings are based on epoxy resins, 2-component-polyurethanes, polysiloxane, oxirane or alkyd resins.
[BREF STS 2007]

Water-based coatings

The solvent content of water-based coatings is about 3 - 18 vol-%.
Water-based coatings often contain organic solvents as a solubiliser and to improve the properties of the wet film layer. Water based coatings are based on alkyd, polyester, acrylate, melamine and epoxy resins.
[BREF STS 2007]

Powder coating

Powder coatings are VOC-free. Powder coatings are typically based on acrylic resins with either an acid or an anhydride.

5.2 Solvent consumption and emission levels

At EU-25 level, VOC emissions of 544 kt from industrial paints have been estimated for 2000 from the following sectors:

- Trade coaters, general engineering, industrial equipment, original equipment, heavy engineering and aerospace industry,
- Continuous processes: furniture, rigid metal packaging and drums,
- Plastic coating: plastic and automotive components. [EGTEI, 2005]

In total, 1601 kt of paints were used, giving an average emission factor of about 340 g VOC/kg paint consumed meaning that emissions from this sector were already partly abated (unabated emission factors range between 690 and 750 g/kg of paint depending on the subsector).

[EGTEI, 2005]

Cleaning

Cleaning processes with organic solvents account for about 20 % of total VOC emissions from paint shops. [BREF STS 2007]

5.3 Key environmental and health issues

In metal coating a broad range of solvents is used for coating materials and cleaners.

VOC emissions, together with NOx emissions, are precursors of ground level ozone formation in the presence of sunlight. Existing occupational workplace limits should be taken into consideration.

Emissions of VOC to air may occur from:

- the storage of the solvents
- the process
- cleaning operations

Spills and leaks from storage areas may result in emissions to soil and groundwater.

Table 3 shows exemplary solvents of paints classified with risk phrases specifically regulated by the SE Directive.

Table 3: Exemplary solvents paints, classified with risk phrases specifically regulated by the SE Directive

Solvents	Risk Phrases
2-methoxy ethanol, CAS 109-86-4	R60, R61
2-methoxyethanol acetate, CAS 110-49-6	R60, R61
2-ethoxy ethanol, CAS 110-80-5	R60, R61
2-ethoxyethanol acetate, CAS 111-15-9	R60, R61
Trichloroethylene, CAS 127-18-4	R45
Dichloromethane (methylene chloride), CAS 75-09-2	R40

[ADEME 2003], [Ökopol 2008]

The risk classification R45 implies that the solvent may cause cancer; the classification with R60 indicates that the solvent may impair fertility, and R61 indicates that the solvent may cause harm to the unborn child. Solvents classified with R40 have a limited evidence of carcinogenic effect.

The SE Directive requires that the abovementioned solvents carrying risk phrases R60, R61 or R45 have to be substituted, if possible, because of their impact on human health. If substitution is not possible, emissions have to be minimized (see section 1).

Existing occupational workplace limits should be taken into consideration.

6 VOC Substitution

The following section describes potential substitutes for VOC (using VOC-free and VOC-reduced systems). The descriptions of the application technologies or special conditions needed and the advantages and disadvantages compared to systems that use solvents with a high VOC content.

6.1 VOC-free systems

This section describes the ways that VOC-free products or systems can be used to replace the organic solvents currently used.

6.1.1 Powder coating

Powder coatings can substitute for solvent-based or water-based coatings in many cases, but this is dependent on heating of the work piece being possible and the work piece having the required surface characteristics (see section 4.2.3 page 29). Material efficiencies of 80 – 95 % can be achieved.

The working piece has to be able to withstand the high temperatures used to melt and cure the powder.
[BREF STS 2007] [Ökopol 2008]

Cross-media effects
More energy is needed for drying of powder coatings compared to conventional solvent-based coatings.
Besides reduction of VOC emissions to zero, resulting waste amount is reduced because overspray from powder coating can be re-used.

6.1.2 Cleaning systems

Detergent systems can be used for equipment cleaning when water-based coating systems are used.
The systems combine detergents with alkalis and other substances, depending on the substrates and the materials to be removed. Cleaning with detergents may take longer than with solvent based systems.
The water based cleaning systems may require additional heating and subsequent treatment of waste water. [BREF STS 2007]

6.2 VOC-reduced systems

If the complete substitution of organic solvents is impractical then changing to systems with a reduced VOC content, such as those described in this section, can decrease emissions.

6.2.1 Reduction of solvent content in coating systems

Often the most significant reduction in VOC emissions can be achieved by changing from conventional solvent-based systems to high solid coatings or water-based systems (see section 4.2.2 on page 9). Total emission reductions of about 30 – 55 % can be achieved in this way. [DFIU 2000]

In the case of high-solid coatings, the higher price per unit weight for the coating is outweighed by the higher efficiency of the product (higher solid content per unit weight). [DuPont 2008]

Water-based systems require stainless steel equipment to be used and also increase drying times. Drying can be adjusted by installing nozzles for air turbulence during flash off, installing heating systems and increasing air exchange rates.

Prior cleaning has to be done with special care when using water-based systems for coating of large parts with non-planar geometries, to achieve surfaces completely free of dust and oil.

A case-by-case calculation, including evaluation of energy demand and costs, needs to be made in order to determine economic impacts when switching to water-based coatings.

Water-based coating systems used for electrophoretic dipping are associated with costs for the new equipment and its maintenance. Here, as a rough estimate, an economic situation can be achieved if the turnover time for the coating solids in the bath volume is < 1 year. [DuPont 2008]

Cross-media effects
More energy may be needed for drying of water-based coatings compared to conventional solvent-based coatings.
More efficient application systems produce less waste from overspray and less emissions from cleaning of the spraying booth.

7 Other VOC emission prevention measures and abatement techniques

Preventive measures, process improvements and abatement techniques can be used to reduce VOC emissions if VOC substitution as described in section 6 is not possible. The following measures are commonly applied for 'other metal coating' processes:

7.1 Process improvements

7.1.1 General measures

General measures to reduce VOC emissions [BayLFU 2005]:

- Use contained conditions when ever possible
- Keeping short spraying distance to the coated surface
- Keeping the spray jet vertical to the surface
- Adjusting the width of the spray jet to the working pieces width
- Apply precise contour coating
- Keeping air pressure as low as possible, but adequate for quality requirements
- Reducing the number of coating layers

7.1.2 Efficient application

By switching from conventional application techniques to improved ones, such as HVLP spray-guns, a significant reduction of VOC emissions can be achieved by higher material efficiency respectively less overspray.
Efficient application can be achieve also by automatic mixing systems. In particular for coating of big parts (sometimes difficult to achieve under contained conditions), automatic mixing of 2-K or 3-K systems reduces the need for long pot life and therefore the need for high solvent content systems. Additionally, automatic mixing systems reduce the cleaning effort cleaning of a container - normally used for interim storage of mixed substances - is no longer necessary.
Table 4 shows efficiencies of application techniques. For a detailed description of each system see section 4.2.3 on page 29.

Table 4: Efficiency of application techniques

Method	**Degree of efficiency [%]**	**Geometry of the work piece**	**Other restrictions**
Compressed air spraying	20 – 65	No limitation	-
Airless	40 – 80	Big, simple	-
Airmix	35 – 75	Big, simple	-
HVLP	45 – 65	No limitation	-
Electrostatic assisted compressed air spraying	50 – 80	No Faraday cage	Electrically conducting materials are necessary
Electrostatic assisted airless spraying	45 – 85	No Faraday cage	Electrically conducting materials are necessary
Electrostatic assisted airmix spraying	40 – 80	No Faraday cage	Electrically conducting materials are necessary
Flooding	85 – 95	Non-scooping parts	High solvent loss
Dipping	75 – 90	Non-scooping parts	High solvent loss
Powder with electrostatic spray technique	50 – 95	No limitation	Electrically conducting temperature resistant materials are necessary

[DFIU 2003]

In general, a possibility of VOC emission reduction is the reduction of the number of coating layers. This is a decision which can only be made taking into account individual circumstances such as durability, corrosion resistance and customer specific appearance requirements.
Another possibility of VOC reduction is applying a thinner layer of the topcoat. If a layer-thickness of 50 µm (via spray coating) instead of 85 µm (via dip coating) can be achieved, the material consumption is lower (even if the efficiency is lower due to spray application). In this case the material and disposal costs are smaller, compared to dip coating. Also a better surface quality can be obtained. [DFIU 2003]
In some cases, emissions may be reduced by changing the coating layer system. For example, agricultural machinery may be coated with a two-layer system with the base coat being applied via electrophoretic dipping and the top coat by spray coating using a conventional solvent based system. Keeping the two-layer system, the top coat may be replaced by a solvent free powder coating. Alternatively, a single layer system may be used, applied via electrophoretic dipping. [DuPont 2008]

7.1.3 Reduction of cleaning effort

About 80 % of the solvent emissions from cleaning can be reduced by using closed systems for the cleaning of guns and applicators. Such systems cost between 150 and 3000 Euros. [BREF STS 2007]
Automatic washing machines are enclosed machines which can clean parts to be coated or coating equipment. The solvents are contained and collected for reuse. Automatic washing can be combined with solvent recycling by distillation that can achieve up to 80 – 90 % solvent recovery. Problems may occur with 2-component clear coat materials, which can lead to clogging of recovery tank pipes. A solvent recovery system costs about 0.4 million Euro per spray booth.

Also, the following measures can be applied:

- Using cleaning solvents as sparingly as possible
- No cleaning of equipment for base coatings or coatings with low optical requirements
- Consecutive coating of same coloured working pieces
- Draining of the supply lines before cleaning, e.g. spraying until the line is empty or use of pig-systems
- Immediate cleaning of parts, leaks, spillages and working environment before coating materials are dried
- Regular inspections of storage areas and working environment to ensure appropriate handling
- Use of the pig-clearing method[8] to avoid residues remaining in pipes
- Minimising exposure of the open surface of liquid solvent for cleaning or from solvent-based coatings in the working station.
- Use of systems that allow flow back of solvents into a closed container. Cleaners are pumped through a tap or sprayed onto the object in a partially enclosed work area above the storage drum. The work area allows flow back of surplus solvents through coarse filters into the drum.

  [BayLFU 2005] [DFIU 2000] [BREF STS 2007]

8 'pigs' are plastic pieces, pressed with compressed air through pipes to transport coating remains left over in pipes back to the storage tank. The system is only applicable, where paints are delivered to machinery through pipes and different colours are sent through the same pipe regularly.

7.2 Abatement technologies / End of pipe measures

There should be VOC extraction for all potential emission sources to prevent and limit exposure of workers.
If primary measures cannot be applied then VOCs may be destroyed by thermal oxidation, biological treatment or decomposition by thermal plasma. Biological and plasma treatments are mainly used for low concentrations of VOC (< 1 gC/m^3).
Thermal oxidisation can achieve VOC reduction efficiencies of > 99.9 %, biological treatment generally has a lower efficiency but also lower investment and operating costs.
Adsorption onto activated carbon or zeolite materials, followed by controlled desorption, may be used to concentrate a dilute effluent for subsequent treatment. Concentrated gas streams must be monitored to ensure that the TOC (total organic carbon) content never exceeds 25 – 50 % of the lower explosion limit.
Thermal oxidation can be used if concentrations are above 1 gC/m^3. Low and varying carbon concentrations may require additional fuelling with natural gas to maintain a constant flame temperature. Autothermic combustion can be achieved with TOC concentrations of about > 2 g/m^3.
Recuperative oxidation systems recover waste heat from the combustion, via heat exchangers, to pre-heat incoming waste gas or for process operations such as dryers, or for room heating.
Regenerative oxidation systems are more efficient than recuperative systems. The hot exhaust gas is passed through chambers containing heat retentive honeycomb-like material. When a chamber has achieved its full heat loading the exhaust gas is routed to another chamber. Cool incoming waste gas is heated by passage through the hot honeycomb-like material before it enters the combustion chamber. The regeneration of waste heat decreases the energy demand of the process significantly.
Catalytic oxidation may be used if no ‘catalyst poisons’ are present; since catalysed oxidation occurs at a relatively low temperature the energy demand is reduced.

8 Summary of VOC emission reduction measures

Table 5 summarizes the various approaches to substitute or reduce VOC emissions as described in chapters 6 and 7:

Table 5: Measures for VOC substitution and VOC reduction in other metal coating

Objectives	**Description**	
VOC-free Systems	Substitution of VOC by change of application systems	Use of powder coatings
	Substitution of VOC cleaners	Use of VOC-free cleaners e.g. water based cleaners (with detergents) for cleaning of equipment and parts
VOC-reduced Systems	Reduction of the solvent content in coating systems	Changing from conventional coating systems to high solid and water based coating systems
Process Improvements	Improvement of application techniques	Optimise the spraying technique, reduce the number of coating layers, improve or replace application techniques by those with a higher degree of efficiency Use of automatic mixing systems.
	Reduction of cleaning effort	Reduction of colour changes. Immediate cleaning (before drying). Minimise use of cleaner. Emptying of pipes by 'pig' systems before cleaning. No cleaning for application of base coats or coats with low optical requirements. Consecutive coating of coloured working pieces. Automatic washing of spray guns and parts.
Abatement Technologies	Destruction of VOC	Thermal oxidation. Biological treatment.

9 Good practice examples

9.1 Water-based coating of special-purpose vehicles

A medium-sized manufacturer in Germany produces a wide range of multi-purpose vehicles (e.g. snow-ploughs and grit-spreader for winter services, vehicles for landscaping and roadside grass mowing and wheel-away platform vehicles for airport maintenance).

The vehicles are adapted to individual client requirements, including customised colour schemes.

Figure 2: Multi-purpose vehicles coated with a three-layer water-based system

Until 2006, for primers and topcoats a 2-component solvent-based system was used on-site whereas pre-coating was done by a trade coater.
Primer and topcoat application was done in 3 spray cabins which were used in series by transporting part with an overhead conveyer. Primer and topcoats were applied in separate cabins.
The company decided to use water-based systems in preference to high-solid coating systems in order to reduce the solvent emission as much as possible.
After carrying out research and consulting with a research association, cathodic dip coating technology was adopted, together with 6 spray cabins, for application of a water-based pre-coat, primer and topcoat system.
In the dip coating installation layers of ~ 20 µm thickness are applied. There are 4 drying ovens where the coating cures at a temperature of ~180°C. The dryers are interconnected to reuse heated air from neighbouring driers when doors are opened.
The dip coating uses a cascade water-supply system that minimizes fresh water demand. It produces sludge that is easier to treat than waste water and reduces environmental impacts of water treatment.
The six spraying booths are adaptations of standard automotive sector cabins, each equipped with a separate overhead conveyer to ease spray application. Both coatings can be applied in one cabin and dried in-situ.
The water-based primer is specially modified to the needs of industrial production and does not need drying time before the topcoat can be applied.
The cabins are equipped with special air nozzles that firstly produce turbulence (~ 10 min) and then dry with direct gas-heated air (~ 50 - 80 min). Flash off, drying time and temperature can be adapted to parts of different shape, size and material (metal, plastic).

The automatic mixing systems formerly used needed modification to cope with water-based system. It was possible to adapt the more recently purchased systems with stainless steel equipment but the older systems had to be replaced. The new equipment allows colour changes in less than 1 minute.
A hatch connecting the spray cabins allows using the same mixing system in two cabins by passing the tubes and pistols through the hatch. This increases productivity and reduces the cleaning effort.
Water-based cleaners can be used for the equipment in contact with the paint component but solvents have to be used for cleaning of equipment in contact with the hardener.
The investment cost for the cathodic dipping installation was 2.4 million €, and 1.2 million € for the top-coating installation.
Due to the exclusive use of water-based coatings for pre-coat, primer and top coat, VOC emissions have been reduced from 15 tonnes to less than 6 tonnes per year.
The success of the reduction was based on in-depth planning effort, valuable consultancy of the Surface Treatment Research Association and effective realisation of suppliers for cabins, overhead conveyer, mixing and application technique and in particular the coating system, selected after tendering.
[Hako-Werke 2008]

9.2 Cleaning of equipment

In a paint shop, manual cleaning of a spraying gun used to take 15 minutes and consume 500 ml of solvent cleaning agent. With the adopted automatic washing machine it takes about 3 minutes to clean the gun.
The cleaning agent is used several times, and fresh solvent is only used for final cleaning.
The solvent is recycled and reused.
[BayLFU 2005]

Figure 3: Spray gun washing machine

[Ökopol 2008]

10 Emerging techniques and substitutes under development

Water based top coats with less than 10 % water content, currently developed for large-scale vehicle coating, may also be applicable in a future to other metal coating activities.
[DuPont 2008]

11 Information sources

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