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Best Available Techniques (BAT) for the Paint- and Adhesive Application in Germany

-Volume I: Paint Application-

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Volume I: Paint Application
Volume II: Adhesive Application

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Annexes

Executive Summary

The Directive on *Integrated Pollution Prevention and Control (IPPC-Directive96/61/EG),* which was adopted by the Council of the European Community, has a significant impact on the permission of various industrial installations. As a main element for the transposition of the IPPC-Directive, according to article 16 passage two, an information exchange about the „Best Available Techniques“ is requested for all industrial sectors, listed in annex I of the IPPC-Directive, on a European level.

On this information exchange the member states of the European Community and also the affected industries participate. Content of the information exchange are: Specifications of the industrial sectors listed in the directive and the sector’s Best Available Techniques for an integrated prevention or reduction of environmental impacts, material consumption and emissions into the atmosphere, soil and water.

This final report represents the results which were examined from the Deutsch-Französischem Institut für Umweltforschung (DFIU-IFARE, German-French Institute for Environmental Research, University of Karlsruhe), on behalf of the Federal Environmental Agency (UBA). This report represents the German proposal for the Best Available Techniques for installations using organic solvents for surface treatment partition *paint and adhesive application* (cf. annex I, 6.7 of the IPPC-Directive) and will be submitted to the European BAT-documents.

Initial Position and Objective

Annex I. 6,7 of the IPPC-Directive defines the industrial activities via the consumption capacities of organic solvents. Industrial installations of the paint and adhesive application with a consumption capacity of 150 kg / h or 200 t / a, fall under the scope of the directive. This definition is different from those of other sectors, where specific plants are listed. Therefore relevant industrial activities had to be identified first.

Already in a very early project stage contacts, to manufacturers, authorities and industrial unions were established and organised in a working party.

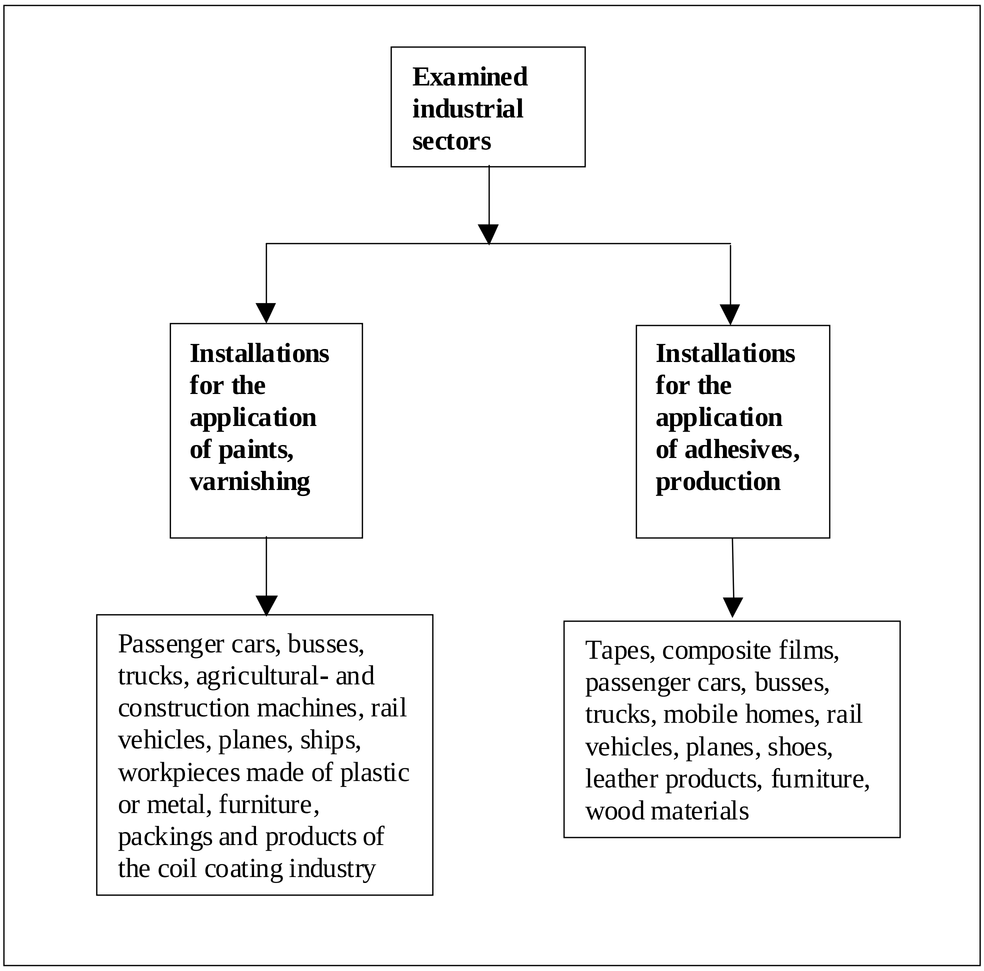

Figure I-1: *Investigated sectors of the industrial paint- and adhesive application*

Since there is only sparse current technical literature available for the problem, the process descriptions are based mainly on case studies of representative installations.

For the description of environmental relevant input- and output flows of enterprises, the applied processes were analysed via case studies. Thereby the process steps pre-treatment, coating and after-treatment were identified on basis of the production of typical workpieces in installations either relevant for the IPPC-Directive or that came under the scope before reduction measures were implemented.

Moreover technical options for a reduction or prevention of environmental pollution were characterised, if available. Main purpose of the case studies was the investigation of the following information:

- General information about the processes / plant
- Emissions into the atmosphere
- Water-side emissions
- Waste
- Material consumption and energy demand

- Other information such as data about waste heat or costs of applied measures.

Due to a keen competition in some sub-sectors, beside general process descriptions, no detailed data (cf. annex VI, volume paint application) could be obtained. Beside the case studies a further data collection from enterprises, was carried out via questionnaires (cf. annex VII). Processes such as drying, application or emission reduction measures, that are utilised within several sectors of the paint- and adhesive application, are sketched out in the annexes of the volume paint application.

On basis of the obtained data and information, the *Best Available Techniques* were identified and as far as possible techno-economically analysed and integrated assessed.

The system boundary for the assessment is the specific plant. Environmental impacts, that result from previous processes within the supply chain, such as during the production of paints and adhesives, or during the products service life or its disposal were generally not regarded. But in the case of significant differences of environmental impacts between applied processes, these discrepancies were documented.

Due to the research project’s support by the industry, legal authorities and industrial unions, it is ensured that a realistic description of the German installations is transmitted to the EIPPC in Sevilla.

The chapters were attuned with representatives from the industry, legal authorities and industrial unions in the context of workshops. During the project’s runtime five workshops were organised by the DFIU. In the following, the case studies are listed.

Table I-1: *Case studies in the sector adhesive application*

Branch	Enterprise
Tapes	Astorplast Klebetechnik AG, Plant Alfdorf
	Tesa AG, Plant Hausbruch bei Hamburg
Paper and packaging, composite foils	CRYOVAC, Sealed Air Cooperation, Plant Flensburg
	Bischof + Klein GmbH & Co. KG, Plant Lengerich
Vehicles	Volkswagen AG, Plant Wolfsburg
	AUDI AG, Plant Ingolstadt
	MAN AG, Plant Salzgitter
	Ford Plant, Saarlouis
	MAN AG, Plant München
	EVO BUS, Plant Mannheim
	Daimlerchrysler, Plant Raststatt
	LHB-ALSTOM, Plant Salzgitter
	Hymer AG, Plant Grefrath
	Johnson Controls, Neustadt
	Johnson Controls, Grefrath
Shoes and leather goods	Salamander, Plant Kornwestheim
	RICOSTA, Plant Donaueschingen
	Gabor, Plant Rosenheim
	Schuh- und Lederwarenmesse, Pirmasens
	Navajo Dr. Genger Schuhfabrik GmbH, Hinterweidentahl
Wood materials and furniture	Schiedermöbel-Wohnmöbel GmbH & Co. KG, Plant Schieder
	ALNO AG, Plant Pfullendorf
	Dunlop AG, Plant Hanau

Table I-2: *Case studies in the sector of paint application*

Branch	**Enterprise**
Serial coating of passenger cars	Ford Plant, Köln
	Volkswagen Plant, Wolfsburg, Hannover und Emden
	DaimlerChrysler, Plant Raststatt
	Audi AG, Ingolstadt
	BMW AG, Plant Dingolfingen
	Verband der Automobilindustrie (VDA), Frankfurt
	Opel Plant, Eisenach
Coating of busses	EvoBus, DaimlerChrysler AG, Mannheim, MAN Plant, München
Coating of trucks	MAN Plant, München,
Coating of mobile homes	Hymer AG, Bad Waldsee
Coating of agricultural and construction machines	Claas Saulgau GmbH
Coating of rail vehicles	LHB-ALSTOM, Plant Salzgitter
Coating of planes	Lufthansa Technik
	Airbus, Hamburg
Coating of ships	Ecco-Paint Workshop, Hamburg
	Jos Lambert GmbH Meyerwerft, Papenburg
	Bremerhafener Dockgesellschaft, Bremerhafen
	Blohm+Voss Repair GmbH, Hamburg und JAFO Technologie, Hamburg
Coating of plastic workpieces	Dynamit Nobel AG, Plant Sterbfritz ECCA,
Coating of metal workpieces	Fachverband Bandbeschichtung VAW Aluminium AG, Grevenbroich
Coating of packings	Verband Metallverpackungen, Düsseldorf Rexam, Berlin
Coating of furniture	Schiedermöbel GmbH, Plant Schieder, Alno AG, Pfullendorf

Results of the Determination of Best Available Techniques for the Industrial Paint Application

The consumption of environmental sound products such as powder coatings, water-dilutable paints and radiation curing materials is increasing over the last years, while the demand of

solvent based paints is declining. This trend was also intensified by the transposition of the 31. BImschV[1] (Federal Emission Control Ordinance). In some sectors such as the coil coating industry or the serial varnishing of commercial vehicles, still mainly solvent based products are in use. In these sectors, the legal restrains are mainly achieved by thermal combustion units (cf. annex V, volume paint application). Biological processes for waste gas cleaning are only utilised against odours in the sectors of paint and adhesive application.
Due to the increasing utilisation of thin films and improved application techniques in all sectors, generally smaller material consumption can be observed.

Descriptions of generally utilised processes in the paint and adhesive application are documented in the annexes of the volume paint application:

Annex I: Possibilities of Energy Savings in the Paint Application

Annex II: Overview of selected Pre-treatment Processes
Annex III: Paint application
Annex VI:Drying
Annex V: Secondary Emission Abatement Measures for Reduction of VOC Emissions

Due to the keen competition in some sectors, it was partly not possible to obtain data from the industry via case studies. The achieved data are listed in annex VI. In addition to the case studies a data collection was carried out via questionnaires, send to enterprises and associations. The obtained data are listed in annex VI.I.
Descriptions of generally utilised processes such as paint and adhesive application, drying processes or emission abatement measures are documented in Annex I-V.

Industrial Paint Application

Serial Coating of Passenger Cars

The process for the serial coating of passenger cars can be subdivided into the process steps:
pre-washing, phosphatization, passivation, cathodic immersion prime coating, underbody protection and seam sealing, application of the filler, application of top coat and clear coat, cavity conservation, if necessary conservation for transport and repair of possible damages of the varnish before assembly (cf. Figure 2).

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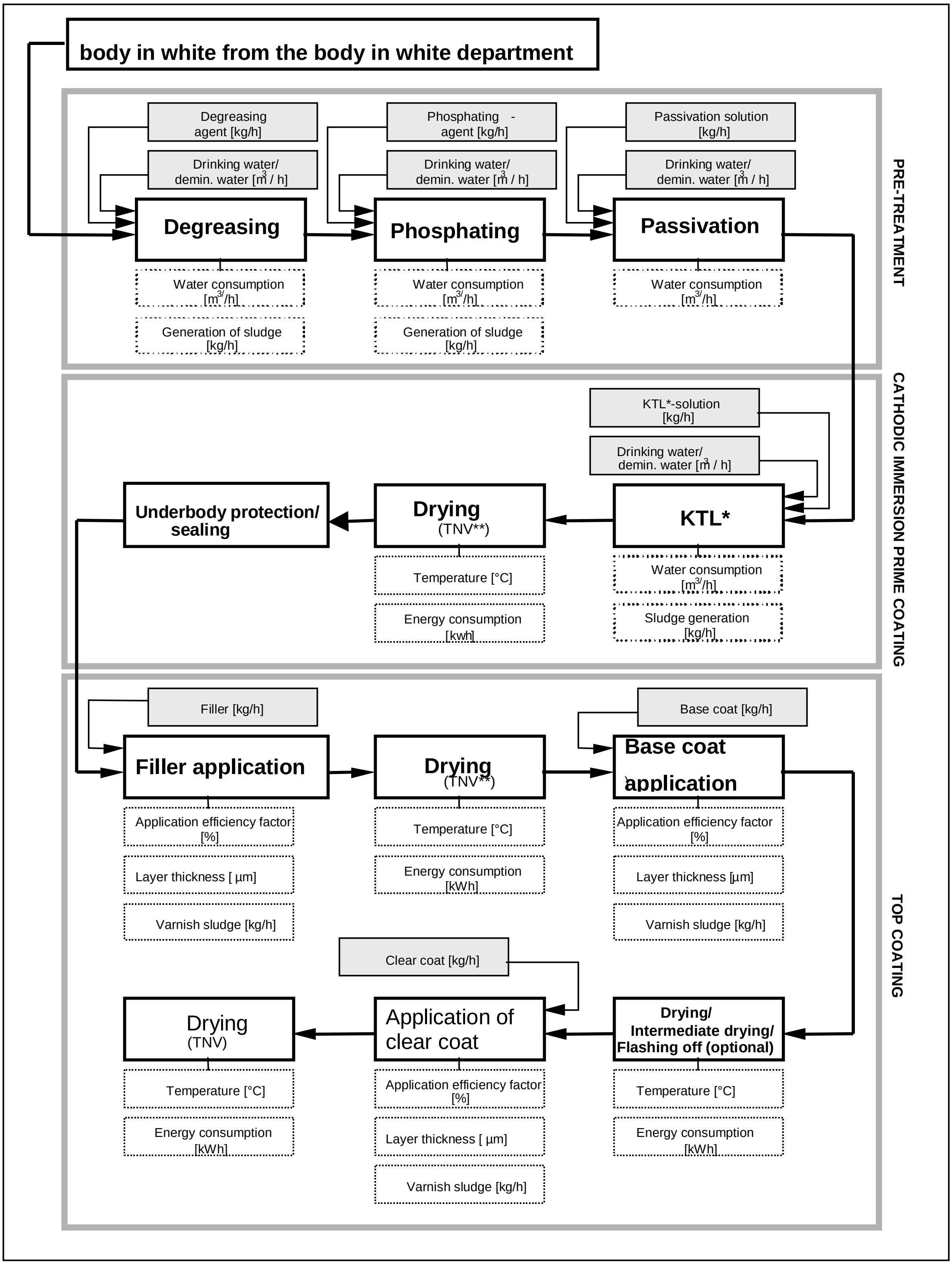
[1] Ordinance for the transposition of the Directive 1999/13/EG

Figure I-2*: Serial coating of passenger cars*



The production processes differ with regard to the material application techniques and the utilised materials.

Table I-3: *Utilisation of different painting concepts in Germany*

Varnishing process		**Filler**		**Base coat (unicolour/metallic)**		**Clear coat**		**Proportion**
		water	*solvent*	*water*	*solvent*	*solvent*	*low-solvent or solvent-free*	*[%]*
process with innovative technique								***13,0***
1		🟦		🟦			🟦	
2				🟦			powder slurry	
3			🟥	🟦			powder	
water-based paint process with conventional clear coat								***60,2***
4		🟦		🟦		🟥		
mixed processes: water-based varnish and conventional paint								***15,8***
5			🟥	🟦		🟥		
6			🟥 *	🟦		🟥		
7		🟦			🟥			
conventional processes (partly including spray booth exhaust gas cleaning)								***11,1***
8			🟥 *		🟥			
9			🟥 *		🟥 *	🟥 *		
	share [%]	**67,2**	**32,8**	**87,7**	**12,3**	**86,5**	**13,5**	100%

* Exhaust gas cleaning for the spray booth

In table 3 the different painting concepts (concepts 1 – 9) utilised by the German automobile producers are listed. The particular share is calculated from the produced passenger cars in the year 2000. The biggest share has the application of water-thinnable filler (67,2 %) and water-thinnable base coat (87,7 %), as well as the application of solvent based clear coat 86,5 %). This so called water lacquer process with application of conventional clear coat, can be referred as state of the art (process 4).

Innovative processes utilise solvent-free products or lacquers with a low solvent content, such as process 2, where no filler is applied.

In the mix-process 6, a waste gas cleaning is utilised during the application of the solvent based fillers.

Exclusively conventional processes are utilised in old plants. In the processes 8 and 9 some manufacturers use a waste gas cleaning for waste gases from dryers and also partly from the application of fillers, base coats and clear coats, as a emission reduction measure.

As **Best Available Techniques for the serial coating of passenger cars,** material specific and process specific techniques can be selected:

***Paint specific techniques*:**

For the application of ground coat, the utilised water-thinnable, lead-free cathodic immersion coatings together with the chrome-IV-free passivation, can be referred as an established best available techniques.

In table 4 the most advanced varnishing processes for the serial coating of passenger cars (processes A – D) for application of filler, base coat and clear coat, are listed.

The painting process A with the use of water-based clear coats leads to a significant reduction of the VOC emissions compared with conventional procedures, using solvent-based products. Recycling of the overspray is possible by appropriate procedures.

Table I-4: *Best available techniques for the serial coating of passenger cars in Germany*

Paint concept	**Filler**		**base coat (uni / metallic)**	**Clear coat**	
	water	*solvent*	*water*	*solvent*	*low in solvents or solvent-free*
A	🟦		🟦		🟦
B			🟦		Powder slurry
C		🟥	🟦		Powder
D	🟦		🟦	🟥	

Water-thinnable varnish 🟦

Solvent-based varnish 🟥

Varnish solvent-free or low in solvents 🟩

The combination of water-based paint and powder slurry (functional layer) in process B achieves very low VOC emissions. The energy-consumptive intermediate drying is avoided by the wet in wet varnishing technique of base coats and powder slurrys.

The application of powder clear coats in process C, leads to energy savings of more than 10 % compared with the use of conventional 2 part clear coats. The powder coat system does not produce waste water and no VOC emissions. The overspray can be recycled. The present used solvent-based filler will be replaced by water-based products until the year 2003.

The water-based paint process with conventional clear coating, as utilised in process D, allows an effective reduction of VOC emissions by a combination of water-based filler and -base coat.

Within these best available techniques, the procedure-specific technologies specified in the following are suitable for a further reduction of the environmental impacts. By the application of the processes and techniques, emission values of 10 – 35 g VOC per coated m² can be achieved.

Procedure-specific Techniques:

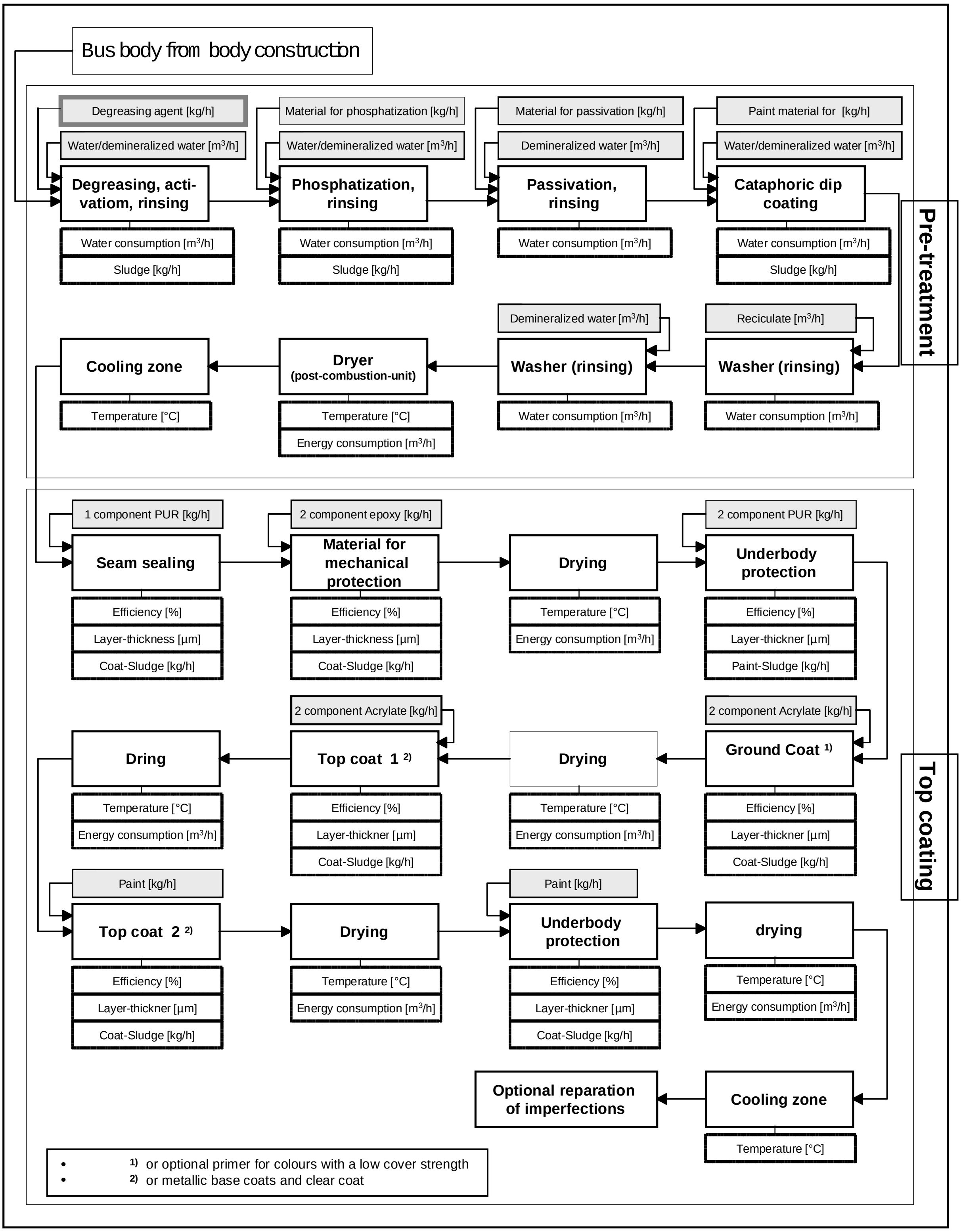
- Paint application with high proportion of electrostatic application
- Reduction of colour changing waste (by pig-clearing systems)
- Optimisation of layer thickness profiles
- Chromium(VI)-free passivation
- Bath maintenance measures by ultra-filtration for degreasing and cathodic immersion prime coating of the raw bodies
- Use of ion exchangers for phosphatization and passivation

Varnishing of Busses and Trucks

Varnishing of Busses

Compared to the serial coating of passenger cars, the varnishing processes for busses are less automated also a standard colour palette does not exist. Busses are generally custom made. Therefore the manufacturers have to store a wide variety of colours in form of material or as formulas. A cost effective varnishing can thereby only be obtained via manual application. The varnishing process is shown in figure 3.

Figure I-3: *Varnishing process for busses*



In table 5 proposals for the best available techniques for the varnishing of busses is listed.

Table I-5: *Proposal for the best available techniques for the varnishing of busses*

Zone	**Best Available Techniques**
Ground coat	Cataphoretic dip coating with water based and lead-free dip paint
Seam sealing	Water based material
Top coat	Solvent based top coats, application via electrostatic coating, post combustion of exhaust gases from painting cabins and dryers
Varnishing of axles	Water based paints
Acoustic insulation	Solvent-free material based on polyurethane

By the application of these materials and techniques, emission values of less than 225 g VOC per coated m² can be achieved.

Varnishing of Trucks

For the varnishing of trucks (both driving cabs and chassis) the use of water-thinnable coatings for ground coat and filler is meanwhile established and proven. The ground coat is thereby applied via dip coating. For top coats water- and solvent-thinnable paints are utilised. For standard colours, water-thinnable materials are generally processed in form of single layers.

Conventional paints are mainly used for special colours. For a reduction of VOC-emissions, the following paint specific- and process-specific techniques can be utilised as BAT:

Material specific techniques:

- Dip coat application onto steel profiles of the chassis via water based groundings,
- use of water based, single-layer top-coats for chassis and driving cabs in form of 1-coat topcoats,
- application of single-layer, high-solid materials for chassis (without priming paint),
- application of water based paints for varnishing of axles in combination with process-specific Techniques.

Process specific techniques:

- High portion of electrostatic application devices, for manual applications use of HVLP-spray-guns.
- Reduction of material loss due colour changes via scrapper-cleanable ring circuits.
- Measures for the reduction of water consumption: Cascade arrangements in the pre-treatment installations and implementation of decanters.

By the application of these techniques, emission values of 45 g / m² for the varnishing of driver’s cabins and 70 g / m² for the coating of trucks (including coating of axles) are achieved.

Varnishing of Agricultural- and Construction Vehicles

In comparison to the varnishing of vehicles such as passenger cars, the optical surface qualities of agricultural- and construction vehicles are of minor significance. The main task of the paint, is corrosion protection. The varnish has to sustain heavy mechanical and chemical stress. Chemical corrosion occurs due to aggressive saps and moisture.

The following environmentally sound technologies are available for the coating of agricultural- and construction vehicles:

- Aqueous-alkaline cleaning and afterwards a chrome-VI-free zinc phosphatisation
- Ground coat application via cataphoric dip coating with water thinnable, lead-free materials using cascade technique and ultrafiltration.
- Application of water-thinnable single layer top coats via manual spray application.

Varnishing of Planes

For the varnishing of planes, different processes are used in the **maintenance** and **new building**. During the maintenance, damages to the paintwork are repaired or a complete varnishing of outside surfaces is applied. Generally 600g VOC per coated m² of outside surfaces are emitted For a reduction of VOC-emissions during the maintenance, only integrated measures can be utilised.

Maintenance

Following techniques are recommended as BAT for the maintenance of aircrafts:

- Paint removal via a mixture of benzyl alcohol and formic acid
- Application of chrome-free ground coats
- Application of high-solid top coats without an additional clear coat layer
- Electrostatic-spray application for paint materials

New building

Following techniques are recommended as BAT for the new building of air crafts:

- Conventional 3-layer system (wash primer, ground coat, top coat) with a high-solid top coat and without clear coat application. Thus the VOC-emissions can be reduced up to 30 % in comparison with the conventional process.
- Electro-statically assisted -spray application for varnishing of outside surfaces
- Automated paint application in combination with exhaust gas cleaning for varnishing of component parts

Varnishing of Rail Vehicles

Besides high optical qualities of the paint also a good corrosion protection is required for rail vehicles. The applied varnishing system must resist climatic impacts, aggressive cleaning agents (used for removal of graffitis) as well as abrasion from sliding contacts. For a reduction of the environmental impacts, the following techniques can be defined as BAT and emission values of 110 g/m² can be achieved:

- Application of water based ground coats, fillers and top coats
- Only for two-layer lacquer finishes and application of a conventional clear coat.
- Minimum use of knifing fillers with a low styrene content
- Processing of pre-coated (coil-coated) materials for new construction
- Reduction of varnished surfaces for e.g. use of adhesive foils for decorative designs or as a graffiti protection

Efficient application devices: HVLP-, airless- and air-assisted airless spraying

Recycling of cleaning solvents via distillation of solvent containing paint wastes and paint sludges.

Varnishing of Ships

For the paintwork of merchant ships adhesion and corrosion protection are the center of attention. Onto the hull, paints are applied that prevent the settling of organisms onto the surface. For a determination of the BAT the maintenance and the new building have to be regarded separately, alike in the varnishing of planes.

While during the new construction of ships, parts or segments of the hull are produced in closed halls, the maintenance operations take generally place in floating docks or dry docks.

Maintenance

- Utilisation of water blasting for paint removal and treatment of dock waste water and reuse of the water.
- For paint application onto non-vertical, bended surfaces, the airless application represents an already implemented BAT. For the coating of plane, vertical surfaces, the use of mobile application devices with an integrated extraction of overspray represents the most environmental sound technique.
- Fortification of nets for the reduction of the air movement and thus a reduction of the discharge of overspray.

New building

- Paint application with a high share of electrostatic air-assisted spraying.
- Closed workshop halls for blasting and varnishing of big ship sections with extraction of exhaust gases and treatment via dust separators and adsorption of VOC with subsequent

thermal combustion as well as recycling of the blasting agent.Clean gas concentrations of 23 mg C/m³ are achieved.

New building and maintenance

- Implementation of a multi-cycle-system for big paint containers for standard coatings. In the new construction and maintenance.
- According to the Application of TBT-free antifoulings, based on copper-compounds or the use of biocide-free coatings, according to the conditions of the vessels use.

Varnishing of Plastic Workpieces

Due to the big variety of products in this sector, a description of this sector will be carried out for selected workpieces of the vehicle supplier's industry predominantly. In most applications already water-thinnable materials are processed. Due to the high variety in workpieces, plastics and requirements for the coatings, best available techniques can only be specified in a very general way:

- High proportion of electrostatic application
- Scrapper cleanable Ring circuits for automated application
- Application of water-based systems for ground and top coating or powder coatings
- Use of UV-curing clear varnishes

Varnishing of Metal Workpieces

The sector of serial varnishing of metal workpieces shows a big variety. The sector will be described, based on the following products: **Household appliances, steel furniture, office appliances, switch cabinets, heating elements, radiators, facade parts, rims, engine blocks, brake discs, windshield wipers as well as frames of motorbikes** and **bikes**. Due to the high variety of used techniques and the highly different requirements for the coating of the products, a uniform BAT selection can not be given, but is illustrated exemplary.

Based on the exemplary consideration of coating processes of different workpieces, the following low-emission techniques can be used for the coating and surface preparation of metal workpieces:

Coating of Steel Surfaces:

- Watery cleaning and rinsing processes with integrated water-saving measures such as circuitry of the rinsing media,
- Cataphoretic dip coating with subsequent top coating with liquid or powder varnish if necessary,
- Low-solvent liquid varnish systems,

- Coating with powder varnish including powder overspray recycling,
- Application techniques low in overspray combined with recovery of liquid varnish overspray.

Coating of Aluminum Surfaces:

- Chromium-free pre-treatment,
- Watery cleaning and rinsing processes with integrated water-saving measures such as circuitry of the rinsing media ,
- Coating with powder varnish or a combination consisting of powder and water-thinnable varnish

For the coating of rims, the VOC emissions can be reduced up to 90 %, the generation of waste up to 85 % and the material consumption up to 10 % by the application of these techniques. The energy demand is comparable to the conventional process

Coil Coating

Corrosion protection and the optical surface quality have a predominant meaning for the coating of steel and aluminium.

The coil coating industry is on the one hand characterized by big enterprises with integrated installations and typically their own further processing (especially in the steel industry).On the other hand there are middle size enterprises with comparably small, slow installations and often very specialized product offers.

At present, two different techniques can be referred as BAT:

- Utilisation of the waste water-free *no rinse* process for the pre-treatment
- Use of conventional, solvent based materials in combination with a downstream located thermal combustion unit. A total VOC emission of 3 % of the utilized solvents and clean gas concentrations (after combustion) of 20 mg / m² are achieved.

Varnishing of Packings: Beverage Cans

For the varnishing of beverage cans, mainly water-thinnable paints are utilized. For an improvement of the workability, these products also contain organic solvents. At present no solvent-free products are available.

- Application of water-thinnable paints and the application of regenerative, thermal combustion units for exhaust gases from dryers and plant components for the application of paints and printing inks.
- For a concentration of exhaust gases with a low VOC-content, adsorption processes can be utilised.
- Application of engraving rolls for a reduction of printing inks.
- Application of the over-varnish-technique for a reduction of exterior paint.

- Installation of extraction hoods at the entrance- and withdrawal areas of dryers for the interior paint.
- Recycling of overspray from spray application of the interior varnish.

A total VOC emission of 3 % of the utilized solvents and clean gas concentrations (after combustion) of 20 mg / m² are achieved

Varnishing of Furniture and Wood Materials

Wood is a natural raw material characterised by its inhomogenity and anisotropy. Furthermore, wood is featured by irregular properties in terms of surface structures (stature irregularities), various substances of content (waxes, water, resins) and a variable electrical resistance. If wooden surfaces are varnished, the colour, the surface structure and the porosity are properties that are supposed to be conserved or strengthened concerning their effects by the varnishing process. Also it is of special significance if a closed cell or open-cell surface has to be generated. In table 6 a proposal for the BAT for varnishing of wood materials and furniture is listed.

Table I-6: *BAT for painting processes in the wood and furniture industry*

Branch of production	**BAT**
Chipboards for living and bedroom furniture	Water-thinnable paints with infrared radiation or UV-radiation curing, for all paint layers
Chairs and tables	Water-thinnable paints as ground coats and top coats. Electrostatic assisted spray application, drying at ambient temperature or forced drying process
MDF-plates	Powder coating, electrostatically assisted spray application
	Water-thinnable UV curing paints, application via rolling, convection drying resp. UV radiation drying
	UV radiation curing powder coatings, spray application
Windows	Water-thinnable paints for grounding and impregnating paint application via flooding, electrostatic assisted spray application for the application of top coatings
Stairs (made of solid wood or wood materials)	Water-thinnable paint for grounding and top coat application
Kitchen furniture	Liquid paints based on PUR and polyester, (water-thinnable: 7 – 9 % organic solvents, 40 – 60 % water)

Branch of production	BAT
Plane surfaces, office furniture, parquet, doors, bedroom furniture	Water-thinnable wood stain (5% solids content, 95 % water), combi-wood stain (5 % solids content, 65 % water, 30 % organic solvents) PUR-paints, applied via rolling, physical drying process (water-thinnable: 7 – 9 % of organic solvents, 40 – 60 % water). UPE-paints in form of open cell flatting (water-thinnable: approx. 5 – 7 % organic solvents, 40 – 50 % water), UPE-thick-layer-paints, paraffin containing: Approx. 47 % organic solvents, thereof 10 – 15 % relevant for emissions since an incorporation by polymerization takes place for the others UPE-rolling coats, UV radiation curing, (ground coat: 2 – 4 % of organic solvents, top coat approx. 10 % of organic solvents)
Spray application	If applicable: Varnish recovery

Results of the Determination of Best Available Techniques of Industrial Adhesive Application

Due to a strong substitution of solvent-based adhesives and to a lower extent due to migration of companies to low-wage countries, there are only a few industrial installations existing in Germany with a solvent consumption capacity of 150 kg/h or 200 t/a originating from adhesives and surface preparations. Installations falling under the scope of the Directive exist only in the sectors of production of adhesive tapes and in the paper and packaging industry for the production of compound foils. For these sectors, solvent-free products are not available for all applications at present. The emission limits are achieved via downstream located emission abatement measures (cf. annex V, volume paint application).

Due to the multitude of adhesives applied within the industrial applications, this sector is very complex.

Production of Tapes

The selection of an adhesive system depends on the requested technical properties of the tape.

Table I-7: *Applications of pressure-sensitive adhesives for adhesive tapes* [KREUTER 2001]

Operative range or adhesive tapes	**Application**	**Pressure-sensitive adhesive**
Packaging	Adhesive labels, adhesive tapes for packaging	SIS block polymer as hot melt, ***solvent-based natural rubber adhesives (SB),*** water based acrylate dispersions
Paper industry	Splicing of paper rolls, transfer adhesive tapes	water soluble polyacrylates
Automotive industry	Transfer adhesive tapes for decorative strips and flank protection strips , insulating slabs, assembly aids for wheel case covers and side skirt pannels, adhesive tapes for winding of wire harnesses	***Solvent-based natural rubber adhesives, esters of acrylic acid and acrylates***
Construction industry	Foamed plastic adhesive tapes for sealing of windows, for caulking of construction splices and expansion joints, carpeting adhesive tapes etc	***Acrylate dispersions based on solvents*** or as watery dispersion
Medicine	Medical tapes, adhesive plasters	***Pure acrylates, polyacrylates***
Furniture industry	Transfer adhesive tapes for mirrors etc.	***Acrylate adhesives, solvent containing*** or watery

A determination of BAT for all products of the sector is therefore not possible. The required technical properties of the tape determine the BAT:

- Hot melts and dispersion for the lower quality range of packaging and masking tapes as well as double-sided tapes.
- UV cross-linking systems for solvent-based adhesives up to the lower quality range of transfer and packaging tapes as well as masking tapes.
- Solvent-based adhesive bulks for adhesive tape applications that require a high stress resistance. Up to now, there are no solvent-free adhesive bulks available that show equivalent properties. Therefore, there is no alternative to solvent-based adhesives in the high quality range. For these applications, techniques such as adsorption installations and inert gas dryers followed by condensation installations are available that reduce emissions to the environment and allow a re-use of solvents. The emission limits, defined by the German 31 BImschV, are achieved.

Detailed data for the production of adhesive tapes are listed in Annex A.

I.3.2 Paper and Packaging Industry: Production of Compound foils

Solvent-based adhesives are almost exclusively utilized for the production of composite foils. The production of composite foils for food packaging has the highest proportion in the lamination of composite foils. Within this sector the production of snack food packages is of utmost significance [VDI 1512]. Due to small amounts of adhesives used in the production of industrial packages, only production of consumer packages will be discussed in the following Due to the high variety of used materials and a similar construction of application devices, the selection of best available techniques is orientated best on the used adhesive system.

- For mass composites without and stricter requirements the application of solvent-free adhesives is already established BAT
- Application of solvent-based adhesives with high solids contents (High Solid Systems) for the high performance sector for mechanically, thermally or chemically stressed packages and in the production of composites changing in material within one lamination installation. Subsequent exhaust gas cleaning techniques such as absorption and adsorption allow a high proportion of solvents to be re-used after distillation. For non-recyclable solvents (e.g. solvent mixtures), thermal or catalytic exhaust gas cleaning can be used (see also [VDI 2587/3]). Concentrations of less than 20 mg C/m³ in the clean gas are achieved.
- Reduction of fugitive emissions by distillation of solvent containing adhesive leftovers and cleaning solvents followed by recycling of the solvents.

I General Information

I.1 Subject of the Document

I.1.1 Context

On September 24th, 1996 the Council of the European Union adopted the Directive on Integrated Pollution Prevention and Control (IPPC Directive, 96/61/EG [IVU-RL 1996]). This Directive aims at harmonizing the permitting procedures for the operation of industrial installations [BECKER 1997]. Consequently, the Member States of the European Union will be committed to an “integrated concept“ when licensing installations contributing to a certain extent to environmental pollution [RENTZ 1998]. According to Article 1, the purpose of the IPPC Directive is the achievement of a high level of protection of the environment taken as a whole. It lays down measures designed to prevent or, where that is not practicable, to reduce emissions in the air, water and land from certain industrial activities. Annex I of the IPPC Directive lists a series of industrial activities that are concerned by the Directive, especially ***“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“*** **(Annex I, No. 6.7).**

I.1.2 Environmental Hazard

Due to the generation of emissions of volatile organic compounds[1] (VOC), the mentioned installations show a substantial potential of environmental hazard. As a consequence of their neurotoxical properties, the emitted organic compounds lead also directly to a damage human health. After their release into the atmosphere, VOC are subject to photochemical reactions in the presence of nitrogen oxides (NOx) and sunlight, leading to the formation of photooxidant substances. Besides PAN (peroxyacetyl nitrate) and aldehydes, the leading photooxidant substance is the tropospheric ozon that mainly causes photochemical smog (so called ”summer smog”).

I.1.3 Significance of the IPPC Directive

The instrument for transposing the purposes of the IPPC Directive relies on the allocation of permits for the operation of industrial installations (new and existing installations). In the framework of permitting procedures, this Directive foresees substantial renewals with regard

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[1] Volatile organic compound (VOC) means any organic compound having a vapour pressure of 0,01 kPa or more at 293,15 K or having a corresponding volatility under the particular conditions of use [LM-RL 1999].

to former approaches dealing with environmental protection, amongst other things with regard to Directive 84/360/EWG that will be replaced by the IPPC Directive. The most significant modification and further development is the integrated approach of environmental protection through a cross-media contemplation taking into account the dangers of a displacement of environmental pollution from one media into another (cf. Article 9 (3) and 9 (4)) [BECKER 1997, RENTZ 1999].

The practical transposition of the IPPC Directive is realized through the application of "Best Available Techniques" (BAT). BAT shall serve for setting emission limit values for certain pollutants that are listed in Annex III of the Directive and for installations submitted to the IPPC Directive.

I.1.4 Definition of the term "Best Available Techniques"

According to Article 2, section 11 of the IPPC Directive, 'best available techniques` shall mean *"the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole":*

- *'techniques` shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;*

- *'available` techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;*

- *'best` shall mean most effective in achieving a high general level of protection of the environment as a whole.*

When determining best available techniques, all considerations that have already been described when assessing BAT-candidates, have to be taken into account and characterized, especially (according to Annex 6 of the IPPC Directive):

1. the use of low-waste technology;
2. the use of less hazardous substances;

3. the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
4. comparable processes, facilities or methods of operation which have been tried with success on an industrial scale;
5. technological advances and changes in scientific knowledge and understanding;
6. the nature, effects and volume of the emissions concerned;
7. the commissioning dates for new or existing installations;
8. the length of time needed to introduce the best available technique;
9. the consumption and nature of raw materials (including water) used in the process and their energy efficiency;
10. the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it;
11. the need to prevent accidents and to minimize the consequences for the environment;
12. the information published by the Commission pursuant to Article 16 (2) or by international organizations.

I.2 Relevant German and International Environmental Legislation

The national and international legislation concerning industrial solvent application (amongst other things) existing besides the IPPC Directive, will be described in the following. This part gives a short overview over relevant environmental legislation on international and German level concerning the given issues.

I.2.1 International Commitments

As international commitments for varnish-processing installations, the UN/ECE Protocols under the Convention on Long-range Transboundary Air Pollution, the European Directive on National Emission Ceilings (NEC Directive) and the European Directive on the Limitation of Emissions of Volatile Organic Compounds in Certain Activities and Installations [LM-RL 1999] can be specified.

I.2.1.1 The Convention on Long-range Transboundary Air Pollution of the UN/ECE and their Protocols

The Convention on Long-range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe (UN/ECE) is a milestone in the international environmental policy. The Convention has allowed the development of international legislation and the creation of the substantial frame for controlling and reducing the hazard of environment and human health generated by the transboundary air pollution. The Convention was signed of 34 States and the European Community in 1979. It was the first international legally binding instrument dealing with air pollution issues in a transboundary context. This

Convention has laid down the general principles of international cooperation for the reduction of air pollution and has created the institutional framework to bring together research and policy.

The Convention was fulfilled through five specific Protocols. The youngest Protocol, *Protocol to Abate Acidification, Eutrophication and Ground-level Ozone* (also called Göteborg Protocol) was signed at the end of the year 1999. This Protocol sets emission ceilings for the year 2010 for the four air pollutants sulphur (SO_2), nitrogen oxides (NO_x), VOC and ammonia (NH_3). The emission ceiling for Germany amounts to 995 tons VOC for 2010, which corresponds to a reduction of 70 % when comparing with 1990. This emission ceiling has to be taken into account when transposing further international commitments (for example Directive 99/13/EG) in order to meet their objectives too.

Furthermore, emission limit values for those four pollutants and best available techniques were set for specific sectors in the Technical Annexes of the Göteborg Protocols. These can or have to be considered respectively when elaborating a national reduction plan (cf. [UN/ECE 2001]).

I.2.1.2 European Directive on National Emission Ceilings (NEC-Directive)

The Göteborg protocol of the UNECE is implemented for the air pollutants SO_2, NH_3, NO_x and VOCs in the European Union by the Directive 2001/81/EG about national emission ceilings (also known as NEC Directive). It defines obliging national emission ceilings for the single member states beginning with the year 2010. There are a few variances compared with the Göteborg protocol. Until October 2002, all member states have to develop plans about how to achieve the necessary emission reductions. In this respect, national authorities specify themselves which measures to be the most suitable in order to fulfill the emission ceilings set. The year 2010 represents only a preliminary target, for which the unprotected ecosystems have to be reduced by min. 50 % when comparing to the situation in 1990. The emission load for Germany shall be reduced to 995 kt until 2010 in Germany (cf. also [EU 2001]).

I.2.1.3 The Solvent Directive of the European Union

The Solvent Directive [LM-RL 1999] deals with the limitation of volatile organic compounds, arising from 21 relevant activities of solvent application. The Directive is subdivided into a general part with the essential requirements and a sector specific part, in which

- the activities are defined (Annex I),
- threshold and emission limit values for installations of the 21 activities are listed (Annex IIA),
- principles and requirements for a reduction plan on installation level are named (Annex IIB) and,

- guidelines for the elaboration of a solvent management plan on installation level are given (Annex III).

The implementation of the Solvent Directive into national legislation was carried out in August 2001 (cf. [MAHRWALD 2000]).
In comparison with the German Technical Instruction on Air Quality Control, the Solvent Directive also covers the largest part of installations dealing with varnish application that were not subject to permissions until now. A substantial constituent of the Solvent Directive is the Solvent Management Plan.

The Solvent Management Plan

The Solvent Management Plan represents a certain form of material accounting in which the plants account regularly for their input and output flows aiming at reaching an efficient input of materials. In this frame, individual solvents have to be expelled separately according to the classification principles of the law of chemical substances as carcinogenic, mutagenic, toxic for reproduction or very unhealthy. Authorities check the presented solvent management plans with regard to completeness and validity, and, if necessary, agree upon precise reduction objectives with the plant [RENTZ 2001, MAY 2001]

I.2.2 Legal Bases in Germany

The essential national requirements for the adhesive and varnish processing enterprises will be listed shortly in the following. Important legal bases for industrial installations in Germany are defined in the following laws and ordinances:

- Federal law for the protection against emissions (BImSchG)
- Ordinance for the implementation of the Directive 1999/13/EG about the limitation of VOC emissions (31.BimSchV)(March 2001)
- Law on lifecycle management and waste (KrW-/AbfG)
- Water resources law (WHG)

For a permission of industrial installations, all damages to all environmental media are considered in Germany. While special emphasis lays on emissions, noise exposure and others are considered as well. As the precautionary principle is applied, limit values for the pollution are defined and their fulfillment is monitored through the authorities dealing with the permissions. The implementation of environmental laws and ordinances falls under the scope of the provinces. Hence emission limits may be different depending on the province.

Furthermore, execution of an environmental impact assessment (UVP[2] law) is required for the permission for the construction of new industrial installations having a potential of environmental hazards.

I.2.2.1 Laws

I.2.2.1.1 Federal Law for the Protection against Emissions (Bundesimmissionsschutzgesetz, BImSchG)

The Federal law for the protection against emissions (Bundesimmissionsschutzgesetz, BImSchG) represents the basic principle and the TA Luft (Technical Instructions on Air Quality Control) the technical administrative instruction with regard to clean air act in Germany. This law formulates targets for installations and deals with principles and sequences of permitting procedures as well as with punishable acts and irregularities. The TA Luft is mainly used by permitting authorities as an orientation valid for the whole republic, whereby the limit values defined via the objectives of § 1 of BImSchG shall be supervised. Besides the documentation of the state-of-the-art, the TA Luft also formulates new principles such as redevelopment of existing installations, dynamisation, mass limitations and others (cf. [MAY 2001]).

I.2.2.1.2 Law on Lifecycle Management and Waste (Kreislaufwirtschafts- und Abfallgesetz, KrW-/AbfG)

According to the Law on lifecycle management and waste (Kreislaufwirtschafts- und Abfallgesetz, KrW-/AbfG), all plants exceeding an annual generation of 2 tons of waste needing special monitoring or 2 000 tons of waste needing monitoring, respectively, a waste management concept (§19) and a waste balance (§20) have to be compiled. For that purpose, information on type, amount and disposal of these wastes have to be collected. The compilation of a *waste management concept* on plant level was required for the year 1999 for a period of 5 years for the first time and shall include details on [MAY 1997]:

- type and amount of generated waste,
- implemented and planned measures for waste reduction, recycling and disposal,
- reasons for the necessity of waste disposal,
- ways to recycle and dispose off waste,
- planning of sites and installations when waste disposal on-site, and
- remaining verification when disposing waste inside or outside Germany.

On the other side, the *waste balance* represents a retrospective description of the passed year with regard to waste management, whereby items 1, 3 and 6 of the above mentioned

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[2] UVP is the German abbreviation of Environmental Impact Assessment

enumeration are to be fulfilled. Corresponding balances had to be elaborated first in 1998 retrospectively for the year 1997.

I.2.2.1.3 Water Resources Law (Wasserhaushaltsgesetz, WHG)

The water resources law (Wasserhaushaltsgesetz, WHG) builds the basis for the protection of ground water and surface water. According to this law, wastewater containing dangerous substances has to be treated in compliance with the state-of-the-art before being drained. For that purpose, the dangerous substances are classified with regard to their degree of water hazardousness (water hazard classes): solvent-based paints correspond to class 2 (WGK 2) (hazardous) and water-based paints to class 1 (WGK 1) (slightly hazardous). The corresponding information is documented on security data sheets for paints and solvents.

The water resources law is completed by administrative instructions for 57 branches, in which emission limit values for certain substances and parameters have been set. Unification is being performed step-wise, flowing into the TA Wasser that corresponds to a general framework of administrative instructions dealing with the minimal requirements for the dumping of wastewater into surface waters. In addition to the requirements set via limit values, the state-of-the-art is formulated through general requirements (cf. [MAY 2001]).

I.2.2.2 Ordinances

I.2.2.2.1 Federal Ordinances for the Protection against Emissions (Bundesimmissionsschutzverordnungen, BImSchV)

Since the targets of the Federal law for the protection against emissions are not sufficient for precise questions dealing with technical planning, 31 Federal Ordinances for the Protection against Emissions (Bundesimmissionsschutzverordnungen, BImSchV) have been adopted. Concerning installations for surface treatment using organic solvents, the following ordinances are of special importance (cf. [MAY 2001]):

- 2nd Ordinance (2. BImSchV): Halogenated hydrocarbons (March 1991)
- 4th Ordinance (4. BImSchV): Installations submitted to permitting (November 1985)
- 12th Ordinance (12. BImSchV): Ordinance on plant failures (September 1991).
- 31st Ordinance (31. BImSchV): Implementation of the EU Directive 1999/13/EG of March 11th, 1999 (cf. II.2.2.3)

I.2.2.2.2 Ordinance Concerning Dangerous Substances (Gefahrstoffverordnung, GefStoffV)

According to § 16, section 3a of the Ordinance concerning dangerous substances (Gefahrstoffverordnung, GefStoffV), the operator is committed to carry out an inventory of all dangerous substances used within the installation. This inventory shall include information on notations, designations and amounts of the dangerous substances within the installation as well as on the departments where dangerous substances are used [MAY 1997]. This ordinance is not oriented towards thresholds, but the elaboration of balances is principally required.

I.2.2.2.3 Ordinance for the transposition of Directive 1999/13/EG related to the limitation of VOC-emissions (31.BImSchV)

This ordinance is the implementation of the EU Solvent Directive into national legislation [31. BIMSCHV 2001]. In this regulation, single requirements of the EU Solvent Directive will be implemented more strictly than it was necessary according to EU instructions. The superior target is achievement of the maximum amount of emissions of 995 tons for the year 2010 as specified in the Göteborg protocol.

I.3 Subject of the Research Project

Within the scope of the implementation of the IPCC Directive, this report about the best available techniques for the sectors of industrial varnish and adhesive application has been created. This report is the German contribution to the European BAT Data Sheets for the named sectors. The Institute for Prospective Technological Studies (IPTS) in Sevilla manages the creation of the European BAT Data Sheets for all sectors. According to the schedule, works on the BAT Data Sheets "Surface Treatment with application of organic solvents for the sectors varnish and adhesive application" are supposed to begin in spring 2002[3]. The German Federal Environmental Agency (Umweltbundesamt) is in charge of the coordination of activities on national level on behalf of the German Government.

Due to extensive literature research of technical literature and numerous expert discussions with industry representatives and representatives of industrial associations, the sectors with maximum solvent consumptions have been selected. These have been investigated for the creation of this report (cf. Table II-1).

The product spectrum of the industry sectors shows a very high variety resulting in strongly different requirements for adhesive bondings and varnish coatings. Hence production processes and applied techniques of the investigated sectors also strongly differentiate, so that they can only be described separately. For the task of a definition of the BAT candidates, a detailed description of the applied techniques is necessary in order to prevent if misinterpretations in the further creation of BREFs (cf. [IPCC 2002]).

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[3] At the beginning of the project, the start of TWG was supposed to be in summer 2000

Table I-8: *Investigated industrial sectors of varnish or adhesive processing*

Adhesive processing installations for production of:	**Varnish processing installations for coating of:**
Adhesive tapes	Passenger cars
Composite foils	Buses and trucks
Passenger cars	Mobile homes
Commercial vehicles: buses, trucks	Large vehicles
Mobile homes	Rail vehicles
Rail vehicles	Aircrafts
Aircrafts	Ships
Shoes and leather goods	Plastic parts
Wood materials and furniture	Furniture
	Metal work pieces
	Products of the coil coating industry
	Packages

In order to describe the input and output flows that are environmentally relevant, the technical processes implemented nowadays are to be submitted to a comprehensive analysis. The investigated production systems are very heterogenous sectors that process a few thousand materials. As there is only a little technical literature dealing with such issues, the process descriptions are based on case studies and enterprise inspections of representative installations. The process steps pretreatment, coating and post-treatment will be identified by means of the cycles of typical work pieces in IPCC relevant installations or installations that have been ICPP relevant installations before the invention of abatement measures. Also the associated mass and partly energy flows are described. Furthermore, technical options for avoidance and reduction of environmental pollution are characterized if existing. The target of the case studies was the achievement of the following information:

- general information on the installation/the process
- emissions into air
- emissions into water
- waste
- input material and energy consumption
- further data such as details on waste heat, eventually details on cost aspects of implemented emission reduction measures.

Based on the acquired data and information, the Best Available Techniques (BAT) have been identified and as far as possible analyzed with respect to technical economic aspects and assessed under consideration of cross-media aspects.
In doing so, the area of balancing for the cross-media assessment is the respective installation. Environmental impacts generated in pre-chains of the considered production processes cannot be considered generally due to the complexity of products and processes. For example such impacts are generated by the production of varnishes and adhesives, during the usage period and disposal of the product. For sectors where there are significant differences with respect to the environmental impact outside of the investigated installations this has been pointed out.

With the support of the research project by industry, associations and permitting authorities, it can be ensured that the efforts are optimized and a realistic picture of the German installations is conveyed to the EIPPCB in Sevilla.

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II General Informations about Solvent consuming Installations of the Lacquer Processing

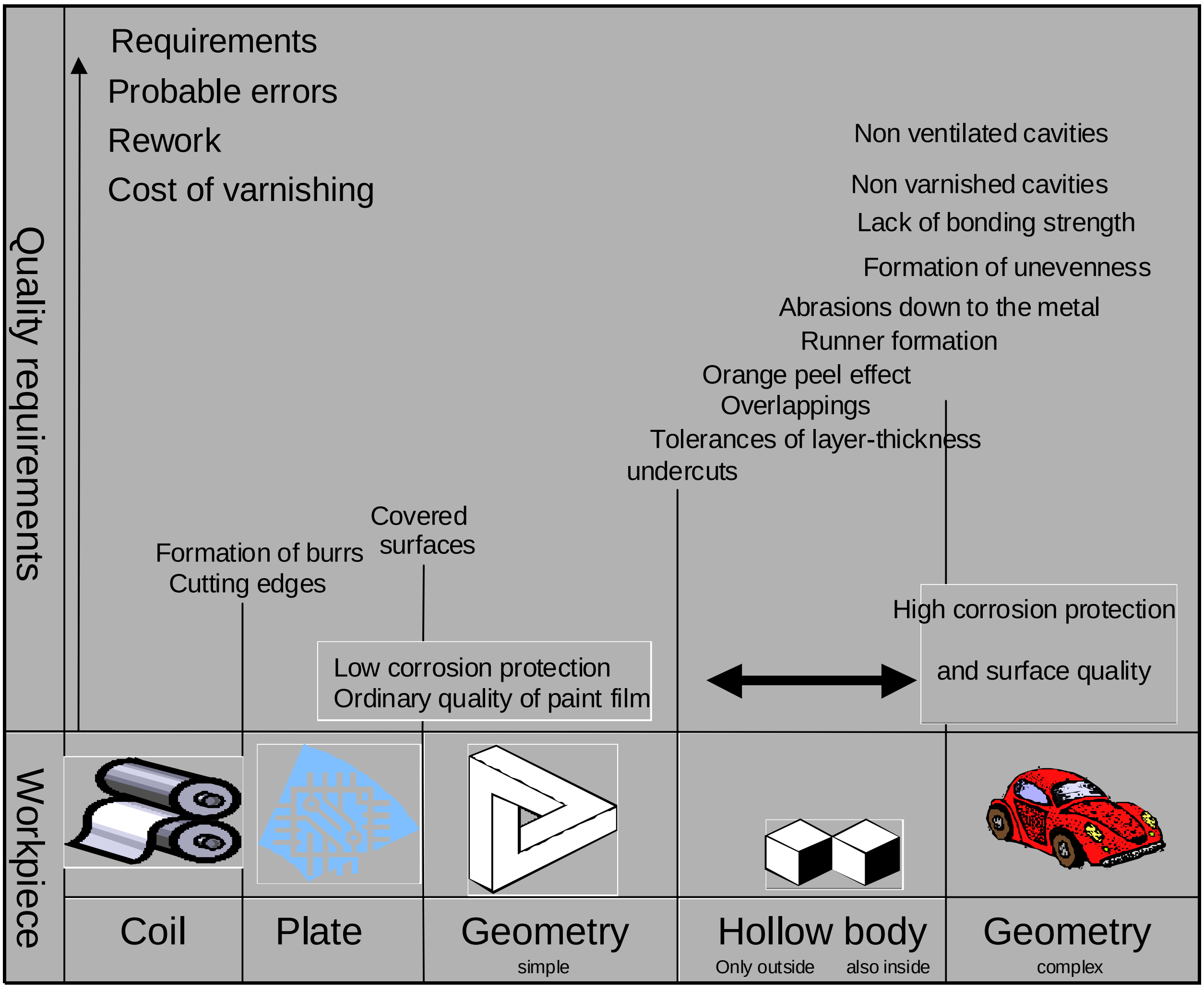
II.1 Requirements of the Paint System

The requirements of the surface coating show significant differences within the sectors of paint application. While the paint-systems used for the coating of ships, manly serve as a corrosion protection, the varnishing systems used in the serial coating of passenger cars also have to have high optical surface qualities. The requirements for the paint system are listed in Table II-1 and Figure II-1.

Table II-1*: Requirements for varnishing processes in different sectors* [BROCK 1998]

Characteristics	**Requirements**	
	High	**Lower**
Technical requirements	Varnishing of ships, long-time corrosion protection	Furniture and devices for indoor use
Optical surface requirements	Passenger cars	(Agricultural-) machines
Size of the workpiece	Ships, planes	Beverage cans, parts for shelfs
Geometry of the workpiece	Hollow workpieces: Cars, pipes	Furniture doors
Special requirements, e.g. electric conductable paints	Electric conductable paints for plastic housings, electric insulating paints for wires	e.g. biocide effects for antifouling paints utilized for ships

Figure II-1*: Dependence of geometry and quality requirements* [GRUPP 1999]



II.2 Coating materials

Paints consist of volatile and non-volatile components. After paint application and drying or curing, the non-volatile components remain onto the coated substrate. The amount of volatile compounds depends on the utilised paint system and the conditions of application. Coloured base coats, used for the serial varnishing of passenger cars, can contain up to 80 weight per cent of volatile compounds [ONDRADSCHECK 2002]. In comparison, powder coatings do not contain volatile compounds. Figure II-2 shows the components of wet lacquer systems.

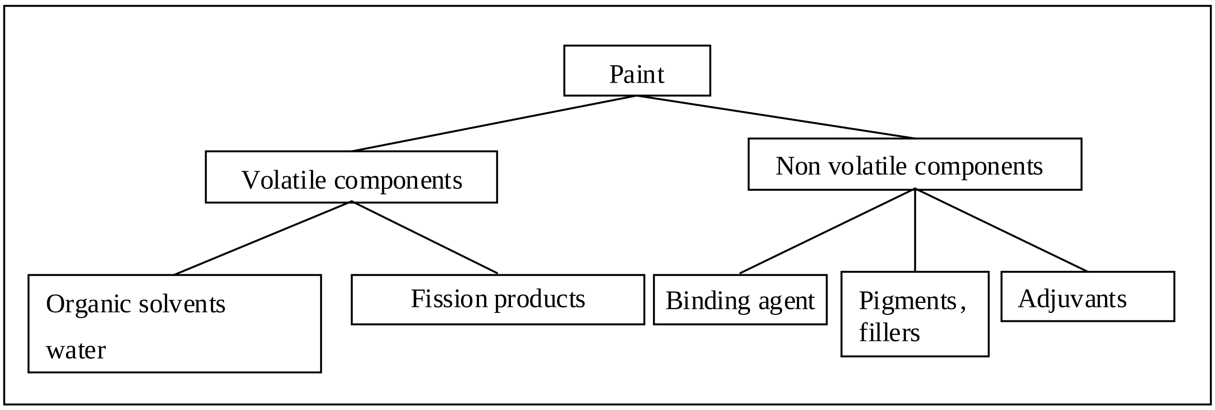


Figure II-2: *Paint Components* [ONDRATSCHECK 2002]

The paint components are solved or dispersed by **solvents** and thus processable. Via an addition of solvents, the material can be adapted to the conditions of application.

During the application and drying of the paint, the solvents are evaporated. Mainly mixtures of organic hydrocarbons (xylene, toulol and benzines), alcohols, esters and ketones are utilized. In water-thinnable paints, water is the main solvent. In the literature, different definitions for volatile organic compounds (VOC) do exist. Thus in the following the VOC-definition given by the Directive 1999/13/EG will be used:

A volatile organic compound (VOC) is an organic substance that has a vapour pressure of 0,01 kPa (or more) at a temperature of 293, 15 K or has a similar volatility under the conditions of application [RL 1999/13/EG].

Fission products, are generated during the cross linking of the film forming agents during the drying process. Partly these components also represent volatile compounds. Mainly alcohols, water and formaldehyde are evaporated. Due to the wide variety of paint compositions, a quantification of these fission products cannot be given.

Pigments and **filling agents** are organic or inorganic materials. Filling agents influence the mechanical properties of the paint layer (hardness, adhesion, flexibility etc.). The colour of the paint material depends on the added pigments.

Film forming agents influence the formation and the properties of the applied film. To affect certain properties such as e.g. run of the paint material onto the surface, (up to 2 %) additives are added.

II.2.1 Paint systems

In the following, the most important paint materials utilised in the investigated sectors (cf. IVU-RL, annex I Nr. 6.7), are described.

II.2.1.1 Solvent Based Paints

Conventional, solvent based paints contain approx. 30 – 80 weight per cent of organic solvents for a regulation of viscosity and film formation. The type of the used solvents mainly depends on the utilised bonding agents. According to the process of film forming, the materials can be subdivided into polycondensation lacquers (e.g. phenol/urea/melamin resin lacquers), polymerization lacquers (e.g. polyesters-, acrylate resin-, alkyd resins), and polyaddition lacquers (e.g. epoxy of PU lacquers).

High-Solids represent an advancement of conventional, solvent based paints. Their solids content amounts more than 65 %. The used film forming agents are mainly based on epoxy resins or 2-component polyurethanes[1]. For paints used for the varnishing of agricultural and construction machines, or household devices, mainly high-solids, based on acrylate and polyester isocyanate are use.

For the future, high solids with solvent contents of 98 – 100 % are expected. Therefore different application devices, e.g. hot spraying, have to be developed and used [CULIK 2000].

II.2.1.2 Water-dilutable Paints

Water-thinnable paints contain water-thinnable or water-dispersible film forming agents. Mainly alkyd, polyester, acrylate, melamine- and epoxy resin. Also water-thinnable paints often contain 3 – 18 % of organic solvents as solubilizer and for an improvement of the properties of the wet film layer. As preservatives for the storage of the paints, often biocides are part of the formulation. If water-thinnable paints are utilised, some particularities have to be considered:

- Inflammability: In gerneral smaller expenditures are necessary for the application, storage and drying of water-thinnable paints, compared to conventional materials.

- Evaporation of solvents: Compared to organic solvents, water has a higher evaporation energy. Therefore the energy demand for the drying of water-thinnable paints is generally higher, if the same drying rate as for solvent based paints has to be achieved.

- Corrosion: Pipelines of paint application devices have to be made of synthetics or stainless steel.

- Air humidity: The drying rate depends on the ambient air humidity. Therefore the application is only possible under suitable or defined air humidity conditions.

Since many years, water-thinnable paints are available on the market and are widely used. Due to the permanent development of these materials, their range of application is increasing steadily. Main improvements of these materials envelop their corrosion protection and exterior resistance (against climatic impacts). Main advantages of water based paints are the reduction of VOC-emissions and the possibility for a recycling in special applications e.g. via ultrafiltration or mechanical processes [CULIK 2000].

1.2.1.1 Radiation-curing Paints

Radiation curing paints contain either only low amounts of organic solvents (approx. 2 - 5 %) or consist entirely of solids. In special cases also paints with a solvent content of up to 65 weight per cent are utilised.

Radiation-curing lacquer consist of reactive resins (e.g. epoxy, acrylates), monomers or oligomers and a photo initiator. In general three different drying techniques are applicated **Ultrared radiation curing** and **UV radiation curing** and **electron beam hardening.**

The irradiation of these paints initiates drying via the adsorption of radiation and thus associated heating or a hardening via chemical cross linking [CULIK 2000].

1.2.1.2 Powder Coatings

Powder coatings are solvent free materials. Their application does neither generate wastewater nor VOC-emissions. As film forming agents mainly polyester or epoxy resins are used. For the most application a recycling of the overspray is possible.

For drying, the material is heated and thus merges into a film. At present powder coatings are mainly applied via electrostatic assisted spraying on the workpieces (primarily metall but also glass surfaces). In several sectors the application of powders is a well-established technique. Due to environmental advantages, possibilities for an automation and good profitability due to the possibility of a recycling of the overspray, the use of powder coatings is increasing. Future

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[1] 2-components

developments aim at low-temperature powder coatings. Most likely also the wood and furniture industry will become an important processor of powder coatings.

Also UV-radiation and ultrared-radiation curing (NIR[2]) powder coatings are increasingly utilized [CULIK 2000].

II.3 Paint systems

At first a surface with defined characteristics is generated via the pre-treatment. Therefore degreasing and cleaning processes are applied. Partly a conversion layer is generated via phosphatization and passivation. The varnish consists of one but mostly of several paint layers of which all have specific tasks.

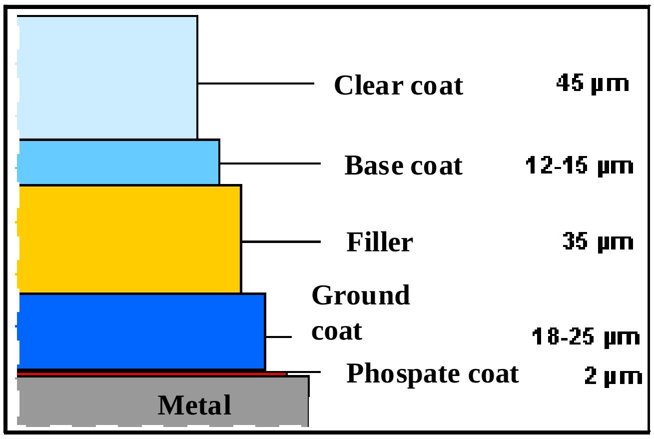

Figure II-3: *Paint system for the serial coating of passenger cars* [HARTWIG 1999])

II.4 Environmental Impacts

Environmental impacts mainly result from VOC-emissions, the energy demand of the installations and the generation of wastes and paint residues. In figure Figure II-4 the material flows for a spray booth are exemplary shown. A spray application for a conventional solvent-based paint (50 % solids content) with an efficiency of 50 % is utilised. Approx. only 25 % of the material remain onto the workpiece. 25 % have to be disposed as paint sludge. If no exhaust gas cleaning is used, the organic solvents are emitted into the atmosphere during paint application and drying. In the atmosphere the VOC together with nitrogen oxides underly complex photochemical reactions under the presence of solar radiation. These reactions generate ozone and other products of the so-called photo-smog. Thereby the VOC as the photochemical products represent a health- and an environmental hazard.

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[2] NIR: Near-infrared

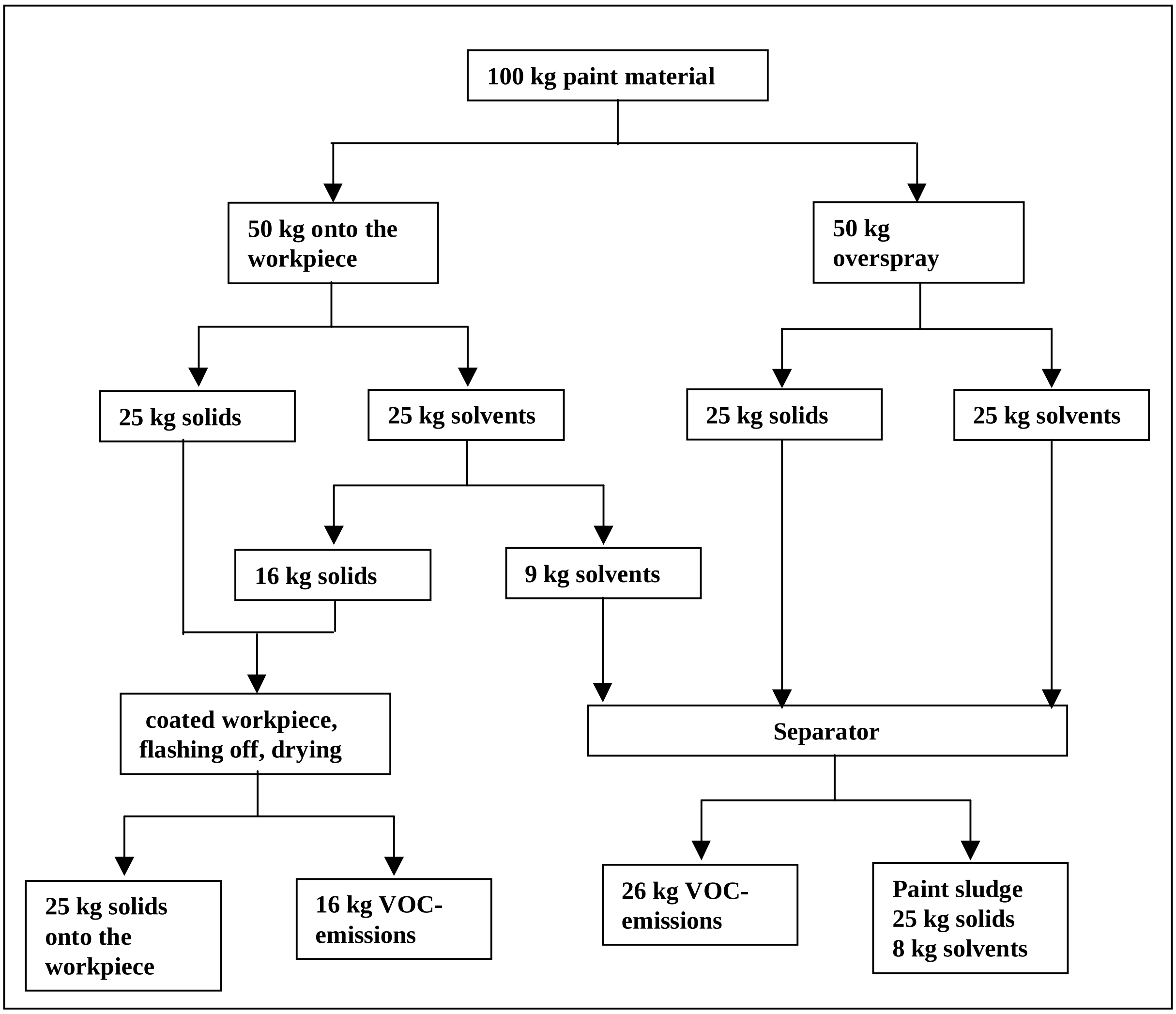

Figure II-4: *Material flows from spray application with conventional technology* [MAHRWALD 2001]

II.5 Paint Consumption and Emissions of paint processing installations

From 1988 to 1997 the total production of paints was increased up to almost 50 % to 1.800 t/a. In spite of the increased paint consumption the amount of organic solvents has decrased up to 5 % within the same period (cf. Figure II-5). This results from the increasing use of solvent-free products or materials with a low solvent content.

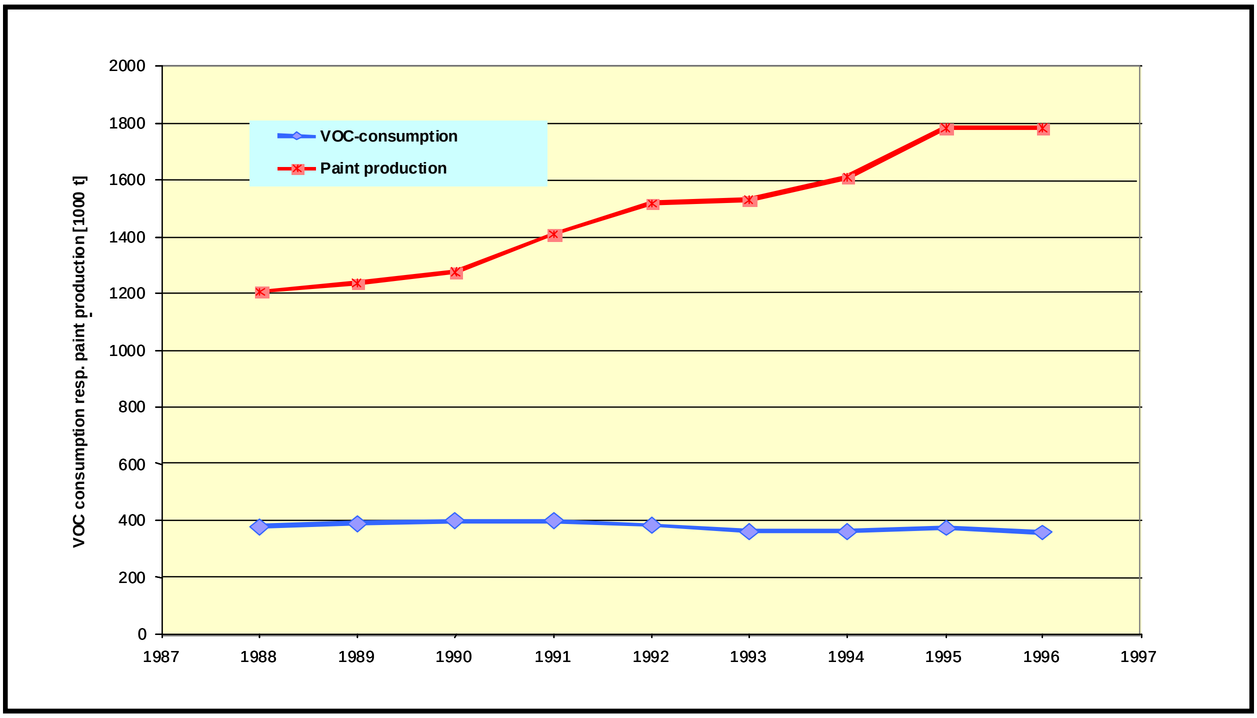

Figure II-5: *Overview of the produced and processed amounts of paints and organic solvents* [BMU 1997]

Table II-2 shows the consumption of paints for the years 1999 and 2000 (prognosis) in Germany.

In the sector of construction approx. 69 % of paints are used. Since the paint application does not take place in stationary installations as defined by the IPPC-Directive this sector is not further investigated. The sector of car refinishing is also not relevant doe to the low amounts of processed paints (2% of the total paint consumption in Germany).

Table II-2: *Overview of the consumption of paints in the year 1999 in Germany and market development for 2000 (prognosis)* [CHEM 2000]

Application	Consumption of paints		Amount of paints [t]	Change compared to 1999
	1999 [t]	1999	2000 (prognosis)	
Construction	1 210 000	69 %	1.234.000	+2,0 %
Wood- and furniture industry	80 400	5 %	82.000	+2,0 %
Serial coating of passenger cars	89 000	5 %	89.000	0 %
Car refinishing	33 700	2 %	33.000	-2,1 %
Corrosion protection	48 500	3 %	47.300	-2,5 %
Machine building	43 400	3 %	45.000	+3,7 %
Electrical industry	35 600	2 %	36 000	+1,1 %
Packaging made of sheet metals	34 900	2 %	35 800	+2,6 %
Metal produkts	30 800	2 %	32 000	+3,9 %
Coil coating	20 500	1 %	21 800	+6,3 %
Other applications[1)]	102 440	6 %	104 100	+1,6 %

1) Inclusive components for the construction sector, car components (metal surfaces), plastics, paper, foils, varnishing of ships etc.

Table II-3: *Market development for different paint materials for 1999 and 2000 in Germany (prognosis)* [CHEM 2000]

Paint material	Amount of paints [t]		Variance
	1999	2000 (Prognose)	
Solvent based paints	247 400	246 400	-0,4 %
High-solids	27 450	28 400	+3,5 %
Water-thinnable paints	191 190	196 200	+2,6 %
Powder coatings	40 000	41 500	+3,8 %
Radiation curing paints	13 200	13 500	+2,3 %

Table II-3 shows an overview of the market shares of different product categories for 1999 and 2000. Within the last years, the demand for environmental sound products (powder coatings, water-thinnable- and radiation-curing paints) is increasing. The request for solvent based paints is declining. By the adoption of the BImschV[3] this trend was further strengthened. In some sectors, such as in the coil coating industry or in the varnishing of commercial vehicles, still larger amounts of organic solvents are processed. In these sectors, the requirements of the environmental legislation are generally met by the application of thermal combustion units.

In general, lower paint consumptions have to be registered due to the application of thin-layers and the use of optimised paint applications [CHEM 2000].

II.6 Industrial Activities with a high Potential of Environmental Pollution

The VOC-emissions in Germany result from the following sources:

- approx. 60 % from non license requiring installations,
- ***approx. 10 % license requiring installations***,
- approx. 15 % from processing outside of installations, and
- approx. 15 % from applications carried out by painters and in the do-it-yourself sector [BMU 1997]

In the following sectors, big amounts of paints are processed:

- Serial coating of vehicles: Passenger cars, planes, commercial vehicles, agricultural machines, ships, rail vehicles (cf. chapter 3)
- Coil coating (steel, aluminium, cf. chapter 6);
- Coating of packagings: Beverage cans (cf. chapter 7)
- Serial coating of plastic parts: Car components (bumpers), housings for TV/hifi/edp-devices (cf. chapter 4);
- Serial coating of metal workpieces with a large surface, household devices, steel furniture, office furniture, control etc. (cf. chapter 5)
- Wood and furniture coating (cf. chapter 8).

For these industrial sectors, integrated and subsequently connected emission reduction measures were investigated with regard to their applicability.

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[3] Ordinance for the transposition of the directive 1999/13/EG

II.7 Developments for the Processing of Paints

Due to the increasing international cost pressure, increasing quality requirements, and the demands for a reduction of waste and resources, the enterprises have already optimised their painting processes. Often processes with lower VOC-emissions were implemented. For the renewal of existing plants, the following goals represent the centre of attention:

- Improvement of the quality e.g. increased scratch resistance and brightness and improved corrosion protection,
- reduction of process times and thus a higher productivity, quicker drying, avoidance of reworking measures, quicker further processing of coated workpieces,
- reduction of space request;
- reduction of overspray and
- reduction of VOC-emissions.

As an alternative for conventional solvent based paints for a reduction of VOC-emissions, high-solid paints, water-thinnable paints or powder coatings are applied. The utilisation of these materials depends on the surfaces to be coated.

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1 Serial Varnishing of Automotives

The surface design (colour, brilliancy etc.) has a high significance in the automotive production, because the optical appearance is a subjective but critical perception of the customer concerning the purchase.

The automotive producers typically possess specific departments for process- and technical engineering of surface treatment due to the high importance of surface quality. Further typically there is a close and intense co-operation between the constructers of the installations, the varnish producers and the automotive producers in order to guarantee optimum conditions for establishment of a new painting plant and the operation of the installation. This explains the fact that automotive production is one of the most progressive sectors concerning varnish technology and therefore shows a high environmental standard in Germany. The processes in this chapter are described in detail due to the good technical documentation of the varnishing processes and the numerous innovations of this sector. Hence the process descriptions also serve as a basis for the following chapters[1].

1.1 General Information

1.1.1 Classification of Vehicle Types (according to the Directive 70/156/EWG)

The classification of automotives into vehicle classes specified by the Directive 70/156/EWG is especially relevant for the VOC limit values that have to be met according to the 31. BImSchV. The definitions of the vehicle classes are illustrated in table 1-1. The varnishing of passenger cars is predominant in the serial varnishing of automotives sector.

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[1] This especially affects chapter 2 dealing with the varnishing of commercial vehicles, rail vehicles, ships and aircrafts

Table 1-1**:** *Definitions of the vehicle classes according to the Directive 70/156/EWG*

Class	Definition according the Directive 70/156/EWG
M1	Automotives designed for passenger transportation with a maximum of 8 seats excluding the driver's seat
M2	Automotives designed for passenger transportation with a minimum of 8 seats excluding the driver's seat . The total mass is up to 5 tons[2].
M3	Automotives designed for passenger transportation with a minimum of 8 seats excluding the driver's seat. The total mass is more than 5 tons[2].
N1	Automotives designed for transportation of goods with a total mass of up to 3.5 tons[2]
N2	Automotives designed for transportation of goods with a total mass between 3.5 and 12 tons[2]
N3	Automotives designed for transportation of goods with a total mass of more than 12 tons[2]

In this chapter, the serial varnishing of automotives belonging to the M1 class (vehicles with a total mass of up to 3.5 tons) and the N1 class[3] is considered.

1.1.2 Production and Sale Figures of the Automotive Industry

The production of passenger cars and commercial vehicles in Germany has increased between 1993 and 1999 from 3.8 mill. units to 5.3 mill. units. Adequately the varnish demand has increased within this time period. Estimations for the year 2000 give a national serial varnish demand for automotives of 89 000 tons. The composition is the following: 40% of topcoats, 37% KTL (cataphoric dip coating) varnishes, 15% fillers and the remaining 8% for special products (e.g. cavity sealing, underbody coating etc.) [CHEM 2000].

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[2] Reference mass: mass of the automotive ready to go minus an average driver's mass of 75 kg plus an additional average mass of 100 kg.

[3] As a prerequisite, the commercial vehicles have to be produced within the same installation as the passenger cars

1.1.3 Emission Limits according to the Regulation for the German Transposition of the Directive 1999/13/EG

The total emission limits defined by the regulation for the German transposition of the Directive 1999/13/EG for finishing of new passenger cars and commercial vehicles are summarized in table 1-2.

Table 1-2**:** *Total emission limits for the coating of new passenger cars and commercial vehicles*

Threshold value for the annual solvent consumption [t/y]	**Total emission limit [g/m²]**	**Emission limit for captured waste gas subsequent to the dryer [mg C/m²]**
Passenger cars:		
> 15	35	50
Commercial vehicles:		
> 15	70	50

A total emission limit[4] of 35 respective 70 g/m^2 is specified as well as an emission limit for captured exhaust gas of 50 mg C/m^3 subsequent to the dryer for the finishing of new passenger cars and commercial vehicles. The total emission limit includes all production steps as well as all cleaning activities of application installations and other immobile installations that are carried out within the same installation. The German passenger car producers already reach the value of 35 g/m^2 and the value is even undershoot in some installations.

1.1.4 Quality Requirements

Following requirements have to be fulfilled by the varnished body and therefore by the paints:

- Long-term protection against corrosion, weather, chemical influence (e.g. birds dejection, acid rain), chipping protection, sun, strain of washers, etc.;
- Ideal optical surface properties: Polish, colour depth, free of veil, faultlessness so as homogeneity and constancy in colouring and formation of effects;

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[4] With the implementation of the EU Solvent Directive into German law, the emission limits have been reduced down to the state-of-the-art in Germany.

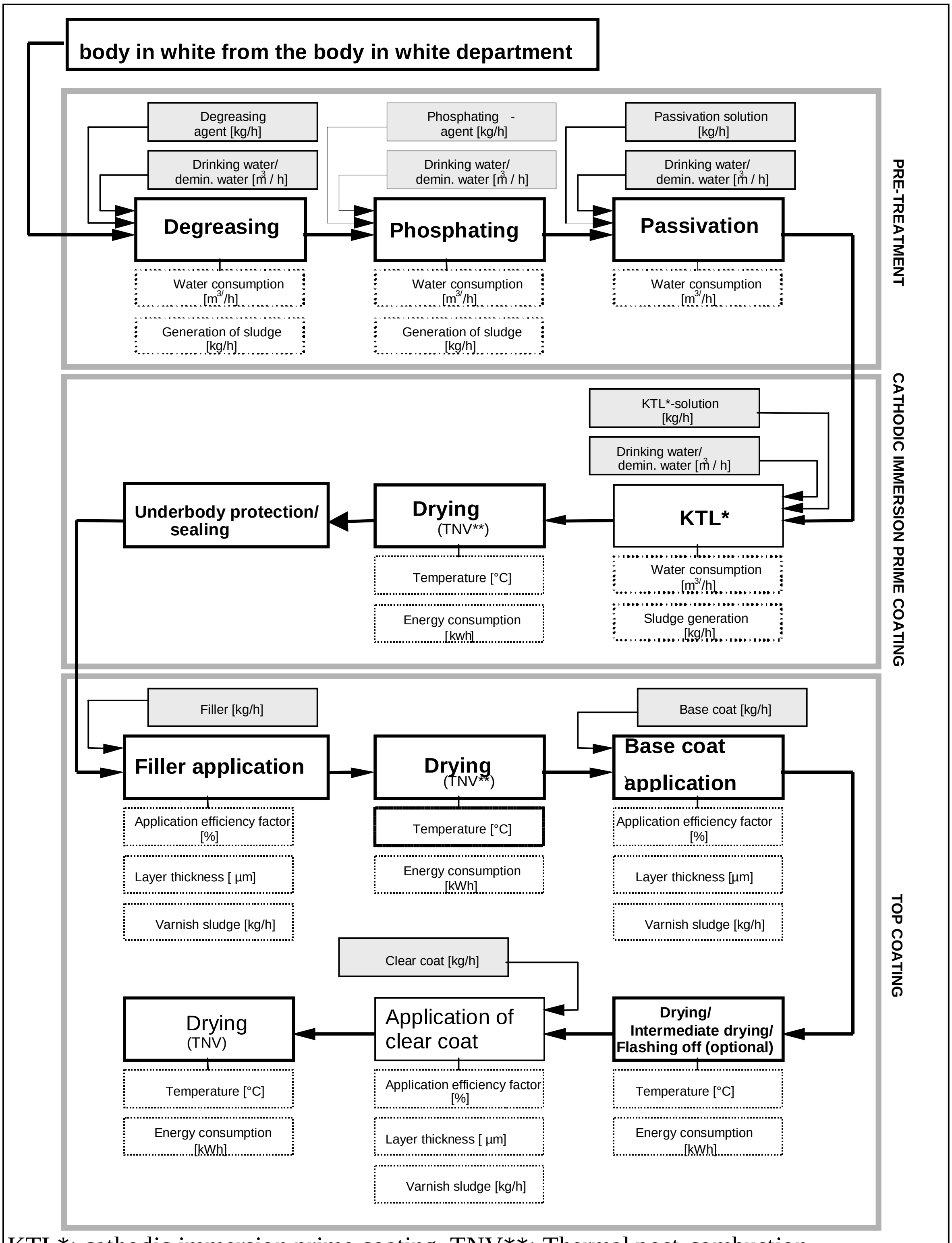
These high requirements can only be achieved by at least three, often four or five adjusted paint layers [BROCK 1998]. In Europe, the following layer construction has become predominant:

- Pre-treatment (cleaning, phosphatization, passivation)
- Cathodic immersion prime coating (KTL)
- Underbody protection / seam sealing
- Filler
- Top coat
- Cavity conservation and if necessary conservation for transport

In the top coat sector beside of one-layer also two-layer systems are applied (base coat and clear coat), e.g. with metallic colours, effect paintings (pearl shine) and sometimes with uni-coloured paints. The cathodic immersion prime coating (KTL) first of all serves for a complete corrosion protection for in- and outside areas including all cavities, overlapping regions and connections. The application of the filler effects among optical properties (masking of the sub-surface, gradient) mainly a protection against chipping protection and a regulation of adhesive strength. The top coat performs apart from optical properties (polish, colour, luminance) essential protection against chemical and physical environmental effects (solar radiation, rain, chemicals, fuel, washers, mechanical stress).

1.2 Applied Processes and Techniques

In spite of serial-coating processes different between each factory (even of the same producer) certain common properties can be listed. The main steps include pre-washing, phosphatization, passivation, cathodic immersion prime coating, underbody protection and seam sealing, application of the filler, drying of the filler, application of top coat and mostly of a clear coat (one or two layers), drying of the top coat, cavity conservation, if necessary conservation for transport and repair of possible damages of the varnish before assembly. In Germany almost exclusively two-layer top coats with a base coat and clear coat instead of one –layer coats are applied. (see also [GAUDOSIO 1996, VDI 1996, ACEA 1997, MAY 2000A]). A general process procedure is shown in fig. 1-1. Selected processes of the automotive serial-varnishing sector (based on case studies) are documented in annex VI.



KTL*: cathodic immersion prime coating TNV**: Thermal post-combustion

Figure 1-1*: Serial varnishing of passenger cars (own illustration based on* [GRUBER 2000A])[5]

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[5] If it is necessary, the following process steps are carried out:
- Underbody protection and seam sealing after drying of the cathodic immersion prime coating
- Refinishing and cavity conservation subsequent to the clear coat drying.

1.2.1 Applied Varnish Materials

A summary of the applied paint materials is given in table 1-3.

Table 1-3**:** *Applied paint materials in the serial varnishing of automotives* [VDI 1996, PIWOWARCZYK 2000]

Varnish system	**Solids content [% per weight]**	**Solvent ratio [% per weight]**	**Layer thickness [μm]**
Primers (composition of the bath)			
Cathodic immersion primer, standard	14 - 22	1 - 6*⁾	18 - 22
Cathodic immersion primer, thick	14 - 18	4 - 7*⁾	25 - 35
Filler			
1part polyester	60 - 65	35 - 40	20 - 40
1part polyester with PU proportion	65 - 70	30 - 35	25 - 40
PE filler, water based	50 - 55	5 - 12*⁾	20 - 40
PU filler, water based	50 - 55	5 - 12*⁾	20 - 40
Slurry filler	38	2	15 - 20
Powder filler	100	0	50 - 60
Protection of swelling	70 - 75	25 - 30	
Chipping protection inter-layer	55 - 60	40 - 45	20 - 30
One- layer top coat			
1part top coat	45 - 52	48 - 55	35 - 50
1part top coat, elevated solids content	50 - 58	42 - 50	35 - 50
2 part top coat, high in solids	63 - 73	27 - 37	40 - 50
Base coat			
Solvent-based	20 - 40	60 - 80	12 - 35
Water-based	17 - 35	10 - 20*⁾	12 - 35
Metallic base coat, elevated solids content	20-40	60 - 80	15 - 30
Base coat, water-thinnable	16 - 25	8 - 18*⁾	12 - 18
Clear coat			
1part clear coat	43 - 48	57 - 60	35 - 50
1part clear coat, elevated solids content	48 - 50	50 - 52	35 - 50
2 part clear coat	56 - 58	42 - 44	40 - 50
2 part clear coat, high in solids	63 - 65	35 - 37	40 - 50
1part clear coat, water-thinnable	42 - 49	10 - 15*⁾	35 - 50
Powder clear coat	100	0	50 - 60
Slurry clear coat	38	2	35-40

Varnish system	**Solids content [% per weight]**	**Solvent ratio [% per weight]**	**Layer thickness [µm]**
Further coating materials			
Underbody protection	95 - 100	0 - 5	
Underbody protection	95 - 100	0 - 5	100 – 1200
Inside protection coat for trunk and engine compartment	60 - 65	35 - 40	
Contrast paints (e.g. matt black)	55 – 65	35 - 40	

*) for water-based paint the remaining proportion is water.

abbreviations:

PE	Polyester resin
PU	Polyurethane resin

A general paint system at the vehicle is sketched out in figure 1-2. The functionality of the different layers as well as the possible environmental impact is also shown.

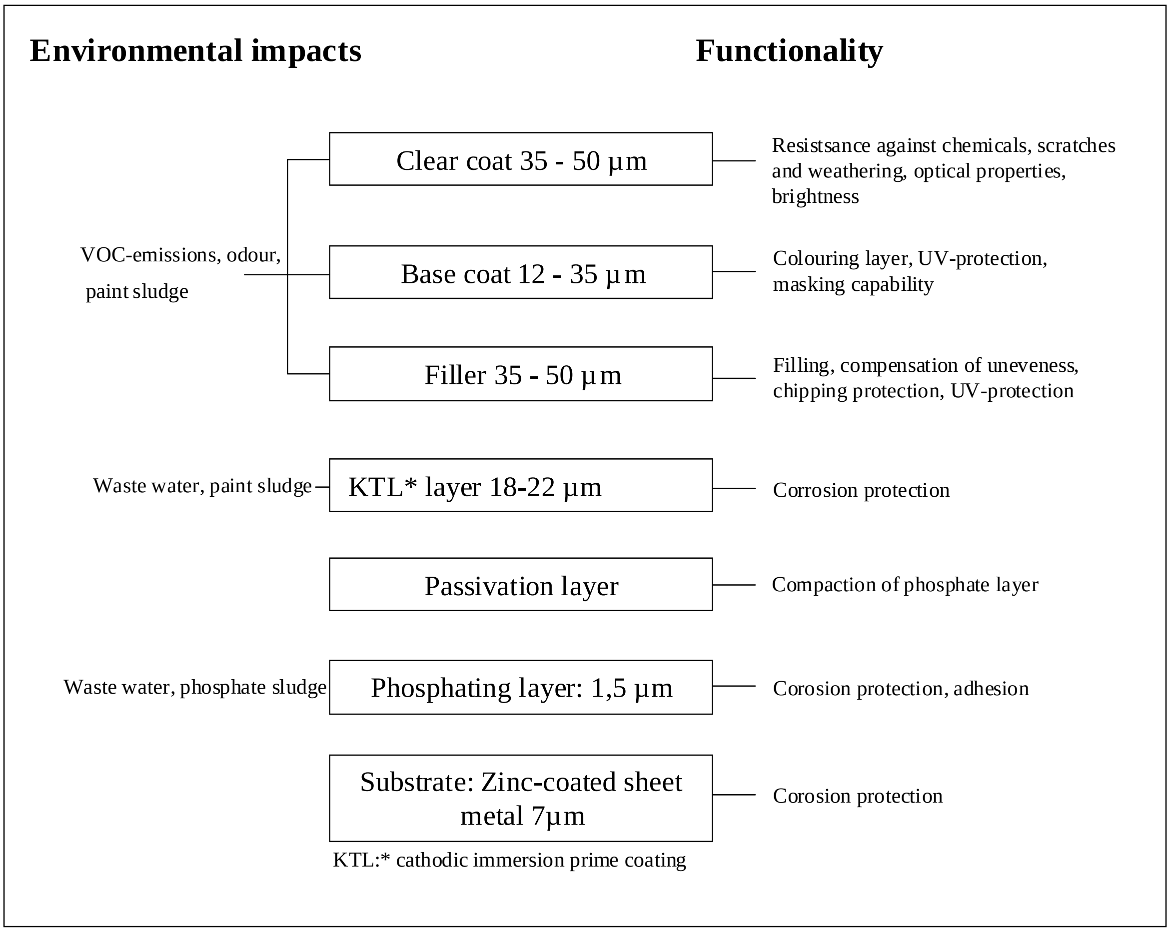

Figure 1-2**:** *Function and environmental impact of the paint system* [GRUBER 2001]

Table 1-4 gives an overview over the paint systems applied by the German automotive industry (concepts 1 – 10). The respective proportions are calculated basis of the automotives produced in 2000. Main proportions are accounted for the application of water-based filler (67,2 %) and water-based base coat (87,7 %) as well as for conventional solvent-based clear coat (86,5 %). This water-based paint process with conventional clear coat (system number 4 in table 1-4) can be defined as state-of-the-art due to its wide distribution.

Innovative techniques use solvent-free or low-solvent clear coat systems. In process 2 no filler is applied.

The mixed process number 6, applies solvent-containing filler however a waste gas cleaning of the spray booth exhaust air is used as secondary measure of emission abatement.

Solely conventional techniques are used in old plants. For emission reduction in processes number 8 and 9, some producers use waste gas cleaning for waste gases from the dryers and partly for the application of filler, base- and clear coat. The process includes partly light commercial vehicles and is listed according to the convention (see also chapter 1.1.1 and 2.1.4.1), because commercial vehicles and cars are partly coated within the same installations in the respective plant.

Table 1-4**:** *Application of different varnish systems for the serial varnishing of passenger cars in Germany in 2000* [GRUBER 2001]

Varnishing process		**Filler**		**Base coat (unicolour/metallic)**		**Clear coat**		**Proportion**
		water	*solvent*	*water*	*solvent*	*solvent*	*low-solvent or solvent-free*	*[%]*
process with innovative technique								***13,0***
1		🟦		🟦			🟦	
2				🟦			🟩 powder slurry	
3			🟥	🟦			🟩 powder	
water-based paint process with conventional clear coat								***60,2***
4		🟦		🟦		🟥		
mixed processes: water-based varnish and conventional paint								***15,8***
5			🟥	🟦		🟥		
6			◩ *	🟦		🟥		
7		🟦			🟥			
conventional processes (partly including spray booth exhaust gas cleaning)								***11,1***
8			◩ *		🟥			
9			◩ *		◩ *	◩ *		
	share [%]	🟦 **67,2**	🟥 **32,8**	🟦 **87,7**	🟥 **12,3**	🟥 **86,5**	🟩 **13,5**	100%

* exhaust gas cleaning for the spray booth

1.2.2 Varnishing Processes

1.2.2.1 Varnish Application Techniques

Serial varnishing of vehicle bodies in white includes pre-treatment and cathodic immersion prime coating. Subsequently the paint is applied by a spraying technique. This takes place in spray booths conditioned with respect to dust proportion in the air, temperature and humidity. For depositing the paint spray, the waste gas is intensively mixed with water in the venturi-washer beneath the grating of the booth. The flashing-off zone joins the spray booth in conveying direction and allows a good gradient and an increase in the viscosity of the applied film before the body comes into the dryer. Especially for water-based paints, this process can be accelerated by hot air and/or infrared radiators (forced flashing-off). Electrostatic assisted spraying techniques are basically suitable for filler, base or top coat application onto outside surfaces. The most important nebulizing techniques include (cf. also annex III, volume Paint Application):

- Compressed air spraying
- Electrostatic assisted spraying with compressed air

- Hot spraying

- Rotation nebulizing (see also figure 2-5)
- Airless spraying

1.2.2.2 Description of the Process Steps

Different progressive techniques are used in Germany due to intensive research and development of the automotive producers. They will be shortly described in the following.

Pre-treatment

At the first step of the pre-treatment procedure, the bodies in white are degreased and subsequently well rinsed. The degreasing serves for the removal of oils, greases, soaps, dirt particles, sanding residues, substances and impurities. It is carried out at a temperature of about 50-60°C using aqueous, alkaline cleaning agents that may also contain phosphates and surfactants. Zinc-phosphating follows as substructure for corrosion protection and adhesion stability of the paint system and also for a sure sub-surface corrosion protection. At a temperature of 50-60°C, a phosphate layer with a thickness of about 1,5 µm is generated by spraying or immersion. The phosphating solution may contain metals, e.g. zinc, calcium, manganese and nickel besides phosphoric acid as well as oxidants, e.g. nitrite, nitrate, chlorate, hydrogen peroxide and hydroxylamine salt as accelerator. After another rinsing process, the phospating layer can be additionally passivated for further compaction. Presently some producers still passivate by using chromium (VI)[6] or zirconium hexafluoride solution. Afterwards a rinsing step has to be carried out again, completed by a rinse with completely demineralised water. Subsequently, the car body gets directly into the immersion coating bath without any further measures.

Cathodic Immersion Prime Coating (KTL)

Nowadays the cathodic immersion prime coating technique is applied exclusively in the varnishing of passenger cars due to the high quality requirements that have to be fulfilled by the ground coat due to corrosion protection reasons. (see also table 2-5, figure 2-3). Presently unleaded electro-immersion paint can be considered as state-of-the-art in Germany [MAY 2000B]. The water based immersion paint generally contains about 14 - 22 % solids (per weight) and about 2 - 6 % solvent (per weight). For removal of not electrically separated paint particles subsequent a rinsing with ultra-filtrate is carried out. For minimization of paint losses, the filtrate generated by ultra-filtration of the immersion bath is recycled cascade-like from the end of the washing zone back to the bath. The cascade washing represents a closed circular flow. Except for deletion of small imperfections, the priming is not sanded any more [BROCK 1998, VDI 1996]. After cathodic immersion prime coating (KTL), the water remaining in the cavities will be removed by suitable measures such as drying, e.g. at 140 °C, toppling of the car bodies or blowing with plenty of air [BROCK 1998, VDI 1996].

Table 1-5**:** *Typical parameters of electro-immersion prime coating* [BROCK 1998]

Parameter	Value
Applied voltage	350 to 500 V
Layer thickness	18 to 22 (partly up to 30) µm
Precipitation time	2 to 3 minutes
PH value of the bath	5,6 to 6,6
Temperature of the bath	26 °C
Size of bath	200 to 500 m^3

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[6] According to Directive [2000/53/EG], materials used for the production of automobiles may no longer contain chrome VI from July 2003 on.

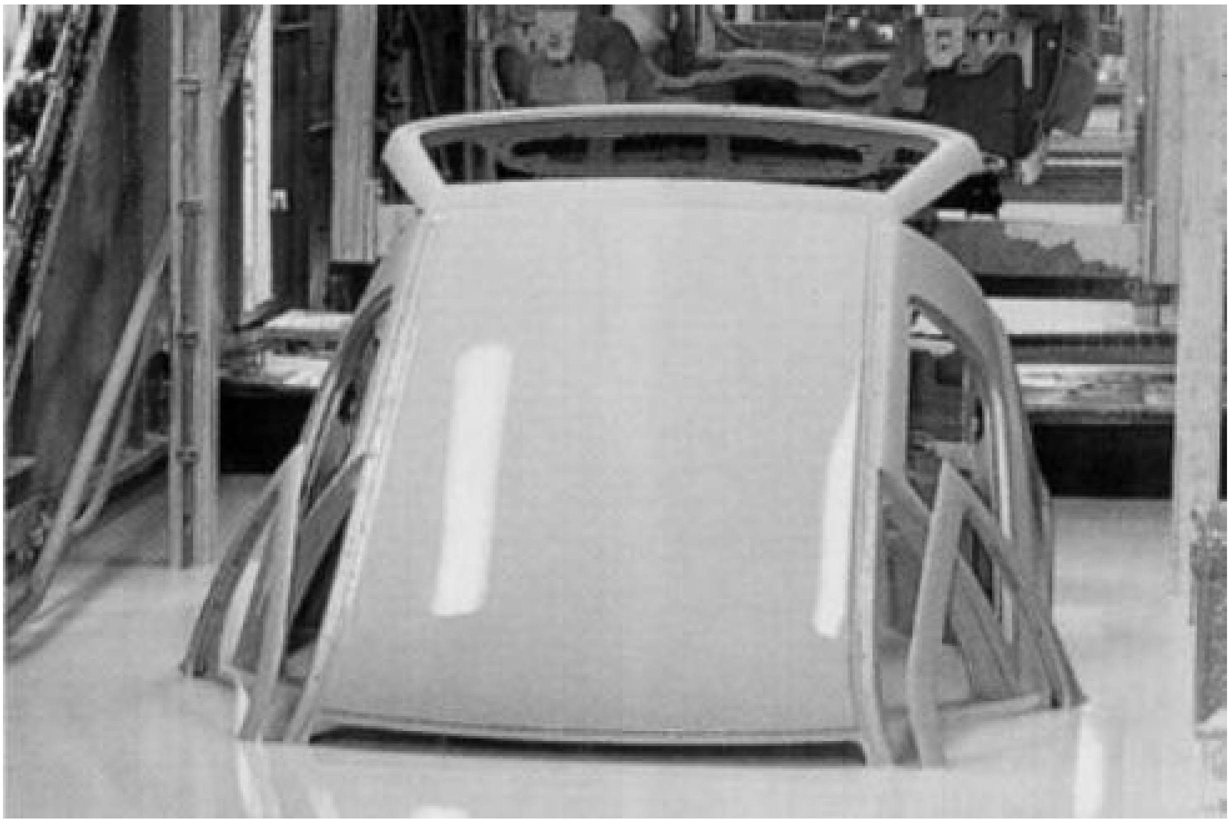

Figure 1-3**:** *Cathodic immersion prime coating* [GRUBER 2001]

Seam sealing and underbody protection

Before applying the filler, joints and folds need to be sealed. This is carried out partly by hand, partly with robots normally using various PVC materials applied with special guns. Also the subsequent underbody protection coating is based on PVC plastisols (100 to 1,200 µm) or on polyurethane. Generally it is applied by robots via the airless techniques. Partly also an additional chipping protection is applied onto critical areas via a sharply bordered airless spray jet. At some producers the termed materials both for underbody and chipping protection as well as for seam- and cavity sealing are applied at later steps of the production, sometimes not until finishing the top layer at final assembly section. [Brock 1998]

At the Volkswagen AG, the application of the underbody protection is carried out by robots and is partly done onto turned car bodies (see also figure 1-4). This technique can only be applied in the case of a suitable underbody structure and stable longitudinal girders. Advantages are a reduction of overspray because of lower spraying pressure and a uniform, reproducible coating. Further the technology has ergonomically advantages for subsequent manual operations.

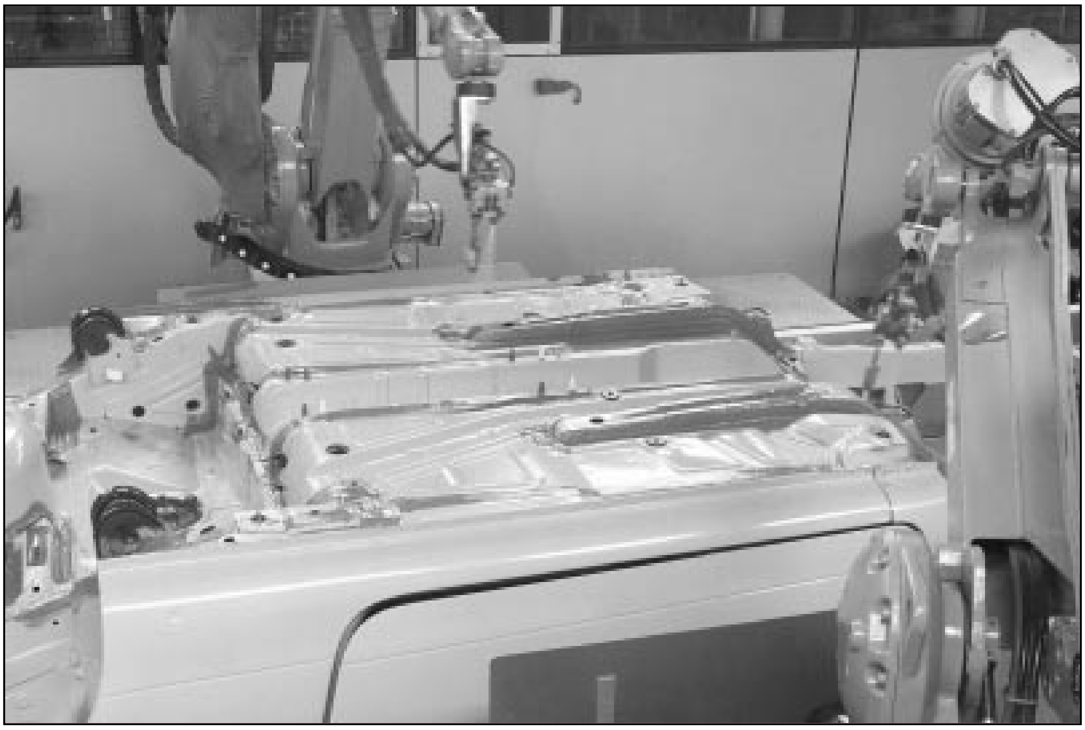

Figure 1-4: *Application of the underbody protection onto the body turned by 180°.*[GRUBER 2001]

Before the filler application, the body is cleaned with dust-bonding cloth, by blowing with ionized air or increasingly also with rolls of emu feathers, because soilings still have effects on the future top coating layer [Brock 1998].

Application of the filler

The filler has the following functions:

- Filling of small unevennesses of the subsurface and preparation of the top coat application.
- Guarantee of adhesion stability and achievement layer thickness required for the desired quality.
- UV protection for underlying electro-immersion layers.

Besides conventional solvent-containing fillers presently water-thinnable fillers are used predominantly (see also table 1-4). In the filler sector, the outside surface coatings are applied electro-statically by high rotation nebulizers; if necessary the filler is applied manually onto some places (e.g. interior). After the passage of a short flashing-off area for solvent elimination, the fillered bodies reach the filler dryer (up to 175 °C).

Figure 1-5: *High rotation bells*

(source: Dr. GRUBER, Volkswagen AG)

A reduction of the consumption of the subsequent base coat can be achieved by an adjustment of the filler colouring to the base coat. In some cases, the base coat can be abandoned completely for interior applications [MAY 2000B].

Since a couple of years powder-fillers have been used in the USA and in Austria (DaimlerChrysler, Graz). However this technology is not reasonable with respect to environmental aspects, because long time experiences have shown that the required surface quality is not achievable this way (among other things because of the high layer thickness) and that there is material consumption. Powder coatings slurried in water (powder slurries) that are processed like liquid varnish are still in the development stage.

Cleaning / Washing techniques

Before applying the top coat, a complete cleaning is absolutely necessary. Presently mostly the following processes are used: Ionized air, blower, emu zones, complete washing of the body including drying and cooling processes.

Top Coat

One-layer top coat

This procedure of one-layer top coating presently is only used in special cases with uni-colours, and even in these cases, because of durability and optical surface quality more and more two- or more layer coatings are used. For coating of light commercial vehicles, one layer top coats still are common, because at the market special colours are required [GRUBER 2001].

Types of top coats

The tendency goes from classical one part alkyl-, polyester- or acrylate burning-in systems towards higher cross-linking one or two-component varnish, often isocyanate cross-linking. These systems exist both water-thinnable as well as solvent-containing. As pigments only extremely light and weather durable compounds are used.

Application

The top coat material is applied predominantly with automatic, electro-statically assisted high rotation nebulizers, allowing fast changes of colour within only a few seconds. Pre- or after-spray of difficult or meanly accessible parts is done manually (pneumatic). The required dry coat layer thickness (one layer top coating) of 35 - 50 µm is applied in one or two steps, if necessary with short intermediate flashing-off periods. Afterwards the coating is burned in at about 130-140°C (depending on the bonding agent) in the top coat dryer.

Two layer top coat

For two layer top coating at first a colouring base coat is applied that is subsequently covered with clear coat. Uni-colours get more attractive, gain in optical deepness and are significantly more durable. Effect respective metallic coatings are applied in two steps (base paint and spraymate). For metallic and effect coats, the spraymate technique is used [MAY 2000B].

Base coat materials

The base coat is applied with a layer thickness of only 12 to 35 µm. The effective thickness depends on the masking efficiency of the colouring. Different filler colours are used in order to guarantee the masking capability. Pearly coloured base coats containing glimmer or other special effect pigments as essential pigments are generally not masking and hence need an additional base coat layer as subsurface. It is typically a white base coat, whereas for an emphasis of interference effects also dark base coats are used (“three layer top coating”). Further new effect techniques, like the colouring of base coats or clear coats with solvable colours or the usage of fluor-containing (more strongly dirt-repellent) clear coats are to be only briefly mentioned here. Solids contents and solvent proportions of the materials are illustrated in table 1-3.

Clear Coat Materials

The conventional clear coat is the last significant solvent emission source in the process of vehicle coating after the introduction of water-based fillers and water-based base coats at the beginning of the 90ties. Solvent proportions of conventional clear coats amount to about 57 to 37 % (see also table 1-3). A water-based clear coat system is already in use (Opel company, plant Eisenach). Further powder clear coats (at BMW, plant Dingolfing) and powder-slurry (powder dispersed in water, at DaimlerChrysler, plant Rastatt) are used serially in Germany. This layer is of milk-like white at first, clears while drying and then the final colour appears. Modified bonding agents and curing systems as well as new two component part mixing technologies are currently under development in order to reduce emissions originating from clear coats.

Application Techniques for Base Coats and Clear Coats

At first the inside surfaces of doors, engine compartment, tailgate and if necessary of the interior are painted either manually or by robots. Following uni-coloured base coats, clear coats and effect base coats (in the latter case only the first spraying process) are applied with electrostatic assisted high-rotating devices comparable to a one-layer top coat. The second application step for metallic and pearl shine coatings is solely pneumatically, because metallic and pearl effects can be exclusively realised with pneumatic application. Base coats both water-based and solvent-based are not cured at first, but they are clear-coated after a short physical (pre)drying with the so-called “wet in wet technique” (30 - 50 µm). For conventional base coats short air circulation drying is enough whereas water-based paints are usually dried within a combination of an infrared and heat blowing zone (the temperature of the object is about 50 °C). Mere air circulation or condensation dryers are further alternatives.

The robotic top layer application as well as the completely automated top layer coating of roof and side parts are shown in the following figures 1-6 and 1-7. Figure 1-8 shows the automated application of metallic/pearl effect paint by air pressure (“spraymate“technique).

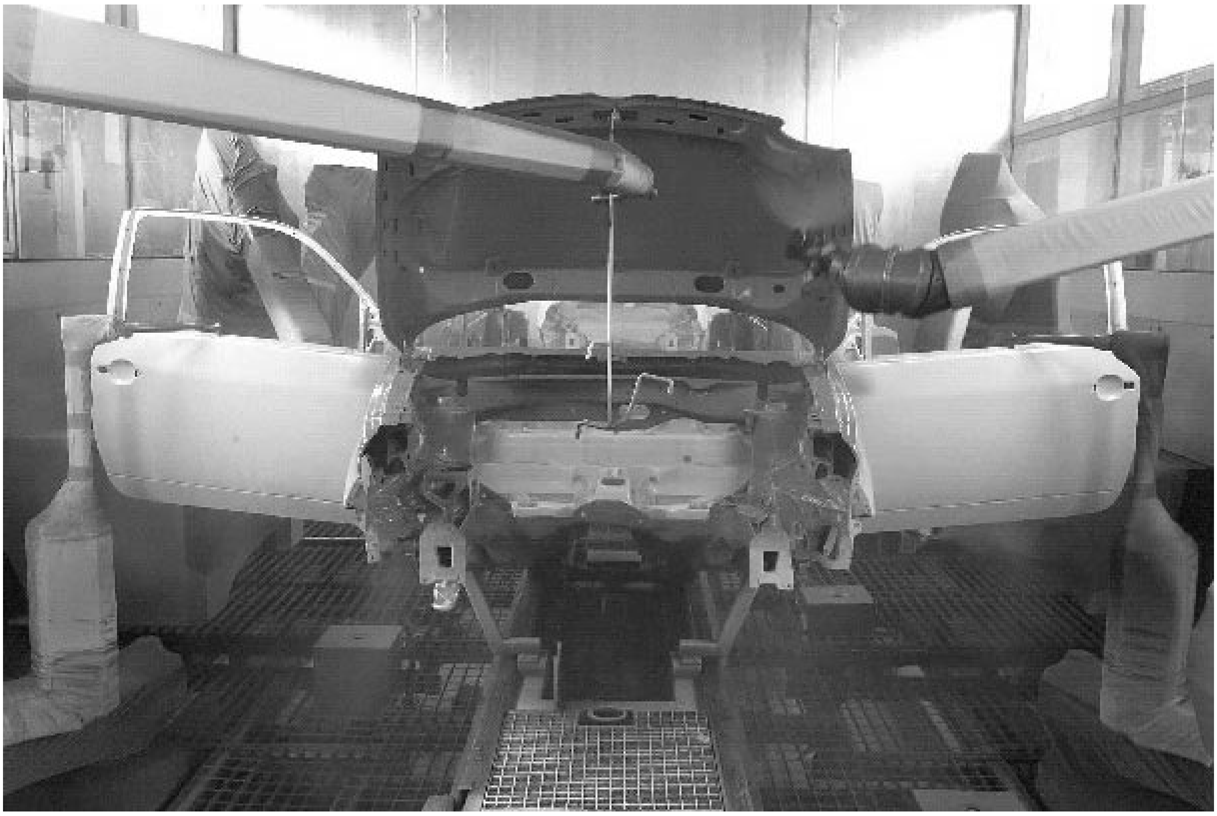

Figure 1-6**:** *Application of top coats by robots* [GRUBER 2001]

Figure 1-7**:** *Completely automated top coating process for roof and side parts* [GRUBER 2001]

Figure 1-8**:** *Automated application of metallic respective pearl effect varnish with the spraymate technique* [GRUBER 2001]

Drying and Curing

Drying terms vaporizing of solvents of the applied paint layer and includes curing of the paint layer by chemical reactions. A drying tunnel is shown in figure 1-9.

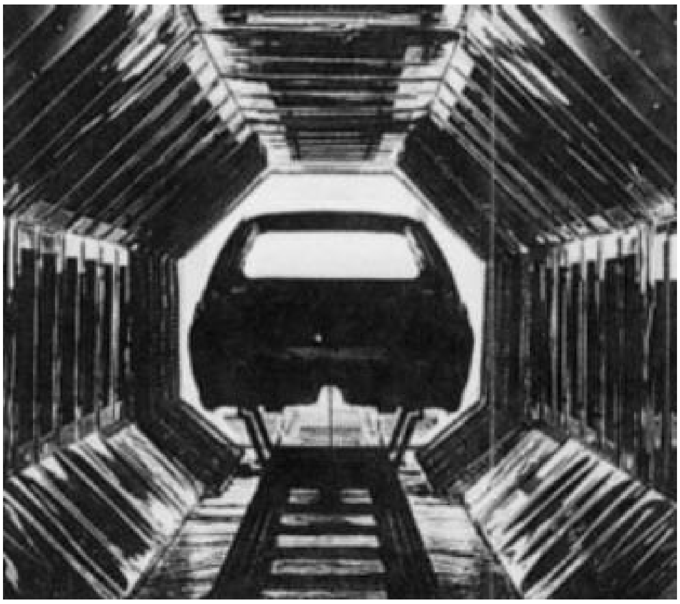

Figure 1-9***:*** *Drying tunnel* [GRUBER 2001]

Three types of drying can be differentiated:

- **Physical drying:** The coating material is applied in liquid state solidifies to a coat by evaporation of the solvents.
- **Chemical curing:** The film that is usually already solidified after physical drying is cross-linked by chemical reactions. These reactions occur at higher temperatures and therefore need a certain heat supply. Additional heat can accelerate the reaction process within certain limits.
- **Curing by reaction-drying:** Two or more reactive components are mixed in pre-set proportions before or during the application and they result in a solid film by chemical reaction. The systems may be either solvent-based or solvent-free. Usually the reaction already starts at ambient temperature. It can also be accelerated by heat supply.

In practise, convection dryers, radiation dryers or a combination of both systems are used, depending on quality requirements of the coating. The car bodies, heated during the drying process, generally have to be cooled prior to further processing. Therefore they are brought in contact with partly cooled fresh air in special cooling zones.

Cavity Conservation

The conservation of cavities consists of an application of a closed wax film for corrosion protection into the cavities (existing for constructional reasons) of the girders and doors of the body. It can be carried out according to the following two techniques:

- If using the *spraying technique*, a conservation wax is applied by spray nozzles. For every cavity there is at least one especially fitted nozzle. The dosage is reproducible due to pre-programmed, volume controlled amounts of material applied. The spraying technique usually uses am material with 60 - 70% wax content in an aqueous emulsion.
- If using the *flooding technique with solvent-free hot wax*, conservation is carried out in a flood installation. Hot wax (paraffin at 120°C) is pressed into the cavities through automatically racked flooding nozzles. The cavities are filled according to the specifications. After the flooding process, the surplus of wax flows through the leak openings back to flooding basin and is re-used in the circulation of wax supply. The body is heated before flooding (50 to 80 °C) in order to obtain a remaining layer as thin as possible. This technique operates solvent-free.

Rework

In spite of all elaborate measures with respect to dust cleanliness, coating defects (dust embeddings, mechanical damage, substances that interrupt wetting, etc) are not completely avoidable. After contingent post-sanding of the spot, it has to be completely new or at least partly top-coated depending on the extent of the defect.

Transport Conservation

For a protection of the vehicle during its transport, mainly water-based waxes are applied. In some older plants, solvent-based wax is still used (70 % solvent proportion). Increasingly foils are used for transport protection or the transport conservation is completely omitted.

1.3 Current Consumption and Emission Values

The most frequently used painting technique in Germany is the water-based painting technique with application of a conventional clear coat. (Table 1-4). So the pursuant consumption and emission value for this process can be set as standard. Detailed paint property data and data of used techniques, consumption, emissions into the air, generated wastewater and waste material are listed in annex VI.

The following sections give presently available consumption and emission values for painting of passenger cars in general. They are taken out of technical literature as well as out of interviews with paint and vehicle producers.

1.3.1 Consumption of Input Materials

Table 1-6 shows specific consumption of paint in gram per varnished m² of the car body's surface. The consumption depends on the different paint systems.

Table 1-6: *Specific varnish consumption depending on varnish system* [RENTZ 1999, MAY 2000B]

Paint system	**Specific paint consumption [g vanrish/m^2]***
Cathodic immersion prime coating: water based, 5 % solvent proportion per weight, Solids content of 14 - 18 %	70 – 80
Filler: solvent-containing , 45 % solvent proportion per weight, electro-statically assisted application	10 – 15
Filler: water-based, 8 % solvent proportion per weight, solids content of 50 to 55 % , electrostatic assisted application	10 – 20
1-layer top coat: solvent-containing, 45 % solvent proportion per weight, electrostatic assisted application	35 – 40
Base coat: solvent-containing, 75 % solvent proportion per weight, electro-statically assisted application (60 %) and pressure air application (40 %)	45 - 55**
Base coat: water-based, 13 % solvent proportion per weight, solids content of 17 to 35 %, electrostatic assisted application (60 %) and pressure air application (40 %)	45 - 55**
Clear coat: solvent-containing, 45 % solvent proportion per weight,	20 – 30

Paint system	Specific paint consumption [g vanrish/m²]*
electrostatic assisted application	
Clear coat: water based, 14 % solvent proportion per weight, solids content of 42 to 49 %, electrostatic assisted application [PERIZONIUS 1994, THOMER 1994]	35 – 45
Clear coat: powder-slurry, about 1 % solvent proportion per weight, solids content of 38 %, electrostatic assisted application [MÜLLER 2000]	42 - 46
Clear coat: powder-based, solvent free, electrostatic assisted application [SPITZNER 2001]	100 - 110
Underbody protection and seam sealing	6 – 12***
Transport conservation	6

* This unit is valid for all cited paint systems except the underbody protection and the seam sealings. For the latter no area-related unit can be given.

** for base coats with a solids content of 20 to 25 % per weight during processing.

*** [kg/car body]

1.3.2 Emissions in the Air

In the serial varnishing of automotives, the group of the volatile organic compounds (VOC) represents the most relevant emission source. They are generated essentially during the application of paint and during the paint drying process and originate of the usage of solvents for paint dilution, for tool cleaning, etc. In the cathodic immersion prime coating, VOC emissions arise that are generally extracted and eliminated by means of the exhaust gas cleaning installation downstream of the drying installations.

Usually application and drying of primer, filler and top coat/clear coat contribute to approximately 80 % of the VOC emissions originating from the varnishing sector of the automotive production. The top coat refinishing, the cleaning procedures as well as additional sources (e.g. coating of small parts, application of underbody protection) are responsible for the remaining 20 %. Approximately 75 to 90 % of the total VOC emissions generated during the application and drying procedure, originate from the varnishing booth; the remaining 10 - 25 % from the dryer. (The dryer exhaust air loaded with VOC is supplied to a thermal exhaust gas cleaning). The indicated percentage rates depend strongly on the used solvent types and the application efficiency factor of the technique [GAUDOSIO 1996, RENTZ 1999].

At present, average specific emissions of volatile organic compounds for the German automotive industry can be assumed to amount 35 to 45 g/m^2 painted surface. It corresponds to an average solvent consumption of 2,5 to 4 kg/vehicle (depending upon model and requirements) [GRUBER 2000A]. For some plants (e.g. BMW plant Dingolfing, OPEL plant

Eisenach, DaimlerChrysler plant Rastatt), the emissions are substantially lower, partly down to 10 g/m² [SEDLMAIER 2000]. For the European automotive industry likewise emission values between 35 and 45 g/m² can be registered, in particular for plants in Sweden and the Netherlands as well as for some plants in Belgium, Great Britain, France, Italy, Portugal and the Czech republic. However this standard does not apply for many plants of Europe where the VOC emissions reach values between 60 and 120 g/m² [MAY 2001A]. (Besides the VOC emissions, also varnish particles and possibly contained heavy metals have to be regarded. Particle emissions from overspray are generally far below 3 mg/m³ which is ensured by the use of wet and dry separators within the varnishing booths.

1.3.3 Wastewater

1.3.3.1 Wastewater of the Pre-treatment and the Immersion Prime Coating

Wastewater originates of the pre-treatment of the bodies by degreasing and phosphatizing and as well of the cathodic immersion prime coating process. The chromium (VI) emissions generated by the passivation are reduced with suitable chemicals. Entrainment of the chemicals is excluded to a large extent by capture systems.

At present unleaded electro-immersion varnish is considered as state-of-the-art. In the future these systems will be used all over the country. However new risk materials, e.g. organotin compounds, arise with some lead-free products. These can reach the wastewater during the cleaning of the installation. Further nowadays electrical immersion prime coating installations can be operated without a principle abandonment of the ultra-filtrate. However the electro-immersion coating installations have to be cleaned occasionally, so that varnish contaminated rinse water is generated. Both the rinse water of the electro-immersion step as well as of the other pre-treatment steps can be led in circuitry. After the electro-immersion, the adhering varnish material has to be rinsed before the following drying process. Due to the ultra-filtration, that nowadays belongs to the standard equipment of electro-immersion installations, this washing process runs without lacquer losses and almost free of wastewater. The wastewater from the pre-treatment is lead to the waste water drains after a chemical, physical and biological pre-treatment [GRUBER 2001].

1.3.3.2 Wastewater of the Varnishing Processes

Generally wastewater is generated by the wet washing-out of paint overspray as:

- a mix of paint, water and coagulating agent leftovers of the wet washing-out,
- a mix of paint, water and solvent generated by cleaning processes of the nebulizer units
- and paint supply conduits,
- a mix of paint and water generated by cleaning processes of the varnishing booths.

During the spraying application of varnish, overspray is generated that is separated in wet washers in industrial varnishing installations respective spray booths. The amounts of water necessary for the exhaust air cleaning are led in circuitry. Therefore separated overspray and varnish sludge have to be removed from this circulating water in order to ensure a trouble-free operation. The same methods are used for the separation of solvent-based and water-thinnable paints. The organic solvents contained in solvent-based paints are mostly easily volatile and rarely soluble in water. However the water-based paints have a substantially smaller solvent proportion, which is almost completely soluble in water. If these solvents have a very small vapour pressure, they can accumulate in the water. Solvents for water-based paints accumulate in the water circulating in the spray booth only up to the equilibrium state (usual concentrations are about 0,5 %) [MAY 2000B]. The rinsing water of the spray booth, that is led in circuitry and that is continuously being cleaned in a partial current technique, is renewed approximately twice a year. Moreover, wastewater is generated by the cleaning of the heat exchangers of the spray booth exhaust air and the heat rotors as well as by the air humidification of the input air supplied to the spray booth [VDI 1996, MAY 2000B].

1.3.4 Wastes

Substantial wastes originating from pre-treatment / cathodic immersion prime coating and the varnishing of vehicle bodies include [LAI 2000]:

- *Solvent waste*: Solvent wastes in form of old solvent, solvent leftovers, used and contaminated cleaning solvents are generated among other things by the calibration of solvent-based paint systems, by tool-, device-, spray booth cleaning and possibly by the exhaust gas cleaning of varnishing and drying.
- *Paint leftover and old varnishes:* Due to their changed physical and/or chemical characteristics, paint leftovers and old paints are no longer usable and therefore have to be disposed as waste material. Unfit surplus batches and dried paints of assisting carriers do likewise belong to this type of waste. One differentiates between not cured paint leftovers with solvent content and cured old lacquers/paint residues. Water-based paints and powder coatings are also taken into account.
- *Paint sludge:* During spray varnishing, non-separated overspray is captured in water and the coagulated lacquer particles are removed from the water. Coagulation agents are added to the water for un-bonding and for improved washing-out processes, hence paint sludge is generated.
- *Used adsorption agents:* If exhaust gas cleaning methods are used like adsorption onto charcoal, solvent-loaded charcoal is generated that has to be disposed of.
- *Phosphate sludge* resulting from pre-treatment
- *PVC wastes* generated by the application of underbody protection
- *Filters and filter pads*
- *Used cellulose cloths, cleaning cloths:* Solvent-saturated cellulose and cleaning cloths are generated in cleaning operations of the application devices. They are partly polluted with paint.

An overview of these waste types with respect to utilization and disposal is arranged in Table 1-7. Possibilities for avoidance and/or reduction of the waste arising are specified in section 1.4.

Table 1-7**:** *Overview of wastes generated in serial varnishing of automotives* [LAI 2000]

Waste type	**Processes possibly generating waste**	**Waste key number**	**Waste name / waste type**	**Wastes for recycling**			**Wastes for disposal**	
				Especially monitoring-needy	**Monitoring-needy**	**Not Monitoring-needy**	**Especially monitoring-needy**	**Monitoring-needy**
Solvent wastes	Paint diluter, application device cleaning	14 01 05	watery, halogen-free solvents and solvent mixtures	X			X	
	Paint diluter, application device cleaning	14 01 03	other solvents and solvent mixtures	X			X	
Phosphate sludge	Phosphating of raw body-in-white							
Varnish leftovers, old varnish	Complete varnishing installation	08 01 11	Colour and varnish wastes containing organic solvents or other hazardous substances	X			X	
	Complete varnishing installation	08 01 05	Cured paints and varnish			X		X
Varnish sludge	Immersion bath and overspray	08 01 13 08 01 15	Sludge orignating of paint and varnish removal	X			X	
	Immersion bath and overspray	08 01 08	Watery sludge containing paint or varnish			X		X

Waste type	Processes possibly generating waste	Waste key number	Waste name / waste type	Wastes for recycling			Wastes for disposal	
				Especially monitoring-needy	Especially monitoring-needy	Especially monitoring-needy	Especially monitoring-needy	Monitoring-needy
Varnish sludge	Immersion bath and overspray	08 01 17 08 01 18	Wastes of paint and varnish removal			X		X
Used adsorption agents	Exhaust gas cleaning installation	15 02 02 D1	Solvent-loaded charcoal	X			X	
Remaining materials of underbody protection	Underbody protection, sealing							
used (solvent-saturated) cloths	Cleaning	15 02 03	Sponging materials, cleaning cloths and safety clothing			X		X
Cellulose and cleaning cloths	Cleaning	15 02 02 D1	Sponging materials, cleaning wipes and safety clothing with hazardous contaminations	X			X	

1.3.5 Energy Demand

Apart from regarding the solvent use and emission, the consideration of the energy demand represents a substantial task. Within the entire production process of a vehicle, the painting process is one of the most energy-intensive steps: Primary energy consumption for the painting process amounts to up to approximately 20 % of the total energy needs of the automobile production [PIWOWARCZYK 2000]. Data about the energy needs for the painting of vehicle bodies are specified in section 2.5. Detailed data about the energy needs of individual production steps could not be investigated, since they do not exist at the enterprises or they are not to be published.

1.3.6 Costs

No data about costs could be obtained, since the enterprises did not give any statements for competition reasons.

1.4 Determination of the BAT Candidates

For the avoidance and/or reduction of solvent emissions and for protection of the environment, the following measures can be specified:

- Use of solvent-free paint systems or paint systems low in solvents
- Use of low-emission application techniques and supply units
- Supplemental peripheral measures
- Paint recycling
- Use of downstream techniques
- Chromium (VI)-free pre-treatment

1.4.1 Use of Solvent-free Paint Systems or Systems low in Solvents

Water-thinnable electro-immersion varnish is used for the priming of automobile bodies. The solvent content amounts about 1 and 6 % per weight (Table 1-3). Water-based paints are used for fillers, metallic- and uni-coloured base coats and are to be regarded as state-of-the-art. The organic solvent content that originally used to amount about 60 to 87 % in conventional metallic base coats was reduced down to 10 - 20% by a substitution with water-based paints. The solvent content for uni-coloured paints was reduced from 27 - 55 % to 10 - 15 %. If water-thinnable base paints are used, an application of clear coat is mandatory [VDI 1996].

Presently clear coats based on water, powder-slurry and powder are in serial use for the first time. Water-based clear coats have been in use since 1991, powder coating systems have been applied for serial use since 1997.

Apart from paint systems with elevated solids content (see also Table 1-3), the following, production-integrated measures are applicable at present.

1.4.1.1 Water-thinnable Paint Systems

Water-thinnable paint systems (solvent proportions of about 10 to 20 % per weight) are increasingly used in serial varnishing:

- Due to the small solvent proportion, high reduction can be achieved in solvent emission;
- cleaning of spraying devices and other tools can be carried out with water/solvent mixtures with an solvent proportion of about 5 to 20 %;
- varying layer thickness is possible with water-based fillers (20 to 35 µm) [MAY 2000A].

However water-based paints can initiate significant corrosion problems within the spraying systems due to the presence of water and oxygen. A substitution with water-based varnish for conventional installations usually requires replacement of the paint supply lines by materials made of high-grade steel. Further it must be pointed out that for water-based fillers and water-based clear coats, increased paint consumption must be considered due to their lower solids content. However this is not the case for water-based base coats [MAY 2000B]. Since the long-term effects of paint components on the human health are at present not completely known yet, further on the same industrial safety measures have to be implemented as for solvent-based systems after the substitution of conventional with water-thinnable paint systems.

The powder-slurry clear coat, which is in use at the DaimlerChrysler AG plant Rastatt since 1997, is applied in form of powder dispersion in water. The powder-slurry clear coat is almost solvent-free and therefore very small values with respect to VOC emissions are achieved, although cleaning is still carried out with conventional solvents. Additionally significant energy-saving possibilities are given in comparison to conventional 2 component clear coat systems, because the top coat layers can be applied by the “wet-in-wet” technique [MUELLER 2000]. Solvents are necessary for cleaning of the application tools and of the paint supply tubes; recapture of the overspray is carried out as with other wet painting systems generating wastewater and varnish sludge.

In the case of a process changeover, usually the end of the technical life span of an installation is waited for, in order to establish a new painting unit that meets the environmental legislation requirements and even anticipates future legislation drafts. Additional space is required for the intermediate drying of the base coat, which is often causing troubles in existing installations [DIETZ 1997, MAY 2000B].

1.4.1.2 Powder Varnish

Powder coatings are solvent-free systems that require electrostatic application procedures and are therefore primarily suitable for metal bodies. At present, only powder clear coats are used in the serial production.

Powder coating systems show following positive properties:

- almost free of solvent emissions;
- no water is necessary in order to absorb lacquer particles in the varnish booth;
- low waste generation if the possibility of paint recycling is used;
- paint recycling is technically possible (up to 95 %) and necessary for economical reasons;
- high application efficiency;
- the high proportion of circulating air in the varnish booth results in a reduction of energy consumption.

However there are also the following disadvantages:

- the control of the film thickness is difficult: Usually a higher layer thickness is created (approx. 65 µm), so that resource consumption for paint usage rises; however increasingly nowadays also thinner layers (approx. 55 µm) are viable.
- higher burning-in temperatures (approx. 140 - 145 °C) are necessary (because of this not any substrate is applicable);
- application conditions are strictly defined (temperature, humidity);
- manual application is only possible if certain safety regulations (against dust, electrostatic) are regarded. [ACEA 1997, MAY 2000A, B, SEDLMAIER 2000]

One application is registered at present in the German passenger car production[7]: A powder clear coat system on acrylate basis is used at the BMW AG, plant Dingolfing since 1997. After the intermediate drying of the water-thinnable base paint, at first the doors and door entrances, afterwards the horizontal and vertical surfaces are coated with powder clear paint by the so-called ESTA procedure. The powder-like white clear coat film is burned in. Figure 1-10 sketches out the clear varnish coating system.

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[7] Abrought also first experiences with the application of powder coatings do exist. At MCC inc. A single layer of a metallic powder coating (80 µm) is applied as a single layer onto the ground coat for the varnishing of the car model Smart.

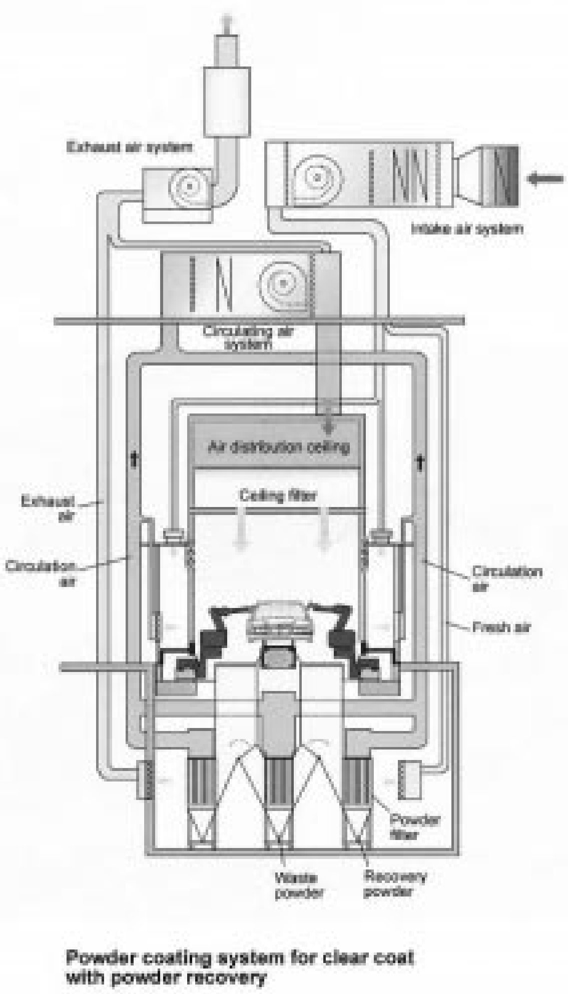

Figure 1-10**:** *Scheme of the powder coating system at the BMW AG, plant Dingolfing* [SPITZNER 2000]

Especially a reduction of operating costs can be observed due to a changeover from conventional 2 part clear coating processes to a powder coating installation. Present estimations describe a reduction by at least of 12 % of energy costs. The powder varnish technique allows a reduced reprocessing of the booth air compared to conventional installations. Moreover, the drying by combinations of infrared and air circulation drying techniques is more effective. Cost reductions due to lower energy consumption already result for these two reasons. Figure 1-11 shows a comparison of operating costs for conventional 2 part clear coats and powder clear coats [SPITZNER 2000].

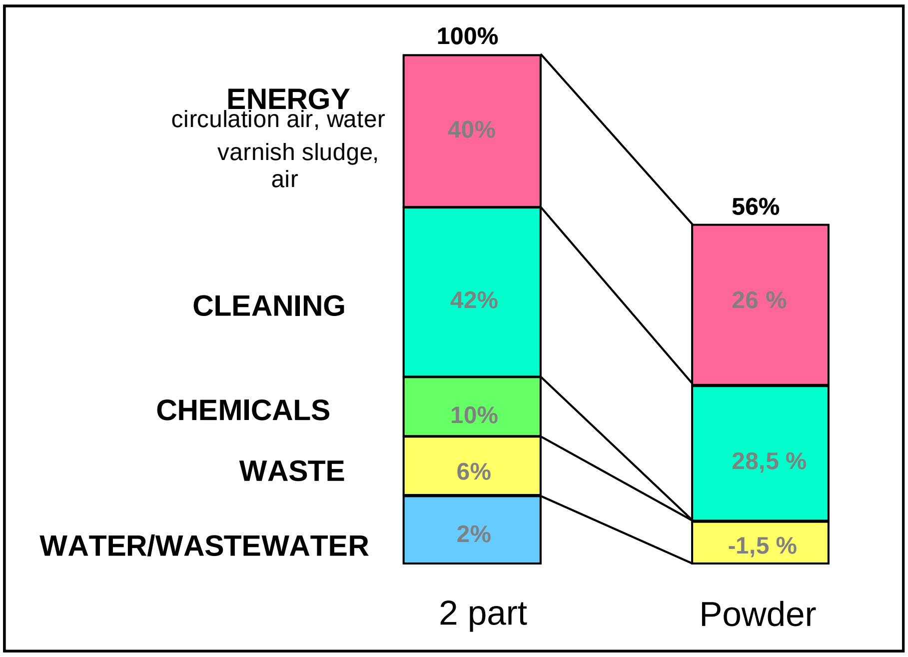

Figure 1-11**:** *Comparison of operating costs for conventional and powder clear coats, without material costs* [SPITZNER 2000]

Additionally, the powder varnish technology does not require a recapture of overspray varnish particles by water. Hence a wastewater reprocessing is not necessary and the use of additives (such as coagulation agents) can be avoided. As opposed to the conventional two component clear coating, where organic solvents are necessary for the cleaning of the tools, both the complete booths as well as the application tools can be cleaned by vacuum cleaning or respective by blowing with compressed air. This way, resources are saved and solvent emissions are avoided.

A certain disadvantage of the technology is the layer thickness. Whereas the layer thickness for conventional two component varnish systems amounts between 35 and 45 µm, a layer thickness of about 65µm is common today. At the BMW company are investigations in process, in order to reduce the layer thickness of the powder varnish to 55µm. This is planned to be reached by 2002. Presently the price for powder varnish systems is still higher than for conventional varnish systems. The operating cost optimization programs for the sectors of raw materials, production and thin-film technology will cause an implementation also in other installations as well as initiate further cost reductions. In the United States, varnish recycling efficiency factors of almost 100 % are achieved nowadays. This trend can also be observed in Europe contributing to the future increasing proportion of the powder clear coating technology [SPITZNER 2000].

Further information about the powder clear coating installation in the plant Dingolfingen is documented in annex VI.

1.4.1.3 Use of Low-emission Application and Supplying Techniques

1.4.1.3.1 Paint Application by Immersion

The optical quality of the lacquer finish is of large relevance in the automotive production, therefore exclusively spraying techniques for the application of fillers and top coats are used. At present the immersion technique is used for the application of the primer (cataphoretic application). Lead-free electro-immersion varnishes can be considered state-of-the-art. Thus low solvent emissions result and at the same time, the paint consumption is low and thus a small amount of waste is generated. [VDI 1996]. Dip coating represents the application procedure with the highest application efficiency [MAY 2000B].

1.4.1.3.2 Electrostatic Paint Application, electrostatic assisted Paint Application

An improvement in the application efficiency factor leads to a reduction of paint consumption and thus to a reduction of VOC emissions. The application efficiency factors for conventional pressure air spray guns without electrostatic assistance amount approx. 18 - 35 %. Electrostatic high rotation application techniques can only be used with automatic applications. Electrostatic support of pneumatic or airless nebulization is also possible for manual application, however less efficient. [ACEA 1997, MAY 2000B]

Electrostatic spraying techniques are based on the phenomenon that charged paint particles are attracted by the substrate charged oppositely. The following advantages are to be stated [STROHBECK 1997]:

- Less generation of leftovers,
- less pollution of the spray booth, thus less consumption of cleaning solvents,
- savings in painting time.

If water-thinnable paint systems are used the paint must not be loaded electro-statically before leaving the application bell. Beyond that a reduction of the application efficiency up to 5 % is to be registered if water based paints are used [MAY 2001A].

Application efficiency factors of 60 - 80 % can be reached with electrostatic assistance. Most car manufacturers use electrostatic spraying applications for automated procedures. However some applications must take further place pneumatically, manually or by means of robots, e.g. the interior fittings. Often an application procedure with a conventional compresed air spray-gun is necessary after the electrostatic application of the base coat in order to achieve the desired optical quality (metallic and pearl effects)[ACEA 1997].

1.4.1.3.3Block by Block Painting

The cleaning of the painting systems and thus both cleaning solvent consumption and the solvent emissions can be reduced, if several vehicles are painted successively in the same colour. However sufficient storage space for vehicles as well as an appropriate production planning system have to be available [ACEA 1997].

1.4.1.3.4 Pig-clearing Systems

In the automobile industry, the trend towards more special colours has initiated the development of new lacquer supply systems allowing an economic change in colours. Among these there is the pig clearing systems. This technique has been transferred from the food and oil industry to the varnish-processing industry. This method only fills so much paint into the system as necessary for the painting process: The paint is pressed back from the tube or the flexible tube into the varnish supply by an elastic separation module (pig clearing) and hence recovered. Rinsing is carried out with sparing use of rinsing agents. The advantages are the lower use of cleaning agents, the reduction of colour and solvent losses as well as the decrease of the manual processes with the colour change [ESSLINGER 2000, SCHOLZ 2000].

1.4.1.4 Supplemental Peripheral Measures

Recovery of Rinsing Diluters

If different colours are led through the same spraying system, a cleaning of the spraying system must take place between each colour change. Modern painting systems are equipped with a recovery installation for the used cleaning solvents.

1.4.1.5 Measures for Reduction respective Avoidance of Wastewater

The following measures applied in German plants to reduce respective to avoid the generation of wastewater can be stated [SCHMIDT 1995]:

- Changeover towards electrostatic application techniques with improved application efficiencies;
- filtration measures as for example bag filter, magnetic separator, cyclone;
- cascade technique for multiple use of process water in pre-treatment[8];
- use of an ion exchanger in the phosphating and passivation step;

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[8] Less contaminated water is reused for rinsing operations in previous processes. Cf. cascade technique.

- use of ultra-filtration.

Ultra-filtration

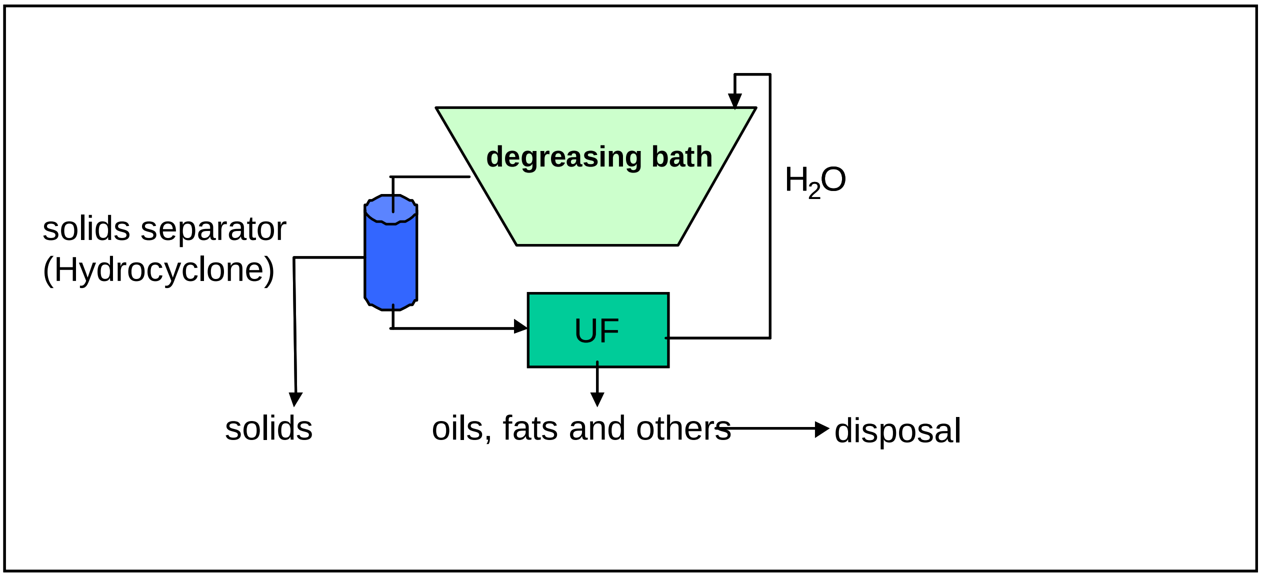
The pre-treatment steps (degreasing, phosphating, passivation and electro-immersion) consume especially high amounts of water.

The ultra-filtration serves as a bath maintenance measure in the degreasing step, that allows

- higher quality of the degreasing bath,
- an extension of service lifetime,
- a reduction of necessary cleaning agents,
- a higher availability of the plant.

A simplified scheme of degreasing is given in figure 1-12. [Gruber 2001]

Figure 1-12**:** *Scheme of degreasing with ultra-filtration* (UF) [Gruber 2001]



In the electro-immersion coating, the ultra-filtration can be used for recycling of paint and completely demineralised water by allowing a closed circuitry. Both an integration into the large cascade (with one UF) or as well if a demineralized water rinsing is used (with a separate UF). A simplified pattern of the KTL range is given in figure 1-13.

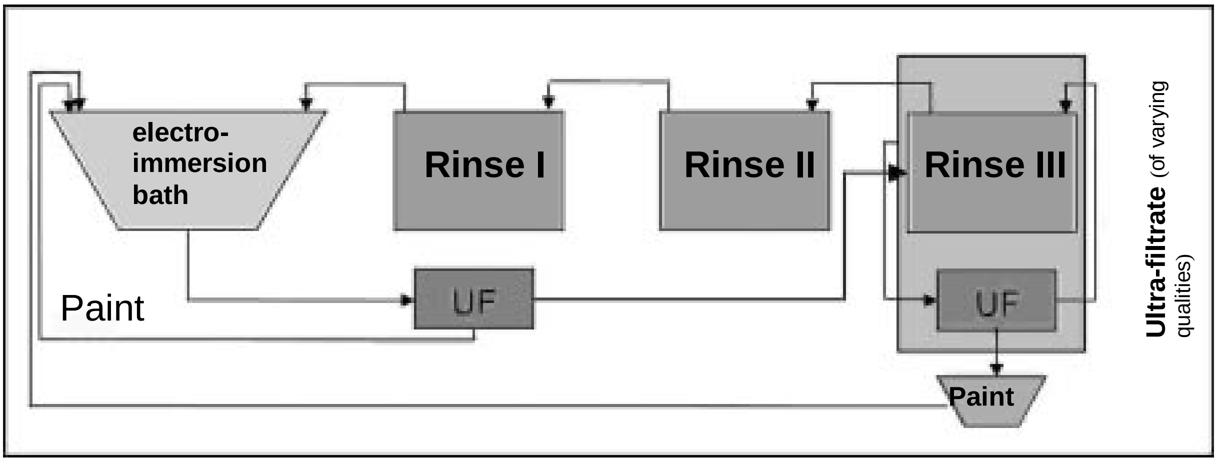


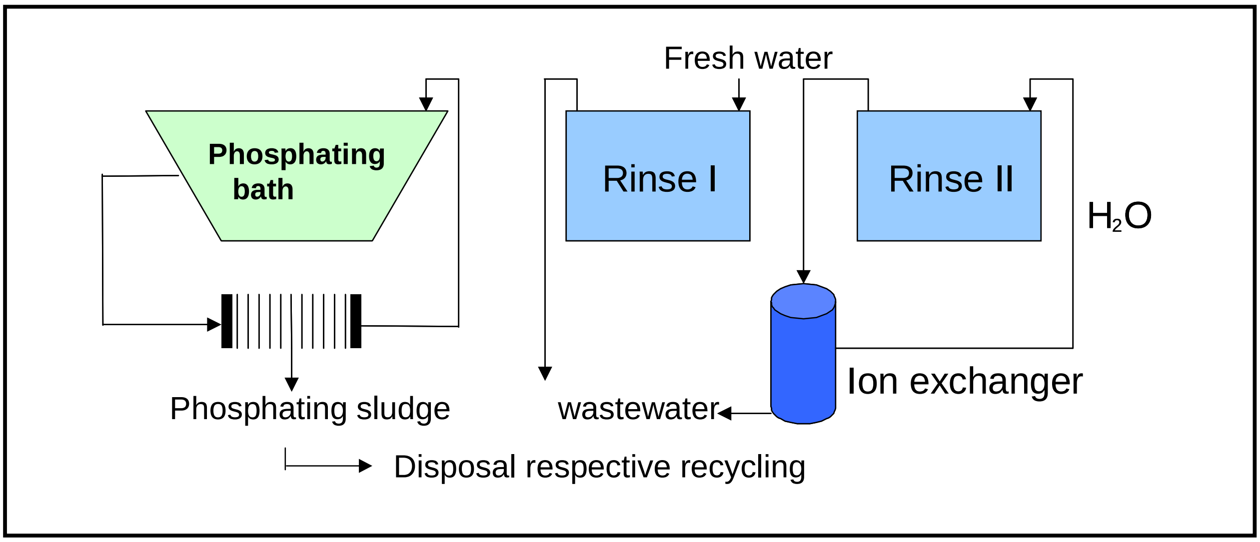
Figure 1-13**:** *Scheme of the cathodic immersion prime coating with ultra-filtration* (UF) [Gruber 2001]

Ion Exchanger

An ion exchanger serves for bath maintenance and water savings. In the procedure of washing in the phospating (cf. also figure 1-14) and passivation steps,

- Wastewater amount and water consumption are reduced
- However there is an increased technical maintenance effort and possibly an impairment of the operation safety if the service is not carried out by experts due to contamination with germs and permanent mechanical abrasion may arise (particle).

Figure 1-14**:** *Scheme of the phosphating sector with ion exchanger* [GRUBER 2001]



Paint recycling

In the past years recycling technologies have increasingly been developed in the paint processing sector. They permit the recovery of paint overspray of spraying application. The recovered paint is re-supplied to the process. The technology principally exists for water-based paints; however it is only partly used in the filler sector at present by the German manufacturers[9]. Process-conditioned, the use of the ultra-filtration is only possible for one part water-based paints; for 2-component water-based paint systems at present no application possibilities exist [ONDRATSCHEK 1996].

Water-saving Measures in the Varnishing Department of the Opel Eisenach GmbH Company

The water consumption has been reduced by about 70 % down to 3 litres/m^2 due to the use of circuitries and multiple stage cascade systems in the rinsing zones of the pre-treatment and the cathodic immersion prime coating installations (see also annex VII) [UBA 94]. The applied techniques are sketched out in the following:

Degreasing:

The degreasing baths are degreased by ultra-filtration. The following rinsing baths are flowed cascade-like by inverse-osmosis-water. The overflow of the first rinse is leaded into the degreasing bath.

Rinsing of the Bodies subsequent to Phosphating and Passivation

The rinse process of the bodies after phosphating and passivation are carried out in two steps, respectively: The water out-flowing of the pre-treatment is reprocessed by precipitation, flocculation and ion exchange and is re-used in the last rinsing bath.

Cathodic Immersion Prime Coating Section

The rinsing of the coated body after emerging of the immersion bath in order to remove loosely bonded varnish particles is carried out with filtrate that is obtained from the immersion varnish material by an ultra-filtration installation. The rinsing is carried out with spraying and immersion rinsing techniques. The water from the first rinse ring is supplied to the cathodic immersion bath and therefore a closed circuitry is achieved. The last rinse is carried out with completely demineralised water. The overflow leaves as wastewater.

Spray Booths

A complete circuitry of the water circulating in the booth can be achieved by varnish coagulation. The waste is a sludge-like coagulate. No wastewater is generated. Evaporation losses are replaced with water from the inverse osmosis of the degreasing.

1.4.1.6 Measures for Reduction respective Avoidance of Wastes

Measures in order to avoid respective to recycle waste are listed according to the waste types in tables 1-8 and 1-9.

Table 1-8**:** *Avoidance of wastes in the serial varnishing of automotives separated according to waste types* [LAI 2000]

Applicable measure	Prerequisites for avoidance	Level of realisation	Level of avoidance
Used and contaminated solvents			
Substitution of organic solvents by watery cleaners	Vitiation of the painting process has to be avoided	Already approved measure for pre-treatment (degreasing) and for water-based paint layers	A complete avoidance is not possible at the moment, because solvent-based paint systems are still used
Use of solvent-free paint systems or paint systems low in solvents	Adjustment of the paint environment (stainless steel equipment), vitiation of the painting process has to be avoided	Already done in several plants for different paint layers	Significant reduction of contaminated solvents
Circuitry of solvents and recovery by distillation	Separation of easily separable solvents from difficult separable solvents and solvent mixtures	Already implemented in some plants, however with external recovery and the recovered solvents are not directly reused because of low quality or aspects of precaution	Recycling proportions of about 60 to 90 % of the used amount of solvents
Paint leftovers, old paints			
Product planning with few changes of colour	Only for spraying paint application	Relatively easy organisational measure that has already been realized in any plant	High
Paint slurry			
Increase of the paint efficiency by optimization of the control of the used spray varnishing technique e.g. - lower nebulizing pressure - adjustment of tools to the vehicle	Automation of the painting plant	In most of the plants those measures are already implemented. However this measures cause big investments, so that these improvements respective optimizations are generally done	10 to 20 % at overspray

Applicable measure	Prerequisites for avoidance	Level of realisation	Level of avoidance
geometry - correct spraying distance		associated with the construction of a new varnishing unit	
Implementation of electrostatical spraying techniques		Implemented for vehicle external painting. For internal coating yet partly.	10 to 50 % at overspray
Used adsorption agents			
Internal regeneration of adsorption medium (desorption process)	Sufficient high solvent accruement	The profitability is has to be checked for every single case. In general in automotive series painting, a thermal post-combustion installation is used due to low solvent concentrations downstream the adsorption.	High

Table 1-9: *Recycling of wastes in the vehicle serial varnishing sorted after waste types* [LAI 2000]

Applicable measure	Prerequisite for Recycling	Level of applicability	Level of damage potential
Paint slurry from overspray			
Material usage by recycling into new paint or into base materials for the paint production (recovery and re-usage of bonding agents, pigments, etc.)	Application only for 1 part paint systems If necessary separated collection of segregated paints Usage of coagulation chemicals that do not cause chemical changes in the bonding agents.	Generally applicable	Damage-free
Paint slurry from the cathodic immersion bath			
Recycling to new paint at the paint producer	Avoidance of drying	Simple technical and organisational measure, furthermore no mixture accrues	Damage-free
External regneration		Generally applicable	Damage-free

1.4.2 Use of Downstream-Techniques

The downstream procedures (end-of-the pipe),described in the following are presently utilised as standard techniques for serial varnishing of car bodies.

1.4.2.1 Primary Separation of Paint Particles

A primary separation of the paint particles is necessary in order to ensure a safe operation of the entire plant, to submit air circulation and to meet working and environmental legal requirements. This technology consists of wetting the cavity under the spray booth completely with water. This way water droplets and exhaust air are accelerated together in a venturi system in a way that an intensive mixing of exhaust gas and droplets takes place. Thus a particle separation of over 99 % is reached and a remaining particle content of < 3 mg/m³ in the exhaust air flow is guaranteed. [VDI 1996]

1.4.2.2 Secondary Separation of Paint Particles

The secondary separation serves as pre-treatment for the solvent concentration. The permissible remaining particle content depends on whether the cleaned exhaust air of the spray booth is directly supplied to an exhaust gas cleaning installation. For a post-separation of paint particles after venturi-washers, additional paint particle separators can become necessary. In particular if a circulating air flow aiming on solvent recovery exists or a protection of subsequent installation parts (rotor, heat exchanger) is required, secondary separation methods are applied. Dry filters show very good separation efficiencies, however they have significantly shorter service lifetimes for the separation of sticky varnish sprays than for other dust types and hence require high maintenance efforts. In practice, the efferverence floor scrubber has become generally accepted. The paint particles are separated in air-flowed scrubber collectors by intensive mixing of exhaust air with water. The paint particles are separated thereby around further 90 %. Further wet-electrostatic filters can be used for the separation of paint spray. Lacquer droplets are charged within an electrostatic field and migrate towards condensation electrodes wetted with water [VDI 1996].

1.4.2.3 Solvent Concentration as Pre-procedure for Separation

In the serial varnishing of automobiles, low solvent concentrations combined with a large exhaust air flow rate are usual. Therefore a solvent concentration is necessary for an economic separation. [VDI 1996].

Internal Concentration

An internal concentration of solvents consists of a feedback of spray booth exhaust air back to the spray booth after sufficient particle separation and dehumidification. This way the solvent concentration of the spray booth exhaust air increases. Only a small part flow of the circulating gas is lead away; this concentrated exhaust air mass can be disposed of economically by one of the exhaust gas cleaning procedures described in the following (section 1.4.4.5). This technique is only suitable for automated systems due to the elevated solvent concentrations.

External Concentration

The concentration of solvents can be achieved likewise via continuous circular flow of the spray booth air generated by a rotor. Adsorption materials e.g. carbon fibre paper, zeolites and charcoal are used. A transmission of the solvent load into an external hot-air stream in the ratio 1:6 to 1:20 (depending upon raw gas concentration) is achieved. This comparatively small exhaust air flow rate can be economically disposed.

1.4.2.4 Thermal Post-combustion

Only thermal and thermal regenerative post-combustion techniques are used in the automobile industry. (Depending upon type of the heat exchanger recuperative and regenerative procedures are differentiated (see also annex V). For minimization of the calorific losses and the energy costs, the thermal post-combustion is thus often integrated in the dryer heating. The heat set free by the post-combustion process can be indirectly supplied to the hot-air air-locks of the drying unit. Cleaned gas concentrations of 10 mg C/m³ are reached [MEHLIS 2001].

Further information about measures for VOC-emission abatement is given in annex V.

1.5 Proposal for the Best Available Techniques

For the selection of the best available techniques for the serial varnishing of automotives, some requirements regarding corrosion protection and optics so as economy and environment-friendliness as well as process security are to be considered. A study of different implemented painting concepts was made by Piwowarczyk with the help of integrated balancing with the software tool GaBi® (cf. also annex VI.II) [PIWOWARCZYK 2000]. However as this study, according to statements of industry experts, assumes theoretical plant constellations, which are not implemented in real plants, the results of this work are not used for the selection of the best available techniques.

As best available techniques for the serial varnishing of automobiles, both lacquer-specific techniques as well as procedure-specific techniques can be proposed:

***Paint-specific Techniques*:**

The water-based, lead-free electro-immersion paints nowadays used can be designated as established best available technique for the vehicle priming sector due to the low solvent proportions and the high material efficiency. Also the chromium(VI)-free passivation is designated as established best available technique. The cataporethic application shows the highest application efficiency factor with regard to the application of primers.

Table 1-10 suggests the most progressive painting processes implemented at present (painting concepts A-D) as best available techniques. They are used nowadays in the serial varnishing of passenger cars for the application of filler, base coat and clear coat. These painting processes undershoot solvent emissions of 35 g/m².

Table 1-10**:** *Best available techniques for serial varnishing of passenger cars in Germany*

Paint concept	**Filler**		**base coat (uni / metallic)**	**Clear coat**	
	water	*solvent*	*water*	*solvent*	*low in solvents or solvent-free*
A	🟦		🟦		🟦
B			🟦		🟩 Powder slurry
C		🟥	🟦		🟩 Powder
D	🟦		🟦	🟥	

Water-thinnable varnish 🟦

Solvent-based varnish 🟥

Varnish solvent-free or low in solvents 🟩

The painting process A with the use of a water-based clear coat leads to a significant reduction of the VOC emissions compared with conventional procedures using solvent-based products. Recycling of the overspray is possible by appropriate procedures.

The combination of water-based paint and powder slurry (functional layer) in process B achieves very low VOC emissions. The energy-consumptive intermediate drying is avoided by the wet in wet varnishing technique of base coat and powder slurry.

The application of powder clear coats in process C leads to energy savings of more than 10 % in comparison with conventional 2 part clear coats. The powder coat system does not produce waste water and no VOC emissions. The overspray can be recycled. The presently used solvent-based filler will be replaced by water-based products until the year 2003.

The water-based paint process with conventional clear coating, as in process D, allows an effective reduction of VOC emissions by a combination of water-based filler and base coat.

Within these best available techniques, the procedure-specific technologies specified in the following are suitable for a further reduction of the environmental impacts:

Procedure-specific Techniques:

- Paint application with high proportion of electrostatic application
- Reduction of colour changing waste (by pig-clearing systems)
- Optimisation of layer thickness profiles
- Chromium(VI)-free passivation
- Bath maintenance measures by ultra-filtration for degreasing and cathodic immersion prime coating of the raw bodies
- Use of ion exchangers for phosphating and passivation

1.6 New Progressive Techniques

Progressive products in the form of improved water-thinnable 1- and 2 component clear coating systems as well as ”very high solid” 2 part clear coating systems (with a solids content of up to 90 % per weight) are to expect for the future [MAY 2001A]. Also an application of powder top coating in larger scale is expected. Thus for example DaimlerChrysler, USA is planning to coat the Jeep Wrangler fully with powder coats starting from 2004 on [NEIS 2001]. According to statements of varnish producers, a variety of pigmented finish coating systems based on powder is already available however it is not yet in the serial application yet.

A further progressive procedure represents the Low Cost Conversion Concept (LCCC, see also [MAY 2001B]), where the solvent-based base coat can be changed over to water-thinnable basis paint with relatively small technical expenditure (compared with a new plant). The developed basis lacquer systems for the LCCC show similar characteristics as water-thinnable systems. For the conversion of solvent based- to water-thinnable base paints, replacement of the paint supply, adjustment of the air conditioning and the application devices (usually high rotation bells) and if necessary adjustment of the existing dryers is required. A first serial application has shown that the energy consumption is lower with the LCCC than with the use of conventional solvent-based basis paint systems, with or without exhaust gas cleaning at the spray booth. It is also lower than for the application of conventional water-thinnable base paint systems (no infrared dryer is necessary). However the use of this concept is restricted by the following varnish layer: Tests have shown that good results are attainable with a 2 part clear coat regarding the surface quality, whereas with 1 part clear coat systems still some quality imperfections (e.g. veils) may appear.

A further development points to an increasing share of completely finished coil coating parts [MAY 2001A], so that certain painting processes will not be performed at the car manufacturer any more.

Further a reduction of the number of varnish layers is to be expected, as fillers and basis lacquer are united in one material applied in one varnish film. This way resources are saved and simultaneously the environment-friendliness of the painting process would increase (abatement of solvent emissions, wastewater and waste generation, reduction of the energy consumption). A first step in this direction has already been implemented: By the use of colouring fillers at the BMW AG, the base coat can completely be eliminated in the vehicle's interior.

For a discussion of new progressive procedures, also paint systems on polyurethane basis are to be mentioned. These paints can be burned-in already at temperatures below 100 °C. This allows lacquer finish of metal bodies and plastic mounting parts within a single painting process. A so-called inline-lacquer-finish would solve the problem of the colour adjustment between metal body and coloured plastic parts. The wide range of PU-based paint systems is available for all layers of the varnish structure, ranging from the filler to the finish coating and as well as for sound absorption and underbody protection. The low burn-in temperatures allow the use of a wide range of plastics.[PETZOLD 2001]

A summary of progressive and best available techniques in order to reduce environmental impact, both in serial use and in a development state, is given in table 1-11.

Table 1-11**:** *Progressive and best available techniques in the serial varnishing of automotives in Germany* [GRUBER 2001]

Progressive technique	**Status**	**Date of**	**Realisation in**		**Concerned sector**	**Advantages in comparison to the current state-of-the-art**				
		Appli - cation	**New plants**	**Old plants**		***Air***	***Water***	***Waste***	***Energy***	***Other/Comments***
1part water-based clear coat	Series	1991	X		Clear coat	Reduction of solvent emissions by about one third				
Powder clear coat	Series	1997	X		Clear coat	Reduction of solvent emissions to almost zero	No wastewater	Due to direct recycling no disposal of overspray necessary	Energy savings by air recycling and lower air sinking velocities	
Powder slurry clear coat	Series	1997	X		Clear coat	Reduction of solvent emission to almost zero				
Functional layer (see also process 2, page 23, figure 2-4)	Series	1997	X		Filler and basis coat combined as one material (Project of the German UBA and BMBF)	no CO_2/NO_x/ CO emissions by elimination of the filler dryer	Less wastewater to be treated	Less paint slurry	Reduction by elimination of the filler dryer	Resource sparing by reduction of layer thickness of filler and basis coat of about 20-30%
Only electrostatic basis paint application	Series	1997	X	X	Basis coat, substitution of the compressed air supported spraymate	Reduction of basis coat solvent emissions		Reduction of base coat overspray		Resource sparing by higher application efficiency

Progressive technique	**Status**	**Date of**	**Realisation in**		**Concerned sector**	**Advantages in comparison to the current state-of-the-art**				
		Appli-cation	**New plants**	**Old plants**		***Air***	***Water***	***Waste***	***Energy***	***Other/Comments***
					(not with all colours possible)					
Organic pre-coated coils, weldable	Series	1997	X	X	Delicate sealing, cavity conservation	Possibly small reduction of solvent emissions			Reduction by avoidance of heating of material and/or body	Reduction of PVC use
Filler with the same colour as the vehicle	Series		X	X	Basis coat and clear coat in the sector of internal painting	Reduction of solvent emissions				Top coat application with closed mounting parts
Low-temperature process	Develop-ment		X	X	Filler, basis and clear coat				Reduction by lower burning temperatures (full potential only usable in new plants)	Extended possibility for inline varnishing of plastics and possibly waiving of separate varnish installations
High-Solid clear coat*	Develop-ment		X	X	Clear coat	Reduction of solvent emissions				
2 part water-based clear coat	Develop-ment		X	X	Clear coat	Reduction of solvent emissions by about one third				

Progressive technique	**Status**	**Date of**	**Realisation in**		**Concerned sector**	**Advantages in comparison to the current state-of-the-art**				
		Appli-cation	**New plants**	**Old plants**		***Air***	***Water***	***Waste***	***Energy***	***Other/Comments***
Organically pre-coated coils, not weldable	Develop-ment		X		Construction, raw construction, pre-treatment, cathodic immersion priming, cavity conservation	Reduction of basis coat solvent emissions	Less waste water to be treated	Less waste resulting of PT, CIP**, cavity conservation	Reduction by elimination of installations	
LCCC	Develop-ment									

* solids content of 80% per weight **PT: Pre-treatment; CIP: Cathodic immersion priming

1.4 Conclusions and Recommendations

Vehicles may not contain hexavalent chrome according to the European Union Directive about old vehicles (2000/53/EG) any more. Hence the passivation has already been changed over in some installations.

In the sector of vehicle priming, nowadays water-thinnable, lead-free electro-immersion prime coats are state-of-the-art. The combination of the water-based paint process with the conventional solvent-based clear coat predominantly used for the serial varnishing of passenger cars represents an available procedure for the reduction of the VOC emissions by the use of water-based filler and base coat. A more far-reaching abatement of VOC emissions is particularly possible by substitution of conventional clear coats. Presently water-thinnable clear coats, powder coats or powder slurry are already in serial use in some plants. The powder clear coats offer the advantage of energy savings and the possibility of overspray recycling apart from the avoidance of VOC emissions and wastewater. For the reduction of the paint quantities required as well as emissions, predominantly electrostatic application processes are used.

Besides the substitution of solvent-based paints, the quantities of colour wastes and cleaning solvents can be significantly reduced by the abatement of colour change losses e.g. by pig-clearing systems or colour sequences/block by block painting. Newer developments aim at the reduction of the number of varnish layers. In addition the painting processes are shifted to the component supplier enterprises.

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2 Other Vehicle Varnishing

The varnishing processes for coating of vehicles shows significant deviations compared to the serial varnishing of automotives due to the application of different coating materials, processes, application techniques and layer constructions (cf. chapter 2). Besides the relevance of optical surface qualities, as in the varnishing of commercial vehicles, in other sectors the corrosion protection is more important. In this chapter the varnishing technologies for the following vehicles are described:

2.1 Varnishing of trucks
2.2 Varnishing of busses
2.3 Varnishing of agricultural and construction machines
2.4 Varnishing of mobil homes and caravans
2.6 Varnishing of rail vehicles
2.7 Varnishing of ships

2.1 Varnishing of Commercial Vehicles

With regard to integrated environmental protection measures the varnishing of cabs and chassies for trucks of the categories N2 and N3 (according to directive 70/156/EWG, cf. table 1-1, chapter 1) is examined. Driving cabs for trucks are defined as drivers cabins as well as all integrated housings for technical equipment. Small and lightweight commercial vehicles are usually termed as busses (cf. chapter 2.2). The combined coating of commercial vehicles (N1) and automotives within the same installation is described in chapter 1.

2.1.1 General Information

In the year 2000, 394.697 commercial vehicles were produced in Germany. Among these number 13.518 busses and 238.593 trucks up 6 t and 142.586 trucks of a permissible total weight over 6 t, were produced [VDA 2001].

In table 2-1 the emission limits according to 31. BImSchV[1] are listed for the varnishing of new commercial vehicles and drivers cabins.

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[1] Ordinance for the transposition of the directive 1999/13/EG for the emission reduction of VOCr Verbindungen

Table 2-1: *Emission limits for varnishing of new commercial vehicles and driver cabins according to the German 31. BImSchV*

Threshold values for the annual consumption of organic solvents [t/a]	**Total emission limit [g VOC/m^2]**	**Emission limits for cleaned waste gases [mg C/m³]**
Driver cabins > 15	45	50
Commercial vehicles > 15	70	50

2.1.2 Applied Processes and Techniques

Like in the serial coating of passenger cars, the applied lacquer systems can vary from plant to plant. Commercial vehicle manufacturers use either serial lacquer systems (with drying temperatures of approx. 140 °C) or 2-component paints for reparation purposes (drying temperature at 80 °C); also often a combination of both systems is used [MAY 2001A].

The painting processes for truck cabins and truck chassis are exemplified by the production plant of MAN commercial motor vehicles AG in Munich, which was examined in form of a case study.

For the varnishing of truck cabins two different processes can be differentiated: **Metallic-varnishing**, which consists of base coat and a subsequent applied clear coat and the **1 coat topcoating,** which consists of a single layer base coat.

The **pre-treatment** of the driving cabs includes cleaning, degreasing with following flushing, zinc phosphatization with flushing and afterwards a chrome-free passivation with flushing with demineralized water. Then a lead free dip coating (KTL) is applied. After two rinsing procedures in ultrafiltrate and with demineralized water, the driving cabs are dried in a dryer, which is equipped with a post combustion unit. Then the application of underbody protection, anti-noise materials and seam sealing takes place. The car body is prepared for the following applications of varnishes by optional grinding and masking processes.

Subsequently a water-based filler is applicated onto the inside and outside surfaces of the drivers cabin, via manual operated HVLP spray-guns. Afterwards a second layer is applied onto outside surfaces via automated electrostatic spray-application. The layer thickness varies from 25 – 35 µm. The painting cabin is equipped with a wet separator for deposition of the overspray.

Robots via high rotation bells apply the most frequently used colours. For special requests a manually paint application is carried out. The most used paints (used for approximately 50 % of the truck cabins) are water-based varnishes; the other materials consist of one- or two-component solvent-based systems. In **metallic-paints** also the base coat and clear coat are solvent based. The layer thickness of the base coats amounts 10 – 20 µm, that of the subsequently applied clear coat amounts approx. 40 ± 5 µm, single-layer topcoats are applied with a layer-thickness of 30 - 40 µm [KIRSCH 2001].

2.1.2.1 Varnishing of Truck Chassis

Truck chassis are assembled from profiles that are already electrophoric dip coated. As varnishes for dip coating, a water-based material with a solvent content of 5 – 10 % is processed. After assembling of the profiles the surface quality is checked and imperfections are repaired, some parts are masked. Subsequently a **single-layer topcoat** is applied. Therefore the chassis are automatically transported through the installation by a conveyer system. The chassis are painted manually due to their variations in size and structure. First the varnish is applied onto the bottom side, then on the upside. Approximately 25 different water based (two-component) topcoats are used for approx. 95 % of the chassis. For special colours two component acrylate paints are applicated. The applied layer thickness varies from 40 to 60 µm. The material is applied via **HVLP-spray guns**. Overspray is intercepted via a wet dust collector with automated discharge of the paint sludge to the decanter.

For drying the coated chassis are first transported to an evaporation zone with a maximum temperature of 40°C. Afterwards the varnish is dried in a forced air dryer at temperatures of 85 – 90°C. The dryer is equipped with a post-combustion unit. Thus emission values of 10 mg C/m³ are archived. After drying, the chassis are transported to a cooling zone [FLECK 2000, KIRSCH 2001].

2.1.2.2 Varnishing of axles for commercial vehicles

Axles for busses and trucks are coated with solvent based paints in general. The biggest portion of the applied solvents is emitted since emission reduction measures are not applied or only the dryer is connected to a post-combustion unit.

The DaimlerChrysler AG, Kassel is operating an installation that is using water based paints for the coating of axles since 1998. For a reduction of overspray, the air-mix process is applied. Due to these measures 160.000 l of solvents are saved annually.

2.1.3 Present Consumption and Emission Values

2.1.3.1 Consumption of Materials

An overview of the spezific consumption values of paints for the varnishing of new truck cabins is given in table 2-2.

Table 2-2: *Specific consumption values of varnishes for the coating of new truck cabins* [RENTZ 1999, KIRSCH 2001]

Varnishing Material	Specific material consumption [g varnish/m^2]
Electrophoric dip coating: Water-based, 5 % (weight per cent) of organic solvents	120 – 140
Filler: Solvent based, 45 % (weight per cent) of organic solvents, electrostatic spray-application	18 - 23
Filler : Water-based, 8 % (weight per cent) of organic solvents, electrostatic spray-application	22 - 27
Single layer topcoat: Solvent based, 45 % (weight per cent) of organic solvents, electrostatic spray-application	30 - 40
Base coat: Solvent based, 75 % (weight per cent) of organic solvents, electrostatic spray-application (50 %) and regular spray-application (50 %)	95 – 105
Base coat: Water based, 13 % (weight per cent) of organic solvents, electrostatic spray-application	100 – 110
Clear coat: Solvent based, 45 % (weight per cent) of organic solvents, electrostatic spray-application	55 - 65

2.1.3.2 Emissions in the Atmosphere

VOC-emissions from varnishing of truck cabins are higher than those from coating processes in the automobile production:

- Most paint application is carried out manually due to different geometrics, dimensions of the workpiecs. Therefore a lower efficiency compared to automated processes is archieved.
- The colour palette is larger due to special customers requests. Therefore colour changes occur more often which results in a higher consumption of organic solvents for cleaning purposes.

Table 2-3 shows the specific VOC-emissions for varnishing of new truck cabins. The emission values due not take emission reduction measures into account.

Tabelle 2-3: *Specific VOC-emissions for varnishing of new truck cabins* [RENTZ 1999]

Material	**Specific VOC-Emissions [g VOC/m^2]**
Electrophoric dip coat: Water-based material, 5 weight-% of organic solvents	5-8
Filler: Solvent based, 45 weight-% of organic solvents, electrostatic spray-application	8-12
Filler: Water based, 8 weight % of organic solvents, electrostatic spray-application	1-3
Single-layer topcoat: Solvent based, 45 weight % of organic solvents, electrostatic spray-application	13-20
Base coat: Solvent based, 75 weight % of organic solvents, electrostatic spray-application (50 %) and regular spray application (50 %)	65-80
Base coat: Water based, 13 weight % of organic solvents, electrostatic spray-application	10-15
Clear coat: Solvent based, 45 weight % of organic solvents, elektrostatic spray-application	20-30

2.1.3.3 Wastewater

Informations about the generated amounts of wastewater by the coating processes of chassis and cabins are not available.

2.1.3.4 Waste

The following wastes are generated by pre-treatment, electrophoric dip coating and varnishing of chassis and truck cabins: Paint-containers, decantated paint sludge, contaminated organic solvents, waste varnishes, masking paper (only from varnishing of chassis) and water with painting material [KIRSCH 2001]

2.1.3.5 Energy Demand

Table 2-4 gives an overview of the gas consumption for the varnishing of chassis and drivers cabins.

Table 2-4:*Overview of the gas consumption and production of chassis and truck cabins for the year 2000 in the installation of MAN in Munich* [Kirsch 2001]

	Varnishing of cabins	Varnishing of chassis
Gas consumption	1.619.479 m³	1.484.304 m³
Porduction	34.246 cabins (Filler) 31.939 cabins (Topcoat)	26.334 chassis

2.1.4 Selection of the BAT-candidates

2.1.4.1 Small Commercial Vehicles

As the only German manufacturer Volkswagen produces both commercial motor vehicles (category N1) and passenger cars in the same installations in Hannover. The varnishing of the different models takes place partially in common plants, therefore in the future the emission values for passenger cars apply to all vehicles produced there (cf. chapter 1.1.3).

For a part of commercial vehicles, a topcoat is applied onto the inside surfaces. This is a significant difference to the varnishing of passenger cars where no topcoat onto inside surfaces is applied generally. Due to the variety of models, the paint application is mainly carried out manually. Due to specific requirements for commercial vehicles, double varnishes and a specific under body coatings are applied. Also the variety of colours is much bigger for commercial vehicles than for passenger cars.

In the production plant in Hannover a re-equipment of the painting line with water-based fillers was not undertaken. Instead of the application of water-based paints, the waste gas from painting cabins and dryers is treated in a post-combustion unit. The installed emission reduction measures consist of adsorption wheels followed by a post combustion unit. Thus odorous substances are eliminated, also [GRUBER 2001]. Four adsorption wheels are needed for cleaning of the approx. 400000 m³ exhaust air per hour. The investment for these emission reduction measures amount approx. 3.9 Mio. EUR, per painted vehicle approx. 12,5 EUR energy costs are generated [WITTKE 2001].

2.1.4.2 Chassis, Axles and Driving Cabs

<u>Painting Materials with a low Solvent Content</u>

For the varnishing of commercial motor vehicles (both driving cabs and chassis) the use of water-dilutable coatings is meanwhile established and proven. Water-based one coat topcoats are applied by MAN and DaimlerChrysler. These water–based products are dried at a temperature of 140 °C. For reparation purposes also solvent based and water-based materials are state of the art [MAY 2000, 2001].

For varnishing of axles, water-based materials represent an alternative to solvent based paints.

Application Processes with a higher Efficiency

Among automated processes, electrostatic spray-application and application via high rotation bells are very efficient and therefore reduce the amount of VOC-emissions and overspray. In manual applications, the use of HVLP spray-guns show a very good utilization of material. Thus generated emissions, waste and wastewater can be reduced [KIRSCH 2001].

Material-Saving Supply Sytems

The lacquer supply system has a high potential both for the reduction of environmental impacts as well as for reduction of costs. An economical lacquer supply can be achieved for example via scrapper-cleanable ring circuits and by a central hardener supply for all workstations. For chassis, which are predominantly painted in black or red, lacquer and rinsing materials can be saved with the colour change [FLECK 2000, KIRSCH 2001].

Meassures for a Reduction of Water Consumption

For the reduction of water consumption cascade arrangements can be utilized in the pre-treatment. In painting cabins that are equipped with a wet dust collector, the service life of the water can be increased up to one year by continous discharge of paint sludges. Also decantation systems for the topcoat cabins increase the service life of the water [KIRSCH 2001].

Measures for the reduction of wastes

Besides the implementation of decanters for topcoat cabins and the installation of scrapper-cleanable ring circuits the use of large containers is reducing the amount of wastes [KIRSCH 2001].

2.1.5 Proposal for the Best Available Techniques (BAT)

For the sector of the truck varnishing the following material-specific techniques which archive emission values of 45 g/m² for driving cabs and 70 g/m² for varnishing of trucks (including coating of chassis and axles) can be proposed as BAT.

A combination of material specific techniques, together with process-specific measures is recommended for a further reduction of environmental impact and reduction of wastes and wastewater.

Material specific techniques:

- Dip coat application for steel profiles of the chassis via water based groundings,
- Use of water based single-layer top-coats for chassis and driving cabs in form of 1 coat topcoats,
- Application of high single-layer High-Solid materials for chassis (without priming paint),
- Application of water based paints for varnishing of axles

in combination with process-specific techniques:

- High portion of electrostatic application devices. For manual applications: Use of HVLP-spray-guns.
- Reduction of material-loss due colour changes via scrapper-cleanable ring circuits.
- Measures for the reduction of water consumption: Cascade arrangements in the pre-treatment installations and implementation of decanters.

2.1.6 New Progressive Techniques

Due to the application of powder-fillers, as a replacement for dip coatings, a further emission reduction can be achieved. Presently the application of powder fillers is disadvantageous due to their high layer-thickness and therefore only applied to increase mechanical resistance.

2.2 Varnishing of Busses

According to directive 70/156/EWG (cf. table 2-1, chapter 2), busses can be divided into the categories M2 and M3. Unlike to the serial coating of passenger cars, a colour palette does not exist. Busses are generally custom made. Therefore the manufacturers have to store a wide variety of colours in form of material or as formulars.

2.2.1 General Information

In 2000, 13.518 busses were produced in Germany.

Table 2-5 gives an overview of the application of varnishes for the coating of busses in GermanyREF.

Table 2-5: Application of varnishes for busses in Germany

Manufacturer	**Cataphoric dip coating**	**Varnish for chassis**	**Filler**	**Base coat**	**Clear Coat**	**Topcoat (1 coat topcoat)**
DaimlerChrysler						
Busse, Werk Mannheim	✓	LM / PUR	LM	LM	LM	LM
Busse, Werk Ulm	✓	WV	LM / WV	LM / WV	LM	LM
Van	✓	-	WV	LM	LM	LM / WV
MAN	-	LM	LM	LM	LM	LM

LM: Solvent based paint
WV: Waterbased paint
✓: cataphoric dip coating is utilized, waterbased material

The German 31. BImSchV determines emission values for the coating of new busses. (cf. table 2-6)

Table 2-6: *Emission limits for coating of new busses according 31.BImSchV*

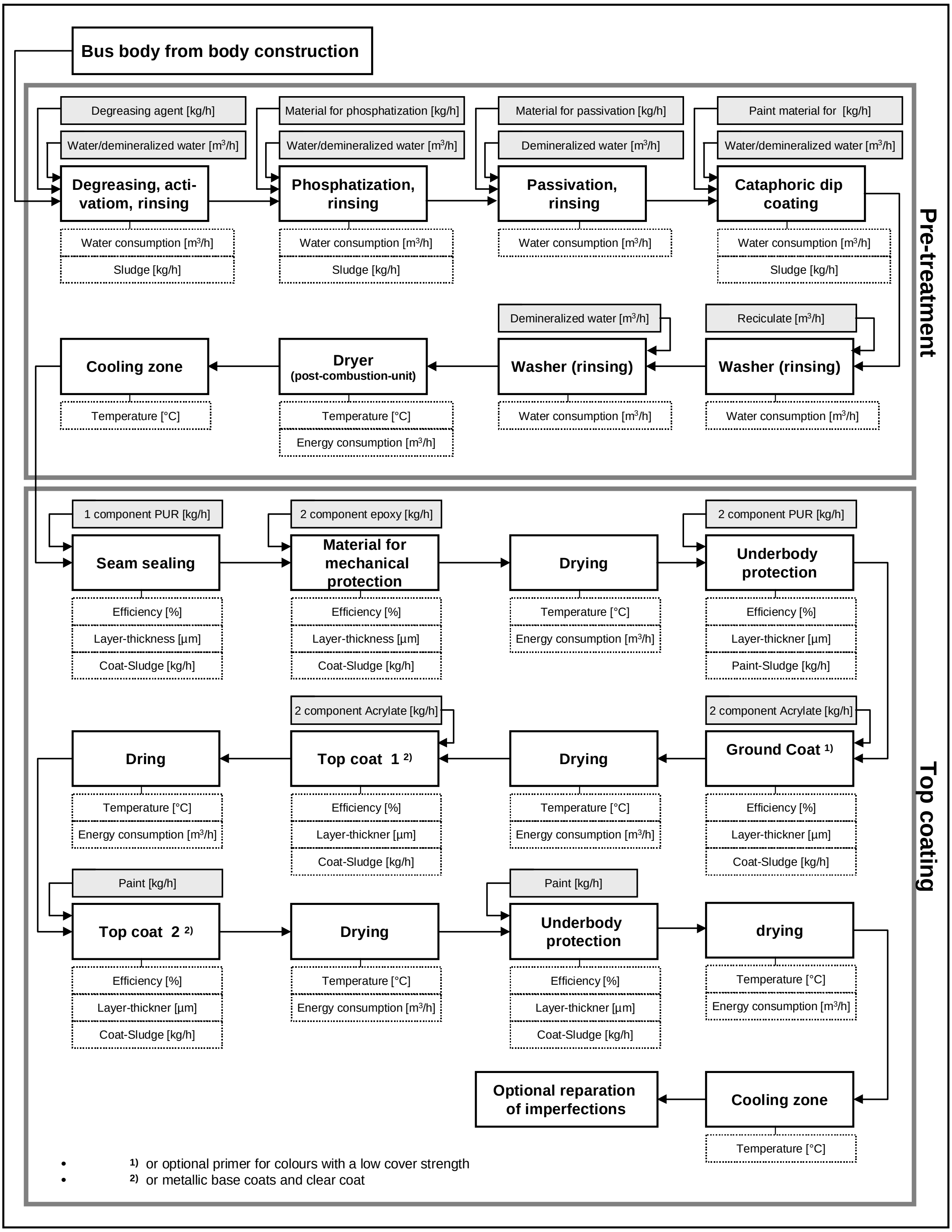
Threshold value for the annual consumption of organic solvents [t/a]	**Emission limit [g VOC/m^2]**	**Emission limit for exhaust gases after dryer [mg C/m^3]**
> 15	150	50

2.2.1.1 Quality Requirements

The requirements of the quality of the coated bus surface are just as high, as in the passenger serial coating. Main requirements cover the corrosion protection and the optical perception. Besides corrosion protection a long-term protection against chemical influences, weather, resistance against mechanical stress (e.g. washer) etc. have to be achieved. The moreover the surface optics is to be high-quality. In order to fulfil these requirements, a multi-layer structure of lacquer made of priming, filler and topcoat is necessary, whereby each individual layer fulfils certain surface requirements.

2.2.2 Applied Processes and Techniques

Unlike to the serial production of passenger cars, an automated varnishing for the coating of busses is not economical due to small unit volumes and special customers requests. Thus a manual paint application is more cost effective. Figure 2-1 shows the coating processes.



- 1) or optional primer for colours with a low cover strength
- 2) or metallic base coats and clear coat

Figure 2-1: General flow sheet of the painting process for busses [SIENER 2001]

2.2.2.1 Pre-treatment

In Germany, the body shells are generally treated via conventional pre-treatment processes such as degreasing and phosphatization, before the varnishing takes place (cf. annex II). After the pre-treatment processes, the ground coat is applied via spray-application or dip coating.

2.2.2.2 Ground coating / dip coating

One German production plant is utilising cataphoric dip coating for the application of grounding onto body shells: To remove grease, oils, grinding residues and other impurities, the body shells are previous cleaned in a aqueous-alkaline process (at a temperature of 60 °C). Then a rinsing takes place.

To prepare the surface for the following phosphatization, activation takes place. Applying the conversion layer on the bodies (with approx. 50-55 °C) ensures the corrosion protection and the adherence of lacquer applied later. For the compression of the phosphatization layer, the body surface is passivated. Afterwards the bodies are rinsed at ambient temperature with demineralized water, several times. Afterward the cataphoric dip coating is applied. The used material is water based with a content of organic solvents of approx. 3 % (weight per cent). Subsequently, the primed bus bodies are rinsed automatically and manually with demineralized water and dried at 175 °C (object temperature) in a dryer provided with a post combustion unit, before they are brought into a cooling zone.

Due to the implementation of the cataphoric dip coating, VOC-emissions could be reduced up to 60 %. The process was implemented in 1990 [SIENER 2001].

Instead of dip coating with water based materials, the spray-application of solvent based (two component epoxy materials is also still common. The materials contain approx. 40 - 50 % solvents and are applied via manual spray-application.

2.2.2.3 Underbody protection and seam sealing

After grinding of the bus bodies, the seam sealing takes place in the interior and outside space as well as in the underbody area. Only on the external body a further priming is applied to increase mechanical resistance. After the seam sealing usually the application of the underbody protection takes place. The underbody protection material is either on 2K-Polyurethan or water-thinnable lacquer. Sealing and underbody protection are carried out manually.

2.2.2.4 Application of filler

The filler serves the preparation of the surface for the subsequent finish coating. With it, unevenness is filled out and imperfections of the grounding layer are sealed so that that adherence and corrosion protection is ensured. Besides the filler increases the mechanical resistance of the bus surface.

At present only solvent based fillers are applied for the varnishing of busses in Germany. The application is carried out manually. Afterwards the drying takes place.

2.2.2.5 Application of topcoat

Due to the individual colour design within the bus production different layer concepts are used. Until different lables or motives are applicated, all busses go through the same painting steps.

Either single-layer topcoatings (1 coat topcoats) or double-layer topcoatings, consisting of topcoat and clear coat are used. For colours with a low cover-strength (such as yellow or red), two layers have to be applied. Also the topcoats are applied manually.

Because not all colours are available as water based paints, exclusively solvent-based topcoats are applied at present. For the application of labels or other motives, foil coatings are in use. Even if foil coatings reduce the paint consumption, this does not essentially reduce the VOC-emissions since solvent containing adhesives are utilised.

The painting processes for busses are carried out manually; therefore no powder coatings are used.

2.2.2.6 Cavity Sealing

For completion of corrosion protection, surfaces of cavities in the body structure have to be sealed up via a wax-layer. As cavity sealant a solvent based wax with a solvent content of approx. 60 % is used.

2.2.2.7 Examples of varnishing installations for busses

Examples for varnishing installations for buses are the DaimlerChrysler AG in Mannheim and Neu-Ulm. The production capacities of these installations amount up to 2.500 and 3.000 busses per year. In Mannheim the car bodies of city busses and touring busses are produced and grounded via cataphoric dip coating. Afterwards city busses are varnished in Mannheim. Touring busses are transported to Neu-Ulm after the dip-coat application, a cleaning with hot water and subsequent a drying takes place. After that the varnish is applied. Painting steps are simular in both installations. Primarily spray application is carried out. For underbody protection a water based 2-component epoxy resin is processed. To obtain a smooth surface, the car bodies are filled and grinded after the flaps have been mounted. Afterwards a water- or solvent-based filler (2 component epoxy) is applicqued and grinded over again.

In the painting cabin an acrylic priming varnish is sprayed onto the car body. The material is dried at a temperature of 110 °C. After a further grinding process the topcoat (2 component material) and then the clear coat is sprayed. As base coats more than 6000 different colours are available. The busses pass through painting cabins and dryers up to 15 times, until all labels and motives are appliqued. Pictures and labels are applied via spray application or even with airbrush techniques, as well as with foil coating [ZELLER 2000]. Dryers are generally connected to post- combustion units.

As a speciality a poyurethane material is used for reduction of structure-born noise in Mannheim. This material is used instead of PVC damping matting which are generally bonded with solvent based adhesives with an average solvent content of approx. 65 %. The polyurethane material is sprayed onto the car body in layer-thickness from 3 – 8 mm. This implementation is also a contribution to working safety, since less cut accidents occur and no VOC are emitted.

In the interior of busses this noise protection material is processed. Afterwards a two-component polyurethane material is applied as an alternative floor covering. In general a PVC-floor covering is utilised in City busses[2]. The material is cut to size and bonded via solvent based adhesives (cf. volume adhesive application, chapter 2). As an alternative a solvent free polyurethane material is applicated via airless spraying. This technique had already been realised in 145 busses. Unlike to PVC floorings this surface has no seams that might not be water tight and therefore no corrosion of the car body can occur [PREISSIG 2001].

2.2.3 Present Consumption and Emission Values

2.2.3.1 Consumption of Input Materials

Approx. 200 m² are coated per bus. Table 2-7 shows specific material consumptions for separate varnishing layers.

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[2] For touring busses different floor coverings are uesd. Partly these materiales are bonded via dispersion adhesives

Table 2-7: *Specific material consumptions for different layers* **[RENTZ 1999]**

Material [weight per cent]	**Spezific material consumption [g varnish / m^2]**
Cathaphoric dip coating, water based material, 3 – 4 % of organic solvents	120-135
Seam sealing and underbody protection (water based, manual application)	No data available
Filler (solvent based: 45 % of organic solvents, manual application)	18-22
Filler (water based: 8 % of organic solvents, manual application)	22-26
1 coat Topcoat solvent based: 45 % organic solvents, manual application)	10-40
Base coat (solvent based: 75 % organic solvents, manual application)	90-100
Base coat (water based: 13 % organic solvents, manual application)	100-110
Clear coat (solvent based: 45 % organic solvents, manual application)	50-65

2.2.3.2 Emissions into the Atmosphere

In the investigated plant the VOC emissions amount approximately 225 g/m² (without consideration of emission reduction measures for exhaust gases from dryers). Due to the following reasons these emissions are significant higher than those from the serial coating of passenger cars (cf.Table 2-8).

- All paint applications are generally carried out manually except for dip coating. In comparison to automated processes, a lower efficiency and more overspray result;
- due to the size of busses, small unit volumes, different geometrics and special customer requests an automation of coating processes is difficult, compared to the serial varnishing of passenger cars;
- frequent colour changes may result in a higher consumption of organic solvents (in form of cleaning solvents)

Tabelle 2-8 FVREFSEQARABISCH*: Specific VOC emissions for different materials* **[RENTZ 1999]**

Coating material	**Specific VOC-emissions [g VOC/m^2]**
Cataphoric dip coating, water based material (3 - 4 % organic solvents)	6 - 7
Seam sealing and underbody protection (waterbased material, manual application)	not specified
Filler (solvent based: 45 % organic solvents, manual application)	9 - 10
Filler (water based: 8 % organic solvents, manual application)	1,5 - 2,5
1-coat topcoats (solvent based: 45% organic solvents, manual application)	14 - 18
Base coat (solvent based: 75 % organic solvents, manuell application)	70 - 75
Base coat (water based: 13 % organic solvents, manual application)	12 - 16
Clear coat (solvent based: 45 % organic solvents, manual application)	24 - 27
Cleaning of pipes, tools, painting cabins	28 - 60

Dust emissions from overspray are below the emission value of 3 mg/m³ [SIENER 2001].

2.2.3.3 Wastewater

For deposition of overspray, painting cabins are generally equipped with venturi washers. The generated paint sludge is used for energy recovery.

2.2.3.4 Wastes

Varnish wastes are either returned to the varnish manufacturer or are utilized for more inferior usage (e.g. coating of bicycle frames). **Paint sludge,** generated by overspray, is used for energy recycling in general. Organic solvents that are used for **cleaning of tools and painting cabins** are generally (external) recycled.

2.2.3.5 Energy Demand

Similar to the serial coating of passenger cars, the highest energy demand is caused by heating of painting cabins and dryers. Data for the energy demand cannot be stated.

2.2.4 Determination of BAT-candidates

In some cases water based paints for varnishing of busses are applied (cataphoric dip coating and underbody protection). With one exception water based paints are not applied as topcoats.

In only one installation, city busses are completely coated with water-based paints. Powder coating is still not used for the serial coating of busses.

The application of primary emission reduction measures is still very limited for the varnishing of buses (as a result of manual application, small volume units and specific customers requests). For emission reduction, end of pipe measures such as post combustion units, are utilised for treatment of exhaust gases from dryers. Thus, only a small portion of VOC-emissions is collected and treated. For more efficient emission reduction measures such as combination of adsorption via activated charcoal and post-combustion units for the treatment of exhaust gases from painting cabins and dryers, no experiences are available up to now.

2.2.5 Proposal for BAT

In table 2-9, a proposal of BAT for varnishing of busses is listed.

Table 2-9: *Proposal for the Best Available Techniques for the varnishing of busses*

Area	**Best Available Techniques / Processes**
Grounding	Cataphoric dip coating with water based and lead-free dip paint
Seam sealing	Water based material
Topcoat	Solvent based topcoats, application via electrostatic coating, post combustion of exhaust gases from painting cabins and dryers
Varnishing of axles	Water based paints
Arcoustic insulation	Solvent-free polyurethane

- Cataphoric dip coating with water based, lead-free dip coatings and treatment of exhaust gases from dryers via post-combustion,
- water based material for seam sealing,
- solvent based topcoatings, application via electrostatic coating devices, post combustion of exhaust gases from painting cabins,
- utilisation of water based paints for varnishing of axles combined with electrostatic coating.

2.2.6 Conclusions and Recommendations

Since mainly smaller installations are in operation, which previously did not underlie specific requirements for emission reduction, emission reduction measures and particular no primary reduction measures are in use. Due to the European Solvent Directive and the German ordinance 31. BImSchV, the total emissions must not exceed the emission value of 150 Cg/m³ and 50 mg C/m^3 for exhaust gases from dryers. Thus an urgent need for the implementation of alternative paint systems and more efficient coverage- and subsequent waste gas cleaning systems is given.

Therefore painting materials with a low VOC content have to be used more intensely in the future. These painting systems are already developed and are available for the varnishing of commercial vehicles (cf. VDI-Directive 3456 Emission control: (Re-)finishing cars and commercial vehicles).

It is most likely, that the BAT of this sector will underlie a significant evolution in the near future.

2.3 Varnishing of Agricultural- and Construction Vehicles

2.3.1 General Information

In comparison to the varnishing of vehicles such as passenger cars, the optical surface qualities of agricultural- and construction vehicles are of minor significance. The main task of the paints is corrosion protection. The varnish has to sustain heavy mechanical and chemical stress. Chemical corrosion occurs due to aggressive saps and moisture. Thus the varnish does generally not stand the vehicles service life [MAYER, SCHÖNBERGER 2001].

2.3.2 Applied Processes and Techniques

For varnishing of agricultural- and construction vehicles different concepts are realised by the German manufacturers.

For pre-treatment also either conventional, manual degreasing via organic solvents or automated processes via alkaline-watery degreasing and subsequent zinc- or iron phosphatisation, are utilised. Since corrosion protection plays a key role, some manufacturers have replaced the manual application of solvent-based ground coats by cataphoric dip coating.

The topcoat is applied via manual spray application [Harsch 1999]. As a replacement of solvent-or water based topcoats in the serial production, powder coatings will be processed in the near future. Some manufacturers apply dip coats and topcoats on workpieces already before assembly takes place. Besides other advantages, more automated processes can be applied.

The varnishing of agricultural vehicles was investigated at Claas in Bad Saulgau. Due to hard competition in this sector only one installation was investigated for an exemplarily description of applied processes and techniques.

Workpieces are coated with grounding before assembly. After the parts are mounted, a single-layer topcoat is applied onto outside surfaces. The workpieces generally consist of steel sheets.

Before the ground coat is applied, degreasing via watery-alcaline cleaning with subsequent rinsing takes place. After degreasing the surfaces are activated and zinc-phosphated.

For pre-treatment no chrome VI is used. After phosphatisation, the parts are rinsed with water and afterwards with demineralized water. Then drying takes place in a conventional dryer via hot air.

Ground coat is applied in form of lead-free dip coating. Preparation of the dip coat material as well as recycling is done by ultrafiltration. The grounding material contains approx. 2 – 6 % of organic solvents and is applied with a layer thickness of approx. 25 µm. After the paint application drying takes place in an convection dryer. Exhaust gases from the dryer are treated by a post-combustion unit [MAYER, SCHÖNBERGER 2001].

After assembly, a single layer of a solvent-based 2-component topcoat (50 % organic solvents) is applied manually via electrostatic HVLP-spray guns with a layer-thickness of approx. 25 µm [MAYER, SCHÖNBERGER 2001]. The overspray is deposited dry. Drying takes place in a convectional dryer which exhaust gases are treated by a post-combustion unit.

The Claas company uses six different colours as topcoats. For minimisation of material losses during colour changes, workpieces with a similar colour are coated together. Cleaning solvents that are used for cleaning operations after colour changes are collected and recycled via distillation.

2.3.3 Present Consumption- and Emission Values

The threshold values given by the IPPC-Directive are not reached in the investigated installation in Bad Saulgau. The total solvent consumption amounted 15,3 t for the year 2000.

The threshold values might be exceeded in other installations due to significant market concentration in this sector.

Emissions into the Atmosphere

Exhaust gas from painting cabins and dryers is treated by post-combustion. Thus concentrations below 20 mg C/m³ in the clean gas are archived. Therefore VOC-emissions result primary from diffuse sources such as evaporation zones, located in front of dryers.

Wastewater

The rinsing tanks used for pre-treatment of workpieces generate wastewater. In the examined installation approx. 18 – 20 m³ of wastewater are generated. This amount can be halved by the implementation of the cascade technique.

Due to installed ultrafiltration, the dip coating installation does not generate wastewater [MAYER, SCHÖNBERGER 2001].

Wastes

For a recycling of dip coat material from subsequent rinsing tanks, the ultrafiltration can be used. The amount of waste paint-containers can be reduced by the use of large returnable containers for standard topcoats.

Data for different installations for the varnishing of agricultural vehicles concerning energy demand, paint consumption, emissions, wastes and costs are specified by [HARSCH 1999] (cf. Table 2-10)

In the work of Harsch, an existing wet lacquer plant for agricultural vehicles is compared to modern plant concepts. Therefore an integrated balancing was undertaken with the software GaBi. The purpose was to support a decision making for the investment into a new painting installation.

In the existing plant a manual cleaning via organic solvents is used. Subsequently the workpieces are spray-coated (via compressed air coating) with the ground coat, manually. After pre-drying, the workpieces are coated with the topcoat via dip coating. Then drying takes place in a conventional convection dryer. The database was obtained from the existing plant by Harsch [HARSCH 1999].

In the planned, more progressive plant concepts, the pre-treatment takes place via an automated aqueous-alkaline cleaning. Additionally a Fe-phosphatization and/or a Zn-phosphatization takes place for the increase of the corrosion protection. Afterwards the ground coat is applied via dip coating. As in the existing plant, the topcoat is also applied by dip coating. Additionally to these variants an other plant concept is compared with manual spray-application of water based topcoat and a hot-air dryer with approx. 2/3 of energy demand, compared to the existing dryer [HARSCH 1999]. Harsch estimated the data for the balance.

Table 2-10: *Technical and economic parameters for three concepts for the varnishing of agricultural machinery* FVREFSEQARABISCH[HARSCH 1999]

Parameter	**Unit**	**Conventional plant**		**Plant with Fe-Phosphatisation and dip coating for ground coat**		**Plant with Zn-Phosphatisation and dip coating for ground coat**		**Plant with Fe-Phosphatisation and dip coating for ground coat ***	
Paint data		*2 component ground coat*	*Water based topcoat (dip coating)*	*Dip coating for ground coat*	*Water based topcoat (dip coating)*	*Dip coating for ground coat*	*Water based topcoat (dip coating)*	*Dip coating for ground coat*	*Water based topcoat, (spray application)*
Solids content	Weight per cent	56	42	20	42	20	42	20	42
Content of organic solvents	Weight per cent	8	11	2	11	2	11	2	11
Water content	Weight per cent	36	47	78	47	78	47	78	47
Layer-thickness	µm	90	185	25	185	25	185	25	50
Efficiency	%	15	80	98	80	98	80	98	60
Energy demand									
Electricity	KWh/cycle	90		180		180		210	
Natural gas	KWh/cycle	450		520		520		410	
Hot water	KWh/cycle	0		250		250		250	
CO_2-emissions									
From pre-treament	Kg/cycle	0		100		100		100	
From ground coat application	Kg/cycle	90		70		70		70	

Parameter	Unit	Conventional plant	Plant with Fe-Phosphatisation and dip coating for ground coat	Plant with Zn-Phosphatisation and dip coating for ground coat	Plant with Fe-Phosphatisation and dip coating for ground coat *
From topcoat application	Kg/cycle	115	115	115	90
VOC-Emissions					
From pre-treatment	G/cycle	10	3	3	3
From ground coat application	G/cycle	80	7	7	7
From topcoat application	G/ cycle	90	90	90	35
Special waste					
From pre-treatment	Kg/ cycle	0	0	0	0
From ground coat application	Kg/ cycle	5,3	0	0	0
From topcoat application	Kg/ cycle	1	1	1	0,6
Costs					
Investment	EUR	1,31 Mio.	2,77 Mio.	2,87 Mio.	-
Material costs: Ground coat	EUR/kg	2,09	1,44	1,44	1,44
Material costs: Topcoat	EUR/kg	1,96	1,96	1,96	1,96
Fe-Phosphatisation	EUR/m^2	0	0,025	0	0,025

Parameter	Unit	Conventional plant	Plant with Fe-Phosphatisation and dip coating for ground coat	Plant with Zn-Phosphatisation and dip coating for ground coat	Plant with Fe-Phosphatisation and dip coating for ground coat *
Zn-Phosphatisation	EUR/m^2	0	0	0,0460	0
Electricity	EUR/a	304040	73318	73318	-
Natural gas	EUR/a	28803	44514	44514	-
Disposal costs	EUR/a	22257	3536	3536	2094
Total costs	EUR/ cycle	124	143	146	123
* Besides an automated degreasing and Fe-Phosphatisation, the water based topcoat is applied manual (via spray application instead of dip coating)					

2.3.4 Proposal for the BAT-candidates

2.3.4.1 Pre-treatment

The lowest emissions are generated from processes using aqueous-alkaline cleaning and subsequent Fe- or Zn-phosphatization (cf.table 2-11). The best corrosion protection is also archived by Zn-phosphatization.

2.3.4.2 Solvent-free Paints and Paints with a Low Solvent Content

For the grounding of workpieces that are produced in big volume units, water based, lead-free ground coat is applied via dip coating. These water based materials have a content of organic solvents of approx. 2 weight per cent. An efficiency of approx. 98 % can be archived by dip coating. For smaller volume units either 2-component epoxy materials with a high solids content or water based epoxy paints are available for spray applications [MAY 2001B].

For application of topcoats, already water-based materials with an organic solvents content of 11 % are utilized.

2.3.4.3 Improved Paint Application

The use of application devices/processes with a better efficiency, such as HVLP (High-Volume low-pressure) spray-guns, is still very limited but represents a large reduction potential for the future. Efficiencies of over 50 % are to be expected.

Another possibility is the application of thin layers of topcoats. If instead of 85 µm, that are archived by dip coating, a thin layer of 50 µm is applicated via spray coating, 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 and VOC-emissions can be reduced. According to Harsch [HARSCH 1999] the costs for manual application (labour costs) can be slightly higher.

2.3.4.4 Waste Gas Cleaning

If solvent based topcoats are applied, VOC-emissions can be reduced effective by post combustion of exhaust gases from dryers and painting cabins. The heat recovery is thereby state of the art.

2.3.5 Proposal for the BAT

Harsch compares different plant concepts for varnishing of agricultural machines with regard to consumption, emissions, energy demand and costs. (cf.table 2-12). For the database and assumptions, confer [HARSCH 1999].

Table 2-1FVREF1SEQARABISCH: *Results of a technical assessment of four different coating concepts* [HARSCH 1999]

Parameter	Conventional plant	Plant with Fe-phosphatisation and dip coating for ground coat	Plant with Zn-phsphatisation and dip coating for ground coat	Plant with posphatisation and dip coating for ground coat / spray application
State of technology	1	3	4	5
Material consumption	1	1	3	4
Automation	2	2	3	2
Emissions	1	1	3	4
Optical properties	2	2	2	5
Flexibility of cycle time	1	1	1	5
Corrosion protection	1	4	5	4

Properties range from 1 (poor, low) to 5 (very good)

By the combination of automated pre-treatment and cataphoric dip coating, a much higher quality can be archived by manual degreasing and manual ground coat application.

Also the corrosion protection of the Zn-phosphatization is better than of Fe-phosphatization. The implementation of dip coating results in a reduction of material consumption, VOC-emissions and also of disposal costs.

The energy demand for phosphatization and ground coat application via dip coating is significant higher than conventional pre-treatment and paint applications. Therefore also the CO_2-emissions are respectively higher. Wage savings can possibly be optained by the implementation of automated processes. With regard to investments and operational costs, Fe- and Zn-phosphatisation show only marginal differences.

The substitution of dip coating by spray-application for topcoatings shows several advantages (cf. chapter 2.3.4). Also the cycle times can be reduced by spray-application for the topcoat, which will also reduce the costs [HARSCH 1999].

In summary the following best available techniques are recommended:

- Aqueous-alkaline cleaning and subsequent (chrome-VI-free) zinc-phosphatization.
- Application of water based, lead-free ground coats via cataphoric dip coating, use of cascade technique and ultrafiltration for rinsing tanks of cataphoric dip coating.
- Application of water based single layer topcoats via electrostatic spray application.

2.3.6 New Progressive Techniques

One manufacturer builds presently a installation for powder coatings. This production line will replace conventional, solvent based, 2-component single layer-topcoatings. [MAYER, SCHÖNBERGER 2001].

2.3.7 Conclusions and Recommendations

The application of powder coatings generates, besides dip coating the lowest emissions. This technology is ready for serial production of agricultural- and construction vehicles.

2.4 Varnishing of Caravans and Motorhomes

2.4.1 General Informations

In 1999 53 German manufacturers produced 60.243 caravans and 21.910 motor homes.

2.4.2 Applied Processes and Techniques

In general a varnishing of the exterior surfaces of travel mobiles does not take place at the manufacturers. The manufacturers process already coil-coated sheet metals.

Edges of sheet metals are usually covered with rubber sealings. An additional underbody protection does not take place, since they are already corrosion-protected from the commercial motor vehicle manufacturer. The bottom plate, which consists of plywood, is also already protected with underbody protection from the supplier industry [PRIEBE 2001].

Varnishing in form of spot-repair, takes place in the finish department [PRIEBE 2001].

2.4.3 Current Consumption and Emission Values

In the finish department, small damages to the paintwork (<< 1 m²) are repaired. Damages to the coil coated sheet metals can occur during assembly. For reparation conventional 2 component paints are applied via spray-application. Small imperfections are repaired in the workshop hall. Larger damages are coated in a painting cabin. The overspray is deposited dry. The total paint consumption amounts less than a view kilograms of paint per week [PRIEBE 2001].

Due to the use of paints only for the damages to the paintwork, this sector has no relevance for the IPPC directive and is therefore not further specified.

2.5 Varnishing Of Planes

In this chapter the varnishing of civil aircrafts, with more than 50 seats, is described. Surfaces consist of light metal and fibre-reinforced plastic composite. Due to different processes this chapter is divided in **maintenance** a **new building**. For maintenance, damages to the paintwork are repaired or a complete varnishing of outside surfaces is applied.

2.5.1 Maintenance

2.5.1.1 General Informations

For maintenance the paintwork is repaired or completely new applied. The paint application is carried out exclusively manually. The selection of the lacquer system depends on manufacturer defaults, international regulations and customer's requests. In the context of this study, the airplane maintenance was examined at the Lufthansa Technik AG, at the location Hamburg.

2.5.1.2 Applied Processes and Techniques

The paint application is carried out in closed workshop halls. Thus temperature and air humidity can be regulated. For the deposition of overspray from exhaust air streams, wet dust collectors are installed. The applied paints dry at ambient temperature.

Paint Removal

In the context of maintenance, the primary coat and the topcoats are removed every 6 – 8 years. If an airline change-over takes place, paint removal is undertaken sooner. This is most common for leasing companies. The paint removal (and new paint application) is done for optical reasons and for examining the structure for wear and corrosion. Paint removal is usually done chemically. Water blasting, which was favored because of environmental reasons, is no longer applied due to the causation of excessive mechanical stress. For cleaning, the aircraft is washed with a water based, alkaline cleaning agent. After drying the windows, running gear and parts consisting of fibre-reinforced plastic composite are masked.

The following paint removal is done via chemical, acid cleaning or by mechanical sanding.

For **acid cleaning** a water-based benzyl alcohol formic-acid is applied via airless application. The sealants are removed manually out of seams. For composite materials and partly for metal surfaces, pre-treatment is done by sanding.

Cleaning

Macerated paint layers are removed by water. Subsequently a aqueous-alkaline neutralisation and cleaning, takes place. Before paint application the surfaces are cleaned manually with organic solvents and cleaning rags. In general a mix of butyl acetate and butyl alcohol is used as solvent.

Pre-treatment

Before the ground coat is applied, a solvent-based washprimer is applied onto metal surfaces. This material contains 76 % of organic solvents and approx. 14 % of zinc chromate (in the solid content), for hardening. Up to now, no zinc-free materials are available. The material is applied via electrostatic spray application. The washprimer is not applied onto composite materials.

Ground Coat

As ground coatings two different materials are used:

- Ground coat, based on polyurethane or epoxy with a solvents content of 70 % without chromate and a

- ground coat with strontium chromate (approx. 20 % in the solids content) and approx. 67 % organic solvents.

Ground coats, containing chromate, are used for increased corrosion protection for climate conditions with a high humidity and high salinity of the atmosphere or upon customers request. Approx. 10 % of the planes is coated with this material. Application is carried out manually via electrostatic assisted spray application.

Topcoat

As topcoats, conventional 2-component paints with a solvent content of approx. 61 % and 3-component high-solids with a solvents content of approx. 43 % are used. Both paints are free of chromate and lead. Application is carried out manually by electrostatic assisted spraying.

Clear Coat

Conventional topcoats are generally coated with a clear coat layer. If high-solid topcoats are applied, an additional clear coat layer is not necessary and therefore only used on customers request. The same application method than for topcoats is used [LUFTHANSA TECHNIK 2001].

2.5.1.3 Current Consumption and Emission Values

Due to different geometries of aircrafts, the consumption- and emission values are exemplified for a B 747-400, which represents a current model (cf.table 2-13). For this aircraft approx. 2780 m² have to be varnished [LUFTHANSA TECHNIK 2001].

Table 2-12: *Material consumption exemplified for a B 747-400 by Lufthansa Technik* [Lufthansa Technik2001]

Process	**Material**	**Material consumption**	**Solvent content**	**VOC-Emissions** (per B747)
Paint removal	Chemical stripping agent	3000 kg		No VOC according to the definition of RL1999/13/EG
Pre-treatment	Washprimer based on Polyvinyl butyral, *containing chromate*	240 kg	76 %	182 kg
	Ground Coat, *containing chromate*	450 kg	67 %	301 kg
	Ground Coat *chromate-free*	450 kg	71 %	319 kg
Cleaning	Butyl acetate, butyl alcohole	250 kg	100 %	200 kg
Topcoat	Topcoat, *High-Solid*	1200 kg	43 %	516 kg
	Topcoat, *solvent based*	1300 kg	61 %	793 kg
Clear Coat	Clear Coat, *solvent based*	1200 kg	65 %	780 kg

According to the utilised paint system, the VOC-emissions amount 1,2 – 2,3 t per varnished B 747-400. If high-solid topcoats are utilised, the VOC-emission amount approx. one ton less, compared to conventional topcoatings and an additional clear coat layer.

Exhaust gas treatment equipment, such as post combustion units, are not installed due to large volume flows (ca.450.000 m³/h) and low VOC-concentrations [Lufthansa Technik 2001].

According to the plants permission, the total amount of VOC may not exceed 180 t/a. As a reference model the varnishing of 150 A-300 aircrafts per year is considered. Since in the plant different types of aircrafts are completely or partly varnished, the VOC-emissions from coating and cleaning processes amounted 67 t in the year 2000 [Lufthansa Technik 2001]. The emission value of 150 kg/h is exceeded temporarily for some coating processes due to the simultaneous paint application from several employees (up to 12 varnishers) [LUFTHANSA TECHNIK 2001].

2.5.1.4 Determination of the BAT Candidates

For the reduction of VOC-emissions from the maintenance of aircrafts, only integrated measures can be utilised. Presently electrostatic spraying with pneumatic atomisation is the state of the art. For paint removal a mixture of benzyl alcohol and formic acid is a suitable technique, which generates low emissions.

If the aircraft is utilized under regular climatic conditions a chrome-free ground coat can be applied [Lufthansa Technik 2001]. The VOC-emissions can also be reduced by the application of high-solid topcoats. In comparison to conventional paints, the optical surface qualities and technical properties of high-solids are equal or even better nowadays [Lufthansa Technik 2001].

2.5.1.5 Proposal for the BAT

Following techniques are recommended as BAT for the maintenance of aircrafts:

- Paint removal via a mixture of benzyl alcohol and formic acid
- Application of chrome-free ground coats
- Application of high-solid topcoats without an additional clear coat layer
- Electrostatic-spray application for paint materials
- Wastewater treatment: By treatment, the following concentrations for chrome can be obtained: Cr VI 0,1 mg / l and for the total concentration of Cr 5 mg / l.

2.5.2 Aircraft Construction

2.5.2.1 Applied Processes and Techniques

Since the manufacturers guarantee corrosion protection for duration of 25 years, only specific paint systems can be utilised. Like in the maintenance of aircrafts, also customer's requests have to be considered.

Varnishing of components

Partly components are varnished before assembly takes place. These component parts are coated with a ground coat and subsequently with a topcoat. A washprimer is only applied in exceptional cases [**F**ANGMEIER **2001**]. Increasingly surface spraying-automates and also convection dryers and ultrared dryers are in use for the varnishing of components.

The surface of the components is approximately four times bigger than that of the planes outside surfaces. Parts that are delivered by external manufacturers are already coated with chromate containing ground coats.

Varnishing of outside surfaces

Outside surfaces of the completed aircraft are coated manually. Applied processes and techniques were investigated at AIRBUS Deutschland GmbH in Hamburg.

Since the final lacquer finish takes place after the first flight, only lacquers can be used, which harden at ambient temperature. At present predominantly solvent-based paints (with solvent contents of approximately 55 - 65 %) are used. However the portion of High-Solid paints (with a solvent portion between 30 and 40 %) is increasing gradually [BAUMANN 1997].

Like the maintenance, the varnishing of new planes is carried out in closed workshop halls. The applied varnishes harden at ambient temperature. At first the hull is coated and dried completely. Than the hull is masked with packaging paper and the wings are varnished subsequently. Thereby the paint layers are applied wet on wet. The painting process is subdivided in **pre-treatment, application of the washprimer, application of ground coat and application of topcoat** [BAUMANN 1997].

Pre-treatment

Before the outside surfaces are laquered, impurities such as kerosene, oils, grease etc. are removed. Therefore the hull is washed with cleaning solvents. The total consumption per plane amounts approx. 200 l [AIRBUS 2002]. Afterwards an anodisation with chromic acid takes place. The purpose is to generate a thicker oxid-layer for an increased corrosion protection. The chromate containing primer is sanded dry and the hull is again cleaned with organic solvents.

Application of the washprimer

After the pre-treatment process the **washprimer** is applied manually via electrostatic spray-application. The washprimer is a solvent- and chromate containing material based on polyurethane- or epoxy resins or polyvinyl butyral (PVB). The materials solvent contents amount approx. 70 – 90 %. For an increased corrosion protection strontium or zinc chromate are ingredients. The layer-thickness varies from 8 – 10 µm. After application evaporation of solvents takes place at ambient temperature.

Application of ground coats

After the washprimer a solvent containing ground coat, based on epoxy resin or polyurethane is applied manually via electrostatic-spray application. The solvent content of these materials varies from 50 – 65 %. The content of strontium or zinc chromate amounts 10 – 20 %. The applied layer-thickness averages 15 – 25 µm. The material hardens at air temperature.

Application of topcoats

The topcoat can be very different according to the customers' requests, however exclusively solvent-based 2-component paints with solvent contents of 55 – 65 % are used. The topcoat is applied in several layers (2 – 4 according to the colour) via electrostatic-spray application.

According to the applied colour, the layer-thickness amounts 60 – 100 µm. After the first layer is applied, a short flashing-off takes place, before a second layer is applied another evaporation (1 hour) takes place. Subsequently the three layers are dried. Afterwards a decoration is applied via spray application or by pressure sensitive foils. For varnishing of outside surfaces also High-Solid paints with solids contents of approx. 70 % are utilised besides conventional paints. On customers request, a clear coat can be applied on the topcoat.

Temporary corrosion protection

The so-called temporary corrosion protection is obtained by application of water-rejecting, layers in the internal area of the aircraft. The material remains in the plane permanently. Main areas are for example doors, gates, wheel wells and cargo storage areas. The Temporary corrosion protection materials are in solvent based, wax like substances from hydrocarbons. The application takes place with a brush or via spraying application. The solvent content of the products amounts to approx. 40 - 60 %. Per airplane approx. 60 - 80 l are processed.

2.5.2.2 Present Consumption and Emission Values

Material consumption

For the determination of material consumption, the aircrafts surfaces have to be measured. Beside the outside surfaces, also surfaces of coated component parts, have to be taken into account. Varnishing of outside surfaces takes up to eight days. Most of the time is needed for masking and finishing. The biggest amount of paints is consumed for the coating of component parts. This surface of component parts is approx. 4 times bigger than, that of outside surfaces of the completed plane [FANGMEIER **2001**]. Table 2-14 gives an exemplified overwiew for a A 320 (150 passenger seats).

Table 2-13: *Coated surfaces for a A 320* **[FANGMEIER 2001]**

Coating surface	**Surface** [m²]	**layers**
Component parts	3.600	1 – 2
Outside surfaces	1.200	2 – 4
Inside area	500	2
Conservation of rived heads	10.000 (running meters)	1 – 2

For the coating of a A321 (approx. 180 passengers) the total surface of components and inside areas approx. 3600 m² and of outside surfaces of the completed aircraft approx. 945 m². The applied, dry material has a total weight of 380 kg **[FANGMEIER 2001]**. For an average paint system (consisting of washprimer, ground coat and topcoat) approx. 0,9 kg/m² material are applied [AIRBUS 2002]. For the varnishing of component parts or single paint layers no data could be obtained. Data of the paint consumption gives [BAUMANN 1997] (cf.table 2-15).

Table 2-14: Consumption of materials for the varnishing of outside surfaces of planes [Baumann 1997]

Paint layer resp. process step	**Material consumption**
Pre-treatment	200 l solvents (30 % Isobutanol and 70 % butyl acetate) für 600 m^2
Washprimer	75 kg wet lacquer (for the hull); overspray approx. 20 %
Primer	100 kg wet lacquer (for the hull); overspray approx. 20 %
Topcoat	200 kg wet lacquer (for the hull)

Emissions Into The Atmosphere

For an average material consumption of approx. 0,9 kg/m² about **600 g VOC/m²** are emitted. The emitted overspray is far below 1 mg / m³ [AIRBUS 2002]. The total VOC emissions per plane amount 450 kg for varnishing of outside surfaces. For a plant with a production capacity of 60 planes per year, approximately 27 t of VOC are emitted from the coating of outside surfaces [BAUMANN 1997].

Since the interior surface is approx. four times bigger than that of the outside surfaces, the entire emission for the plant can be estimated up to approx. 100 t per year. (The varnishing of component parts is generally carried out in different plant locations). In the plant of the Airbus Deutschland GmbH in Nordenhamm, the total solvent input was approx. 131 t in the year 2000. In the Airbus plant in Hamburg 69 t VOC / a may be processed, according to the permission [AIRBUS 2002]. In the year 2001, 70 aircrafts were produced there. Also the emission value of the IPPC-Directive of 150 kg/h was also not exceeded [AIRBUS 2002].

The values for material consumption of the IPPC-Directive are most likely not reached in the German installations.

Wastewater

Along with the paint sludge, wastewater is generated from the wet deposition of overspray. [BAUMANN 1997]. The treatment of wastewater is similar to the processes used in the serial varnishing of passenger cars (cf. Chapter 2.2.7).

Wastes

Varnishing of aircrafts generates the following wastes:

- paint sludge (hazardous waste),
- filters,
- cleaning rags,
- organic solvents (recycled),
- packaging paper (recycled),
- foils,
- grinding dust,
- empty paint containers [BAUMANN 1997].

Energy Consumption

Data for the energy consumption could not be aquired.

2.5.2.3 Determination of BAT Candidates

For a reduction of VOC-Emissions from varnishing of new aircrafts, only integrated measures can be utilised. Waste gas cleaning is not applied due to low VOC concentrations in the exhaust gas, big volume flows and discontinuous operation of installations.

For some applications products with a low VOC content can be processed. Instead of a conventional 3-layer system, consisting of washprimer, ground coat and topcoat, a high-solid system consisting of a high-solid epoxy primer and a high-solid topcoat can be utilised. Compared to the conventional paint system the VOC emissions can be reduced up to 30 % thereby.

The disadvantages of this procedure are higher material costs and the more expensive paint removal for maintenance operations. This coating system can only be removed via grinding [LUFTHANSA TECHNIK 2001]. The chromate containing dust, which is generated from grinding, represents a health hazard. Chromate-free primers are not processed continuously due to warranties against corrosion. Thus this coating concept is not requested from European customers and is predominantly applied for the American market [AIRBUS 2002].

Besides a reduction of the solvent content, more efficient application processes can also reduce emissions. Presently electrostatic-spray application represents the state of the art.

For the varnishing of component parts an automated paint application combined with the use of exhaust gas cleaning, results in a reduction of material consumption and emissions.

2.5.2.4 Proposal for the BAT

In the following the recommended Best Available Techniques for the varnishing of new aircrafts are listed:

- Conventional 3-layer system (washprimer, ground coat, topcoat) with a high-solid topcoat and without clear coat application.
- Elektrostatic assisted spray application for varnishing of outside surfaces.
- Automated paint application in combination with exhaust gas cleaning for varnishing of component parts.

2.5.2.5 New Progressive Techniques

For varnishing of inside surfaces, water based paints are developed at present. Water based products can still not be processed due to their low resistance against chemicals (such as hydraulic oil) [AIRBUS 2002]. A great saving potential for VOC is given by the use of a 2-layer paint system (cf. Chapter 2.5.2.3). For these paint systems, developments are undertaken to do the paint removal via acid cleaning.

2.6 Varnishing of Rail Vehicles

2.6.1 General Information

Besides high optical qualities of the paint, also a good corrosion protection is required for rail vehicles. The applied varnishing system must resist climatic impacts, aggressive cleaning agents (used for removal of graffitis) as well as abrasion from sliding contacts [Pires 2001]. Locomotives that are operated by the German Deutsche Bahn AG are re-varnished every eight years.

2.6.2 Applied Processes and Techniques

In general the varnish system, according materials, colour and layer-thickness is determined by the customer (cf.table 2-16). Due to big volume flows and discontinous operation, a waste gas cleaning by thermal combustion for exhaust gases from painting cabins and dryers is not utilised in smaller installations [ZIEMS 2002]. In some bigger installations a waste gas cleaning for exhaust gases from dryers is already implemented.

The varnishing processes of rail vehicles can be divided in the **coating of new vehicles** and **mantainence operations**. Both activities usually take place at the manufacturers. The applied lacquer systems are identically. Therefore the characteristics of the maintenance operations are outlined in the following.

Maintenance

Essentially the following activities of the maintenance operations are of importance regarding environmental issues:

- **Reparation of the paintwork in the finish department or during maintenance operations**: The paintwork is partly sanded and renewed.
- **Complete lacquer finish of old vehicles:** As a function of the lacquer condition, the paint is sanded off up to the ground coat or completely removed by blasting [BAUMANN 1997, NEUTZLER 2001].
- **Paint removal and new paint finish**: After reconstruction of waggons, the old paint is removed via blasting or sanded up to the ground coat layer. Then a new coating is applied. In general the paint removal is done manually via grit blasting. For paint removal from aluminium and stainless steel (e.g. superstructure) corundum is used as blasting shot. The material is recycled. For regular steel, steel is utilised as blasting

agent. After blasting, the dust is removed from the surface via compressed air [NEUTZLER 2001].

Since the applied painting processes of construction and maintenance operations are identical, the processes are exemplified for the construction and varnishing of new rail vehicles.

Varnishing of New Rail Vehicles

Table 2-16 shows the paint systems used for car bodies according to the regulations of the Deutsche Bahn AG as an example for one possibility for a layer construction.

Table 2-15: Layer construction for rail vehicles according to the instructions of the DB AG [NEUTZLER 2001]

Area	Layer construction	Material Sb: solvent based Wb: water based, EP: Epoxy, PU: Plyurethane	Layer-thickness of dried material [µm]
complete car body	Pre-treatment	Blasting	
Outside surface:	1. primary coat	EP, wb	60
Front- and side wall including door- and window housings, roof and also head areas made of glass fibre reinforced plastic (without position 1)	2. knifing filler	Sb	60
	3. intermediate coat	PUR- or EP-primer, wb	60
	alternative:	PUR-primer, sb	40
	4. topcoat or	PUR, sb	40
	topcoat or	PUR, wb	20 – 30
	topcoat or	Base coat, wb	40
	topcoat or	PUR, sb and anti-graffiti paint, sb	40 40
Roof	1. primary coat	EP, wb	80
	2. topcoat	EP, wb, thick film	140
	alternative:	EP, sb, thick film	140
Base frame, floor, underbody	1. primary coat	EP, wb	60
	2. topcoat	EP, wb, thick film	140
	alternative:	EP, sb, thick film or1-component underbody protection	140, 200
Bogie frame	1. primary coat	EP, wb	60

	alternative: 2. topcoat alternative: DIN component parts	EP, sb EP, wb, thick layer EP, sb, thick layer Anti-corrosion wax	60 140 140
Interior surfaces: Floor, roof, side- and front walls	1. primary coat 2. topcoat alternative: 3. seam sealant 4. arcoustic insulation	EP, wb EP, wb, thick layer EP, sb, thick layer Sealing agent Artificial resins, wb	

2.6.2.1 Pre-treatment of Car Bodies

An optional degreasing via aqueous-alkaline cleaning agents is carried out after assembly (especially for aluminium). Subsequently the interior surface and outside surfaces are cleaned via blasting. The blasting agent is recycled partly.

2.6.2.2 Ground Coat Application (onto outside areas and interior surfaces)

The ground coat is applied onto the entire waggon. The paint application is carried out manually via airless spray-application. Beside conventional paints, also water based, 2 component, chromate-free paints, based on epoxy resins are available. The solvent content of these materials varies from 3 – 5 %. Approximately 60 – 100 µm are applied onto roof and side walls abut 200 µm onto the [BAUMANN 1997]. Component parts such as luggage racks are coated with solvent-based paints or powder coats [NEUTZLER 2001].

2.6.2.3 Filling

After the ground coat is dried, a filler is manually applied via palette knifes. The material has a solvent content of approx. 16 % (thereof 8 % reactive, not relevant for emissions). After hardening of the material, sanding of side walls takes place. The grinding dust is removed via compressed air and cleaning solvents [BAUMANN 1997]. Mostly the filler material is only applied onto welding seams (minimum filler application) [NEUTZLER 2001].

2.6.2.4 Filler Application (generally only onto outside surfaces)

The filler is applied onto sidewalls via airmix-spray application. As filler either a 2 component, amine hardening, water based epoxy material (3% of organic solvents) or a solvent-based polyurethane (60% of organic solvents) is utilised. The layer-thickness amounts approx. 60 µm. The drying time amounts 2 – 3 hours. If a dryer is used (80°C) drying takes about 45 minutes. The object temperature may not exceed 45 °C for completed waggons due to the electronic equipment [BAUMANN 1997, NEUTZLER 2001].

2.6.2.5 Topcoat Application (generally only onto outside surfaces)

Depending upon kind of the railroad, several layers of topcoat are applied (cf.table 2-16). For the Deutsche Bahn AG six different colours are utilised for city rail vehicles, among these three colours are utilised for varnishing of the sidewalls, one for the roof, one for the underbody and one for the bogie frames. The lacquer is applied via airmix-spray application. Predominantly solvent based topcoats and clear coats are processed.

Although water based materials are already available, the customers do often not accept them.

The use of these lacquer systems is accepted after the terms of delivery of the Deutsche Bahn AG [ZIEMS 2002].

In between the paint applications evaporation takes place (1 hour). After the last layer is applied the paint is dried at temperatures of 50 – 60 °C. After two hours finished surfaces are masked and the next paint layer is applied. The layer-thickness of the paint that is applied onto side walls amounts 40 µm (depending on the number of paint layers up to 120 µ. Onto the roof approx. 120 µm are applied [BAUMANN 1997].

2.6.2.6 Underbody Protection

The underbody is coated with a water based underbody protection via airless-spray application. A minimum layer-thickness of 120 – 200 µm is applied.

2.6.3 Present Consumption and Emission Values

In table 2-17 the material consumption for specific paint layers is listed. The total solvent input (from thinners, cleaning solvents and paints) of the inspected installation was about 177,6 t in 1999. Thus the emission values given by the IPPC-Directive are not exceeded. Data for individual films of varnish could not be determined.

Table 2-16: *Material consumption per varnished waggon* [BAUMANN 1997]

Varnish / substarte	**Consumption [kg]**
Ground coat	200
Filler	35 - 40
Topcoat	
Roof	35
Fenestration	35
Braids, decor strips	5
Side wall underneath windows	15
Underbody protection	150 - 200

2.6.3.1 Emissions into the Atmosphere

In respect of waste gas cleaning only dust from overspray and blasting is deposited. Emission values of less than 3 mg/m³ are archived. VOC from coating processes are emitted into the atmosphere in form of direct or diffuse emissions. In some installations, which are subject to approval, thermal combustion units are already implemented for waste gas cleaning from dryers. Thus emission values from less than 50 mg/m³ are archived.

If a standard, solvent based paint system (consisting of layer 1-4, cf. Table 2-16) without waste gas cleaning is applied, approx. **326 g/m² VOC** are emitted [ZIEMS 2002]. From the total solvent input of 177,6 t into the inspected plant, approximately 134,08 t were emitted. (A thermal combustion unit is not installed). 53,52 t was disposed as waste.

2.6.3.2 Waste Water

Wastewater is generated by the wet precipitation of overspray and the cleaning of application devices [BAUMANN 1997]. More detailed data could not be determined.

2.6.3.3 Waste

Amongst other things, the following wastes are generated from varnishing of rail vehicles:

Paint sludge, air filters, cleaning agents, masking paper, waste paints, paint containers, blasting agents etc. [BAUMANN 1997].

2.6.3.4 Energy Demand

Due to discontinuous operation of the installation and different geometries of the vehicles, the energy demand per coated surface cannot be specified [NEUTZLER 2001].

2.6.4 Determination Of BAT-candidates

Thermal combustion units for waste gas cleaning from dryers are only installed in a view plants. Thus an emission reduction is basically carried out by the use of paint systems with a low solvent content.

Solvent-free paints and materials with a low solvent content

The use of materials with low solvent content or solvent-free products represents a possibility for the reduction of VOC-Emissions. For varnishing of new rail vehicles, water based fillers and ground coats are already processed from some manufacturers.

For the application of topcoats, different materials are used. The selection of a specific paint depends on customers' requests, design, and application technology. Even though water based topcoats (1 coat topcoats and metallic) with equal properties are available but still not accepted by the customers and therefore applied only sporadic [ZIEMS 2002]. The Deutsche Bahn AG is using water based ground coats, fillers and topcoats, as a consistent water-based coating system for maintenance operations [GLÜCK 2000, PRIEß 2001]. The application of water-dilutable lacquers must take place under certain conditions. Therefore humidifiers for paint application and dehumifiers for drying might be installed if necessary.

For the application of clear coats for metallic-paints, usually a solvent-based material is used.

In table 2-18 an example for the predominatly application of water based paints for the varnishing of the car body is given. With the application of this painting concept, emission values of 110 g/m² can be archived.

Table 2-17: *Coating of car bodies with predominant use of water based paints* [ZIEMS 2002]

Area	Coating material
Complete Waggon (interior and outside surfaces)	Water dilutable grounding material based on epoxy resin
Roof, substructure, inside coating	Epoxy resin thick-film, water dilutable or 1 k-Acrylate dispersion, water dilutable
Kinfing filler	Application only partly, material with a lo2w content of syrene
Side- and front walls	Solvent based paints based on epoxy resins and clear coats (solvent based)

Paint application with an increased efficiency

Since the lacquer is applied manually, efficient airless-spray guns for the application of ground coat and airmix- or HVLP-spray guns for application of topcoats (in form of thick layers) can be utilised [ZIEMS 2002]:

Efficient paint supply systems

Lacquer savings can be obtained by the use of a stationary 2-component system. Further savings can be achieved by the use of only one ground coat material for the entire product range, since colour changes and thus rinsing processes are reduced.

Measures for the reduction of water consumption

Painting cabins, which are equipped with a wet washing, the water is led across cascades or circulated via air introduction. Additionally a coagulation agent is added to the water manually. By these measures the service life can be substantially extended.

Measures for the reduction of waste

Coating materials (ground coats and thick-layer topcoats), which are used in large quantities, could be supplied in large bundles (200 l-barrels) for a reduction of waste.

2.6.5 Proposal for the BAT

For the reduction of the VOC emissions as well as for the reduction of the waste and the water consumption, the following material-specific techniques in combination with procedure-specific techniques can be recommended:

Material-specific Techniques:

- Application of water based ground coats, fillers and topcoats
- Only for two-layer lacquer finishes an application of a conventional clear coat.
- Minimum use of knifing fillers with low styrene content
- Processing of pre-coated (coil-coated) materials for new construction of fright cars

Procedure-specific techniques

- Reduction of varnished surfaces for e.g. use of adhesive foils for decorative designs or as a graffiti protection.
- Efficient application devices: HVLP-, airless- and air-assisted airless spraying.
- Recycling of cleaning solvents via distillation of solvent containing paint wastes and paint sludge.

- Use of automated supply of coagulant for wet precipitation for increased service life of the water.

By the implementation of these measures emission values of less than 110 g/m² are archived.

2.6.6 New Progressive Techniques

New progressive techniques for the varnishing of rail vehicles are based on water dilutable two-component paints. This concerns fillers and also topcoats. Even though the technical properties of water-thinnable, 2-component polyurethane paints are already equal to solvent based materials, their acceptance is still low (with exception of the municipalities) [ZIEMS 2002].

Also the development of water based, 2-component clear coats is far advanced. The cleaning characteristics of these new materials come close to the presently used, conventional anti-graffiti clear coats. First water based clear lacquers are already used for maintenance operations of the Deutsche Bahn AG.

Metallic-lacquers in form of 1-component, water-thinnable base coats are well established. As soon as the evolution of 2-component clear coats has reached the same stage of development it will be possible to use the two-layer system in form of complete water based paintwork.

For the production of boxcars, coil coated sheet metals[3] are processed, increasingly.

Compared to a modular design, a complete lacquer finish for the whole car body with one colour (cf. "Inline"- painting concept for the serial coating of passenger cars) is reducing the paint consumption via a reduction of overspray and rinsing losses. For the modular design, which is increasingly used for some types of rail vehicles, pre-coated sheet metals should be used [ZIEMS 2002].

2.6.7 Conclusions and Recommendations

Due to manually paint application, discontinuous operation and large volume flows with a low VOC-concentrations, a thermal combustion of exhaust gases for a reduction of VOC-

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[3] The paint application via coil- coating takes mainly place in closed installations that are equipped with thermal combustion units (cf. Chapter 6).

emissions is often not efficient. In a few bigger installations exhaust gas cleaning for waste gases from dryers are implemented due to legal regulations.

Since approximately only 20 % of the total VOC-input are emitted from dryers, the exhaust gas cleaning is not very efficient. Therefore the use of water-based paints is more suitable for a reduction of VOC-emissions that are generated from the varnishing of rail vehicles.

The changed legal situation (due to the Europe-wide limitation of VOC-emissions) will intensify the evolution of BAT. This will also increase the customers' acceptance for water-based lacquers. In spite of sufficient practical experiences with water-based varnishes the present acceptance is still low.

2.7 Varnishing of Ships

2.7.1 General Information

The requirements for the coating of **merchant ships** and **luxury yachts** are different. For the paint of merchant ships, adhesion and corrosion protection are the center of attention. For the coating of yachts also the optical properties play a crucial role apart from adhesion and corrosion protection [BAUMANN 1997].

Therefore the coating of yachts and trading ships is described separately. The varnishing of **warships** takes place according to the building regulations of the Bundeswehr BV 1900/1. Therefore only the coating of ships for the civilian navigation (such as trading ships) is regarded. Due to different coating and pre-treatment processes, the **maintenance** and the **varnishing of new ships** have to be regarded separate.

In 2000 63 trading ships (60 % containerships, 15 % ferries- and passenger ships) as well as 47 inland navigation vessels [VSM 2001]. For the production of warships and also for the maintenance sector no data are available. The German ships that were built in 2000 had a share of approx. 5 % of the world market. [VSM 2001]

The threshold values for the solvent consumption of the IPPC-Directive are not exceeded by the German installations. The processed amounts of material are probably significant larger in other European countries. Because of the partly availability of more environmental sound techniques and the sectors environmental relevance, the applied processes and BAT are described in detail.

2.7.2 Applied Processes and Techniques for the Varnishing of Merchant Ships

Generally the ship owner determines the applied coating system for maintenance and also new ships. The applied layer-thicknesses are predetermined from the paint producers. In comparison to other paint applications, the paintwork of ships have a very high layer-thickness that varies from 700 µm to 2 mm. In general merchant ships are made of shipbuilding steel. Pre-treatment and paint application in **maintenance** and **new construction** show significant differences, which are specified in the following.

New Construction

Sub contractors carry out mostly the paint application in shipyards. Therefor the applied processes can vary. Some manufacturers varnish single segments and modules already before assembly. After completed assembly the whole ship is coated with the final paintwork.

Steel plates that, are welded to sections by the manufacturer, are usually pre-coated with a shop primer as corrosion protection by the supplier. This layer represents the surface for the following varnishing of new ships. In some ship yards the pre-treatment and coating operations of segments are carried out in closed coating- and blasting plants but mostly these operations are done in open workshops, under hoods or in the open air.

Ship Maintenance

For reparations of the paintwork or before a complete new varnish is applied, the ship hull is cleaned and the old paint is removed or rubbed (via grinding). According to the conditions of the surface either damaged areas are treated via spot blasting or grinding and are then re-coated or the paint is removed from the hull, completely and repainted. Paint application onto the hull is carried out in dry docks.

2.7.2.1 Pre-treatment

New construction

First degreasing takes place: Hull and superstructure are cleaned via an aqueous-alkaline cleaning agent. Partly cleaning solvents are used for more contaminated areas. This degreasing / cleaning process is optional and depends on the surfaces conditions. Predominantly degreasing takes place for aluminium surfaces. As an alternative for cleaning and degreasing, dry ice cleaning can be applied partly. Thereby the surface is blasted with dry ice in form of pellets. The dry ice cools down the surface, which leads to an embrittlement of adhering impurities, which are mechanically removed by the impact of the dry ice pellets. This process can partly replace the use of cleaning solvents but is however very energy-intensive [Heck 2001].

Ship Maintenance

Before the paint is repaired or renewed, the hull is cleaned from fouling[4] and salt with fresh water.

Blasting and grinding

For the removal of rust and for roughening of the steel plate surfaces, grinding and blasting represent the state of the art for **new construction** and **maintenance**.

For maintenance of the hull, the damaged paint is removed via shot blasting with steel-blasting agent or copper cinder. In general only damaged paint areas are treated.

At present blasting is the predominant technique for paint removal from the hull. As blasting agent mostly fine-grained cinder (mainly copper cinder) is used. The blasting agent is accelerated by compressed air. Because of the contamination with paint residuals, the blasting agent has to dispose as hazardous waste. For a reduction of dust emissions from blasting, water is added to the blasting agent. After blasting in dry docks, the dock surface has to be cleaned by sweeping before flooding takes place [MEYER, GUBER 2001].

Dust-emissions and contaminated blasting agent can be avoided completely by water blasting. For water blasting pressurised water with a pressure of up to 2.800 bars is used for paint removal. By variation of the water pressure either single layers or the entire paintwork can be removed. Water blasting has already been applied for several years. Essential plant components are high pressure pumps, mobile, automated application devices for the ship sides, the underbody and bilge range as well as a dock waste water treatment [PASTUCH, PALM 2001].

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[4] Foling bezeichnet die Besiedlung im Unterwasserbereich des Rumpfs durch Meeresorganismen.

Figure 2-2: *Paint removal via water blasting* [PASTUCH, PALM 2001]

Essential advantages of water blasting compared to grit blasting are:

- Significant reduction of wastes.
- Improved surface qualities of the varnish (less salinity)
- Reduction of environmental impacts (dust)

2.7.2.2 Coatings

The application of coatings for **new construction** and **maintenance** is usually carried out via the airless technique. Depending on the terms of application the overspray can amount up 30 % of the material input. The Overspray can be emitted from docks and open workshop halls into the environment by wind. The Blohm + Voss Repair GmbH, Hamburg uses automated, mobile paint application plants that are equipped with a paint application head and integrated extraction for overspray. Due to this technique the overspray amounts less than 5 % of the material input. However these paint application plants can only be used for even, perpendicularly surfaces [PASTUCH, PALM 2001]. Due to the increased efficiency, the material consumption and the VOC- and also the overspray emissions are reduced significantly.

Figure 2-3: *Automated, mobile paint application plant with integrated extraction of overspray [PASTUCH, PALM 2001]*

In some shipyards, closed workshop halls with exhaust gas cleaning devices are in operation for coating of new ships (segments, modules)

2.7.2.3 Application of Primers

After blasting and/or cleaning a primer is applied onto the entire ship via airless-spray application. The material is solvent based but free of chromate. The primer layer dries at ambient temperature on air. The layer thickness amounts 40 - 80 µm. Often the steel plates and profiles are already pre coated with a shop primer from the suppliers. The purpose of the shop primer is to protect the surface against corrosion.

Due to different processes steps the coating of the **hull** and of the s**uperstructure** are described separately in the following.

Hull

2.7.2.3.1 Corrosion Protection of the Hull

Two to four layers of a solvent based, elastic epoxy coating material are appliqued via airless-spraying. The layer thickness amounts approx. 100 µm per layer.

2.7.2.3.2 Coupling Agent (hull)

As coupling agent between the corrosion protection paint and the subsequently applied anti-fouling, a solvent-based (1- or 2 component) vinyl resin is applied. For some paint systems a coupling agent is not necessary if the application of the anti-fouling paint is undertaken within 36 hours after the application of the corrosion protection material. The coupling agent is also applied via the airless-technique. The layer thickness amounts approx. 40 µm.

2.7.2.3.3 Antifouling (hull)

For protection from settling of fouling (plants and invertebrates) onto the hull an anti-fouling coating material is applied. Fouling causes higher friction between the water and the hull. The increased frictional resistance can raise the fuel consumption up to 40 % [VSM 2001]. Up to 150 kg of organisms can settle on one m² within six month. The fouling can also damage the paintwork and therefore cause corrosion. The still predominantly used anti-fouling coatings contain biocides in their bonding agents. As biocides so far mainly tributyl tin (TBT) as well as other copper compounds are used, besides other components) [Deutsches Lackinstitut 2001].

The paint material consists of approx. 10 - 15 % TBT [Krauter, Maack 2000]. The content of copper compound amounts maximal 50 %. This biocides are released under water due to self polishing effect. Thus a biocide concentration is generated onto the surface that reduces settling of fouling. The majority of copper-compounds and TBT is bound to suspended particles and thus transported into the food chain. Due to sedimentation of the suspended particles primarily port muds and the Wadden Sea are heavily contaminated.

According to the World Health Organization (WHO), presently TBT is one of the most toxic substances that is emitted. TBT causes heavy damages on the maritime fauna. The ecological toxicity of copper-compounds is rated 1000 times less dangerous, compared to TBT [IMO 1999].

Every 2 – 5 years this coating is renewed in dry docks. Self-polishing anti-fouling materials have a service life up to 5 years. The damaged paint is removed from via grinding, blasting or brushing and the corrosion protection paint is repaired. Subsequently the complete hull is coated with a solvent-based anti-fouling via airless-spraying. In up to four coating processes 100 – 150 µm of the material are applied [SCHIFFBAUTECHNISCHE GESELLSCHAFT 1998]. The overspray is partly emitted into environment via wind, rain runoff or via flooding of the dry docks [Krauter, Maack 2000].

In October 2001 the International Maritime Organisation (IMO), a sub-organisation of the UNO, adopted a resolution against TBT-containing paints for ships which prohibits the application of TBT-paints for ships from January 2003 on. According to this resolution, old

TBT-paints have to be removed or coated with a sealer from 2008 on. Presently the market share of TBT-containing products amounts approx. 70 % [ARBEITSKREIS ANDERE NÜTZLICHE PRODUKTE 1999].

Numerous TBT-free, copper based anti-fouling materials and products without biocides are available on the market. But long-term experiences exist only for paints containing copper-compounds as ecotoxic biocides. Approx. 10 % of the German ship owners use TBT-free materials or products without any biocides [WWF 2001].

Alternative anti-foulings:

Pollutant-free silicone coatings (non-adhesive coating)

The settling of fouling shall be prevented by the slick surface of these paints. Also cleaning should be eased. When mechanical damages of silicone coatings occur these substances are emitted into the environment. Silicones are very persistent but their toxicity is rated low [Watermann 1999].

In a pilot project for the testing of environmental sound anti-foulings which was carried out by the Department of the Environment of Lower Saxony, the WWF and paint producers, biocide-free paints based on silicone showed a good or sufficient effectiveness against the settlement of organisms. Fouling settled onto the hull occured but however the adhesion of the organisms on the surface was strongly reduced compared to anti-corrosion coatings. During the driving of the ships, the fouling was detached in dependence of the speed. Silicone-based anti-foulings proved to be more effective in the North Sea for fast moving vessels (e.g. ferries), than for slower driving ships with long downtimes. Therefore this coating material is more suitable for ships with an average speed of approx. 10 knots [Daehne et al. 2000].

A transfer of these results to other sea areas is difficult due to significant differences of ecosystems. The procastination of organisms onto silicone anti-foulings without biocides represents a potential hazard for ecosystems [Scharf, Stefan 2001]. During the coating with silicone-based anti-foulings no overspray may be deposited onto surfaces that have to be coated with other paint materials (adherence). Therefore these surfaces must be masked carefully.

Coatings with special surface properties for a reduction of fouling

Coatings with a special surface structure, such as micro roughnesses, for a reduction of fouling performed the best results of all biocide-free materials, in the pilot project, which was carried out by the Department of the Environment of Lower Saxony, the WWF and paint producers. The fouling inhibition occured independently of the vessels speed and was comparable to TBT containing anti-foulings [Daehne et al. 2000]. The application of the material is carried out with special devices.

Mechanical methods

Brushing and scraping off of fouling in short intervals and the use of hard, resistant coating material might represent an alternative to anti-foulings.

There is already a variety of devices with rotary brushes, which can remove the fouling during short downtimes. The disadvantages of the procedure are short cleaning intervals and an accumulation of organic materials and paint residues. This process is suitable for ships operating in brackish water or freshwater [Daehne et al. 2000].

Electrochemical processes

The surface is protected by voltage, which causes an electrolysis. Thus toxic chlorine compounds are produced and / or the pH-value is shifted which inhibits the settling of fouling. In addition the electrodes can be made of copper. Than toxic copper ions are emitted. The released amounts of copper are comparable to copper based anti-foulings. The method proofed to be very effective but also abets corrosion [IMO 2001].

Paints with natural biocides

Paints containing natural biocides are in testing. Natural biocides are produced for e.g. by some coral species as a protection for fouling. These substances show a lower persistence due to a better biodegradability compared to inorganic materials such as copper compounds or TBT (EU-Projet Camellia, 1996-2000).

Super structure

Coating of the super structure is generally carried out at sea. Since these processes are not taking place in stationary installations in terms of the IPPC-Directive, the applied processes are only scarcely described in the following.

2.7.2.3.4 Ground Coat

As one of several possibilities, a solvent based, two-component, polyurethane ground coat can be sprayed onto the primer layer. Generally two layers, each with 60 µm, are applied.

2.7.2.3.5 Topcoat

Onto the ground coat a two-component; solvent-based polyurethane material is appliqued in two layers. Each layer has a thickness of 40 µm.

The layer-thickness of the complete paint amounts approx. 500 µm – 1mm for the hull (underwater area) and 250 – 300 µm for the super structure.

2.7.3 Varnishing of Yachts

Yachts are vessels with a length of up to 130 m. Parts of the yachts are already painted before assembling. Depending upon customers' requests the applied coating system varies. Thus only one possibility is exemplary described in the following.

Between the application of painting layers sanding takes place. Yachts are made of ship building steel and aluminium. Partly the whole yacht or only the superstructures are made of aluminium. Depending on the material pre-treatment and application of the primer are different. The use of water-based materials is only negligible.

2.7.3.1 Pre-treatment and Primer Application onto Shipbuilding Steel

First the hull and the superstructure are treated via grit blasting. As primer either a material based on zinc phosphate or a chrome- and zinc-free shopprimer are applied. Both materials are solvent-based epoxies. The layer-thickness varies from 40 – 60 µm.

2.7.3.2 Pre-treatment and Primer Application onto Aluminium

For degreasing and removal of oxide layers, aluminium surfaces are treated with cleaning agents. Also cleaning solvents can be utilised. Afterwards a two-component epoxy primer or a 1-component PVC primer is applied. As like in the coating of merchant ships, corrosion protection paint is sprayed onto the primer layer. This solvent-based epoxy material is applied airless in 2 – 4 layers with approx. 120 µm each.

Onto this corrosion protection paint a coupling agent is applied. Conterary to merchant ships this material is always utilised. The coupling agent is a solvent based, one-component vinyl paint, which is applied via airless-spraying. The layer-thickness amounts approx. 40 µm.

Afterwards two layers of a solvent-based anti-fouling material are appliqued airless. The layer thickness of the anti-fouling amounts approx. 100 µm for each layer. Contrary to merchant ships a non self-polishing anti-fouling is applied. In Germany TBT-containing anti-foulings are prohibited for yachts with a total length of less than 25 m. Usually copper based anti-foulings are may also contain other biocides.

2.7.3.3 Superstructure made of Shipbuilding Steel or Aluminium: Corrosion Protection Paint

Like the hull, the superstructure is also coated with two layers of a solvent-based (1- or 2-component epoxy paint) corrosion protection material, which is applied via airless-spraying. The applied layer-thickness amounts approx. 120 µm.

2.7.3.4 Filling

After the corrosion protection paint is dried, solvent-free filling materials are applied onto aluminium and shipbuilding steel of the super structure in order to cover roughness and to obtain a smooth a surface. The materials are processed via trowels and spatulas. Sanding takes place in between these processes.

2.7.3.5 Filler

After the filling a solvent based 2-component polyurethane filler or a solvent based epoxide filler are applied via airless-spraying. The layer-thickness amounts 50 – 100 µm. After the material is dried the yacht is test driven. After the test drive, the yacht is cleaned with fresh water and sanded. Afterwards the final topcoat is applied.

2.7.3.6 Topcoating

The topcoat is applied via wet on wet spray-application. Two or three layers are appliqued. The used materials are generally solvent based, two-component, polyurethane combination lacquers. The complete layer thickness amounts to approx. 100 µm.

2.7.4 Current Consumption and Emission Values

For the coating of ships, solvent-based paints are applied. Depending on the used material, the solvent content amounts 20 – 25 % Gew. %. Due to the processing conditions (humididty, temperature, air draft etc.) and surface conditions, water based paints have only a very limited area of application (only partly used for interior areas and onto mounting parts) [**S**CHIFFBAUTECHNISCHE **G**ESELLSCHAFT 1998].

Table 2-18*: Material Consumption per varnished ship* **[BAUMANN 1997]**

Paint material	Consumption [kg]
Primer	400 – 500
Hull, (underwater area)	
Corrosion protection paint	750 - 1 000
Coupling agent	80
Antifouling	300
Superstructure	
Ground coat	400 – 500
Topcoat	300
Total	*2 200 – 2 700*

Table 2-19: *Material Consumption per varnished yacht* **[BAUMANN 1997]**

Paint material	Consumption [kg]
Shipbuilding steel: Primer	300 – 400
Hull (under water area, shipbuilding steel)	
Corrosion protection paint	400 - 500
Coupling agent	80
Antifouling	300
Filling Material	8 00 - 10 00
Filler	150

In the sector new construction, the threshold values of a total solvent consumption of 200 t/a are not exceeded by the German shipyards since even in bigger installations only a small number of ships (1 – 5) is built each year [MÜNCHAU 2001]. HDW processed approx. 59 t / a. The amount of paints that are processed in the maintenance plants is bigger [VSM 2001]. Blohm + Voss Repair GmbH in Hamburg processes approx. 60 t / a of organic solvents by if the plant is use by maximum capacity. Therefore the threshold values of the IPPC-Directive are also not reached in maintenance installations [VSM 2001]. Possibly plants with higher consumption capacities exist abroad.

2.7.4.1 Emissions into the Atmosphere

Processes in ship yards are mainly carried out outdoors, in dry-docks, in open workshop halls or on the quay. Therefore pollutants that are generated by grinding and blasting or varnishing operations are emitted into the environment. VOC from paints are completely emitted in form of diffuse emissions. Besides VOCs, dust from blasting agents (steel, silicate or copper compounds), metals as well as Overspray are of environmental relevance. Depending upon weather conditions, these particles are shifted over several kilometers and thus emitted into the environment. If painting processes take place in the outdoors or in open workshop halls without an exhaust gas cleaning, the VOC are emitted completely.

On average, the utilised paints contain approx. 20 – 25 % (weight per cent) of organic solvents. **Per varnished m² approx. 100 g VOC are emitted** [PASTUCH 2001].

Emissions of environmental hazardous materials from coating processes in the new construction can be reduced effective by the utilisation of closed workshop halls for painting and blasting operations (HDW, Werk Kiel). At the HDW, Kiel closed workshop halls with exhaust gas treatment for varnishing and blasting were implemented. Another possibility for the reduction of dust and overspray is the application of water blasting with wastewater treatment and water recycling. The amount of overspray can be reduced down to 5 % with mobile application devices and integrated extraction of overspray. Additionally a further entry of overspray into the environment can be reduced by closing the dockends with nets (via a reduction of wind.

2.7.4.2 Wastewater

Maintenance operations generate decontaminated blasting agent, paint residuals and overspray. After finishing of the maintenance operations the dock is cleaned via sweeping for a reduction of the environmental impacts. The wastewater is dangerous due to its pollution with heavy metals from the dust from the different coating and pre-treatment steps as well as because of hydrocarbons from fats and oils. For a reduction of these substances several measures are applicable:

As an alternative for the maintenance operations for reduction of environmental impacts, is the cleaning of the surface via water after sweeping. The water is subsequently collected and separated from particles in a separator. Then the water is either disposed as wastewater or reused. The costs for the installation of coamings, pumps, pipework and separator amounts approx. 0,5 Mio. EUR (depending on the surface of the dock)[MEYER, GUDER 2001].

For an avoidance of dusts from blasting, which can be transported into the environment under unfavorable weather conditions, water blasting can be applied. The process water is treated and reused. Thereby the input of blasting water can be further reduced by the use of mobile application devices with an integrated extractation (e.g. Dockmaster, Blohm+Voss Repair). These devices implement paint removal and cleaning with a wash head that is pressed onto the hull. Waste water and paint residuals are collected effective. The waste water treatment is done in several different steps that consist of precipitation and flocculation via iron-III-cloride, separation and filtration.

For a reduction of volume and weight, the emerging sludge is pressed and disposed as waste. The cleaned waste water is reused or in the case of water surplus, disposed as waste water.

Figure 2-4: Dock wastewater treatment at Blohm & Voss, Hamburg [PASTUCH, PALM 2001]

In a development project additional process steps for an improved separation of heavy metals, and organotin compounds are realised. Thus the entry of toxic compounds from antifolings, such as TBT and copper or tin-compounds, should be reduced.

2.7.4.3 Wastes

Waste from the maintenance operations of ships is: Paint sludges from wet deposition, organic solvents, paint wastes, contaminated paint containers, paint sludges and filters [BAUMANN 1997]. The implementation of big, reusable containers (1000 l) instead of 10 – or 20 l one-way-containers leads to a reduction of waste containers and the amount of waste paints that remain in old containers.

During the varnishing of ships, above all in maintenance operations, big amounts of contaminated blasting agents are generated. Of environmental relevance are especially heavy metals, and TBT from blasting and grinding dusts. By the utilisation of water blasting the generated waste amounts only 1,5 % of the conventional grit blasting.

2.7.4.4 Energy demand

Data according the energy demand could not be obtained.

2.7.5 Determination of BAT-Candidates

An intensified use of water-based lacquers is not possible at present due to the application conditions. The techniques specified in the following represent a selection of the most environmentally sound processes for the ship industry.

Ship Maintenance

Varnishing in the new construction

- Application of paints with the electrostatic airmix technique for varnishing in closed workshop halls of the new construction. The use of this technique is limited even for the sector of new construction, since no air movement may occur [ETZOLD 2001]. Due to electrostatic charge, the process is also not applicable in potential explosive areas such as tanks or other poor ventilated areas [HECK 2001]. As a result of the application conditions, this technique can also not be used for maintenance operations in dry docks.

- Entries of hazardous dusts in to the surrounding area can be reduced by the implementation of closed workshop halls for varnishing and paint application. At the HDW, Kiel the existing open workshop halls for varnishing and blasting operations, were replaced by closed installations. During grit blasting operations the dust containing air (max. 150.000 m³/h) is extracted and cleaned from the dust via fabric separators (with pressure surge cleaning). After finishing of the blasting operations, the blasting agent (based on corrundum) is collected via pneumatic suction apparatuses from the interior of the ship sections and the workshop floor. The material is cleaned in a treatment plant reused. (The material can be reused up to approx. 60 times) The dust- and VOC containing exhaust gas from varnishing and blasting operations is extracted and cleaned via filters for suspended particles (overspray and dust). VOC from exhaust gases are adsorbed via activated charcoal. The saturated activated charcoal is regenerated in a desorber with inert gas and the solvents are recovered. The organic solvents are treated via thermal combustion and thus used for the generation of heat for the desorption process. By the exhaust gas treatment, the dust emissions content of the cleaned gas could be reduced to less than 1 mg/m³. The total dust emissions were reduced by 95 %. The VOC emissions could be reduced by 75 % and an average clean gas concentration of 23 mg/m³ could be archived. The plants capacity amounts 300.000 m³/h. By the recycling of the blasting agent, the material consumption and waste generation was reduced by 98 % [UBA 1997/HDW-Abschlussbericht]. Filters and exhausted charcoal generate wastes. The investment for the installation amounted approx. 20,9 Mio. EUR (inclusively the implementation of a multi-cycle-system for paint containers). The annual operation costs amount approx. 1,02 Mio. EUR. In comparison to the conventional process the operational cost could be reduced slightly due to the savings of blasting agent and the reduction of hazardous wastes.

New Construction / Maintenance

- Implementation of a multi-cycle-system for big paint containers for standard coatings. In the new construction and maintenance. In comparison to the usually used 10 – 20 l containers, the amount of waste containers and paint residues is reduced significantly.

- According to the application of TBT-free antifoulings, based on copper-compounds or the use of biocide-free coatings, according to the conditions of the vessels use. For systems without biocides, still no long-term experiences are present. Projects for testing, run at present (e.g. ECOPAINT).

2.7.6 Proposals for the BAT

New Construction

The following techniques are recommended as BAT:

- Paint application with a high share of electrostsatic air-assisted spraying.

- Closed workshop halls for blasting and varnishing of big ship sections with extraction of exhaust gases and treatment via dust separators and adsorption of VOC with subsequent thermal combustion as well as recycling of the blasting agent.

Maintenance

- Utilisation of water blasting for paint removal and treatment of dock waste water and reuse of the water.

- For paint application onto non-vertical, bended surfaces, the airless application represents an already implemented BAT. For the coating of plane, vertical surfaces, the use of mobile application devices with an integrated extraction of overspray represents the most environmental sound technique.

- Fortification of nets for the reduction of the air movement and thus a reduction of the discharge of overspray.

New Construction And Maintenance

- Utilisation of TBT-free or biocide-free antifouling paints for new construction and maintenance.

- Implementation of a multi-cycle-system for big paint containers for standard coatings.

2.7.7 New Progressive Techniques

- At present test are undertaken at Blohm+Voss Repair GmbH for an improved waste water treatment for a further reduction of concentrations of hazardous substances in the waste water via UV-radiation, treatment with ozone or chemical precipitation, especially for heavy metals and organic tin compounds.

- For the mobile application devices special coating heads for the use onto bended surfaces are developed at present.

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3 Serial Varnishing of Plastic Workpieces

In this chapter, the serial varnishing of plastic workpieces will be discussed. However due to the big variety, not all products could have been investigated within the framework of this research. The varnish consumption of this sector can be structured as in the following: About 75% of the processed varnishes are applied for **plastic mounting parts of vehicles** and about 25% are applied for coating of **TV or hi-fi units** [MAY 1997]. Hence a description of this sector will be carried out for selected workpieces of the vehicle supplier's industry predominantly. Due to the strong competition of enterprises and a very restrictive information policy resulting from this situation, only a few data have been created.

3.1 General Information

The production sites of plastic varnishing are often equipped with departments working with process technology and process engineering of surface treatment. Hence these enterprises not only apply emission abatement measures (state-of-the-art) but furthermore take part in their development [BMU 1997]. Parts of the vehicle industry being coated, include parts that are varnished at the vehicle producer (by the same installations like the vehicle itself or in separated varnishing lines) as well as parts that are coated by the component supplier. Plastic parts integrated in the car body have to be adjusted to its colouring so that transitions are invisible. Car bodies and the different parts are varnished in an extreme example in different installations with varying application devices and varnish materials. In this case the colour matching is of high significance [STEGEN 2001]. Due to the increase in applications of recyclable plastics in the vehicle component supplier industry, the use of polyolefines has strongly raised over the last years. These materials are non-polar and need a surface preparation that guarantees the necessary adhesion for the varnishing.

3.1.1 Special Characteristic Properties of Plastic Materials

Plastics show a few particularities such as for example:

- Restrictedly resistant against mechanical or thermal stress as well as against aggressive media,
- electrically non-conducting,
- other wetting and adhesion properties if compared with metal surfaces,
- leaking/migration of plastic ingredients is possible.

These particularities of the substrate result in different substantial requirements for the surface preparation and the varnishing process if compared to metal coating. For example the varnish has to contain suitable solvents (e.g. aggressive solvents may cause swellings and embrittlements or they may create cracks in the plastic or reduce adhesive strength). The varnish has to be more elastic than the substrate in order to resist deformations [BROCK 1998].

3.2 Applied Processes and Techniques

In the following, the applied processes and techniques for the serial varnishing of plastic parts will be sketched out generally followed by a description based on selected workpieces of the sector:

Surface Pre-treatment

The surface preparation serves for a reduction of faults in the surface that are created by leaking of ingredients for example, for an increase in adhesive properties (especially for applications of water-based varnish systems) as well as for an activation of the surface.

Furthermore, an increase in electrical conductivity can be required (e.g. in order to use electrostatically supported application devices with an intended increase in the degree of efficiency of the application).

Used preparation techniques of this sector include chemical pre-treatments in baths, flame treatment, plasma processes, the corona technique as well as fluoridation (see also annex II) [BAUER 2000, FISCHER 2000]. If the fluor preparation is used, partly the filling layer is not necessary (One layer coating) because this technique already creates a homogenous surface independent of the geometry of the workpiece. A further advantage of the fluoridation is that the fluoridated parts can be stored for a long time before being supplied for a following varnishing process.

Structure of the Varnish

Depending of the requirements a two, three or four layer structure of the varnish is necessary.

First, a ground coat can be applied that serves especially for a sufficient composite. On the surface of especially difficult surfaces such as polypropylene for example, an additional primer may be necessary. For soft PVC or PUR soft foam, an isolating or inhibiting ground coat has to be used in order to avoid softener migration. In order to smooth the surface roughness, an elastic filling is applied. The top coating can be of the one or two-layer type. It is also elastic [BROCK 1998].

Applied Varnish Systems and Application Techniques

Predominantly solvent-based one and two part varnish systems based on PUR and one part varnish based on acryl melamine are processed for plastic varnishing in Germany. Besides these, water-thinnable systems, UV cross-linking systems and powder varnish are in use [GRUPP 1999].

Typically pressure air spraying with the high-pressure method is used for the processing of wet varnishes. Depending on the workpiece's geometry, the varnish application efficiency factor amounts between 20 and 40 %. The paint application via HVLP-methode (HVLP: **H**igh **V**olume **L**ow **P**ressure) is also common for some applications. Achievable application efficiency factors vary between 25 and 50 %. There is an increasing use of varnishing robots, because with this technique, especially a more homogenous layer thickness can be achieved if compared to manual varnishing.

Electrostatic application techniques have been used for multi-layer superstructures exclusively up to now. Generally, an electrically conducting ground coat is appliquéd first with conventional guns. The following base coat is also often applied with conventional guns. The application of the clear coat layer can then be carried out electrostatic assisted (e.g. by high rotating bells). Up to now the electrostatic coating technique cannot be used for one-layer coatings, because it is only possible onto electrically conducting pre-coats [HOFFMANN 1999]. Also for this sector, application efficiency factors can highly be increased with electrostatic techniques. If high rotating bells are used, application efficiency factors of up to 85 % can be achieved.

In general, drying and curing are carried out at a temperature of 80° C maximum due to the heat sensitiveness of the substrate. For some plastics, a yellowing of pale colourings may be caused by UV and electron beam curing [BROCK 1998].

The 31. BImSchV defines the following emission limits for plastic coatings:

Table 3-1**:** Emission limits for plastic coating according to 31. BImSchV

Threshold value for annual solvent consumption > 15 [t/a]	**Emission limit value for cleaned gas [mg/m³]**	**Proportion of solvent in the raw exhaust gas including fugitive emissions [in % of solvent input)**
For automated coating of sheet-like materials	20	10
Other coating	50 for post-combustion: 20	20

In the following, the applied techniques will be described exemplarily for the varnishing of workpieces including bumpers, wheel covers, steering wheels, TV, hi-fi and computer housings as well as reflectors.

3.2.1 Varnishing of Bumpers

The varnishing of bumpers with conventional varnishes has been studied at the Omnium Automotive Components GmbH company and the Dynamit Nobel Kunststoff GmbH company (cf. annex VI). Additionally, data from the Volkswagen AG company [GRUBER 2001] have been used for a description of applied processes and materials consumptions.

A simplified processing procedure is illustrated in figure 3-1.

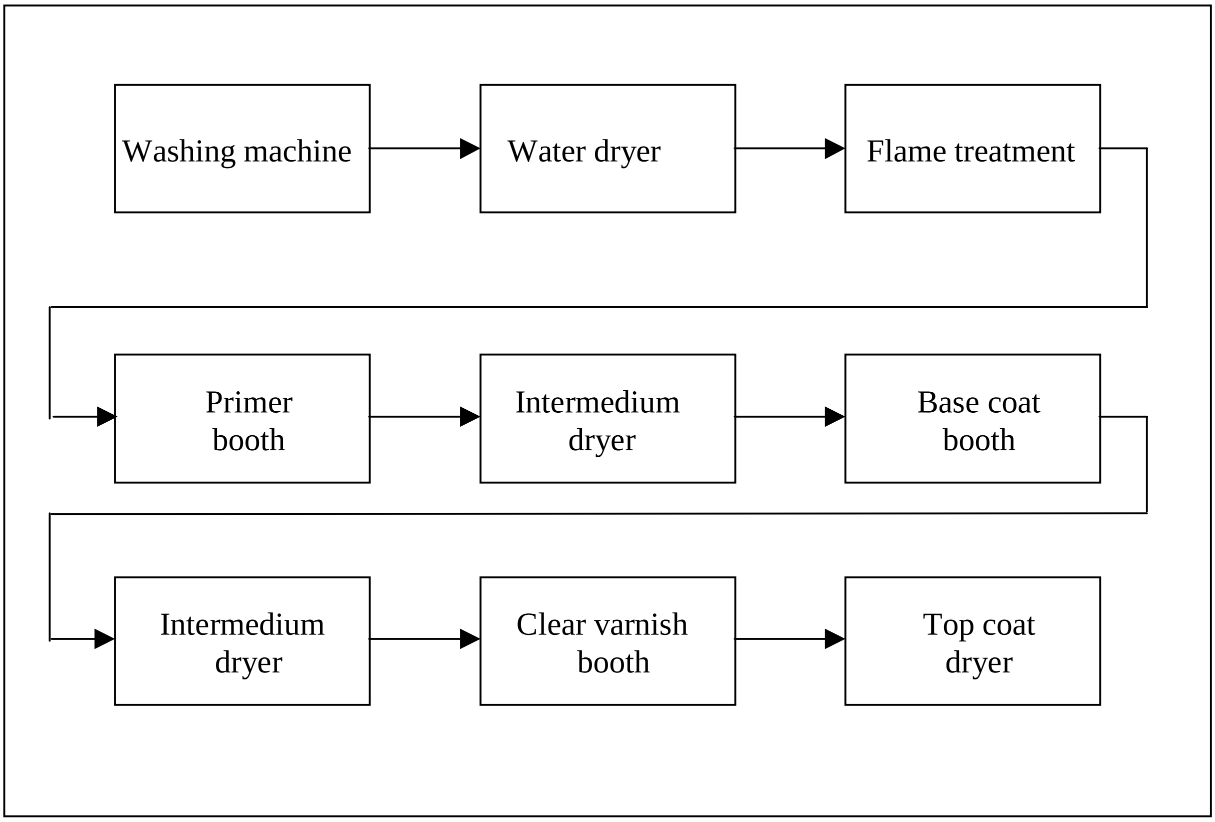

Figure 3-1: *Process procedure of bumper coating* [GRUBER 2001]

The workpieces being varnished, consist of polyurethane moulded pulps and thermoplastic plastics.

Surface Preparation

Different techniques are used for surface preparation in the investigated installations. These will be described in the following.

As a preparation for coating, the bumpers are cleaned manually with a water-isopropanol mixture (proportion of isopropanol: 5% per weight) and afterwards they are dried in convection dryers. Often a spray cleaning with water is used as an automated technique. In this process, the parts migrate through different zones [FREIMANN 2001]:

- First degreasing by a aqueous-alkaline cleaning agent.
- Rinsing with water
- Second degreasing by a watery, alkaline cleaning
- Rinsing with water
- Rinsing with deionized water

In general a cascade rinsing technique is used in order top reduce water consumption. The water discharging from the parts can be used for substitution of evaporation losses of the degreasing step. Also the deionized water can be cycled. These measures allow a wastewater-free surface preparation [SCHMID 2000]. After the cleaning process, the parts are transported through a blowing, drying and cooling unit. Partly condensation dryers (so-called Hydrex dryers) are used for the remove of retained water. If a condensation dryer is used, the cooling unit is not necessary.

After the drying, the workpiece’s surfaces are activated by flame treatment. Polyurethane parts do not need any further preparation.

Varnish Application

In general, bumpers are coated with a three-layer varnish consisting of ground coat, base coat and clear coat varnish. Varnish application is carried out automatically and manually by electrostatic assisted spraying with HVLP guns. First, the plastic parts are primered with a solvent-containing two part ground coating or a water-thinnable primer and afterwards they are dried in a drying zone within a circulating air flow (at 80° C).

Application of the base coat is carried out with the same technique as the ground coat. One-part varnish systems both water-thinable as well as solvent containing are appliquéd as base coats. After varnish application, evaporation and application of conventional solvent-containing two part clear varnish is carried out.

After evaporation, the varnish layers are dried in the dryer. Solvent-loaded exhaust air flows originating from flashing off areas and dryers are captured and supplied to a post-combustion unit. The achieved efficiency factor is higher than 99 %. The concentration of about 277 C/m³ in the raw exhaust gas is reduced to 25 mg C/m³ in the cleaned gas. Cleaning of the overspray is carried out via wet deposition. Table 3-2 shows solvent proportions of different varnish systems.

Table 3-2**:** *Solvent proportions for varnish systems used for the coating of bumpers*

Varnish structure and varnish systems	Solvent contents and solvent emissions
Ground coat	
Solvent-containing	44 - 50 % per weight
Water-thinnable	15 % per weight
Base coat	
Solvent-containing	50 % per weight
Water-thinnable	15 % per weight
Clear coat	
Solvent-containing	50 % per weight
Water-thinnable	30 % per weight

3.3 Current Consumption and Emission Values

The bumper surface that is coated, amounts between 0,9 and 1,5 m². Data for specific varnish consumption [g/m²] cannot be generated due different geometries of the workpieces. Hence in the following, the total amount of solvents applied, will be discussed exemplarily for the bumper varnishing installation of the Volkswagen AG Company at the production site in Wolfsburg. In 2000, about one million bumpers were coated in this installation. The ground coating and the clear coat are the solvent-based materials among the materials processed in this installation. The base coat is water-thinnable. In total, 351 tons VOCs were used in varnishes and diluting agents [GRUBER 2001]. The VOC input for the year 2000 is itemized in figure 3-3 according to varnishes and rinsing media.

Table 3-3**:** *VOC use of the year 2000* [GRUBER 2001]

Varnish system	Solvent use [t]
Ground coat	125
Base coat	31
Clear varnish	84
Sum of varnish	*240*
Rinsing diluent ground coat	61
Rinsing diluent base coat	9
Rinsing diluent clear varnish	41
Sum of rinsing diluent	*111*

Emissions in the air

The fate of the solvents used is illustrated in figure 4-2.

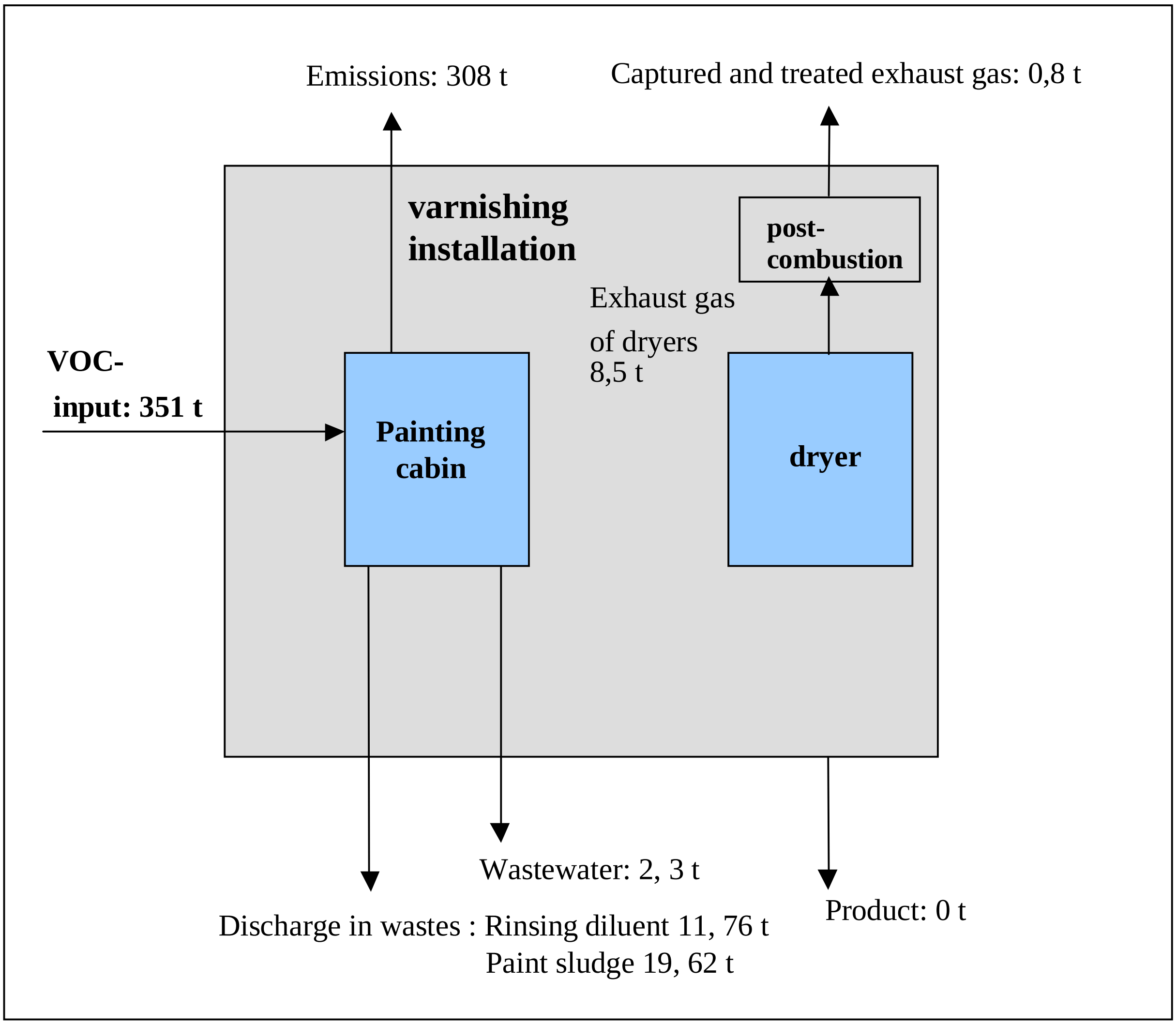

Figure 3-2**:** *Fate of the VOC input* [GRUBER 2001]

Emission Abatement Measures

The amount of used solvents can be reduced by up to 48% by the use of water-thinnable ground coatings compared to solvent-based ground coatings according to a study of Volkswagen AG Company in Wolfsburg [GRUBER 2001]. Hence also solvent emissions can be reduced accordingly. An effective reduction of VOC emissions can be achieved by capture and treatment of the painting cabin's exhaust gas flows.

As for base coats, water-thinnable varnishs are already applied. For a further increase of the application efficiency for water-thinnable primers and base coats, more and more high rotation bells are in use for automated application techniques. Scrapper-cleaningable ring

circuits are used in installations with automated application techniques in order to minimize varnish leftovers and rinsing losses.
Color block building can reduce varnish material and rinsing diluents. Further, the rinsing thinner can be captured and re-used. About 66 tons of rinsing diluent can be saved per year in the investigated installation (see also figure 3-2) for a recapture proportion of 90% and a subsequent processing [GRUBER 2001].
Condensation dryers can be used for drying layers of water-based varnishes. About 25 % of the supplied energy can be saved, compared to the use of conventional dryers as a energy-intensive subsequent cooling zone is not necessary [SCHMID 2000].

If the deionized water is leaded in a circuitry, a generation of wastewater can be avoided in the cleaning section [SCHMID 2000]. The consumption of fresh water can be reduced by the cascade flow technique.

3.3.1 Varnishing of wheel covers

The varnish structure for wheel covers is characterized by two layers. First a conventional or water-thinnable metallic base coat and subsequently a conventional solvent-containing two component clear coat or and UV clear coat is applied. The requirements for the coating include scratch resistance, water resistance and resistance against stone-chips as well as a high surface quality. The coating is carried out automatically.

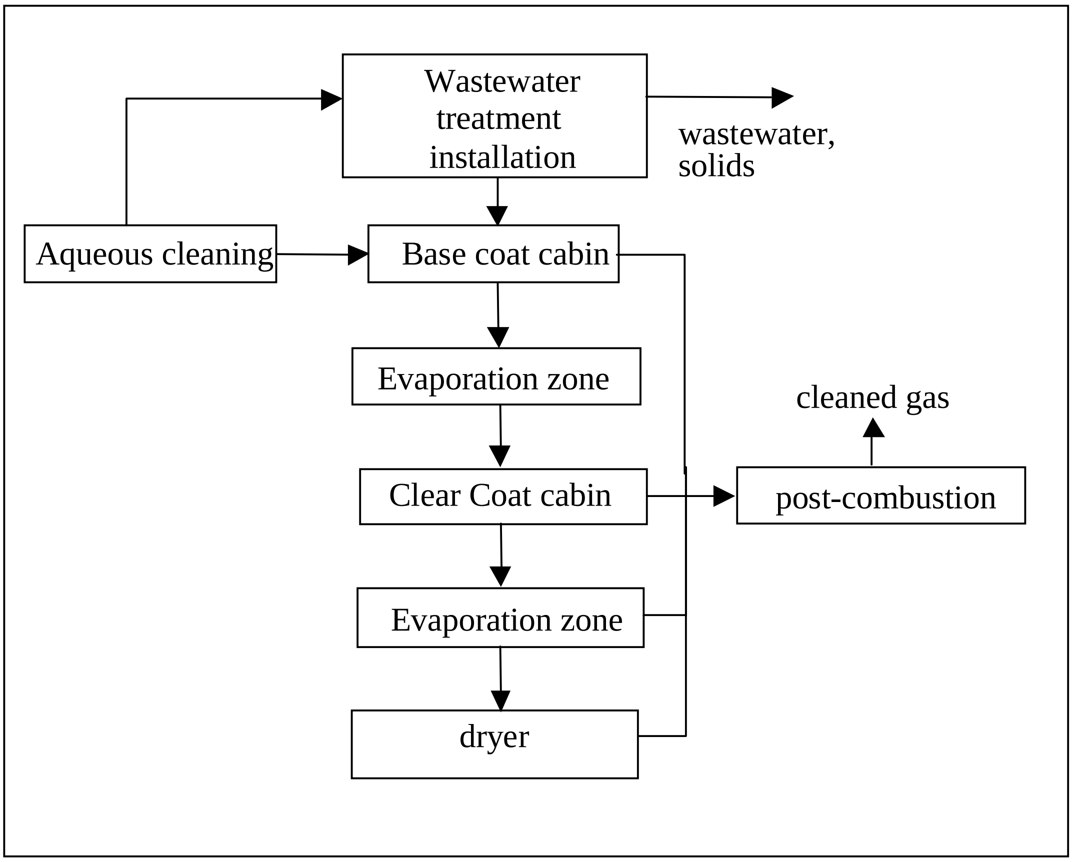

Figure 3-3**:** *Varnishing of wheel covers with conventional varnish*

Figure 3-3 illustrates the production procedure of wheel covers with solvent-containing varnish exemplary for the Montaplast company. The exhaust air originating from spraying cabins, dryers and evaporation zones is leaded to a post-combustion unit, so that a cleaned gas concentration of 20 mg C/m³ is reached. The cleaning process is carried out with aqueous alkaline cleaners. Table 3-4 compares different systems in use [REINER 2000].

Table 3-4**:** *Comparison of solvent proportions of varnish systems applied for varnishing of wheel covers* [REINER 2000]

Varnish system and construction	Solvent proportion
Base coat	
Solvent-based	75 % per weight
Water-thinnable	10 % per weight
Clear varnish	
Solvent-based	50 % per weight
UV curing	10 % per weight
Water-thinnable	16 % per weight

3.3.2 Varnishing of Steering Wheels

The tendency to a stronger design of colours in the automotive sector has lead to an increased significance of the interior decoration. For example, nowadays also the steering wheel is matched in terms of colour to the instrument board or to interior. For steering wheels, properties such as resistance against sun radiation, cleaning agents or sweat from hands have to be guaranteed by the varnish. At present, steering wheels are typically coated with the so-called **in-mould technique**. For this technique, a release agent is applied onto the heated mould and the in-mould varnish is sprayed onto the release agent. This way, the proportion of overspray and therefore the material loss is comparably low, with 20 %. After a short evaporation time, the mixed PUR components are poured in. During the foaming process within the closed mould, the material creates a strong connection with the varnish. The applied varnish has to be adjusted to the used mould release agent and to the used polyurethane system. Up to now, solvent-containing one and two component varnish systems have been in use. Water-based in-mould varnish systems are currently in a testing stage. First results indicate that barely longer drying times are necessary in comparison to conventional systems and therefore integration in existing processes is possible. However no large-scale use has been carried out yet [MECKLENBURG 2001].

3.3.3 Varnishing of Reflectors

A special significance for the varnishing of reflectors is the creation of an extremely smooth and homogenous surface. The varnish structure is a one-layer type. A progressive technique is the automated application of UV curing varnish systems (about 5 to 10 % solvent proportion per weight). With this technique, the solvent emissions are reduced significantly compared to conventional varnish systems with solvent proportions of up to 70% per weight, the varnishing process is accelerated, the quality is increased (scratch resistance, high opacity), there are savings of space and energy due to the fast curing process and the temperature stress during the coating process is reduced [REINER 2000].

3.3.4 Varnishing in the production of TV, hi-fi and computer housings

Nowadays, there is a trend in the audio and video sector towards a demand of colourful products and even individual customer requests regarding the colour design. The demand of black and brown colours has decreased. The quality requirements for the coating of the housings include essentially the resistance against alcohols, skin fat, and others, the scratch and abrasion resistance as well as good optical surface properties [FAUSER 2000]. State-of-the-art is the serial use of water-based coatings [MAY 2001]. At the moment, possibly far between solvent-containing varnish systems are used. An efficiency factor of 45 % can be achieved in the varnishing of TV housings. The coating is carried out automatically [GRUPP 1999].

3.4 Selection of the BAT Candidates

Use of Water-thinnable Varnishes

In the vehicle component supplier industry, water-based varnishes are already in use as fillers and base coats. These products are applicated via high rotation atomizers. This way, both the solvent emissions as well as the varnish consumption, are significantly reduced. As plastic is an electrically isolating material, electrostatic application techniques with potential isolation are used. The establishment of this system does not need any special safety measures. Existing installations can be upgraded (see also [ESSLINGER 2000, SCHOLZ 2000]).

At present, water-thinnable varnish systems are already in use for ground coatings of plastic parts. These systems consist of acrylate or polyester dispersions, two part PUR systems and two part epoxy ground coatings. The compositions, advantages and disadvantages of these varnish systems are specified in table 3-5.

Table 3-5*: Comparison of compositions, advantages and disadvantages of the most common water-based ground coatings* [BÄNERLE 1999]

Varnish system	**Solids content during processing** [% per weight]	**Solvent content during processing** [% per weight]	**Solvent proportion related to 100 % solids content** [% per weight]	**Advantages**	**Disadvantages**
One component acrylate dispersion	50	5	10	Fast drying	Restricted resistance, adhesion problems with difficult substrates
Two component PUR system	60 60	10 15	17 25	Good resistance, good adhesion to most substrates	Formation of voids
Two component epoxy resin	70	5	7	Good resistance, good adhesion to most substrates	Low resistance against permanent moisture

Use of Powder-based Varnish Systems

Especially for environmental protection reasons, there is a high interest in the coating of plastic parts with solvent-free powder varnish systems. However the use of these systems is currently limited due to the missing electrical conductivity and the temperature sensitiveness of plastics. Large-scale applications have not been observed yet. Only small batches in the coating of small parts are currently coated with powder varnish, for example composite parts of metal and plastics for car radiators [KARLE 2000].
A relatively new industrial application of UV curing powder varnishes is the coating of PVC floor tiles. In this context, .the high flexibility, the strong chemical resistance and the good scratch resistance have to be emphasized [BUYSENS 2001].

Establishment of electrostatic varnish application techniques

Generally, the use of electrostatic coating techniques requires workpieces that are able to form an electric antipole to the electric charged varnish particles. As plastic parts are electrically non-conducting, the charge of the varnish particles has to be withdrawn while wetting the workpiece's surface. This problem is currently under investigation (cf. [ONDRATSCHEK 2000B]). Results show the withdrawal of the charge is carried out via the wet varnish film. Further, the investigations oriented at the applications have shown that the electrostatic varnishing of plastic parts is partly possible under production conditions without additional working steps and without the application of electrically conducting varnish materials. The investigations have been carried out for three applications and the results are shown in table 3-6.

Table 3-6**:** *Results of the investigations on the use of electrostatic varnish application techniques* [ONDRATSCHEK 2000B]

application	**Reduction potentials* [%]**			
	Varnish consumption	Solvent use	Clot creation	Coating time
bumpers	50	50	75	10
TV enclosures	40	40	70	30
Door handles of cars	55	55	75	25

* compared to conventional high-pressure application techniques

Besides the described reduction potentials, there are further advantages including significant energy savings, an improved automation capability as well as lower postprocessing and scrap proportions [ONDRATSCHEK 2000B].

Capture of VOC-containing exhaust gases from spraying cabins and evaporation zones

If conventional varnish is used, an effective emission reduction can be achieved by the capture and post-combustion of exhaust air originating from spraying cabins, evaporation zones and dryers installations. The common capture of exhaust air flows originating from dryer installations only affects 20 to 30 % of the emissions.

3.5 Proposal for the Best Available Techniques

As indicated by the description of the used methods, the most applications already use coatings low in solvents or solvent-free coatings for serial production. Due to the high variety in workpieces, plastics and requirements for the coatings, best available techniques can only be specified in a very general way:

- High proportion of electrostatic application.
- Scrapper cleanable Ring circuits for automated application.
- Application of water-based systems for ground and top coating or powder coatings.
- Use of UV-curing clear varnish.

3.6 New Progressive Techniques

Currently, powder coating of plastics is close to the limit of powder varnish applications: Plastics are both electrical isolators and temperature sensitive substrates. Hence at the moment, developments of thermal curing low temperature powders and UV curing powder coatings are strongly promoted especially by the varnish producers. Promising results show the application capability of such powder varnish systems for representative plastic parts [ONDRATSCHEK 2000A].

For future considerations it is questionable if invisible surfaces should be coated at all and if they need a complete varnish construction. Further, the question if the ground coating is necessary at all for some cases may arise, because generally surface preparation techniques such as plasma treatment of fluoridation equip the plastic substrate with very good adhesion properties.

3.7 Conclusions and recommendations

For the varnishing of TV housings, water-thinnable varnishs are already in use [BMU 1997]. Also for further applications the tendency towards the use of water-based varnish systems is still maintained [HOFFMANN 2001].

It can be observed that the component suppliers of the vehicle industry are strongly bound to the requirements and conditions of the vehicle producers and therefore they don’t have a big scope concerning the selection of materials and techniques. This fact constricts the way towards more environmentally friendly varnish techniques.

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4 Serial Varnishing of Metal Surfaces

4.1 General Information

The sector of serial varnishing of metal workpieces shows a big variety[1]. The sector will be described based on the following products: **Household appliances, steel furniture, office appliances, switch cabinets, heating elements, radiators, facade parts, rims, engine blocks, brake discs, windshield wipers** as well as **frames of motorbikes** and **bikes**. Due to the high variety of used techniques and the highly different requirements for the coating of the products, a uniform BAT selection can not be given, but is illustrated exemplary.

4.1.1 Requirements for the Varnishing of Metal Surfaces

The technical requirements for the varnish properties are various and depend on the specific application conditions of the metal workpieces. The essential requirements for the coating construction include: Mechanical and chemical resistance, corrosion protection as well as optical quality of the surface [CORLEY 1991]. The optical surface quality has a lower significance for metal surfaces than for other sectors such as the furniture- or vehicle industry. As the varnishing step does have a minor significance in the total production process, various producers do not operate their own varnishing department but place suborders for suppliers. The producing enterprises and the suppliers enterprises are structured middle-sized predominantly.

The majority of the workpieces, mainly casting parts or enclosures consisting of low-alloy steels, chromium/steel alloys, aluminum and magnesium are coated completely or partly.

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[1] Serial varnishing means here the manual or automated coating of workpieces in high quantities.

4.2 Applied Processes and Techniques

As opposed to the vehicle serial varnishing, the general industrial varnishing shows a bandwidth of coating materials and application techniques. The coatings have to meet different requirements. As for coating materials, there are often one-layer top coatings used besides ground coatings. Then only one top varnish layer is applied without a subsequent application of clear varnish (see also [BROCK 1998]).

In practice, different varnishing concepts and techniques are used for coating of metal workpieces. In the following, some of them will be described and compared as far as possible[2] .

Typically, the cleaning with watery, alkaline degreasers is used as preparation technique for the surfaces being coated.

Depending on the type and composition of the degreasing baths and rinsing processes, the operating conditions vary between 50 and 90 °C and pH values between 9 and 12. The use of spraying or dip coating installations is constituted by the workpiece’s geometry [ONDRADSCHECK 2002].

4.2.1 Varnishing of Steel Furniture

In the varnishing of steel furniture, **conventional** and **water-thinnable** varnish systems as well as **powder varnish** are processed. Besides the costs, especially corrosion protection and the optical surface properties have an essential significance. Standard testing methods such as the salt spray test and the condensation test show, that both water-thinnable dip varnish and powder varnish achieve a good to very good corrosion protection effectiveness compared to the conventional wet varnishing (with solvent-containing varnish with the electrostatic spraying technique).

In the following, the different varnishing concepts are sketched out (see also annex VI.I):

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[2] For the comparison, partly results from [HARSCH 1999] are used. In the course of the study of Harsch, varnishing concepts have been investigated with the method of integrated balancing. In doing so, the balancing software GaBi and the database LACKY have been used. Hence for the basic data, data sources and assumptions for the calculations, the reader is referred to [HARSCH 1999]. More detailed information about costs, consumption and emission values are documented in annex VI.I.

Conventional Varnish System

Generally for the conventional varnish system, a solvent-containing varnish (solvent proportion of 40 % per weight) is applied by an automated and manual electrostatic spraying technique. Separation of the overspray is mostly carried out by wet separators. For a reduction of VOC emissions, only the exhaust air flows originating from dryer installations are leaded to a post-combustion. Therefore the majority of the VOC emissions is emitted untreated. The advantage of the conventional varnish concept is the high flexibility in **colouring**.

Powder Varnish System

The powder varnish system does **not generate any VOC emissions** and only s**mall varnish waste amounts**. A disadvantage can be the higher layer thickness, however this disadvantage can be equated by a circuitry of the powder varnish and the resulting higher achievable efficiency factor s for the application. However a reduction of layer thickness is expected for the near future. Quality problems may arise for high requirements for the optical surface properties. Powder varnish systems are less flexible concerning a change in colouring compared to wet varnish systems, because each change in colouring requires a cleaning of the varnishing booth. However this does typically not require a high technical and time effort [HARSCH 1999].

Cathodic Dip Coating Installation

The cathodic dip coating installation in continuous operation is the best alternative with respect to ecological and economical considerations. This technique has high application efficiency factors, creates a homogenous layer thickness, is very low in solvent emissions and achieves a very good corrosion protection. Post-processing of the workpieces is not necessary due to the high surface quality. However this varnishing concept ins only suitable for high production rates with one colouring, because changes in colour are not possible.

4.2.2 Varnishing of Shelves

Typical characteristics for the varnishing of shelves is the big variety in colours and different geometries. Hence often a combined installation with automated and manual varnishing lines is used, because the workpieces with different geometries cannot be varnished together in a completely automated installation (see annex VI.I) [HARSCH 1999].

The metal parts are degreased, phosphatized (iron), cleaned and dried afterwards. Partly this surface preparation is not carried out. A final coating with **conventional varnish** applied by a spraying technique or with **water-thinnable liquid varnish systems**. This is mostly carried out within a dip coating installation for standard colours. Partly, the products are coated with

powder varnish. The powder varnish booths are generally equipped with varnish recovery systems. Extremely long parts such as frames are coated manually.

The coated products are leaded to a dryer, passing through a flashing-off zone before drying and curing. Partly, combined liquid varnish/powder dryers are in use [SCHÖNING 1999].

A comparison between conventional liquid varnish, water-thinnable liquid varnish and powder varnish shows that:

- Solvent-containing and water-thinnable liquid varnish systems essentially have the same properties regarding technical, ecological and economical aspects. Water-based varnish systems generate lower VOC emissions compared to conventional solvent-containing varnish, however due to the lower solids content, bigger amounts of varnish material are consumed.
- The powder technology can only be recommended with respect to VOC emissions. Criteria such as energy consumption, material consumption and operating costs are currently higher than for liquid varnish. The essential reason is the layer thickness still being high. It can be expected that with the development of thin layer coatings with powder varnish, the powder varnish systems will have significant advantages compared to liquid varnish systems [HARSCH 1999].

4.2.3 Varnishing of Household Appliances

In the production of **refrigerators** and **stoves**, predominantly *coated coils* are processed (cf. chapter 6) so that no coating operations are carried out in the production.

Producers of **washing machines**, **dishwashers** and **dryers** currently use powder varnish systems following after the phosphatization and partly after the electrical ground dip coating (see annex VI.I). Seldom, solvent-containing liquid varnish systems are used. Currently, thin layer coatings with powder varnish systems are already in use for household appliances (layer thickness 45 µm) [AKZO 2000].

A comparison of conventional liquid varnish and powder varnish indicates that the powder technique creates the same surface quality and resistance against corrosion but it has the better environmental properties, whereas the conventional wet varnish technique generates VOC emissions and lower costs [HARSCH 1999].

4.2.4 Varnishing of High Voltage Switch Cabinets

Typically an **electric dip coating** is applied after the phosphatization for the varnishing of high voltage switch cabinets. Afterwards, the top coating is applied. Conventional two part final coatings, water-thinnable top coatings as well as powder varnish systems are used (see annex VI.I). The energy consumption is higher for liquid varnish than for powder varnish. Significant differences have been observed with respect to the VOC emissions: The better alternatives are the powder coating as well as water-thinnable varnish systems. Waste generation is also lower for a powder application due to powder recovery systems. Further, the operating costs of powder coating for switch cabinets are significantly lower than these for varnishing with liquid varnish.

4.2.5 Varnishing of Engine Blocks

Engine blocks are coated with a powder varnish based on epoxy resin with an electrostatic spraying technique. The powder overspray is captured and re-used. This varnish material is resistant against temperature (up to 500 °C) and chemicals. Drying is carried out by irradiation at a temperature of 200 °C. In comparison to enamel varnish, a shortage of processing times and an increase in the operating lifetime of the motor housing coating can be observed [BESSER LACKIEREN 2000].

The first industrial coating installation for UV-curing powder varnish systems has been put on stream for coating of pre-assembled motor blocks containing heat-sensitive cable skeins. The powder varnish is applied by a corona gun with the electrostatic spraying technique, then melted by IR emitters and cured with UV emitters [BUYSENS 2001].Table 5-1 shows a comparison of costs between conventional varnish and UV powder varnish.

Table 4-1: *Comparison of costs between a conventional varnish and a UV powder varnish in the coating of pre-assembled motor blocks* [BUYSENS 2001]

Cost or other information	Conventional varnish	UV powder varnish
Costs for material	2,52	2,02
Solids content [% per weight]	10	100
Efficiency factor [%]	35	98
Dry film layer thickness [µm]	30	50
Costs for varnish [EUR/kg]	2,78	26,5
Energy costs [EUR/m^2]	0,27	0,24
Processing, maintenance costs [EUR/m^2]	1,52	0,83
Costs for disposal (overspray) [EUR/m^2]	0,74	0
Costs for post-processing [EUR/m^2]	0,12	0,08
Installation depreciation [EUR/m^2]	0,09	0,42
Investment [EUR/m^2]	184 000	900 000
Total costs [EUR/m^2]	**5,26**	**3,59**

Although the costs of powder varnish are higher than for conventional varnish (related to a kg of varnish), the material costs are significantly lower than for the solvent-containing varnish due to the reduced overspray. Further the energy costs are lower for the powder varnish as a result of the shorter curing process. Furthermore, the processing and maintenance costs are significantly lower if compared to conventional systems. Finally it has to be noted that due to the high application efficiency factor and due to the recycling properties of the powder, essentially no waste is created [BUYSENS 2001].

4.2.6 Varnishing of Windshield Wipers

For the varnishing of windshield wipers, **water-thinnable varnish** (partly via high rotation bells) and **powder varnish** are processed (see annex VI.I). The powder technique has ecological and economical advantages. However a disadvantage of the powder technique is the high layer thickness which can cause impacts on surface quality and also problems in the assembly of the parts [HARSCH 1999].

4.2.7 Varnishing in Mechanical Engineering

Especially resistant coatings such as **conventional PUR fillers and top coatings** have to be used for tool machines and other metal processing machines. They have to be resistant against oils, cooling agents and other liquids. Besides the surface quality, the corrosion protection has a predominant significance. Varnishing of mechanical engineering products can be classified after the following process steps: Surface preparation (cleaning, degreasing, filling and masking), varnishing (ground coating, final coating and drying processes), post-processing (repair of imperfections, removing of cover paper) and cleaning of the tools and appliances. [CORLEY 1991]

Surface Preparation

Typically, the metal substrate being varnished is impurified with fats, oils, wax or dust. For removal of these, the surface is cleaned with aqueous watery cleaning agents or seldom with organic solvents. Depending on the size and batch size of the workpiece, the degreasing is carried out in dipping baths, by spray washing, by brushing or manual wiping (solvent and rag). If water is used for the degreasing, the workpiece is dried before varnishing.

Ground Coating

The electric dip coating technique with water-thinnable varnishes as ground coatings is the most widely used method. Besides this, conventional or water-thinnable ground coatings are applied with spraying techniques.

Top Coating

Typically, two top coating layers are applied in the machine varnishing. These varnish systems are based on acryl, PUR or epoxy acting as colouring base coat (followed by an application of clear varnish) or otherwise, two layers of colouring base coat are applied. Partly, powder varnish systems are already in use.

The liquid varnishes are applied predominantly manually with the pressure-air technique (HVLP), with the airless- or air-assisted airless spraying.

For certain applications, overspray-free varnish application techniques such as casting, rolling, dipping, flooding can be used. Here, application efficiency factors of up to 95% can be achieved. Similar application efficiency factors can be achieved in the electrostatic powder varnish method.

Powder Varnishing

Powder varnish systems based on epoxy, epoxy/polyester or polyester are in use. The powder varnish is either applied directly onto the degreased substrate or as a top layer onto a ground coating. Typically the application is carried out with the electrostatic spraying technique.

4.2.8 Varnishing of Facade Parts

Facade parts have been coated with powder varnish systems for a long time. Nowadays also TGIC-free[3] powder varnish systems are at the market and are used in this production sector [ALFORT 1999].

A producer of aluminum facade parts coats about 420 parts per day and about 100.000 per year. Annually more than 1000 colours are processed for powder coating exclusively. The varnish systems used for this sector are based on polyurethane, acrylate, epoxy, amide and ester [WAREMA 2000].

4.2.9 Varnishing of Hospital Furniture

Hospital furniture is already coated with polyester powder coating, since it has to be disinfected, hot water and scratch resistant. Among other things, for example hospital beds are superheated steam-sterilized for reasons of disinfection. At present already TGIC free varnish systems are available and in use, which meet the mentioned requirements [BOYSEN 2000].

4.2.10 Varnishing of Heating Elements

For varnishing of heating elements, the use of powder coatings is state of the art [MAY 2001]. Presently an extension of the colour palette can be observed at the radiator manufacturers due to the risen demand for special colours.

4.2.11 Varnishing of Bike and Motorbike Frames

Bike and motorbike frames are ground-coated with watery liquid varnishes, then coated with a colouring base coating and finally coated with a liquid clear varnish [BESSER LACKIEREN 2000]. The base coat and clear is mostly solvent-based. Also powder varnish is used increasingly for the base coat and clear varnish. Bike frames and motorbike frames are produced of carbon, alloyed steels or adhesive bonded aluminium tubes and aluminium sleeves. A potential problem is that some adhesive bondings are not temperature resistant above 180 °C. For these applications, a liquid varnishing method is used. The varnishing of bike and motorbike frames includes the following process steps:

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[3] As hardener mainly TGIC (Triglycidyl-Isocyanurat) was used. Since these substances are rated as mutagenicity, nowadays alternative hardeners are applied [ALFORT 1999].

Surface Preparation

Typically the pre-treatment is carried out by irradiation. This way a plain metallic surface is created that is free of any remains (e.g. fat, oil). After the degreasing process, an iron phosphatization is carried out in order to generate an optimum substrate for the following coating.

Coating

There are three possibilities for the coating of bike and motorbike frames:

- For a one-layer type coating, a top coat is applied directly onto the plain metal surface.
- For a two-layer type coating, a ground coat and a top coat or a top coat and a clear varnish are applied onto the plain metal surface.
- For a three-layer type coating, a ground coat, a top coat and a clear varnish is applied onto the plain metal surface.

The powder coating is carried out electrostatic with the manual Tribo- or Corona technique. With this technique, a homogenous layer thickness is achieved. The surface shows very good properties concerning mechanical stress and corrosion resistance. After the coating, the varnish is burned in, this means the powder film is cured in the oven at a temperature of 180 to 200 °C and it melts to a closed and smooth varnish film [WEIST 2000, WEIST 2001].

4.2.12 Varnishing of Radiators for Passenger Cars

Water-based varnish is applied manually by an electrostatic spraying technique for the coating of completely assembled radiators in vehicle construction. This way the radiators showing a complicated geometry with cavities and different plastic parts are coated homogenously. Varnish recovery systems are already integrated in this sector. The varnish overspray is separated and the recovered varnish is post-treated (e.g. cleaned with a vacuum sieve). The recovered varnish is mixed with new varnish in a defined proportion in order to increase the capability to regulate its properties such as the viscosity. The combination of electro-statically applied water-based varnish and a subsequent varnish recovery allows significant varnish savings and hence a strong reduction in operating costs [R + H 2000]. Besides the application of water-thinnable varnish, there is an increasing use of UV curing powder varnish. As the radiators being coated consist of metal and plastic parts, only UV curing systems are suitable due to the limited temperature resistance.

4.2.13 Coating of Brake Disks

Until a few years ago, brake disks have not been coated completely. Certain parts such as friction and screwing surfaces used to remain uncoated. Predominantly for corrosion protection and optical reasons, also these vehicle parts are nowadays coated completely. The coating shows further properties such as for example an improved heat exchange whereas there is no influence on the braking behaviour. If a mechanical processing of the brake disks is carried out at the same place as the subsequent coating, the degreasing process can be omitted. However generally this is not the case in Germany and therefore, the parts have to be degreased, rinsed and dried. There are two different subsequent types of techniques for corrosion protection:

- The most common techniques for the surface preparation of metal substrates are chromating and phosphatization. The top coat is applied subsequently with a spraying technique. Typically this sector still works with conventional solvent-containing varnishes.
- Alternatively, the so called Geomet technique is used. Geomet is a corrosion protection coating that creates corrosion protection and a decorating coating at the same time. This varnish consists of zinc and aluminium lamellas/segments and gives the substrate a silver colouring . The Geomet is processed in watery solution. The varnish is burned in within induction dryers at a temperature of up to 340 °C in order to guarantee an optimum surface preparation. Application is carried out with a spraying technique depending on the installation in the clean room and partly HVLP guns are used. The applied layer thickness varies between 3 and 15 µm [JOT 2001].

4.2.14 Varnishing of Aluminium Rims

Besides the corrosion protection, the optical properties have a high significance for the coating of rims. The conventional coating of *aluminium rims* includes a surface preparation step that is generally equivalent to a yellow chromating under usage of the highly toxic chromium VI compounds. Subsequently there is a three layer coating consisting of **solvent-based varnish**: base coat, metallic layer and clear coat. This conventional coating technique has an environmental impact due to the usage of toxic chromium (VI) compounds and the use of solvent-containing varnish. There is a new industrial installation for the production of rims where this yellow chromating is substituted by a chromium-free technique and the conventional solvent-containing varnish is replaced by solvent-free varnish and varnish low in solvents. The **ground coat and the clear varnish layers** are applied as **powder varnish**. The application of the metallic base coat is carried out as **water-thinnable varnish**. Compared with a conventional installation, the new installation eliminates 150 tons of chromium-containing hazardous waste per year. Instead, about 70 t/a chromium-free waste needing monitoring are generated by the wastewater treatment. The wastewater generation remains constant in spite of the more elaborate preparation. The following table 5-2 shows the achieved environmental improvements of the coating process.

Table 4-2: *Comparison of the techniques in the coating of rims* [ABAG itm GmbH 2002]

Emissions, referring to 1 million wheels/year			
	Conventional technique	**Progressive technique**	**Comments**
1. coating / ground coat application			
Powder waste	< 2,5 t/year	< 2,5 t/year	No change, as the process step is maintained
2. coating with metallic base coat			
Volatile organic proportions	ca. 37 t/year	ca. 4 t/year	Minimization with water-based varnish by about 90%
Discharge of solids via the wastewater	ca. 8 t/year	ca. 2 t/year	Minimization and improvement in quality
3. coating with clear varnish			
Volatile organic proportions	ca. 29 t/year	0 t/year	Reduction by 100 %
Discharge of solids via the wastewater	ca. 20 t/year	-	Reduction by 100 %
Powder waste		ca. 1 t/year	New

The new installation generates significantly lower VOC emissions (only 4 g/wheel as opposed to 66 g/wheel). The waste is reduced (only 5,5 g/wheel as opposed to 30,5 g/wheel). The amount of varnish used is reduced from 210 g/wheel down to 170 g/wheel whereas the layer thickness is constant. The energy consumption does not increase although the drying temperature of the powder varnish is higher. Basically this new coating technology is transferable to coatings of other aluminium surfaces, e.g. luggage racks, frames, building components and others. [ABAG 2002]

4.3 Selection of the BAT Candidates

Based on the exemplary consideration of coating processes of different workpieces, the following low-emission techniques can be used for the coating and surface preparation of metal workpieces:

Use of watery-alkaline cleaning

Watery cleaning and rinsing processes can be considered as state-of-the-art for the degreasing of metal surfaces (cf. also annex II, section II.1.2).

Use of low-solvent and solvent-free varnish systems

Water-thinnable varnish systems or powder varnish systems are an alternative for conventional solvent-containing varnish for nearly all sub-sectors. For the coating of workpieces with high production numbers and without changes in colourings, the electric dip coating is a technique already established. If an electric dip coating is used for the ground coating, a top coating with powder varnish or liquid varnish with high solids contents (one component oven-drying or two component accelerated drying) is already widely common. For metal furniture, water-thinnable varnishes have significant applications [MAY 1997].

Introduction of more effective varnish application techniques

Besides the optimization of the spraying parameters (e.g. spraying air pressure, spraying angle), a variety of application techniques can be used for the coating of machines. Table 5-3 shows the achievable application efficiency factors and limitations for some application techniques. A detailed description of the itemized varnish application techniques is contained in annex III.

Table 4-3**:** *Achievable application efficiency factors and limitations of some different varnish application techniques for metal workpieces* [CORLEY 1991]

Technique	**Application efficiency factor [%]**	**Suitable varnish systems**	**Geometry of the workpiece**	**Other limitations**
Compressed air spraying	20 – 65	One part, two part	No limitation	-
Airless	40 – 80	One part, two part	Big, simple	-
Airmix	35 – 75	One part, two part	Big, simple	-
HVLP	45 – 65	One part, two part	No limitation	-
Electrostatic assisted compressed air spraying	50 – 80	One part, two part	No Faraday cage	Electrically conducting materials are necessary
Electrostatic assisted airless spraying	45 – 85	One part, two part	No Faraday cage	Electrically conducting materials are necessary
Electrostatic Assisted airmix spraying	40 – 80	One part, two part	No Faraday cage	Electrically conducting materials are necessary
Rolling	Nearly 100 %	One part	Flat, sheet-like	-
Casting	Nearly 100 %	One part	Flat, sheet-like	-
Flooding	85 – 95	One part	Non-scooping	High solvent losses
Dipping	75 – 90	One part	Non-scooping	High solvent losses
Powder with electrostatic spraying technique	50 – 95	powder	No limitation	Electrically conducting temperature resistant materials are necessary

4.4 Proposal for the Best Available Techniques

The following techniques are especially progressive techniques for the coating of metal surfaces and are available for the most applications. These varnishing techniques are efficient with respect to the utilization of the varnish whereas the environmental impact is minimized.

Coating of Steel Surfaces:

- Aqueous cleaning and rinsing processes with integrated water-saving measures such as circuitry of the rinsing media,
- cataphoretic dip coating with subsequent top coating with liquid or powder coats if necessary,
- low-solvent liquid varnish systems,
- coating with powder varnish including powder overspray recycling,
- application techniques low in overspray combined with recovery of liquid varnish overspray.

Coating of Aluminium Surfaces:

- Chromium-free pre-treatment,
- Aqueous cleaning and rinsing processes with integrated water-saving measures such as circuitry of the rinsing media,
- Coating with powder varnish or a combination consisting of powder and water-thinnable varnishes.

For the coating of rims, the solvent emissions per rim can be reduced by 90 %, the varnish waste by more than 85 % and the varnish consumption by more than 10 %. The energy consumption remains constant compared to the conventional process.

4.5 New Progressive Techniques

A tendency towards a reduction in workpiece complexity can be observed. This means that increasingly pre-coated sheet metals are purchased and re-formed. The first applications can be observed in the household appliances sector by the use of coated coils [GRUPP 1999].

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5 Coil Coating

The metal surfaces to be coated are rolled coils that are further processed in the coil and sheet metal processing industry such as in the construction-, vehicle-, appliance-, iron-, sheet metal- and metal products industry. The most important substrates are aluminium in its pure form or as alloy together with magnesium and manganese as well as steel or steel with metal coatings made of zinc and zinc alloys (seldom not zinc-coated steel) [MEUTHEN 2000A].

5.1 General Information

5.1.1 Structure of the Coil Coating Industry and Plant Locations in Germany

The coil coating industry is characterised by big enterprises with integrated installations and typically their own further processing (especially in the steel industry) as well as mid size enterprises with comparably small, slow installations and often a very specialised product range (cf. table 5-1).

Continuous coil coating belongs to the processes with significant growth rates, because it provides an economic coating technique for sheet metal for the further processor and also generates low emissions. This usually makes coating processes for the further processor unnecessary, including pre-treatment, storage of coatings, testing laboratory, disposal of wastes etc. Markets for coil-coated metals can be found predominantly within the following branches [MEUTHEN 2000A].

- Construction industry (building parts for roofs and walls, garages, gates, doors and separating walls, shutters)
- Appliance industry (such as bigger electric appliances for household use, shells of audio-equipment and video recorders)
- Vehicle industry (passenger cars, commercial vehicles, mobile homes, caravans)

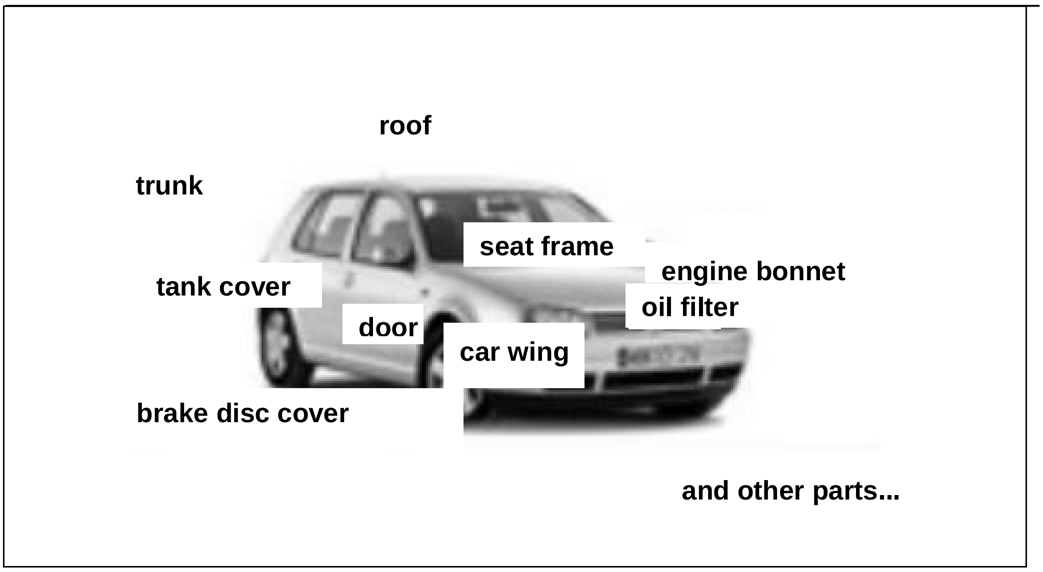

Figure 5-1**:** *Coil coating applications in vehicle construction* [ECCA 2000]

Table 5-1*:Locations of coil the coating installations in Germany* [MEUTHEN 1998]

Enterprise	**Installation**	**Metals**	**Coatings**
Concerns			
EKO Stahl	Eisenhüttenstadt	Steel	Varnish/foil
Salzgitter Flachstahl	Salzgitter	Steel	Varnish/foil
	Salzgitter	Steel	Varnish/foil
Thyssen Krupp Stahl	Duisburg	Steel	Varnish/foil
	Duisburg	Steel	Varnish/foil
	Kreuztal-Eichen	Steel /aluminium	Varnish/foil /metal
	Kreuztal-Ferndorf	Steel /aluminium	Varnish/foil
Alcan Deutschland	Göttingen	Aluminium	Varnish /metal
	Lüdenscheid	Aluminium	Varnish /foil
	Nachtersted*	Aluminium	Varnish
Alcan Singen	Singen	Aluminium	Varnish
VAW aluminium	Grevenbroich *	Aluminium	Varnish
	Grevenbroich *	Aluminium	Varnish

Enterprise	Installation	Metals	Coatings
Medium-sized enterprises			
HFP Bandstahl	Bad Salzungen*	Steel /aluminium	Varnish
Ewald Giebel	Hagen-Hohenlimburg	Steel /aluminium	Varnish
Helmut Lingemann	Wuppertal	Aluminium	Varnish
Hühoco Metalloberflächenveredelung	Wuppertal Wuppertal	Steel/aluminium Steel/aluminium	Varnish Varnish
Klaus Stahl Industrielackierungen	Schifferstadt	Aluminium	Varnish
Rudolf Wiegmann Metallcolor	Bersenbrück	Steel/aluminium	Powder

* combined installations: Combination of zinc-coating and coating with organic paints (steel) or soft annealing and coating with organic materials (aluminium)

In Germany, the rating amounts about 1.2 million tons of coated steel and aluminium. Estimations for the year 1999 give scales of 800000 tons and 200 million square meters of coated steel and aluminium surfaces for Germany. This represents a share of about 20% in Western Europe [MEUTHEN 2000A].

In table 5-2 the amounts of coil coated metals produced in Western Europe are listed. The figures of the year 2000 show an increase of 17 % compared to the year 1999 with respect to surface area and weight. However the amount of processed coatings does not follow this trend, because thin film coatings are increasingly used (especially in vehicle construction) [MEUTHEN 2001A].

Table 5-2: *Quantity of coil-coated metals delivered in Western Europe in 1999 [Meuthen 2001b]*

Metal	Surface area [mio. m^2]	Weight [mio. t]
Steel	969	4.48
Aluminium	284	0.39
Total	1.25	4.88
Compared with 1998	+ 17.2 %	+ 16,6 %

In table 5-3 the amounts of coatings, used for coil coating in Germany over the last 3 years are listed. In the year 2000, about 65% of the coatings were used in the building industry. The remaining 35% were used for other industrial applications. An increased need of the industrial sector can be observed for the same year: The use of coated coils for household appliances has increased significantly. Also in the vehicle construction industry, an increasing use of pre-coated aluminium parts and zinc-coated sheet metals such as mounting parts (e.g. car wings) and spare parts (e.g. oil filters) can be observed. Leading automobile producers have decided to use thin-film-coated sheet metals also as replacement for secondary corrosion protection measures (for cavities, beadings and flanges). At present, coated coils are also already in use for superstructures of trucks and mobile homes/trailers (cf. chapter 3) [CHEM 2000].

Table 5-3: *Amounts and developments in national demand for coil coatings in Germany* [CHEM 2000]

Year	Varnish amount [t]	Annual increase [%]
1998	19 000	+3,6
1999	20 500	+7,9
2000*	21 800	+6,3

* estimated

A representative capacity of installations cannot be given here due to differences in aluminium and steel processing and the mixture of techniques within a single installation.

5.1.2 Requirements for Coil Coated Products

Corrosion protection and the optical surface quality have a predominant meaning for the coating of steel and aluminium. According to [DIN EN 10169-1], the following properties are required:

- Aesthetic characteristics such as colour and brilliance;
- hardness of the coating;
- adhesion;
- extension capability and flexibility;
- durability, means resistance against chemical influences or outdoor exposure.

5.1.3 Legal Requirements for the VOC-reduction

Emission limits for waste gases according to the German 31. BImSchV are listed in table 5-4.

Table 5-4: *Emission limits in coil coating according to 31.BImSchV*

Emission limit for captured and treated waste gas [mg C/m^3]	**Emission limits for diffuse emissions [mg C/m^3]**	**Emission factor for determination of the allowed maximum total emission* per processed solid material**
20 (after treatment with post-combustion)	New installations: 3 % of the used solvents old installations: 6 % of the used solvents until 2013	0,2
75 downstream from a solvent recovery installations		

*Total emission = Sum of processed solid material multiplied with the emission factor. All German installations are equipped with thermal combustion units and thus achieve waste gas limits of 20 mg C /m^3.

5.2 Applied Processes and Techniques

Coil coating is a technique where rolled sheet metals are coated continuously (organically). This technique includes cleaning (if necessary) and chemical preparation of the metal surface as well as the application of fluid or powder coating materials followed by film formation under heat impact. The wet lacquer or powder coating application can be carried out on one side or on both sides in one or more process steps [DIN EN 10169-1, DIN En 1396]. The lamination with plastic foils that can be used alternatively is not considered in this context.

At present, coils of up to 2700 mm and 1850 mm in width can be coated for aluminium and steel, respectively. However, also products originating from narrow band installations are an important business section: Applications such as for shutters, for baking appliances or for materials made of rubber and metal composites have to be cited. Most of the installations for flat products are designed for a metal thickness of up to 1,5 mm. However an extension for a thickness up to 3 mm can be observed. The coil velocity amounts between 15 and 200 m/min with an average speed of 60 - 95 m/min. The slowest installations are the powder coat installations[1], whereas the quickest ones are operated by the aluminium industry [MEUTHEN 1998].

5.2.1 Process Flow

Coil coating is a linear process (cf. figure 5-2), where conserving or decorating organic coating materials are applied onto flat metal bands. Afterwards, they are winded up as rolls or coils. Although the technical structure of coil coating processes varies depending on the installation, all techniques have a common procedure that will be described in the following [RENTZ 1999, BROCK 1998].

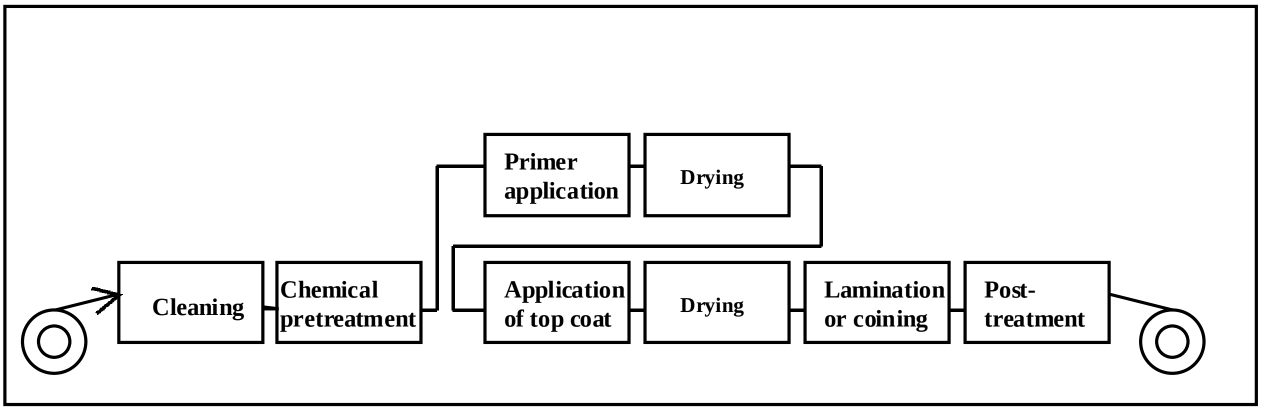

Figure 5-2**:** *Simplified coil coating process* [ECCA 2000]

In all newer installations, the solvents emitted during the coating processes are treated in a thermal combustion units together with the dryer’s exhaust gas. Nowadays, the use of the waste heat (e.g. for heating of the dryer’s air supply or for heating of water for pre-treatment) is state-of-the-art. For a reduction of diffuse emissions, the application devices for varnish are encapsulated [MEUTHEN 2001].

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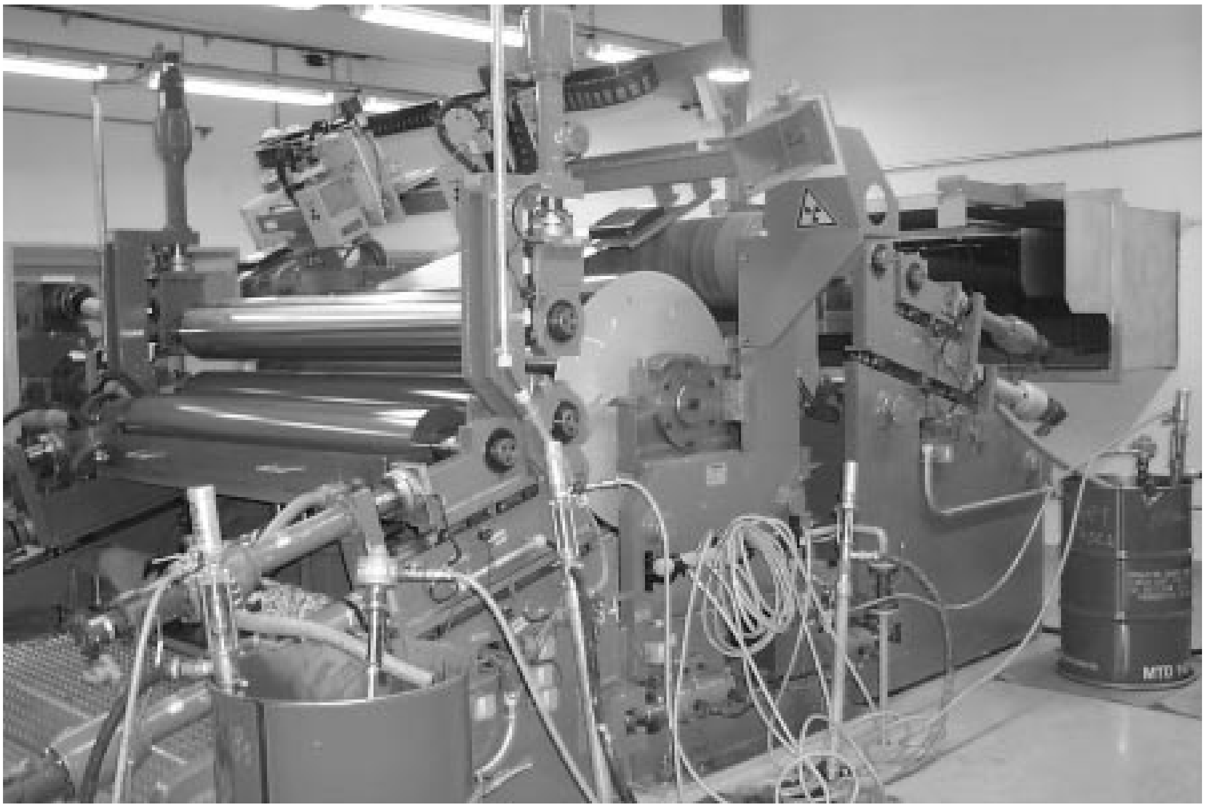
[1] Powder varnishes cannot be applied via the rolling technique

Fig 5-3 shows a coil coating varnishing station with varnish barrels out of which the paint is provided. On the right side the exit of the coated coil towards the oven fissure is shown.

Figure 5-3: *Coil coating installation* [Meuthen 2001]



5.2.2 Cleaning and Chemical Preparation of the Metal Surface

The coil is unwinded at the entrance of the coating line. It is leaded through a wet zone, where the metal surface is cleaned first. Afterwards, the chemical preparation is carried out. This is **predominantly an alkaline passivation and chromating (seldom phosphatization)** depending on the carrier material. Increasingly chromium-free surface preparation techniques are used also in the so-called no-rinse technique (roller application). The pre-treatment via spraying, plunging and rolling methods serves as a corrosion protection and prepares the surface for the subsequent coating. Before the coating, the metal band is dried [MEUTHEN 2000A]. As an upgrading for certain products, the cleaned coil can be electrolytic zinc-coated, after acid cleaning with sulphuric acid followed by a rinsing as pre-treatment. The zinc-coated coil can be further coated with varnishes, creating so-called duplex systems.

5.2.3 Conventional Coating of Metal Surfaces

The application of coatings within the coil coating process is carried out with rollers almost exclusively. Predominantly, solvent-containing coatings are used. The substrates are coated one-sided or double-sided and with one or mostly two layers, occasionally with up to four layers (with a twofold installation passage). Dry film thickness ranges between 3 µm (so-called thin-film coating) and 200 µm per top surface however mostly they are around 25 µm thick. Afterwards, the coated coil is transported into a circulating air dryer, where the varnish layers are dried and cross-linked. Typical object temperatures range between 200 - 260 °C [MEUTHEN 2000A]. As soon as the coil leaves the dryer, it is cooled by water jets and dried again.

In two-layer installations, a ground coat is applied first before the top coat application is carried out.

The top coat is also dried and cured in an oven. Before being processed to coils and being packaged for delivery or further processing, the coil is cooled and dried again.

5.2.4 Powder Coating

At present, there are six powder coil coating installations in operation in Western Europe.

One of them is located in Germany [MEUTHEN 2000C]. The powder coil coating installations are equipped with electrostatic spraying guns and infrared dryers. An application with a roller technique is not feasible. The processing velocity is limited to 15 m/min. Predominantly, powder varnishes based on polyester are used. Due to the limited selection of varnish materials, only a small variety of surfaces can be created. The powder varnish technique can only generate a layer thickness of more than 30 µm. Conventional coatings for technical applications generate a layer thickness of less than 1 µm [MEUTHEN 2000A]. Post-combustion installations are not necessary, because no or very low emissions of organic compounds are generated.

5.2.5 Further Processes and Surface Post-Treatment

The following further treatments of the metal surfaces can be realized [FILTHAUT 2000]:

- Lamination with plastic foils
- Decorative impressing of polyvinyl chloride plastisol layers

- Application of peelable protection foils if special stresses during transport, storage or processing have to be expected. This is predominantly carried out adhesive-free by hot lamination.

In some cases, the coated coils can also be waxed or oiled. The applied oil or wax has to be removed via cleaning agents, before a further processing at the customer takes place [DIN EN 10169-1].

5.2.6 Applied Coating Materials

In the coil coating sector, solvent-containing varnish systems are used almost exclusively (see table 5-5). The varnish systems are based on polyester and polyurethane (or combinations of both), epoxy resin and polyvinyl diene fluoride (PVDF). For a creation of special surfaces, coatings with thermoplastic foils based on polyvinyl chloride, polyvinyl fluoride (PVF) and polyolefines are carried out where heat-activated solvent-containing adhesives are used. Also weldable, metal pigmented ground coatings and other designs are feasible. As the coil coating industry is very homogenous in Europe, these figures are also valid for Germany. An increasing application of thin film coatings especially in the vehicle industry as well as a decrease in the use of polyvinyl chloride plastisols can be observed [MEUTHEN 2000B].

Table 5-5: *Composition of applied top coat systems for coil coating of metals in Western Europe in 1999* [MEUTHEN 2000B]

Varnish system	**Share of total production [%]**
Polyester, polyester/polyurethane	62
Polyvinyl chloride plastisol	30,5
water-based varnish	0,2
Others	7,5

The coating statistics show that only 0.2 % of the applied top coat systems in Western Europe are water-based. The proportion of foil coated metals of total delivery is about 6%. Over the last years, the combination of liquid coating with transparent coating of foils has increased in significance especially in the production of household appliances.

The solvent-based coatings currently applied have a solids content of 30 - 70 % weight per cent [MEUTHEN 2001]. The layer thickness amounts up to 60 µm for systems based on acrylate, epoxy, polyurethane or polyester. For plastisols a layer thickness of up to 200 µm is typical. For powder coating systems, a common layer thickness of 30 - 100 µm is achieved [DIN EN 10169-1].

5.3 Current Consumption and Emission Values

5.3.1 Consumption of Raw Materials

An installation is described exemplarily in annex VI.

In Germany, about 22,000 tons of solvent-containing liquid coatings were approximately applied in 2000 [MEUTHEN 2000A]. In big installations, a few 100 kg of solvents are applied per hour. The threshold values, specified in the Directive, are therefore exceeded by far.

Varnish application by rolling has an efficiency of almost 100%, because the surplus coating material of the varnish tub is recycled completely [FILTHAUT 2000]. Specific varnish consumptions, depending on the amount of coated coil, are summarised in table 5-6. An average layer thickness of 0,5 – 0,6 mm is assumed. Due to the various coating systems and layer constructions, these statements represent only a rough approximation.

Table 5-6: *Varnish consumptions in dependence on the coating system* [MEUTHEN 2000]

Coating system	**Varnish consumption coefficient [g / m² Band]**
Coating system based on organic solvents (solvent proportion 50 weight per cent)	32 – 53
Powder varnishes (solvent-free)	11 – 32

5.3.2 Emissions into the Atmosphere

Especially during the process steps coating (approx. 8%), drying (approx. 90 %) and deterring with water (approx. 2 %), of the processed solvents are released as VOC emissions. [RENTZ 1999]

Table 5-7 shows specific VOC emission values for different technique variations and an average coil thickness of 0,55 mm. Due to different coating systems and different layer constructions, these data represent only a rough approximation. All installations in Germany are equipped with thermal post-combustion units; the solvent-loaded exhaust gas of the dryers is lead to the integrated thermal post-combustion and treaded. Hence VOC emissions are low [FILTHAUT 2000, MEUTHEN 2000A]. About 0,12 kg solvents are emitted per kg of used varnish solids for a varnish with a solvent proportion of 75 %. This is the case if only 3 % of the emissions are fugitive and if 97 % of the VOC emissions are lead to a post-combustion unit with an efficiency factor of 99 % .

Table 5-7: Emission coefficients for VOC emissions

Utilized coating technique	**Specific VOC-emissions [g/m² coated coil]**
Varnish system based on organic solvents (solvent proportion 50 % per weight) without exhaust gas cleaning	28 – 29
Varnish system based on organic solvents and post-combustion coupled with the enamelling stove (state-of-the-art)	0,73 – 0,84
Powder varnish (solvent-free)	0

5.3.3 Wastewater

Wastewater is generated by degreasing, passivation and chromatization [Brock 1998]. Chrome-free preparation techniques have an increasing proportion also with the so-called no-rinse method (application by a roller technique). The latter technique does not generate wastewater.

5.3.4 Wastes

Solvent-containing cleaning agents are used for cleaning of the coating devices. They can be collected and treated externally for re-use. Further varnish leftovers are generated in small amounts and can be treated externally or used for coating of the coil’s back side.

5.3.5 Energy Consumption

For the utilisation of thermal post-combustion units, heat recovery represents the state-of-the-art [Meuthen 2001].

5.4 Determination of the BAT Candidates

5.4.1 Application of Solvent-containing Varnishes and Cleaning of Exhaust Gases

In Germany all existing coil coating installations that process solvent based paints, are equipped with a post-combustion [Rentz 1994]. The recovered energy is used for the heating of the pre-treatment baths and the varnish installations. A description of the post-combustion techniques can be found in annex V. Catalytic post-combustion installations are not in use. The application booths as well as the zones that serve for cooling of the coils are sealed in order to reduce diffuse emissions and to avoid dust inclusions. Further, the dryers subsequent to the application installations are operated with under-pressure, so that a release of VOC emissions from the installation is prevented of principally. These waste gas is treated in the combustion unit. The efficiency factor of the exhaust gas cleaning amounts more than 99 %. Clean gas concentrations with a load of < 20 mg C / m³ are achieved [Meuthen 2001]. In new installations, the diffuse emissions amount only 3 % of the processed solvents. With respect to the solids content of the used paints, VOC-emission values of 0.2 kg/kg are undershoot.

5.4.2 Application of solvent-free Varnish Systems and Paints with a low Solvent Content

Presently the only substitution alternative is the application of powder coatings. The utilisation of water-thinnable paints for the coil coating is complicated. Presently it is clear that High-Solid varnish systems are not expected to achieve a high significance.

Application of Powder Varnishes

Powder varnish installations allow coating of aluminium and steel surfaces up to big widths. The existing installations are according to a conventional type of construction, however the coating velocity is limited to 15 m/min. This low metal flow is besides the limited variation in producible surfaces and besides the high layer thickness a reason that a supplement or changeover to powder varnishes is not feasible for conventional installations at present. Hence the production costs are higher [MAGGIORE 2000]. Chemical pre-treatment of the surface is analogical to the application of solvent-based varnishes. Drying or curing is carried out by a combination of infrared and circulating air drying. Object temperatures of 180 - 250 °C are achieved. The curing process is completed within 1,5 minutes. Coating systems are powder coatings based on polyester. Application is carried out one-sided and with one layer with a typical layer thickness of 50 to 60 µm. A two-sided powder coating is an exception [MEUTHEN 2000C].

This technique is especially used by the construction sector, e.g. for flat panels, window frames, sanitary cabins and by the sheet metal processing industry (computer enclosures and others).

Application of Water-based Coating Systems

The application of water-based varnish systems represents a possibility for abatement of VOC emissions on principle. However, water-thinnable varnish systems are not applicable for a wide-range use. If water-thinnable coatings are used, the application is mostly limited to ground coating. The processed water-thinnable paints do not exceed 0,2 % of the total varnish consumption in any German installation [ECCA 2001].

5.5 Proposal for the Best Available Techniques

The following combination can be recommended as best available technique for the coil coating:

- Use of the wastewater-free no-rinse techniques for the surface preparation

- The application of solvent-containing varnish systems combined with a subsequent thermal post-combustion. Thus cleaned gas concentrations are less than 20 mg C /m³ and the fugitive emissions are limited to 3 % of the used solvents. The VOC-emission limit amounts less than 0,2 kg / kg solids.

5.6 New Progressive Techniques

Powder Coatings

For the future, alternative application techniques for powder coating are imaginable. This way, significant higher coating velocities could be achieved. [Alfort 1999]. However, the critical step in the powder coating of coils is the melting phase, in order to achieve a good coating result.

Water-based Varnish Systems

Presently, the development at the varnish producers with respect to the use of water-thinnable varnish systems is only limited to the development of varnish systems for the application of thin-film coatings for the vehicle varnishing sector.

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6 Varnishing of Packings

6.1 General Information

In this chapter, the varnishing of beverage cans is described as a subsection of the packings industry. Due to different processes, the varnishing of barrels and of beverage cans have to be differentiated. The lacquer finish of barrels,, is not comparable with the lacquer finish of beverage cans, since the barrel lacquer finish varies depending upon the barrels size and special filling material requirements (chemical resistance, food contact) much more than processes and materials utilised for the varnishing of beverage cans. It was not possible to obtain data for the lacquer finish of barrels. Thus the processes utilised for the varnishing of beverage cans are described in the following. Besides high optical surface qualities also food regulation requirements have to be fulfilled by the used materials.

For the exterior finish, printing and also the interior finish of beverage cans, water-thinnable paints are available. However these products contain organic solvents for workability reasons.

For the production of beverage cans the materials *aluminium* and *tinplate* are processed and have to be differentiated. The plants for the production of beverage cans have a production capacity of approx. 2 Mio cans per production line and day [VMV 2001].

Generally the applied paint- and printing system regarding material basis, layer-thickness and layout is determined by the customer (beverage producers).

Table 6-1**:** *Emission limits for new installations, according to 31. BImSch*V

Emission value for extracted and treated waste gas [mg C/m³]	Emission value for diffuse emissions	Emission factor for the determination of the maximal permited total emission* per used solids
20 mg C_{total}/**N**m³	20 % of the utilised solvents	0,375

*total emission = sum of utilised solid material, multiplied with the emission factor

6.2 Production of Beverage Cans made of Tinplate

The production of beverage cans made of tinplate was examined at two member enterprises of the Verband der Metallverpackung e.V. The data of the case studies are listed in annex IV (plant A, B).

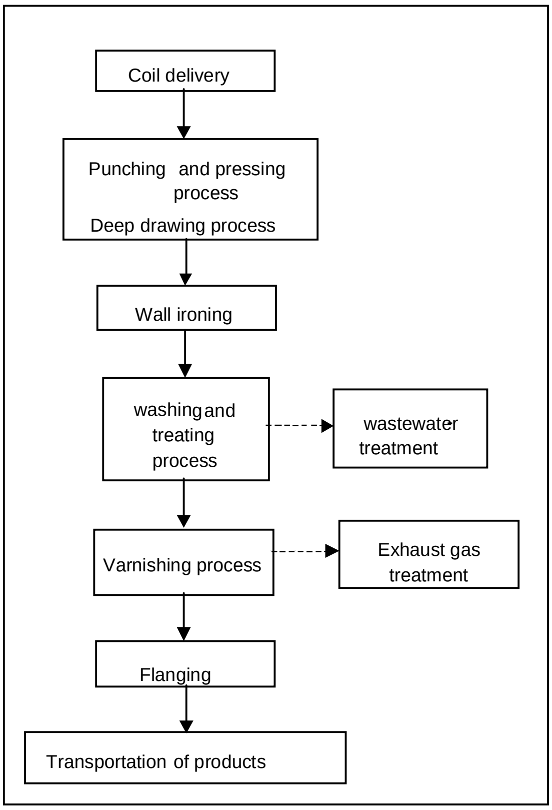

Figure 6-1: *Production process for beverage cans* [VMV 2001]

6.2.1 Utilised Processes and Techniques

In the production of tinplate cans the lids and the beverage can-body are partly produced in spatially separated installations due to logistic reasons. The lid is generally made of completely coated aluminium (coil coats). Therefore an additional varnishing is not undertaken at the beverage can producer. The beverage cans are made of electrolytic galvanised coil coats (tinplate) via deep-drawing and subsequent wall ironing. During the wall ironing process, the wall thickness is reduced within several steps. Before the varnishing takes place, the cans are cleaned from the deep-drawing emulsion via alkaline- or aqueous cleaning agents. Subsequently drying takes place. The generated waste water from the washing processes are generally treated and conducted into the waste water channel. The oil from the deep-drawing emulsion is cleaned from particles via several filters and is re-used within the process **[VMV 2001]**.
The varnishing of beverage cans consists of the application of exterior paint and subsequently of interior paint. In between the application of exterior- and interior varnish, the printing of the beverage can body takes place. The printing is applied via the offset-process[1]. Due to changing orders, several hundred decoration changes per year take place. Like the complete production process, also the paint application is carried out automatically. The interior finish is applied via compressed air spraying. The exterior paint is applied via roll coaters. The overspray is separated dry in filters. The paint materials are water-thinnable. For an improved workability they contain 15 – 45 % of organic solvents. The interior lacquer contains approx. 10 – 15 % of organic solvents. The applied layer-thickness amounts approx. 2 – 3 µm.

For a reduction of the material consumption for the exterior varnish, the can is printed directly via the offset-process and then coated with a thin layer of overvarnish (clear coat) for a protection of the print. The printing ink contains approx. 18 - 38 % of organic solvents [VMV 2001]. In newer installations engraving rollers are utilised for the application of the printing ink. The amount of organic solvents from printing inks have to be considered for the calculation of the threshold values defined by the IPPC-Directive.

Drying of the applied paint layers takes place in convectional dryers at temperatures of 180 – 200 °C. The VOC-containing exhaust gases from dryers and also paint application units are generally treated via regenerative, thermal combustion (cf. Annex 5). The process heat can be used via heat exchangers e.g. for the washing process [VMV 2001].

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[1] For more informations about printing, confer volume „Integrierter Umweltschutz bei bestimmten industriellen Tätigkeiten- Anlagen zum Imprägnieren, Apperetieren, Bedruckern, Beschichten, Tränken

6.2.2 Present Consumption- and Emission Values

Material Consumption

The solvent consumption of the investigated installations (plant A and B, annex IV) depends on the design and the filling (beverage) and amounts approx. 0,0072 kg per coated m² of tinplate. The capacities amounted approx. 100.000.000 m² resp. 120.000.000 m², in the year 2000. Thus maximal 670 t resp. 864 t of organic solvents from paints, printing inks were processed. The consumption depends on the plant's operating hours, the plant's permission and the production quantity and the size of the produced cans.

Emissions into the Atmosphere

Due to an extraction and treatment via regenerative, thermal combustion of exhaust gases from printing machines, paint applications and dryers units, the amount of VOC-emissions is relatively low. The efficiency (C-exhaust gas compared to C-clean gas) of the exhaust gas cleaning amounts more than 99 % [VMV 2001, Mehlis 2001]. The mass flow of total-C in the clean gas (after the thermal regenerative combustion, amounts 0,6 – 1,2 kg/h. Clean gas concentrations of < 20 mg C_{total}/Nm^3 are achieved.

VOC are mainly emitted in form of diffusive emissions from e.g. transport processes, conveyor systems or at the withdrawal of dryers. From the investigated plants approx. 31 – 47 t VOC per year were emitted as diffuse emissions.

Wastewater

Waste water is generated from the pre-treatment processes. The concentrations of tin result from the washing of the deep-drawn cans, made of tinned tinplate. After precipitation and flocculation the concentrations of tin amount < 2 to max. 4 mg / l, (MKW's $\leq$ 20 mg/l depending on the local statue).

Waste

Significant wastes from the production process include:

- Paint sludge from cleaning of installations
- Cleaning solvents
- Contaminated filters from the separation of overspray and cleaning of the deep-drawing emulsion

The amount of waste originating from containers, can be reduced significantly by the utilisation of re-usable containers (for varnishes, printing ink paint and oils). Smaller layer-thickness (varnish) and wall-thickness (tinplate) results in a lower amount of waste and material consumption.

6.2.3 Determination of the BAT-candidates

For the production of beverage cans made of tinplate, nowadays mainly water-thinnable varnishes are processed. For an improvement of the workability, these materials contain organic solvents. At present no solvent-free materials are available [VMV 2001]. For a reduction of VOC-emissions, efficient exhaust gas cleaning devices are installed in the plants. Thus a further reduction of VOC-emissions can only be achieved by a minimisation of diffuse emissions and via a reduction of material consumption of paints and printing inks.

Diffuse VOC-emissions can be reduced by an improved encapsulation of plant components and an extraction and treatment of exhaust gases, especially from the entrance and withdrawal areas of the dryers (for drying of the interior varnish). For an economic treatment of these exhaust gases with a low VOC-concentration adsorption wheels (filled with charcoal) with a subsequent thermal combustion unit can be utilised.

With the implementation of the over-varnish-technique, the use of solvents can be reduced by approx. 10 %. Also the recycling of cleaning solvents represents the state of the art. A recycling of overspray from the spray application of the interior and bottom varnish can be used.

6.2.4 Proposal for the BAT

- Application of water-thinnable paints and the application of regenerative, thermal combustion units for exhaust gases from dryers and plant components for the application of paints and printing inks. For a concentration of exhaust gases with a low VOC-content, adsorption processes can be utilised (cf. chapter 7.3.1). Thus concentrations in the clean gas of $\leq$ 20 mg Cges / Nm^3 can be achieved. According to the 31. BImschV, the maximal VOC-emission per processed lacquer solid is limited to 0,375 kg.

- Application of engraving rolls for a reduction of printing inks.

- Application of the overvarnish-technique for a reduction of exterior paint.

- Installation of extraction hoods at the entrance- and withdrawal areas of dryers for the interior paint.

- Recycling of overspray from spray application of the interior varnish.

6.3 Varnishing of Beverage Cans made of Aluminium

For the production of beverage cans made of aluminium only one installation exists in Germany. Data of the production process were provided from the Verband Metallverpackungen e.V. and are documented in annex VI. (Plant C).

6.3.1 Applied Processes and Techniques

Similar to the production of beverage cans made of tinplate, also aluminium cans are varnished after the cleaning process.

Therefore a ground coat is applied onto the beverages can’s exterior via a varnishing roller. Afterwards the exterior surface of the can’s bottom is coated via rolling. Subsequently the cans are dried in a convection dryer.

After the drying the decoration is printed onto the outside surface via the offset process. Up to six different colours are applied. Additionally a overvarnish (clear coat) can be applied. After the printing ink is dried in a (temperature-controlled) convection dryer.

Subsequently the interior varnish is applied via compressed air spraying. The drying also takes place in a convection dryer.

For the varnishing water-thinnable paints with an average content of organic solvents of 12 - 16 % are processed. The varnish, used for coating of the can’s bottom, contains approx. 33 % of organic solvents. During the production process, the VOC-containing exhaust gases from the application processes of printing ink and paints are extracted and concentrated via an adsorption wheel. After desorption, the VOC are treated via thermal combustion. VOC-containing exhaust gases from dryers are extracted and directly treated in the thermal combustion unit. Clean gas concentrations of less than $20mgC_{total}/Nm^3$ are achieved.

For a reduction of VOC-emissions, the same techniques as for the production of tinplate cans can be utilised.

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7 Varnishing of Furniture and Wood Materials

7.1 General Information

Wood is a natural raw material characterised by its inhomogeneity and anisotropy. Furthermore, wood is featured by irregular properties in terms of surface structures (stature irregularities), various substances of content (waxes, water, resins) and a variable electrical resistance. If wooden surfaces are varnished, the colour, the surface structure and the porosity are properties that are supposed to be conserved or strengthened concerning their effects by the varnishing process. Also it is of special significance if a closed cell or open-cell surface has to be generated. Thereby mode trends play an important role. At present, the wood and furniture industry is confronted with new requirements, as complicated product geometry and higher qualities (e.g. colour variety, new surface effects) are demanded. Thus the spray application techniques are increasingly utilised. Further the swelling and erecting of fibres under the influence of liquids (water in particular) is a substantial characteristic of wood. Due to the characteristics of wood varnishing, the experiences from other industries are only transferable in a restricted way. Therefore the necessity exists for this sector to characterise specific environmentally friendly varnishing techniques.

7.1.1 Structure of the Wood and Furniture Industry

A substantial characteristic of this industry is the strong predominance of medium-sized companies: 75 % of the enterprises have less than 100 employees. In Germany, the following enterprises exist:

- 45,000 joineries (with an average of 4,5 employees)
- 1,500 wood and wooden furniture paint shops (with an average of 75 employees).
- Approx. 8 very large enterprises with more than 1000 employees [BAUMS, HANSEMANN 2001].

In the German wood and furniture industry, more than 80.000 t of paints were processed in the year 1999. Among this amount, approx. 60 % were used in industrial applications, the remaining 40 % were consumed by handcraft enterprises. Over the last years, the processed amounts of varnishes are slightly decreasing. It is expected that this trend will also continue in the future for the following reasons: The shifting of production capacities to Eastern Europe, the increasing utilization of plastic films for the surface design, a continuing reduction of coating layer thickness and the increasing use of paints with a high solids content [CHEM 2000, VDI 3462].

It has to be stated that over the last years, the level of automation of paint application in the furniture industry has increased significantly, especially due to increasing quality-, efficiency and environmental requirements [HALLACK 2000].

A variety of materials are processed and coated in the wood and furniture industry. The following applications can be differentiated:

- Outside applications such as for example: Outer doors, window frames, garden and leisure furniture, chairs for stadiums, elements for bridges, towers, buildings.
- Indoor applications such as for example: Inner doors, stairs, wall- and head coverings, floors, furniture for offices, dining and living rooms, bathrooms, kitchen furniture, bedroom furniture, school and youth furniture and object-furniture.
- Wet applications such as for example for swimming pools or saunas.

7.1.2 Emission Limits according to the 31. BImSchV

The emission limits for varnishing of wood as specified by the 31. BImSchV are listed in Table 7-1.

Table 7-1: *Emission limits for the varnishing of wood, according to the 31. BImSchV*

Threshold value for the annual solvent consumption [t/a]	**Emission limit [mg C/m^3]**	**Emission limits for fugitive emissions [% of the solvent input]**	**Emission factor for the determination of the maximum permissible total emissions* per utilized solids input**
>25	50$^{1)}$ 20$^{2)}$	20	0,75

*total emissions = sum of utilised solids multiplied with the emission factor

$^{1)}$ for coating and drying

$^{2)}$ if a post-combustion unit is in use

7.2 Applied Processes and Techniques

Depending on the work piece's conditions of use, different requirements have to be met concerning the behaviour in use such as for example resistance against:

- Chemical impacts,
- mechanical stress,
- climatic impacts,
- staining,
- performance with respect to emissions / odour.

Test standards define a ranking of practicability in addiction to the usage of the furniture. An integrated assessment is especially important allowing for the raw wood to be painted, the staining and paint systems up to the application machines and devices. For example, the parts' geometry influences the drying and curing technique.

7.2.1 Applied Coating Materials for Wood and Wood Materials

After a pre-treatment of the wood surface, usually a ground coat and a top coat layer is applied. Depending on the desired surface structure (open or closed-cell pore structure), different paint systems are used. If the wooden grain shall be visible, as it is the case for solid wood or veneer for example, uncoloured paints (clear coats), oils and waxes are utilised. For example, MDF[1] panels are coated with pigment paints in the desired colour. If pigment paint systems are used, a barrier layer is applied before the ground coat, which restricts permeation of paint to the wooden sub-surface and effectuates a uniform paint layer [OBST 1993].

7.2.1.1 Pre-treatment

Due to irregular growth and different surface structures as well as different substances of content, a proper pre-treatment of the surface to be coated is essential. Hence the existing surface flatness, a removal of working marks, a treatment of colour differences, unevenness, fibre erections, cracks, boughs as well as the wood moisture can be allowed for. The pre-treatment techniques include mechanical working steps (e.g. sanding) as well as colouring methods such as staining, glazing or bleaching (see also [Hoffmann 2001]). For some special kinds of wood, also chemical cleaning processes with soap solutions, ammonia or organic

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[1] [1] MDF (Medium Density Fibreboard) is a wooden derivative received of strongly pressed material based on short wooden fibres and glues. This substrate is cheap and relatively temperature resistant. These panels are increasingly used in there furniture industry.

solvents have to be utilised besides the sanding technique e.g. for the disposal of paint incompatible wood substances of content (resin, wax) [OBST 1993, HOFFMANN 2001].

Mechanical Pre-treatment: Intermediate Sanding

Aiming on ideal paint results wood and wooden base materials need an intermediate sanding after the application of ground coat or staining or other paint layers, since an erection of wood fibres is caused by the interaction with fluids. This kind of napping of the wooden surface is especially significant when water-based paint systems are used. (cf. also [OBST 1993]).

Staining

Staining changes the colour of the wood basically towards a darker colouring. The wooden structure and the pore structure remain, respectively. Depending on the applied type of staining the drying time varies considerably.

Stains are suspensions of pigments in water or organic solvents. If chemical stains such as for example one-part positive stains are used, the residence time has to be regarded. If water-thinnable stains are processed, the swelling phenomenon (napping) has to be allowed for. Partly also combinations of water-miscible organic solvents and water are used (combi-stains). The traditionally applied stain is a water-thinnable material. However in the industrial sector, water-thinnable material has been substituted by solvent-based stains in order to reduce the drying time. Also the napping by the contained water is decreased. The composition of different types of stains are listed in Table 7-2.

Table 7-2*: Composition of wood stains*

	Water content [%]	**Content of organic solvents [%]**	**Proportion of pigments [%]**
Water-thinnable stain	95	0	5
Solvent-based stain	0	95	5
Combi-stain	70-65	25-30	5

The application is either carried out manually (with sponge, brush, rolls, spraying) or automated (automated spray applications, rolling, foam rubber rolls). Subsequently, the drying at ambient temperature or in convection dryers, flat dryers or jet dryers takes place.

Glazing

Originally a glaze is a transparent paint or grounding which is only slightly coloured for allowing a maximum of translucence of the wooden surface whereas having only a small change in colouring. Modern glazes are high liquid wood covers based on lacquer resins. The materials show a good penetration of the wood and often contain water repellents and fungicide ingredients for improvement. They can be colourless or pigmented with different colourings. Different materials are used for outdoor- and indoor usage. Glazes without fungicides as well as colourless wood glazes are only suitable for indoor usage.

Bleaching

In general, bleaching brightens the wood colour. Sometimes it is necessary to bleach several times, for example if maple is used. For bleaching, hydrogen peroxide (30-35 %) and several additives are used. The impact time has to be adjusted to the desired effects. As bleaching splits off oxygen, a sufficient drying is necessary in order to avoid blistering. Bleaching is also used for wood with non light-resistant colourings such as cherry or rosewood. After bleaching, a staining with highly light resistant pigments is used to reproduce the original wood colouring. If PUR varnish systems are used, the curing agent has to be peroxide-resistant.

7.2.1.2 Ground Coat Application

As ground coat, a material suitable for sanding is applied. The application techniques include:

- Spraying (manually or automated; airless, air assisted airless (so called airmix) and electro-statically assisted)
- Casting
- Rolling (e.g. UV curing lacquer suitable for rolling)
- Dipping (only for special workpieces).

After drying, sanding (with appropriate grain size) takes place before a colourless ground coat is applied. Afterwards the surface is sanded again before a top coat paint system (with the required matting level) is applied. In some cases, a wooden structure is printed directly onto the ground coat. As substrate mainly simple veneers are processed or the surface to be coated consists of coloured ground coat/stopper.

7.2.1.3 Top Coating

For coating of wood and wood materials varnishes, foils or other panel-like coating materials[2] as well as textiles or leathers are used.

In the following, the processed varnish materials will be described shortly.

Nitro Cellulose Paint NC (Cellulose nitrate CN)

Nitro cellulose paint is a classical solvent-based furniture paint consisting of cellulose nitrate, resins, plasticizers, organic solvents and additives. The solvent proportion amounts approx. 70-75 %. Drying is carried out physically. The drying period is very short. Light resistance and resistance against diverse media is restricted.

Acid Curing Paint (SH)

Acid curing paints are used as 1 or 2 part varnish systems. The respective compounds include: Film forming agents, reactive urea resins, melamine resin, artificial resins (partly alkyd resins), plasticizer, additives and organic solvents. The curing is based on physical or chemical mechanisms. In addition to evaporation of organic solvents, the urea resin is part of a chemical reaction with the acid compounds. Due to the condensation reaction, low amounts of formaldehyde[3] are split off. The resistance against different media is high. In Germany this type of paint is only used in small volumes.

Polyurethane paints (PUR)

This material is processed in form of a 2-compound paint. The components are reactive resins, organic solvents, film forming agents and additives. Drying is carried out physically/chemically. By adding of the curing agent (polyisocyanate), the material cures through an addition reaction. There are no splitting products. Resistance (against light, climate and against media) is high. Wood substances of content (e.g. resin-like compounds) that may interfere drying and curing are well isolated against chemical diffusion. The proportion of organic solvents amounts between 30 and 70%.

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[2] High Pressure Laminate, HPL

[3] In Europe, formaldehyde-free paints are available however these products contain organic solvents

Unsaturated Polyester Paints (UP/UPE)

Two different types can be differentiated:

- Open-cell UP materials with a solvent proportion of approx. 60 - 70 %. An addition of curing agents (organic peroxide) and accelerators) (organo-metallic compounds) is essential for the curing process. The drying is carried out physically/chemically.

- Thick-film-layer systems: The reactive polyester resin is dissolved in an reactive organic solvent (styrene). Due to chemical reactions (polymerisation) a high proportion of the styrene is polymerised. The curing component consists of organic peroxide and the catalyser component of an organo-metallic compound. The drying carried out by chemical reactions.

Approx. 12 – 15 % (referred to the varnish amount) of the organic solvents are emitted depending on the processing conditions. The curing reaction can also be initiated by energy-rich radiation (ultra-red or ultraviolet radiation). In this case no curing agents are necessary however a photo initiator has to be added. UV-curing varnish types have been in use for several years.

Water-thinnable Paints / Hydro Paints (WL)

In general, these materials are aqueous dispersions based on acrylate, polyurethane or polyester. Co-solvents (organic solvents) are contained with a proportion of 7%. Main components are film forming agents, dispersing agents, additives, water and organic solvents (co-solvents). The drying can be carried out physically e.g. for conventionally drying water-based paints or by a combination of chemical/physical processes: 2-component PUR paints cure by an addition reaction and UV-curing polyester flatting varnishes cure by a polymerisation reaction. For processing, the medium film forming temperature must be kept.

Powder Coatings (PL)

These materials are coating powders generating a varnish after application and fusion. The film-forming phase of the powder coatings consists of binders, curing agents, fillers, pigments and additives like the solvent-containing varnish systems. Main components are thermal-reactive plastics forming the duromer paint layer after burning-in. Powder coatings are applied via electrostatic powder spraying (EPS). Subsequently baking takes place and the material cross-links chemically to a film after melting of the powder layer. For melting of the electrostatically applied powder layer and for the chemical curing of the film, the substrate has to be heated at a temperature above the minimal film forming temperature of the powder (that is higher than its boiling temperature). The film forming process includes sintering, melting, wetting, ventilation, running and cross-linking. Up to the present, only wood materials, mainly medium dense fibre boards (MDF), can be coated with powder varnishes in a good surface quality. However only closed-cell surface coatings can be achieved. At present, single production plants are in operation using low-temperature UV-curing powder coatings abroad in Sweden and England. Presently one plant for the powder coating of MDF plates (for the production of desk tops, office and bathroom furniture and kitchen furniture) is under construction in Germany.

Alkyd Paints / Glazes

Alkyd paints are predominantly used as glazes for outdoor applications. Glazes are transparent painting systems being applied to emphasize the appearance of the wood surface. Glazes can be both water-thinnable or solvent-based (approx. 70 % organic solvents). Water-thinnable systems are predominant. The market share of the alkyd paints is strongly declining in benefit of acrylate systems.

Combined/Mixed-paint Systems

An important trend in the wood varnishing is the use of material combinations consisting of water-thinnable, UV-curing and solvent-based high solids varnish systems instead of the application of a paint system based on the same raw materials. Most widely spread is the application of a water-thinnable ground coat. This material generally combines filling as well as colouring-functions. Furthermore this material shows good drying and sanding properties. As topcoat generally a UV-curing clear coat is applied in order to guarantee the required properties concerning optical and resistance aspects [BERGOLIN 2000].

7.2.1.4 Summary

Table 7-3 itemises the essential properties of the most used wood stains and paints.

Table 7-3: *Overview of the properties of wood stains and paints*

Wood stain or paint type	Solvent proportion [weight per cent]	Water proportion [weight per cent]	Components	Type of reaction	Catalyst	Comments
Wood stain						
• solvent-based						Organic solvents,
- type a)	95	0				water-thinnable solvents
- type b)	70	25 – 30				Combi-wood stain; water-thinnable solvents
- type c)	25 – 30	70 – 80				
• water-based	-	90 – 95				Napping of wood
NC-paint (CN-paint)					-	
• uncoloured	Approx. 75	0	Collodium wool	Physical drying		Surface resistance with limited usability
• pigmented	Approx. 60	0	(Cellulose nitrate)			
SH- paint			Alkyde-/Melamine	Condensation reaction	Acid	Older paint systems emitted formaldehyde; high resistance
• 2-component; uncoloured	30 – 60	0	Urea resins	(physical /chemical)		
• 1-component; uncoloured	65 – 75	0	Polyoles			
PUR- paint			Isocyanates;	Addition reaction (physical /chemical)	-	Generally 2-component materials;
• uncoloured	65 – 70	0	Acrylates;			high resistance
• pigmented	35 – 60	0	Polyesters			
• medium solid, uncoloured	40 – 50	0				

Wood stain or paint type	Solvent proportion [weight per cent]	Water proportion [weight per cent]	Components	Type of reaction	Catalyst	Comments
UP paint				Polymerization		Component systems;
- Conventional	approx. 35 (15)*	0	Polyester, unsaturated (organo-metallic materials)	• Heat	Organic peroxides	For infrared-curing UP varnish pre-drying and curing times have to be allowed for
- Containing paraffin	approx. 35 (15)*	0		• Radiation		
- Free of paraffin	approx. 35 (15)*	0				
• UV- curing	approx. 35 (15)*	0				
- Rolling lacquer	approx. 20 (20)*	0				
- Stopper	approx. 20 (10)*	0			UV radiation	
• UP spraying paint					Photo initiator	
- Uncoloured	65 – 70	0				
- UV- curing	65 – 70	0				
Acrylate paint						
• UV- curing	2 – 40		Polyacrylate, unsaturated			
- Rolling lacquer	2 – 10				Photo initiator	
- Spraying paint open cell structure	65 – 70					
• Electron beam curing	2 – 5			Electron beam		
Water-thinnable paint						
• conventional drying	5 – 7	60 – 65		Physically drying		Napping of the wood; longer drying times; possibly application of UV ground coat followed by a water-based varnish application; UV-curing water-based varnish is getting more and more significant
• UV-curing	approx. 2	58 – 60		Polymerization	UV radiation	
• PUR, 2-component	approx. 9	60 – 65		Addition reaction		

Wood stain or paint type	Solvent proportion [weight per cent]	Water proportion [weight per cent]	Components	Type of reaction	Catalyst	Comments
Powder coat • conventional drying • UV-curing	0	0	Epoxy resins Polyester-acrylate resins	Addition and condensation	UV radiation	Powder coatings with conventional convection drying are not suitable for the varnishing of wood at present. Only for the coating of MDF applicable systems exist.
Alkyde resin paints	10 – 80	0	Alkyde resins	Oxidation at air physical/chemical drying	Organo-metallic compounds	Organic solvents

** Data printed in brackets represent the actually emitted solvent quantity*

7.2.1.5 Paint Application Techniques

The following application techniques are used for wood and wood materials:

- Painting, rolling,
- Manual spraying (partly also electrostatically assisted processes),
- Automated spraying (partly also electrostatically assisted processes),
- Spraying automat with or without recycling of overspray (partly also electrostatically assisted processes),
- Rolling,
- Vacumat-technique,
- Filling with stoppers,
- Casting,
- Dipping/flooding,
- Printing.

The processes of paint application are described in annex III. In table 7 – 4, the achievable application efficiency factors are itemized.

Besides manual spray application, spraying installations or spraying automates equipped with two-component dispensing units are in use in the furniture industry.

Table 7-4: *Achievable application efficiency factors for several application techniques*

Application technique	Efficiency factor*	Remarks
Painting, rolling	95 – 100	Reduced uniformity of surface
Spraying, conventional	30 - 60	High amount of overspray
Spraying, HVLP	40 - 75	Application of low viscous wood stains, increasing use also for other paint systems
Hot spraying	40 - 60	Application of paints with a high solids content also applicable for hot-wax-spraying
Airless spray application	40 - 75	Bundeling of sprayed material
Air-assisted airless technique	35 - 50	Bundeling of sprayed material
Spraying, electro-statically assisted, wet lacquer	50 - 70	Electrical conductivity has to be considered
Spraying, electro-statically assisted, powder	80 - 95	Electrical conductivity has to be considered. At present only applicable for the coating of MDF (only a few applications).
Casting	95	Limitation by workpiece's geometry
Rolling	95	Limitation by workpiece's geometry
Vacumat-Technique	95	Only applicable for narrow parts and edges, water-thinnable paints and UV-curing materials with a high solids content, also the workpiece's geometry has to be considered

*depending on the occupancy rate and geometry of the workpieces, etc.

7.2.1.6 Flashing off and Drying / Curing Processes

Drying respective curing of the paint layer requires an intense flashing off. The flashing off takes place in special installations that are generally located upstream of the dryers. If solvent-containing paint systems are dried, the air exchange rate has to be adjusted in a way that the minimum half explosion limit is undershoot securely. For water-thinnable paints the humidity of the evaporating air must be regarded to enable a sufficient drying.

In the following the drying / curing processes applied for the coating of wood are described. The drying processes are described in detail in annex IV.

Convection Dryers

After flashing off, the drying respective curing period starts. Generally convection dryers or circulating air dryers are in use. They are built as flat-line dryers, nozzle-dryers, tray systems or tower dryers. Hydrex-dryers (convection dryers with air dehumidification devices) are used for a reduction of drying times for water-thinnable paints.

Infrared Systems

Infrared emitters of different wavelength are in use:

Thermal Reactors

A thermal reactor is a radiator that emits infrared radiation (2 – 8 µm) as well as convection heat. The infrared radiation is generated by combustion of natural gas or propane gas. Thermal reactors are also suitable for water-thinnable paint systems. Depending on the paint system and kind of production, the total drying time amounts 6-10 minutes.

NIR Drying (NIR = Near Infra Red)

The IR emitter is equipped with a specifically adjusted wavelength range. Thus the substrate is only heated minimally. The NIR process is very suitable for water-thinnable paints. Via the NIR technique, the shortest drying and cycle times are achieved. At present this technology is tested at practice conditions.

UV-radiation Drying

UV-radiation curing is most widely spread for drying of varnished furniture and especially applied for the drying of flat parts. With special installation designs also the drying of 3D workpieces (e.g. chairs) is possible. For pigmented or glazing paint systems, doped emitters (gallium or other metals) have to be used. An ozone extraction is state-of-the-art.

Microwave and High-frequency Dryers

For microwave and high-frequency dryers electromagnetic waves with varying wavelengths and different frequency ranges are used. Both drying systems are applicable for water-thinnable paints exclusively. The evaporated water has to be extracted. Microwave dryers are generally combinations of emitters and appropriate extraction equipment. Often also subsequent flash off zones are used additionally.

High frequency dryers (HF-dryers) consist of a high frequency generator, the transmission unit, collector electrodes and the appropriate flashing off zone for suction of the evaporated water. Evaporation and drying takes place from the inside of the paint layer to its outside. Heating is homogenous. The total efficiency factor of the process amounts approx. 65 – 70%. The unit is ready for use after a short initiation time. Due to the fast evaporation of water, the napping of wood fibres is significantly reduced as well as the dust proportion.

7.2.2 Exemplary Varnishing Processes

Varnishing of Chairs

Chairs made of beech wood are generally coated with a colouring wood stain or a glaze first. After pre-sanding, a first layer of a water-thinnable coat (120 g/m^2) is applied. The material dries at ambient temperature or via forced drying. After a second sanding, a second layer of hydro-varnish (120 g/m^2) is applied and subsequently dried [HESSE 2000]. The electrostatically assisted spray application of water-thinnable paints is suitable for varnishing of chairs due to their geometry. Thus the overspray and therefore the varnish amount and the VOC emissions are reduced.

Varnishing of Stairs

Stairs are generally made of wood or wood materials. After grinding a water-thinnable ground coat and a top coat are applied via airless spray technique combined with a paint recovery. Approx. 120 g/m² are applied per layer and the overspray amounts approx. 50 %. Drying is carried out in two steps via convectional drying and subsequent radiation curing [HESSE 2000].

Varnishing of Window Frames

The market share of wooden windows is strongly decreasing in Germany and amounted approx. 25 % in the year 2000 [FRIEBEL 2001].

Compared with other sectors of the wood industry, the coating of wooden windows is often still carried out manually. As the wood surfaces of windows have to resist weather influences and blue stain infestation, partly up to four coating layers are necessary to achieve a sufficient resistance. Both the grinding and the drying processes are very sumptuous with respect to time and work Several varnish applications are necessary to achieve a certain layer thickness and hence a certain protection function [PIETSCHMANN 2000].

The use of water-thinnable paints (e.g. acrylate paints) for the varnishing of windows is state-of-the-art in Germany. Besides these paint materials also solvent-based varnish systems (e.g. alcyde paints) are used. Water-thinnable paints show a lower wet adhesion if compared to conventional solvent-based varnish. Flooding has won recognition as an application technique for the coating of pressed frameworks for wood impregnation and ground coating. The top coat is applied via spray application in one or two layers in the form of a water-based paint system. Due to the workpiece's geometry, a high amount of overspray is generated even if an electro-static assisted spraying process is used. For a reduction of costs and environmental impacts lacquer recovery installations are utilised. Furthermore, partly the spraying booths are equipped with a dry separation of overspray in order to avoid coagulation or disposal of paint sludge (see also [ACKER 1999, EISENMANN 2000]).

At present the application of UV-curing powder coatings and wet lacquers is being investigated in a pilot plant. The processed materials are mainly glazing paints and also pigmented paints (only white colouring). First results show that it is possible to varnish wood with UV-curing hydro-varnish for ground- and top coat. The paint application can be carried out by all common spray application techniques. However best results are achieved via electro-statically assisted spray application. An intermediate sanding after the application of ground coat before top coat application is not necessary. Additionally a smooth, uniform surface with a good quality and a visual appearance, adhesion, elasticity and weather resistance is achieved. Furthermore a significant reduction of cycle times and overspray could be observed resulting in a significant reduction of costs. On the other hand, additional energy costs result by the operation of the UV installation that are not compensated by the short cycle times in the UV-dryer.

Also the coating of wooden window frames with UV-curing powders has been investigated. By the selection of optimum melting and curing conditions, void-free surfaces onto wood can be obtained without intermediate sanding. However it is necessary to apply a barrier-layer in form of a UV-curing wet-lacquer before coating. The powder clear-coats show very good results: Good adhesion, elasticity and weather resistance. Whereas if pigmented materials are applied, problems concerning the adhesion of the powder varnish and the ground coating have occurred. Further experiments are necessary in order to solve the following problems:

- Continuous melting of the powder onto 3-dimensional workpieces,
- Volatility of wood ingredients and residual moisture in the substrate that may cause blistering while melting of the powder in the infrared dryers,
- Curtailing of melting and running of powder coatings for short exposition to the IR radiation [PIETSCHMANN 2000].

Varnishing of High Quality Furniture

The following process steps are carried out for the varnishing of high quality furniture [NÜßER 1998]:

1. At first, the edges of the workpiece (in pile) are ground-coated with a solvent-based nitro clear-coat followed by drying and sanding.
2. The front sides are coated with UV-curing paints via rolling. (The material has a solvent content of up to 20 %).
3. UV-curing ground and top coats are applied via rolling.
4. Finally the fronts and edges are coated with a pigmented, water-thinnable UV-curing paint (Solids content 25 – 45 %, <2 % solvent proportion) via spray application.

For furniture made of massive wood (whose surfaces are oiled or waxed) destined for kitchens, bedrooms, living rooms and children rooms, the following processes are carried out generally [NÜßER 1998]:

1. The pre-sanded furniture parts are treated with smoothing brushes.
2. After de-dusting, the oil is applied onto the wood surface with a spraying automat.
3. Subsequently the oiled workpieces are brushed.
4. A hot wax is applied via spraying.
5. The waxed surface is brushed.
6. Then the workpieces are turned over and processes 1 – 5 are repeated.

Coating of wooden Kitchen and Bathroom Furniture

Kitchen and bathroom furniture is made of massive wood (e.g. oak, beech, maple, stone pine, cherry) and wood materials (e.g. MDF) and coated. For varnishing, wet varnish systems are used exclusively with a predominance of water-thinnable UV varnish as well as water- or solvent based wood stains. Presently solvent-based polyester and PUR varnish is only applied in small amounts, partly for varnishing of spare parts. Wood stains are applied via automated roller coating heads.

A conversion to water-thinnable UV curing paints for ground and top coats was undertaken due to environmental, labour protection and technological reasons and in order to reduce the fire hazard [FINK 2001]. The applied materials have a solvent proportion of 1 – 2.5 % per weight. The coating is mainly carried out in fully automated installations. The material is thereby applied via compressed-air spraying (Fa. Miele & Cie, Warendorf, Münsterland, Fa. ALNO AG, Pfullendorf). The overspray is collected (via doctor blades) and reused [FINK, 2001]. Paint particles of the exhaust air are separated dry. In general, the paint system consists of two layers. The ground coat surface can be sanded before the top coat is applied.

Due to the use of water-thinnable UV-curing paints, the amounts of emitted solvents are very low and amount even in big installations less than 10 kg/h [FINK 2001]. An exhaust gas cleaning concerning VOC is therefore not in use. The exhaust air is extracted directly via the roof. Cleaning solvents are recycled via distillation (ALNO AG).

Due to the small amounts of processed organic solvents, not even bigger installations are in the scope of the IPPC-Directive.

Varnishing of Chipboards for Living Room and Bedroom Furniture

For the industrial varnishing of chipboards for living- and bedrooms, several different varnish systems are applied depending on the desired design. The according varnishing processes are used in the industry and have proved themselves.

First the surface is coated by a stopper with a water-based paint (60 g/m^2) within a stopper machine. After infrared radiation drying (NIR), the surface is grinded. Subsequently a water-thinnable ground coat (30 mg/m^2) is applied via rolling followed by IR radiation drying. An additional ground coat layer (25 g/m^2) with the same material is applied and NIR dried. The colourless top coat is a UV-curing material which is applied via rolling (8-10 g/m^2). The achieved surface is of uniform colour.

If a chipboard surface in a wood decoration should be obtained, an additional printing process has to be utilized. After the surface is ground-coated with a water-thinnable stopper (60 g/m^2) in an automated process, a water based ground coat is applied and dried in two steps. Two print layers (2 x 5 g/m^2)of water-thinnable inks are applied and dried. Subsequently a colourless, solvent based clear-coat is applied. As an alternative to this application, the water-based stopper can be applied with a UV-curing ground coat (also 30 g/m^2) via rolling [BERGOLIN 2000].

Varnishing of box-like furniture

The description of the processes that are used for the coating of box-like furniture is based exemplarily on the production plant of the Schiedermöbel Wortmann GmbH at the location Schieder.

For colouring of wooden surfaces of furniture parts, water-thinnable wood stains are processed. These materials are applied via automated roll coaters. The stained surface is coated automatically with water-thinnable UV-curing acrylate paint several times through repeated coating processes including intermediate drying steps. The total amount of paint material ranges between 5 and 8 g/m² (main coating, subsequent coating) with a solvent proportion of 3%. The application devices are cleaned with water.

As finish, a solvent-based NC paint is applied partly onto surfaces of the assembled parts of the furniture (e.g. onto forefronts, edges and plates). The paint improves the optical properties of the surface and serves as a pollution protection. The material is applied manually via compressed air spraying. The overspray amounts up to 40 %, and is separated via wet separators. A maximum of 10 kg of paint material are processed per hour. The varnish layer is subsequently dried in a convection dryer. The exhaust air is extracted and emitted [Krain, Schouwenaars 2001].

Due to the low amounts of processed organic solvents not even big installations for the production of box-like-furniture fall under the scope of the IPPC-Directive.

Powder Coating of MDF Panels

The powder application onto MDF panels for the production of TV and office furniture is carried out without previous priming. The entire plant length for preheating, coating, curing and cooling is significant shorter than for a conventional plant: Coating takes place in a single working cycle. Grinding processes following the respective drying steps are inapplicable. Due to the recycling and re-use of powder, significant cost savings can be achieved. However this application technique is restrictedly applicable for certain colourings and surface structures (Fa. Stilexo).

Due to the very low electrical conductivity of MDF, the plates are pre-heated up to 60 – 70 °C before the powder is applied via corona spray guns. At this temperature, the powder particles adhere to the MDF surface creating a consolidated varnish layer that is subsequently dried by UV radiation. [JOT 2000].

7.2 Current Consumption and Emission Values

For the coating of wood and wood materials a main topic concerning air pollution control is the emission of VOCs. Further wastes and wastewater as well as the energy consumption have to be regarded. At present there are no German installations known that reach the threshold values of the IPPC directive. [HANSEMANN 2001].

7.3.1 Material Consumption

Table 7-5 itemizes the applied quantities of paint materials for different application techniques.

Table 7-5: *Application quantities for different application techniques* [VDI 3462]

Application technique	Quantity [g/m^2]	Remarks
Rolling	25 – 60	
Casting	60 – 250	In exceptional cases up to 500 g/m^2
Dipping	60 – 200	
Flooding	60 – 200	
Spraying	Up to 250	Material losses due to low efficiency
Printing	1 – 2	

Table 7-6 shows applied varnish and solvent amounts averaged for different production sectors.

Table 7-6: *Applied paints and amounts of organic solvents for different applications in the wood and furniture industry* [BRINKMANN 2001]

Product	Varnishing process	Amount of varnish [g/m^2]	Solvent amount [g/m^2]
MDF panels	1) Ground coat, water-based, roller application 2) Hydro paint, roller application 3) printing ink, water-based 4) AC-paint, roller application, UV-curing Drying: Convection or UV dryers	80	3
Stairs	1) Parquet seal, water-thinnable (coated pendulously) 2) Grinding 3) Parquet seal, water-based, spray application of one or two layers (coated pendulously). Hot spraying Drying: At ambient temperature, convection dryers or infrared radiation drying	180	12
Bedroom-furniture	1) Spray application of two layers of pigmented water-based paints, with intermediate sanding 2) Lime paste, spray application 3) grinding 4) colourless, water-based paint, spray application drying: Ambient temperature, tray system dryers	150	9
Doors	1) Ground coat, water-based, roller application 2) Wood stain, roller application 3) AC ground coat via roller application, UV radiation curing 4) Grinding 5) Two layers of AC paint via roller application, UV radiation curing Drying: Convectional dryers or UV-Radiation curing	60	10
Tables	1) Combi-stains, spray application 2) AC ground coat, roller application, UV curing(3 layers) 3) Grinding	100	30

Product	Varnishing process	Amount of varnish [g/m^2]	Solvent amount [g/m^2]
	4) AC paint, roller application, UV curing Drying: at ambient temperature		
Living room furniture	1) Natural oil, hot spraying Drying: at ambient temperature 2) Grinding 3) Natural wax, hot spraying Drying: Infrared radiation curing 4) Polishing	23 55	0 9

7.3.1.1 Emissions in the Air

Table 7-7 summarises the specific VOC emissions for primary emission reduction measures. Thereby the coating system consists of materials for the pre-treatment (such as bleaching agents), ground coating and top coatings. The solvent content (printed in brackets) refers to the complete coating system.

Table 7-7: *Specific VOC emissions for various emission reduction measures* [Rentz 1999]

Application technique	VOC-Emissionen [g/m^2]
Paint system with a high organic solvent proportion (65 % per weight), conventional application (spray application)	80 - 120
Paint system with a high organic solvent proportion (65 % per weight), application techniques with an increased efficiency factor (rolling, flooding, dipping, electro-statically assisted spraying, airless spraying) and good housekeeping	40 - 60
Paint system with a medium solvent content (20 % per weight), application techniques with an increased efficiency factor (rolling, flooding, dipping, electro-statically assisted spraying, airless spraying) and good housekeeping	10 - 20
Paint system with a low organic solvent proportion (5 % per weight), application techniques with an increased efficiency factor (rolling, flooding, dipping, electro-statically assisted spraying, airless spraying) and good housekeeping.	2 - 5

7.3.1.2 Wastewater

The volume of generated wastewater in the coating of wood is very small, because the process water circulates in a closed loop (see also [VDI 3462, OBST 1993]). Amounts of generated wastewater for single applications will be discussed in section 9.5.

7.3.1.3 Wastes

Especially for the varnishing of profiled, wooden workpieces, the ground and top coat are applied via spray application. Thereby, losses via overspray are generated within the spraying booths. Depending on the separating technique, the overspray is of a different type:

- If the *wet separation* technique is applied, the overspray forms paint sludge. The paint sludge consists of paint particles, small amounts of organic solvents, coagulation agents and water. Paint sludge is generally regarded as monitoring-needy waste. In general, the material is energetically used in special refuse combustors.

- If the overspray is *separated dry*, contaminated glass fibre filter mats have to be disposed. As soon as a specific minimum velocity of the air flow is reached, the filter mats have to be replaced. The filter mats, contaminated with dried paint particles are generally non monitoring-needy wastes and therefore energetically utilized in regular waste incineration plants.

Furthermore, contaminated solvents are generated from cleaning of application devices, conveyer systems, paint pipelines, spray booths and others. In general these cleaning agents used in the wood industry are recycled via distillation. They can be used as recycled cleaning solvents. The distillation generates varnish leftovers in solid, liquid or paste-like phase. Contaminated solvent leftovers that are not reused have to be disposed as hazardous waste in special refuse combustors as they are classified as monitoring-needy waste.

If 2-component paints are used, dried paint residues are generated that are brought back to the paint manufacturer together with old paints. These materials are then recycled and used for new paints of lower quality or used as additives. Non-cured paints have to be energetically used in special waste incineration plants (especially monitoring-needy waste) [OBST 1993, VDL 1994].

7.3.1.4 Energy Consumption

At present no information concerning the energy demand for varnishing of wood and furniture is available. General information is given in annex I.

7.3.1.5 Costs

In table 7–8, the prizes for different application and drying devices in the wood and furniture coating industry are itemized.

Table 7-8: *Prizes for different devices and units for the wood and furniture coating* [HANSEMANN 2000]

Devices	Prize [EUR]	Dimensions, particularities, comments
Application devices, basic equipment without electrostatic assistance		
Roller, planar, e.g. made of foam rubber	26 000	Working width: 1,3m; installed electrical load: 3 kW
2x rollers, double system, smooth	52 000	Working width: 1,3 m; installed electrical load: 6 kW
Filling machine, light weight version	55 000	Working width: 1,3 m; installed electrical load: 5,5 kW
Casting installation	35 000	Working width: 1,3 m; installed electrical load: 3 kW
Application devices, dryers and curing devices ***UV radiation dryer including control cabinet, standard equipment, length of emitter: 1400 mm, working width: 1,3m***		
Gelatation zone, 1 module	15 000	installed electrical load: 11,2 kW
Curing zone, 2 modules colourless, 1 module doped	27 000 15 000	installed electrical load: 22,4 kW installed electrical load: 16,8 kW
Compact plant (one-man plant)	36 500	installed electrical load: 38,0 kW
New, fast drying techniques, standard equipped, without electrical control, without conveying unit		
Thermal reactor (6 min)	95 000	installed electrical load: 10 kW air output: 2 000 m^3/h heating medium: gas
Dry air dryer (10 min)	60 000	installed electrical load: 30 kW air output: 1 500 m^3/h Heating medium: electricity
HF dryer (2 min)	150 000	installed electrical load: 120 kW air output: 1 500 m^3/h heating medium: electricity
Microwave dryer (2 min)	75 000	Installed electrical load: 60 kW air output: 1 500 m^3/h

Devices	Prize [EUR]	Dimensions, particularities, comments
		Heating medium: electricity
Spray application, standard equipped, without electric control		
Spray booth, water sprinkled, stainless steel	16 000	Installed electrical load: 5 kW air output: 7 200 m^3/h
Spray booth, dryer	4 000	Installed electrical load: 2,5 kW air output t: 7 200 m^3/h
Spray booth, wet on wet application	80 000	Installed electrical load: 15 kW Air output: 7 200 m^3/h
Spray booth, coolack system	37 000	Installed electrical load: 20 kW air output: 7 200 m^3/h
Spraying automat, wet separation with paint rccycling	150 000	Installed electrical load: 13 kW Air output 7 000 m^3/h
Spraying automat, dry separation with paint reccycling	130 000	Installed electrical load : 13 kW Air output: 7 000 m^3/h
Dryers, standard equipped without electrical control, working width: 1,3 m		
Flash off wall, semi-open 2,0 m	2 000	Installed electrical load: 0,6 kW air output: 4 300 m^3/h
Flash off zone with belt conveyor, flat bed, 10 m length	20 000	Installed electrical load: 4 kW air output: 4 000 m^3/h
Dryer with belt conveyor, flat bed, 20 m length	35 500	Installed electrical load: 7,5 kW air output: 2 000 m^3/h
Nozzle dryer with belt conveyor, flat bed 10 m length, air speed at nozzle approx. 25 m/s.	30 000	Installed electrical load: 7,5 kW Air output: 1 500 m^3/h
Tray system dryer with conveyor system and standard equipment		
Flash off zone 10 m	27 500	Installed electrical load: 4 kW air output: 4 000 m^3/h
Drying zone 10 m	30 000	Installed electrical load: 4 kW Air output: 1 000 m^3/h

7.3 Determination of BAT Candidates

The major environmental impact caused by the varnishing of wood is the emission of VOC. Also the generation of waste and waste water have to be regarded for the assessment of BAT candidates.

7.4.1 Low-emission respective Emission-free Paints

The following paint systems can be used for a reduction VOC-emissions [HALLACK 2000]:

- ½ component water-thinnable paints
- UV-radiation curing water based paints
- UV-radiation curing paints (100% solids content)
- UV-radiation curing powder coatings
- Powder coatings
- High Solids

- Oils and waxes

To obtain coatings of technical and optical high quality, the geometry of the workpiece has to be regarded for the selection of the paint systems and the concept of the appropriate installation.

For casting and rolling application techniques, mainly paints with a solids content of up to 100 % are utilized. Also UV radiation curing paints are increasingly demanded. These materials do still contain organic solvents, but due to the better chemical and physical properties of the cured paint layer the layer thickness can be smaller. Thus the material efficiency is increased and emissions can be reduced [VDI 3462].

Presently, waxed or oiled surfaces show a lower resistance against chemical or mechanical impacts if compared to painted surfaces [Ministerium für Umwelt und Verkehr Baden-Württemberg 2001].

Water-thinnable Paints

Water-based paint systems (mainly 2 component and UV-radiation curing water-based paints) are presently used for several applications that have been dominated by conventional solvent based varnish systems [HESSE 2000].

2 component water-thinnable paints contain a special composition of film forming agents. Curing occurs via hardeners based on isocyanate**.** Curing occurs due to cross-linking reactions of the master batch and hardener as well as due to reactions of the hardener with water. 2 component water-thinnable paints show an improved (especially mechanical) resistance and a very good isolating function even onto ingredient-rich woods, especially applicable for durable surfaces such as for example floor coverings and kitchen fronts.

UV-radiation curing water-thinnable paints consist of a physically non-drying Hydro-UV paint emulsion and of special radiation-curing film forming agents in water. Additionally physically drying Hydro-UV paint systems are used in form of the dispersions with radiation-curing compounds. Thereby the following advantages have to be registered:

- The material can be processed in automated installations.
- Spray application combined with a varnish recovery installation is applicable.
- Drying takes place in two steps: Physical pre-drying and curing via UV-radiation.
- The coated workpieces can be stacked directly after curing.

Fields of application for **UV-radiation curing water-thinnable paints** are chairs, box-like furniture, office and kitchen furniture, room doors, panels etc.

If water-based paints are processed, the following requirements have to be met generally [HESSE 2000]:

- The ambient temperature has to be between 18 - 22 °C,
- the surface temperature of the workpieces may not be lower than 15 °C,
- an optimum processing is given at an air humidity between 55 – 65 %,
- corrosion resistant application devices, paint supply units and conduits are necessary,
- water-thinnable paints may not be stored below 0 °C (frost damage).

Powder coatings

Powder coatings for the serial coating of wood are only applied in a very limited number of installations [HOFFMANN 2000].

MDF substrates show best properties for the powder coating. If MDF-Substrates are coated conventional, several layers have to be applied. Also grinding is necessary after each paint layer has dried. If UV-curing powder materials are utilized, only one single working cycle is carried out. Furthermore smaller coating layers (60 to 80 µm) can be achieved. The view of aspects of costs leads likewise to the conclusion that in the case of a conversion to UV powder coating both working- and energy costs can be reduced, significantly. Besides economical aspects of this technology, there is also the good scratch and chemical resistance that are very advantageous properties of the UV curing powder coats. At present three-dimensional MDF-workpieces for the production of housings for hi-fi equipment and TVs are coated with UV-curing powder materials. The application is carried out via spray application. The melting and cross-linking is carried out via a combination of infrared radiation drying and convection drying [FOITZIK 2001, BUYSENS 2001].

7.4.2 Paint Application Techniques with Improved Efficiency Factors

The selection of a particular application process strongly depends on the workpiece´s geometry. For the varnishing of plane parts, rolling or casting are suitable techniques. For profiled workpieces or flat parts with rounded edges or partly mounted parts, a spraying automate can be used. Conventional spray application is used for example for coating processes of completely mounted chairs [HALLACK 2000].

Application techniques contributing to emission abatement include rolling, casting, dip coating/flooding systems and electrostatic assisted spray application [VDI 3462].

Rolling

Rolling can only be applied for coating of plane workpieces. An efficiency as high as approximately 95 % can be achieved. Thus the amount of generated waste is reduced. In general rolling techniques are in use for the application of water-thinnable paints and UV radiation curing paints.

At present an increasing demand for closed-cell paints for beech, maple, pear, birch, and cherry woods is being observed. So far this has only been possible with the conventional rolling or spray application for best veneer qualities. The utilisation of heated, smoothing rolls for the application of ground coat shows significant advantages. It enables the filling and smoothing of porous surfaces without the application of excess material. Furthermore cracks in the surface of the veneer and joint connections, raw chipboards, MDF panels and other wood material panels can be filled. Thus a smoother surface is created and the wood gets a filled and smooth appearance. Also material savings up to 40 % can be achieved. These advantages are caused by the opposite rotating heated smoothing roll that processes the UV paint applied onto the workpieces surface via the application roll. This way the paint is worked in the workpieces surface. Pores, veneer cracks and splices are also filled that way. The heating of the smoothing roll insures, that the cohesion within the paint layer is reduced, so that the material remains in the filled pores. Additionally the paint material shows better running properties and forms a plane, even surface [HYMMEN 2000].

Casting

In comparison to rolling, the wooden workpieces do not have to be absolutely plane. Within a casting device, the used paint material is pumped into a sinkhead from where the paint is discharged in form of a fine closed casting film. The workpieces to be coated are send through this film. Excess paint material is collected in a reservoir and pumped back into the sinkhead. Thus an efficiency of approx. 95 % is achieved. Via casting, all types of paint materials can be applied.

Dip coating/Flooding

The highest efficiency factors (up to 100 %) are obtained by dip coating. However the application of this technique is limited in its application for the wood and furniture industry. It can be used if high quantities are produced (e.g. windows in serial production). The workpieces are either dipped manually or transported and dipped via conveyor systems. Thereby only 1-component paint systems are applicable. The technique is not applicable for open-cell surface structures of the coated products. Also mostly, parts of furniture, that are treated differently (e.g. fronts, corpus, inlays, backsides) and also profiles can not be dip coated (pore formation is not possible) due to the unfavourable overstretching of profiles. Therefore this technique is not used widely. Flooding represents an alternative to dip coating, especially for wooden workpieces that tend to swim. In flood coating installations, the workpieces are transported via conveyor systems into closed channels. There the workpieces are flooded with the paint material via injection tubes. The surplus paint material is absorbed at the bottom of the channel and reused.

Electro-statically assisted Spray Application

Electro-statically assisted spray application can be utilized if more electrically conductive materials such as e.g. massive wood for the production of windows, chairs and pad racks are processed (see also [OBST 1993, VDI 3462, HOFFMANN 2001])

Paint Recovery

If water-thinnable paints are applied via spray application, the generated overspray can be intercepted and re-used, depending on the paint material. The efficiency rate for the recycling of overspray amounts 50 – 90 %, depending on the type of the processed paint material.

Another possibility is the uptake of overspray by surfaces that are sprinkled with the circulating paint material. Thus the overspray is collected and directly supplied again (so-called paint-in-paint spraying). This process is applicable for water-thinnable paints and 1-component materials without hardeners. Furthermore ring blade systems or other blade systems are used for collecting of water-based paint from the conveyor belt. After filtration the paint material can be reused.

Another process for the recycling of overspray is the ultrafiltration. The overspray loaded spray booth water (from wet separation) is supplied to the ultrafiltration unit. Thereby the paint material is separated from the water. The water is reused for wet separation in the spray booth and the recovered paint material is reprocessed e.g. by mixing with new paint material [VDI 3462].

7.4.3 Paint Supply with low Material Consumption

A trend in the furniture industry is the increasing demand of furniture painted in individual and special colours. This requires an economically efficient change of colours that can be achieved by the implementation of scraperable pipelines (see also chapter 2) [ESSLINGER 2000, SCHOLZ 2000].

Measures for a Reduction of Wastes

The following measures for a reduction of waste generated by overspray can be utilized [OBST 1993]:

- Implementation of paint application processes with small generation of paint overspray, such as rolling, casting and flooding (see also section 9.4.3);
- Increase of the level of paint material utilisation by an improvement and optimisation of parameters of the spray application;

An avoidance respective a reduction of contaminated solvents can be achieved by the following measures [OBST 1993]:

- Implementation of cleaning devices with a low consumption of cleaning solvents due to the recycling of contaminated cleaning solvents (circuitry);
- Application of distillation devices for a recovery of solvents originating from solvent wastes or contaminated cleaning solvents;
- External distillation (usually at the supplier).

7.4.4 Waste Gas Cleaning

Theoretically several processes for waste gas cleaning are applicable (cf. annex IV). In Germany only one plant with a subsequent exhaust gas cleaning installation exists: At Fa. Schimmel, Braunschweig, a bio-filtration is implemented for the reduction of odour nuisance.

7.4 Proposal for the BAT

For the production of **chairs** and **frames** two varnishing concepts are utilised that will be compared in the following. For the conventional process a 2-component, colourless, solvent-based, PUR-wood stain is applied manually via electro-statically assisted airless spraying. Subsequently two layers of a colourless, solvent based PUR paint are applied.

The more progressive concept includes a first coating of the workpieces with a wood combi-stain via HVLP-spray application. Subsequently a colourless water-thinnable UV radiation curing paint is applied via air-assisted airless technique within a paint-in-paint booth. A waste gas cleaning does not take place (cf. 8.4.5)[HANSEMANN 1998].

Table 7-9: *Comparison of a conventional and a progressive painting* [HANSEMANN 1998]

Parameter	Conventional paint concept	Progressive paint concept
Content of organic solvents [weight per cent]		
Wood stain	95	40
Top coat	70	5
Amount of paint [g/workpiece]		
Wood stain	180	180
Top coat	300	200
Paint efficiency factor [%]	60	95
VOC emissions [g/workpiece]	150	5
Amount of waste water[4] [l/workpiece]	0,038	0,038
Paint sludge [g/workpiece]	180	Negligible

The advantages of the progressive paint concept are the lower material consumption and VOC emissions as well as smaller amounts of generated paint waste. Investments for the UV

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[4] From the spraying booth

radiation curing zone and the additional technical equipment of the paint-in-paint spray booth have to be considered.

For the varnishing of **doors and constructional components** also a conventional and a progressive process are compared. For the conventional process a solvent-based wood stain and subsequently a solvent-based 2-component PUR paint (2 layers) are applied manually via casting. The more progressive process includes application of a solvent-based wood stain and subsequently application of a solvent-free UV radiation curing ground coat. Afterwards a UV radiation curing top coat poor in solvents is applied. All paint layers are applied via rolling [HANSEMANN 1998]. A comparison of both painting concepts shows table 7–10.

Table 7-10: *Comparison of a conventional and a progressive painting concept* [HANSEMANN 1998]

Parameter	Conventional painting concept	Progressive painting concept
Solvent content [weight per cent]		
Wood stain	95	95
UV radiation curing ground coat	-	0
Intermediate wood stain	-	95
Top coat	70	5
Processed amount of paint[g/m^2 coated surface]		
Wood stain	150	20
UV radiation curing ground coat	-	30
Intermediate wood stain	-	8
Top coat	180	10
VOC emissions [%]	100	10
Amount of waste water[5] [l/m^2]	0,025	0
Paint sludge/-waste [g/m^2]	40	3
Contaminated thinners [g/m^2]	30	13

The painting concept consisting of wood stain/UV radiation curing ground coat/intermediate wood stain/top coat is advantageous due to lower VOC emissions.

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[5] From the spray booth

Table 7-11 shows the influence of manual respective automated paint applications on the material consumption and the generation of wastes. In the automated paint application a paint recovery is implemented via the use of a ring blade system.

Table 7-11: *Impact of the plant construction on the paint and solvent consumption and the generation of wastes* [HANSEMANN 1998]

Parameter	**Manually spray application (wet spray booth)**	**Automated spray application (without recycling of overspray)**	**Automated spray application (with recycling of overspray)**	**Rolling**
Paint demand [g/workpiece]	450	300	280	50
Solvent consumption [g/workpiece]	60	158	55	21
Amount of waste [g/workpiece]	205	133	16	3

In Table 7–12 a proposal for the selection of BAT for different production branches of the wood and furniture industry is given.

Table 7-12: *BAT for painting processes in the wood and furniture industry*

Branch of production	**BAT**
Chipboards for living and bedroom furniture	Water-thinnable paints with infrared radiation or UV-radiation curing, for all paint layers
Chairs and tables	Water-thinnable paints as ground coats and top coats. Electro-statically assisted spray application, drying at ambient temperature or forced drying process
MDF-plates	Powder coating, electro-statically assisted spray application
	Water-thinnable UV curing paints, application via rolling, convection drying resp. UV radiation drying
	UV radiation curing powder coatings, spray application
Windows	Water-thinnable paints for grounding and impregnating paint application via flooding, electro-statically assisted spray application for the application of top coatings
Stairs (made of massive wood or wood materials)	Water-thinnable paint for grounding and top coat application

Branch of production	BAT
Kitchen furniture	Liquid paints based on PUR and polyester, (water-thinnable: 7 – 9 % organic solvents, 40 – 60 % water)
Plane surfaces, office furniture, parquet, doors, bedroom furniture	Water-thinnable wood stain (5% solids content, 95 % water), combi-wood stain (5 % solids content, 65 % water, 30 % organic solvents) PUR-paints, applied via rolling, physical drying process (water-thinnable: 7 – 9 % of organic solvents, 40 – 60 % water). UPE-paints in form of open cell flatting (water-thinnable: approx. 5 – 7 % organic solvents, 40 – 50 % water), UPE-thick-layer-paints, paraffin containing: Approx. 47 % organic solvents, thereof 10 – 15 % relevant for emissions since an incorporation by polymerization takes place for the others UPE-rolling coats, UV radiation curing, (ground coat: 2 – 4 % of organic solvents, top coat approx. 10 % of organic solvents)
Spray application	If applicable: Varnish recovery

7.5 New Progressive Techniques

At present, the application of powder coatings for varnishing of wood materials and furniture is limited due to the low heat resistance of wood that is exceeded by the curing temperatures of most powder coatings. Therefore the implementation of powder coatings in the woodworking industry is strongly associated with the development of new generations of powder coating materials, with more suitable melting and curing processes. Powder coating systems cross-linking by UV radiation are still in an early stage of their development [FIOTZIK 2001].

So far electro-statically assisted painting processes can only be applied in rare individual cases of the wood processing. Therefore further research is necessary. In this context, the purging of electric charges via the wet lacquer film just produced was examined. This painting principle has been used for furniture fronts. Thereby the following results have been registered: In comparison to the low pressure procedure (HVLP), the electrostatic high rotation atomisation increases the application efficiency of approx. 35 %, and the according material efficiency of approx. 30 %. Also the generation of waste (paint clot) is reduced by approx. 80 %. At present the electro-statically assisted application of powder coatings onto non-conductive wood and wood materials is being under examination [ONDRATSCHEK 2000].

7.6 Conclusions and Recommendations

In Germany, no IPPC-relevant plants of the wood and furniture industry are known. Large installations have substituted solvent based paints with water-thinnable UV radiation curing paints for many branches. For a reduction of paint and solvent consumption as well as for an increase of application efficiency, the spray application has been widely replaced by roller application. Powder coatings are already utilized for the coating of MDF panels. However the application range of powder coatings is still very limited up to now. With the progression of further development of these technologies, the range of applications is expected to become wider.

Frequently the ventilating phase takes place at the final customer due to shorter and shorter delivery times of furniture. This often leads to complaints. According to investigations, the VOC from paints contribute predominantly to the furniture emissions during the first weeks after production [FINK 2001]. This problem can be reduced by the application of paints with a low solvent content or the use of solvent-free varnish systems. Also for job safety reasons, the share of solvent containing paints will be further reduced.

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Best Available Techniques (BAT) for the Paint- and Adhesive Application in Germany

-Volume I: Paint Application-
Annexes

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Contents

Annex I:

Possibilities of Energy Savings in the Paint Application

1.1 Energy Flows in Coating Installations

Energy flows in coating installations include electricity and heat. Thereby electricity is mainly required for the operation of electro motors, electrophoretic deposition and illumination. In rare cases electric energy is used for heating purposes. For heating up of solid, liquid and gaseous media heat is generated from gas or oil. In figure I.1 the energy flows are summarised.

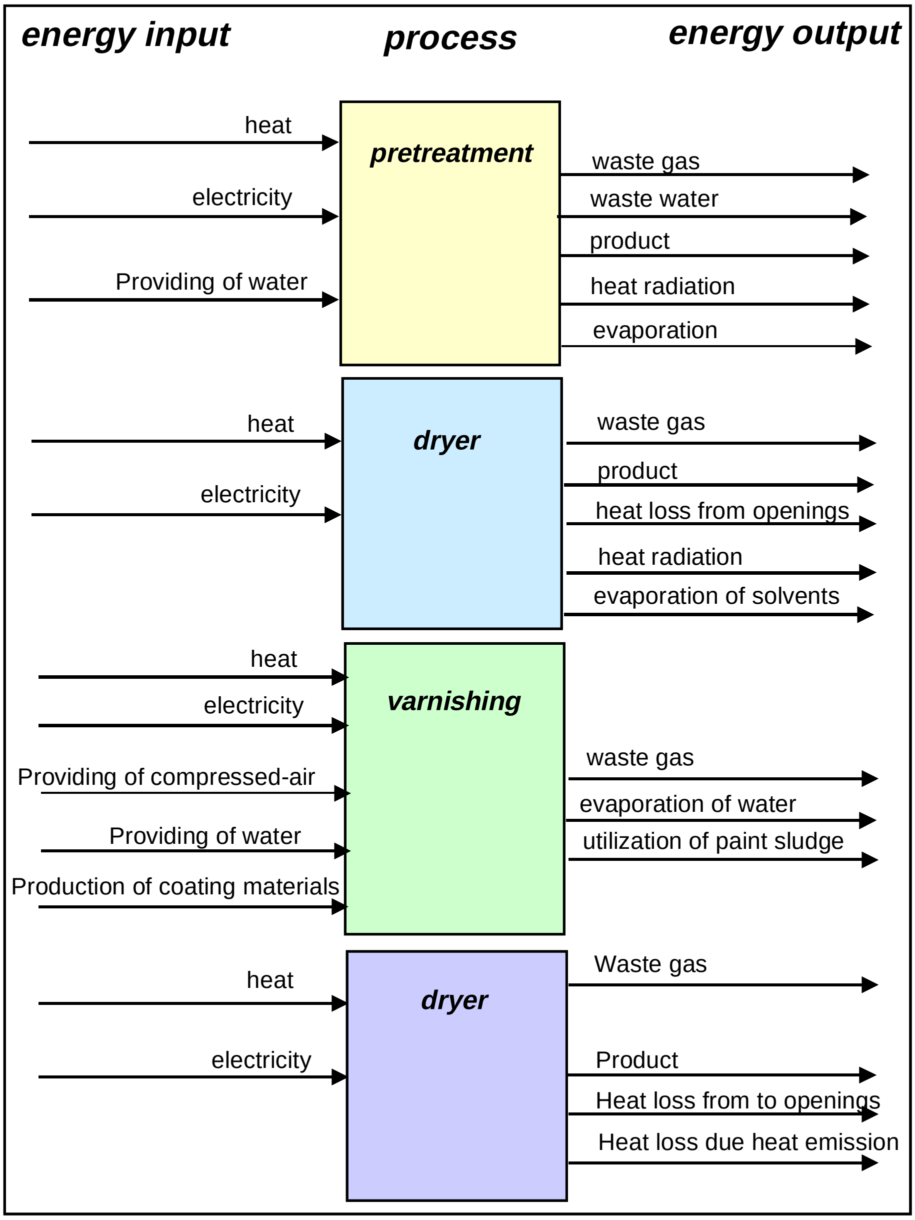

Figure I.1: *Main energy flows in coating installations* [KLEIN 1999]

The energy flows shown in figure I-1 can not be applied for all surveyed installations. In paint applications such as the coating of ships a pre-treatment method such as blasting is used.

Subsequently an air-drying lacquer is applied airless or by compressed air. Therefore the energy demand results basically from the production of compressed air and conveying of painting materials.

Usually energy is necessary for pre-treatment in the coating cabin and in the drying zones. When pre-treatment is performed by spraying a substantial part of input engergy flows from heated to the colder rinse zones. If a waste water treatment is installed, for instance via evaporation, additional heat is required for the evaporation process. Energy is also necessary for drying of the product after pre-treatment. For the coating cabin electricity is required for operation of ventilators and compressors. When water based coatings are applied, usually a temperated evaporation zone is needed partly waste heat from a subsequent dryer is utilised. Also additional energy is needed, when the dryer is equipped with an exhaust gas purification since usually the solvent concentrations are not sufficient as a fuel.

Costs related to energy consumption often contribute to nearly 20 % of the total operating costs. Usually 60 % or more of the energy input is discharged with waste air or waste gas and thereby delivered to atmosphere. Energy consumption due to insufficient insulations or discharged media is rather low (nearly 10 %). Approximately 30 % of the energy consumption are used for the operation of electrical engines. [KLEIN 1999]

1.2 Applicable Measures for the Reduction of Energy Input

I.2.1 Reduction of Energy Input in new Installations

When building a new coating line the energy consumption is an important criteria with regard to the choice of an adequate coating process. Through the introduction of application techniques generating less overspray with reduced air flow rate in spraybooths or the use of automated paint application technologies, smaller engines can be utilised for the operation of compressors. Furthermore, an adequate design of the burners allows for significant energy savings. When planning a new coating line, starting points for the optimisation of energy consumption are available in all parts of the installation, especially in coating cabins and dryers. Measures aiming at reducing the energy demand when planning a new coating line are listed in table I.1.

Table I-1: *Energy saving measures for new coating installation* [KLEIN 1999]

Part of installation	**Measures**	**Notes**
Pre-treatment	Use of dip processes (coating)	Low energy loss due to evaporation and heat radiation
	Low processing temperatures	Depend of the chemical substances
	Drying tunnels with small width	
	Optimised water drainage from work pieces	
Coating cabin	Heat recovery from waste gas via heat exchangers	
	Low pressure application devices with low overspray	For example. HVLP
	Automatic shutoff at breaks	
	Paint material with low energy demand	for example powder systems
Evaporation zone	Devices using circulated air	for solvent concentration
Dryer	Direct heating	for ex. gas
	Heated parts of installations grouped together	Bloc-dryers
Thermal combustion	Heat recovery via heat exchange	For ex. Heating of dryers
Conveyer systems	Optimised system for the transport of products	Operating time

I.2.2 Applicable Measures for existing Installations

When looking for possibilities to reduce energy consumption in existing coating lines, an analysis of the present situation is recommended in order to possibly register all energy relevant parameters and to optimise them with regard to the state-of-the-art. [KLEIN 1999]

After a comprehensive collection of energy flows, a catalogue of measures can be set up aiming at optimising, or at least improving, the efficiency of the energy demand. In the following table selected measures aiming at reducing the energy consumption are listed for each installation part. However, for each single coating line, the applicability of a given measure has to be analysed.

Table I.2: *Energy saving measures for existing coating installations* [KLEIN 1999]

Part of installation	Measures	Notes
Pre-treatment	Insulation of conductions, pumps and tanks	Low operating expense
	Low process temperatures	Depending on used materials
	Optimised water drainage from work pieces	
Coating cabine	Heat recovery from waste gas via heat exchangers	Verification of operation efficiency
	Automation of coating processes and reduction of pressure in spray application	Reconstruction of the wash-out system
	Automatic shut off during work breaks	Investigation of feasibility
	Use of coating materials with low curing temperatures	For ex. Two component materials
Evaporation zone	Retrofitting of air circulation system	For e. concentration of VOC
Dryer	Retrofitting of direct heating	For ex. gas
	Heat recovery for other heating purposes	

1.3 Developments and Views into the Future

In order to reduce comprehensively environmental constraints and simultaneously the energy costs, new coating concepts are required. A looming trend is the increasing importance of the coil coating sectors, whereby coated coils are used in different production fields to be processed to finished products in the coated status. Thereby, the possibility is given to perform the pre-treatment and the coating on large and plane surfaces. It is thus possible to perform the coating with application processes that produce very little overspray, as for instance rolling or pouring. High air flow rates, as required with spraying techniques, are thus no longer necessary. Also in the pre-treatment zone, the energy intensive spraying of water-based cleaning materials can be replaced by rolling. A further development resides in the reduction of the spraybooth surface, whereby it must be analysed whether the moving parts of paint application equipment or the paint application equipment itself is inside or outside the coating cabin.

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Annex II:

Overview of selected Pre-treatment Processes

The objectives of applying paints on substrates are various: The substrate shall be protected against harmful environmental influences; its surface shall be embellished or upgraded through special effects etc. However, these functions can be fulfilled only when the adherence between the substrate and the coating layer is given. Nevertheless, the adherence is not only given by the paint system, but depends also on the characteristics of the substrate. Therefore, a pre-treatment of the surface to be coated is generally necessary.

In the following pre-treatment of metal-, wood- or plastic substrates are differentiated. An overview of possible surface contamination and pre-treatment methods according to different materials is given in table II-1.

Table II-1: *Impurities on substrates and applicable surface pre-treatment processes for different substrates* [BROCK 1998]

Substrate	**Impurities**	**Cleaning**		**Surface preparation/ pre-treatment**
Metal	Metal shavings, oils, fats, rust, oxides, dust, silicon, possibly traces of old paint, coating layer	Mechanical:	wiping, sanding, polishing, brushing, blasting	Activation, phosphatation, chromatation, passivation, grounding
		thermal:	flame cleaning	
		Chemical: (if necessary with mechanical support)	pickling, cleaning with solvents or water-based cleaning agents	
Plastic	Oils, fats, separating agent, dust, hand sweat	Mechanical:	abrasion, blowing, rinsing	flame treatment, plasma process, corona-discharge, fluoration
		Chemical:	solvent or water-based cleaning agent	
Wood	Sanding residues, dust, humidity, wood components, possibly traces of old paint	Only mechanical:	sanding, polishing, brushing	Impregnation, sealing, priming

1 Pre-treatment of Metal Substrates

Table II-2 gives an overview of common impurities for different metallic substrates. For the removal of impurities and disturbing layers, mainly mechanical-, chemical-, and degreasing processes are used.

Table II-2**:** *Impurities for different metallic Substrates* [BROCK 1998]

Metallic substrates	**Contaminations**
Steel	Rust, cinder, layers (f.ex. old coating layers, rests of adhesives and sealants), fats, oils, salts, dirt
Zinc, galvanised steel	So called “white rust” (layers of hydroxidsulfate)
Aluminium	Layer of aluminium oxide

1.1 Mechanical Processes

One of the most efficient methods for removing of disturbing layers and other impurities is abrasive blasting. Abrasive blasting consists of steering multi-way blasting agents, for instance steel shot (edged), steel scrap (round), glass pearls or one-way blasting agents with high speed on res. over the surface to be treated. Basically, the following abrasive blasting processes are differentiated:

- Dry abrasive blasting, whereby the blasting agent is blown on the surface with compressed air from guns;
- moist abrasive blasting, for which the blasting agent is dampened in order to reduce the formation of dust; and
- wet abrasive blasting, whereby water, with or without addition of blasting agent, is sprayed with compressed air or without air under a pressure of max. 2,500 bar on the substrate.

In industrial branches, abrasive blasting is performed in closed housings, cabins or halls and the blasting agent is usually recycled and re-used. Through abrasive blasting clean and bright metallic surfaces are obtained. Metallic surfaces that are just blasted are highly reactive and incline thus to corrode relatively rapidly. Therefore, the blasted metallic substrates have to be immediately chemically passivated or primed. The adhesion of paint on blasted surfaces is generally good. [BROCK 1998]

1.2 Degreasing Processes

Degreasing processes are utilised in order to remove contaminations from the surface to be coated subsequently, as far as firmly adhering layers (as for example rust) are not concerned. For that purpose, organic solvents are currently used only restrictively, for instance for manual degreasing of small and/or working pieces with a complex geometry or for cleaning of aircrafts hulls. Nowadays degreasing is usually carried out with water-based cleaning agents, since they contribute to increase environmental and labour protection. Degreasing can be carried out by dipping or spraying. While spraying causes lower treatment times, temperatures and concentrations possible, the surfaces inside the working pieces can be better reached when dipping. In the case when degreasing is difficult, a multi-stage cleaning, if necessary with additional brushes, is used. After cleaning with water-based agents, rinsing operations are mostly necessary and just before coating an additional rinsing operation with demineralised water and subsequent drying stage is generally required. Via different process-related variants (for example the cascade technique) and equipments (such as ultrafiltration) cleaning installations can usually be operated in a way that water and chemical substances can be economised. [BROCK 1998]

1.3 Chemical Processes

Chemical pre-treatment processes for metallic substrates include pickling as well as different methods[1] allowing the application of conversion layers, such as phosphating, chromating and passivating.

1.3.1 Pickling

Contrary to pickling of wood (confer chapter 8. paint application), pickling of allic surfaces means the chemical dissolution of the layers of oxides resp. the corrosion products that reside on the metal. For the pre-treatment of steel, acid pickling agents such as hydrochloric acid, sulphuric acid and nitric acid, are mostly used. Working pieces made of aluminium or zinc can be pre-treated with acid (for instance nitric/sulphuric acid) as well as with alkaline pickling agents (water-based caustic soda); however, when a pre-treatment is carried out with

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[1] These processes are not further regarded in this study since they do not belong to the solvent sector. Chemical treatment processes are score of another BAT study (cf. Annex I, IPPC-Directive)

alkaline pickling agents, a subsequent treatment with acid pickling agents turns generally out to be necessary. For certain metallic substrates, the pickling is achieved with phosphoric acid. Thereby, a thin conversion layer is created, leading to a short corrosion protection, but representing a good basis for the subsequent paint application.

Currently, the pickling of metallic substrates is mainly realised with hydrochloric acid, since also surfaces of light alloyed steel can undergo a more efficient treatment. The addition of surface-active agents confer a limited degreasing effect to the pickling baths. [KLEIN 1999]

1.3.2 Phosphatation

For many years, phosphatation is one of the recognised state-of-the-art technique for the pre-treatment of diverse equipment parts destined to the automobile industry, the engineering and many other industrial branches. Phosphatation aims at achieving:

- An increase of the adhesion of the coating layers;
- an improvement of the corrosion protection;
- no interferences in the coating process due to failures on the surface; and
- a homogenous coating structure.

The materials to be phosphated include mainly steel and pre-coated steel; however, with adequate regulation of the phosphating bathes aluminium can be phosphated, too. The following tables II.3 and II.4 show the phosphating processes that are mostly used currently, their applications and characteristics.

Table II-3: *Phosphating processes and their applic*ations [STOZ 2000]

Process	Application
Iron phosphating	Simple pre-treatment process for immediate subsequent coating
Zinc phosphating	High-grade pre-treatment process for immediate subsequent coating
Manganese phosphating	Pre-treatment process easing the gliding(for example in engines, transmission or when reforming)
Thick layer phosphating	Protection against rust, mostly in combination with subsequent greasing or waxing

Table II-4: *Phosphating processes and their characteristics* [STOZ 2000]

Processes	**Coatable**	**Corrosion protection**	
		uncoated	**coated**
Iron phosphating	Yes	very low	good
Zinc phosphating	Yes	low	very good
Manganese phosphating	No	low till medium	-
Thick layer phosphating	only oil/wax	low till medium	medium

Iron phosphating represents a low-cost process that is essentially applied for products dedicated to interior space and which therefore are not subject to extreme corrosion strains. However, from the series of processes mentioned above, the zinc phosphatation is utilised to the largest extent: It allows for a very good protection against corrosion and represents an excellent substrate on which coating layers show very good adhesion properties. Among the zinc phosphatation processes, the low zinc phosphatation (approx. 0,5 – 1,5 g zinc per litre) plays a significant role. Since their arrival on the market, they have supplanted the regular zinc-based phosphating (approx. 5 g zinc per litre) pre-treatment processes. In comparison with the normal zinc phosphating, they possess clear advantages with regard to corrosion protection, resistance against stone chippings and adhesion of the coating layers.

The layers obtained via zinc phosphating are crystalline layers that are built on clean metallic surfaces. The determining component of the phosphating solution is primary zinc phosphate. The use of further cations, such as nickel and manganese, allows for adapting the chemical composition and structure of the zinc phosphate layer to specific requirements. The steering of the formation velocity of the layer, oxidation agents such as nitrate, chlorate, nitrite, etc. are added to the bath solutions. [KLEIN 1999, BROCK 1998]

The low zinc phosphating process was developed in the context of the introduction of cataphoretic dip coating. While normal zinc processes build plane crystals in a fan-shaped form that may partly stickout from the flat surface, the conversion layers obtained via low zinc phosphating show predominantly a structure that is parallel to the metal surface and are substantially more mircro-crystalin and compact.

1.3.3 Chromatation

A chromatation consists in the treatment of a metal surface with a solution on chrome (VI) basis, whereby one differentiates between so called yellow and green chromatation. “Green chromatation” is performed with water-based solutions containing chromic acid (CrO_3), fluorides and phosphates. The green colour is obtained by addition of chrome-(III)phosphate.

The water-based solution to obtain the “yellow chromatation” contains mainly chromic acid. The yellow colour is induced by the additional presence of chromate. [KLEIN 1999]

1.3.4 Passivation

Passivation is carried out after a previous phosphatation step in order to extend the effect of protection against corrosion and to improve adherence. Passivation is mainly used in the sector of passenger car coating after electrophoretic coating, but also in the production of parts dedicated to the automobile industry.

Currently rinsing solutions on chrome (VI), chrome (III) and chrome (IV) basis are utilised. The drawbacks of chrome with regard to environmental aspects and working conditions (among others possible chemical reactions with subsequent coating layers) have led to the development of passivation solutions free of chromic acid that are already used in some branches. This share will probably increase in the next years, since according to EU Directive on car fragmentation [2000/53/EG] the use of chrome (VI) will be forbidden from 1.7.2003 for treatment processes against corrosion in the automobile industry and the corresponding supply industry. However, the protection against corrosion is worse with chrome (VI) free systems, since thinner layers are achievable and the applied coating layer cannot be rebuilt in case of damages (as for layers on chrome (VI) basis). Therefore, chrome (VI) free solutions can currently not be used in all sectors. [KLEIN 1999, PAULSEN 2001]

In order to improve protection against corrosion when using chrome (VI) free systems the passivation layer can for example be sealed. For that purpose sealings on silicate basis or combination sealings (organic/ inorganic) are utilised. On the other side resistance against corrosion can also be increased by use of zinc alloys instead of zinc alone. Currently zinc/iron, zinc/cobalt and zinc/nickel alloys are available and the outlooks for zinc/manganese promising. (confer [PAULSEN 2001])

2 Pre-treatment of Plastics

Plastics contain foreign compounds that arise from side reactions of synthesis (such as softening agent, colorant) or that are added as auxiliary material during the process (for example lubricants and separating agents such as waxes, oils, etc.). These substances have mainly a negative influence on the paintability of the plastic substrates; therefore, a pre-treatment is mostly necessary. Further problems are dust particles on the substrate to be coated and an insufficient moistening and adherence of the substrate. Special difficulties for the coating of the relevant plastics polyethylene (PE) and polypropylene (PP) are to be mentioned. However, different preparing and pre-treatment processes are available, among others [BROCK 1998]:

- In order to remove surface defects (such as pores, hollows, blows, etc.) the plastic undergrounds are polished or blasted, eventually even filled. Thereby the surface achieves a defined wrinkling influencing the coating adherence positively.
- For the degreasing of plastic surfaces water-based degreasing agents are prevailing nowadays. As for metal undergrounds, the degreasing is followed by rinsing steps with water and deionised water and with a drying step.
- The removal of dust particles from plastic substrates is performed at the spray booth entrance with ionised air.

In order to improve the wettability and coating adherence, several processes are available. The most relevant processes are described in the following.

2.1 Flamming

Flame treatment represents the most commonly used pre-treatment process for plastic substrates: A gas flame with excess of air is led manually or automatically over the surface to be treated; therefore mostly less than one second is necessary. The flame treatment induces an oxidation on the surface, whereby the polarity is increased. Advantages of this process include the possibility to work continuously, the easy handling and the high efficiency. The thermal stress of the material and the generation of waste gas represent drawbacks. [BROCK 1998]

2.2 Corona Treatment

The principle of corona treatment is very similar to the flame treatment. Instead of the flame an alternating voltage electrode is used generating high-energy oxygen ions via corona discharge that oxidise the plastic substrate. Besides the possibility of continuous treatment the corona process has the advantage that the plastic surface is not subject to thermal stress. However, only flat elements can be treated and the period of activeness of the treatment is limited. [Brock 1998]

2.3 Plasma technology

To improve the coating of plastic surfaces very good results can be achieved via plasma technology. This technology consists in the dipping of the plastic components to be treated in microwave activated plasma sources. In the conventional plasma technology the process is carried out under low pressure. However, currently it is possible to shift the pressure range in the direction of atmospheric pressure [SUNG 2001]. Thereby an essential advantage is that the treated plastic surfaces are stable for weeks, that means that they can be stored in order to be coated later. Furthermore, the process is free of auxiliary substances.

2.4 Fluorination

Fluorination is particularly suited for unpolar plastics (such as thermoplastic elastomers) that gain increasingly importance and represents therefore an alternative to standard pre-treatment. The process is as follows: First the reactor chamber is evacuated until the necessary lower pressure limit is reached. After that the chamber is filled with dry air until the required upper pressure limit is achieved. This pre-rinsing step is necessary in many cases to remove adherent rest moisture from the surface. Then the chamber is evacuated again until lower pressure limit and is feeded with a fluorine/nitrogen mixture that is necessary for the surface treatment: that is the beginning of the treatment of the plastic surface in the reactor chamber. At the end of the required reaction time the fluorine/nitrogen mixture is extracted from the chamber and either drawn off over an absorber or pumped into a storage accumulator so that no waste gases is generated. Flooding in three to five steps and evacuation of the reactor chamber with dry air follows, in order to extract eventually available rest molecules from the chamber and from the treated substrate. Finally the reactor chamber is opened and emptied [Bauer 2000].

Fluorination is a pre-treatment method offering a wide range of advantages, such as [Stoz 2000]:

- *Stability of the effect for several months:* Fluorinated plastic components can be either directly coated or stored for months. Even a subsequent washing step does not affect the polar substrate.
- *No defects of the base material:* No thermal or other strain of the base material does occur, thus no defect is generated.
- *Environmentally friendly:* After the fluorination alternative coating materials can be utilised such as water-based paints.

3 Pre-treatment of Wood

Besides solid wood (such as spruce, fir, birch, nut-tree), also numerous materials that are produced from different wood types and binding agents (for example laminated resins) are used. The most important wood materials include [BROCK 1998]:

Veneers, plywood, chipboard, and fibreboards.

The pre-treatment processes most commonly used in the wood and furniture industry are polishing, pickling, glazing and bleaching. For detailed information, please refer to chapter 9.

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Annex III:

Paint Application Processes

1 Application Techniques with a high Efficiency

Processes with a high application efficiency include filling, rolling, casting, dipping, flooding and vacuum coating. With regard to dipping two processes can be differentiated: Conventional and electrophoretic coating. These high processes with a high application efficiency generate less overspray as spray applications but are not as universally applicable.

1.1 Filling

For filling pigmented, paste-like surfaces, stoppers and coating materials are applied. In automated processes the filling material is applied by rolling in reverse coaters whereas excess material is wiped off. This process is only applicable for flat workpieces. Therefor the process is mainly used for plates made of derived timber products. The effectiveness is very high. For more curved surfaces stoppers are applied by hand operated equipment such as palette knives. Subsequently hardening, a grinding is necessary to obtain a smooth surface. (cf. [EICHHORN 2000])

1.2 Rolling

In general rolling is used for flat, metallic work pieces. Also two side coating is possible. Application takes place by rotating rubber coated back-up rolls. The application weight can be adjusted by a variation of space between the rolls. If work piece and roll are moving in the same direction, only layers up to 12 µm can be applied, only a limited range of coating materials viscosity can be used. These problems do not occur in reverse coating processes (opposite rotating direction of roll and movement of work piece) [ONDRATSCHECK 2001].

By rolling 2 component materials, as well as polymerisation materials with high viscosity and 100 % solids content are applicable. When using 2 component Systems generally the master batch is applied before the hardener is placed). Mainly flat workpieces are coated but also slightly curved products such as wooden panels can be processed. (cf. [EICHHORN 2000])

1.3 Casting

In the casting process plane or almost plane workpieces are coated by a curtain of lacquer. In the casting machine, the coating material is pumped into a sinkhead that extends over the entire workpiece width. Dosing of coating materials is either regulated by adjustment of the sinkhead or by speed of the workpiece.

Application weights from 40 – 500 g/m² can be processed, according to the machine type. By casting equal layers can be applied with a high efficiency of approx. 98 %. Excess coating material is caught in a reservoir and pumped back into the sinkhead.

Casting is manly used in the furniture industry for coating of doors, wall units and other plates. Mostly solvent free lacquers based on polyester are applied but also other types of coating materials can be processed (cf. [EICHHORN 2000]).

1.4 Dipping

For the serial production of bulk articles that are coated in a single tone without colour changes, dipping is suitable. The workpieces are submerged into a reservoir, filled with the coating material and subsequently dried (similar to other coating processes). Also vents might be necessary to assure a sufficient coating. Advantageous of dipping is the high efficiency, complete coating of workpieces (of outside surfaces as well as inside surfaces), cost effectiveness, high operational capacity and good possibilities for automation.

In general two different dipping processes are used for industrial application. These methods are described in the following. [BAUMGÄRTNER 2000]

1.4.1 Conventional Dipping

In conventional dipping processes the workpiece is submerged into the coating material. A chemical reaction does not take place. When using solvent based lacquers, almost all common 1-component materials can be used. In this case, the fire hazard is very high due to he evaporation of organic solvents. This risk can be minimised by the application of water based coating systems due to their smaller content of VOC. Also a drying step after pre-treatment such as washing processes, is often not necessary. But the application of water-based coatings has also some disadvantages: When processing these products foam forming can become a problem, water based lacquers are only stable in a small range of pH and therefore very sensitive to contaminations that might stem from the pre-treatment processes. (vgl. [BAUMGÄRTNER 2000])

1.4.2 Electrophoretic Dipping (ETL)

For electrocoating an direct electric current circulates between the workpiece and electrodes, located in the paint tank. According of the polarity of the workpiece, anodic or cathodic electro coating can be differentiated. Since all used electro coatings are water-thinnable, their content of organic solvents amounts approx. 1 – 4 %.

The advantages of electro coating are the consistent and complete coating (also in cavities), no forming of edge runners, a high efficiency and the possibility for fully automated processes. Disadvantageous are the high investments, higher material costs and high efforts for the maintenance of the paint tanks as well as for quality assurance (cf. [BAUMGÄRTNER 2000])

1.5 Flooding

For flooding, the paint material is poured onto the workpiece. In modern installations the workpieces are coated in a closed chamber, which is then flooded with the paint material. The excess material is absorbed and reused in the chamber. Material losses amount only 1 – 5 %, depending on the geometry of the workpiece. In comparison to dip application the evaporation losses are higher. Thus only water-thinnable materials are processed. The process is especial suitable for big workpieces with a big surface as for e.g. for heating elements and varnishing of parts for truck chassis or agricultural machines and also for the application of cavity sealings in the serial coating of passenger cars. (cf. [EICHHORN 2000])

2 Spraying Techniques

2.1 Spraying without electrostatic Charge

Despite the increasing use of electrostatic application techniques, spraying without electrostatic charge is still widely used for various applications.

In comparison to electrostatic processes the investments are significant smaller. Also no special requirements concerning geometry, paint materials and electrical conductivity exist. The disadvantages of these application techniques are low efficiencies. Thus several techniques were developed for a minimisation of the overspray. Their efficiency is comparable to electrostatic processes.

The atomisation of the paint material is carried out mechanically. Thereby compressed air (high or low pressure technique) or the hydrostatic pressure (airless spraying) or a combination of both (Air-assisted spraying) are used for atomisation.

2.2.1 Spraying with compressed air

For atomisation the paint material and compressed air are conducted to a jet where the varnish is atomised in conventional spray guns. The discharging air transports the paint particles onto the surface. The higher the air pressure, the more small paint particles are archived but also the overspray losses are higher due to the distracted air flow. If the air pressure is to low a poor surface quality is archived.

High- and low pressure spraying are for example applied for coating of vehicles, furniture and machines. All surfaces can be coated with this technology. A high surface quality can be archived. The efficiency amounts approx. 5 % for lattice-like workpieces and 40 – 50 % for parts with a larger surface. Low pressure spraying is used for the varnishing of furniture and machines. A wide variety of parts can be coated but also the surface qualities depend on the paint material and the adjustments.

For an increase of efficiency surface quality and the utilization of material spray applications such as HVLP, hot spraying, and spraying with CO_2 are applicable. These processes are described in the following.

Hihg-volume low-presure-spraying (HVLP)

The HVLP represents an application technique that achieves a material utilization of up to 65 % via a reduced air pressure. This high efficiency rate results from a smaller amount of atomized small paint particles. In comparison to high-pressure compressed-air spraying material savings up to 20 % are achievable. Due to the generation of bigger paint particles, the optical appearance can be different, compared to conventional spraying [ONDRATSCHEK 2000]. Modern low-pressure guns yield coatings of a quality equal to that achieved with high pressure guns with a similar work rate [VDI 3456].

Hot Spraying

For hot spraying the paint material or the compressed air or both are heated. Thus the viscosity of water-thinnable or solvent based paints is higher. Thus the amount of thinners can be reduced which results in lower VOC-Emissions. The heating (70°C) of the paint material is carried out in the spray gun container or via heated pipes for compressed air and the paint material. Flow heaters for heating of the compressed air are utilised for paint materials that otherwise would already start to react at temperatures of 70 °C. By an increase of temperature, higher layer-thickness can be applied without the forming of edge runners. Compared to conventional spraying the number of layers can be reduced [ONDRATSCHEK 2000]. Disadvantageous is the reheating after colour changes, which makes this technique not suitable for processes with frequent colour changes.

CO_2-Atomization (Unicarb-System)

In this process the volatile organic compounds are replaced by CO_2, which is fed to the high viscous paint material The paint-CO_2 mix is processed at temperatures of 40 – 70 °C and with a pressure of approx. 100 bar. The atomisation is done via airless spray application. Due to the fast evaporation of the CO_2 a bell-shaped spray sheet with a lower velocity of paint particles compared to regular airless-spraying. First practical experiences obtained in several sectors, mainly in the USA, show significant reductions of material consumption and VOC-emissions [ONDRATSCHEK 2000].

2.2.2 Airless spraying

The paint material is forced at material pressures of 80 – 250 bar through a relatively small hard-metal (< 2mm) nozzle. The paint jet is then broken up by the forces of expansion and interaction of the paint jet with the stationary air outside the nozzle. Fast colour changes are not possible due to the essential high pressure pumps.

Airless spraying is usually utilised for industrial coating for sizable objects such as aircrafts, ships or heavy machines. To obtain similar surface-qualities, compared to high-pressure compressed-air spraying, the processing conditions have to be adjusted.

The same conditions occur when using the air-assisted airless-technique, which is used for the paint application onto machines, commercial vehicles and furniture. All listed processes can either be applied manually or automated. The material efficiency for the HVLP, airless spraying and air-assisted airless-technique approx. 5 % for lattice-like workpieces and approx. 60 - 70 % for workpieces with a bigger surface [ONDRATSCHEK 2000]

2.2 Electrostatic assisted Spraying

For the electrostatic assisted spraying, an electric field is generated between the workpiece and the spray gun. Thus the following advantages concerning environment as well as coat effectiveness, are reached:

- Lower material consumptions, lower emissions, smaller amounts of paint sludge and a reduced staining of painting cabins.
- Improved possibilities for automation of varnishing processes, faster coationg and therefore a higher productivity.
- Smaller air consumption (smaller energy demand).

Disadvantages of electrostatic assisted spray applications are the risk of edge runners and too big layer-thicknesses onto cavities and interior edges do to a concentration of paint materials onto these areas. Several electrostatic assisted spray applications are in use, which are described in the following.

2.2.1 Electro-statically atomising Processes

For this processes the paint material is atomised via an electric field. The paint material is transported to the workpiece along the same electrical field that also causes the atomisation. There are three different implementations:

- *Spraying gap*, suitable for workpieces without depressions. The maximum material flow rate amounts 2 – 3 ml/min. The demanded time for colour changes is high (approx. 30 minutes. Depending on the workpiece and the conditions of processing, the efficiency amounts up to 99 %.
- *Spraying bell*, suitable for small parts and tubular structures with only small depressions. According to the size of the spraying bells a maximum material flow rate up to 250 ml / min is possible. Colour changes can be carried out within a several minutes. The material efficiency is also very high (up to 95 % depending on the conditions of processing and the geometry of the workpiece).
- *Spraying disk,* also suitable for tubular structures and small parts with depressions. A maximum material flow rate up to 800 ml / min is possible according to the size of the disk. Times for colour changes as well as the efficiency are comparable to spraying bells.

A disadvantage of these processes is the limited variety of processable materials. Water-thinnable materials can not be processed with this technology. Thus processes with electrostatic atomisation are only utilised for a few special applications. The advantage of such devices is the good reliability and the high effectiveness (cf. [KLEBER 2000])

2.2.2 Mechanically atomisation via high Rotation

The atomisation of the paint materials is carried out mechanically. Thereby the electrical properties of the paint material are not relevant. Compared to electrostatic atomisation these processes show a higher flexibility with regard to paint materials and material flows. Two processes can be divided (cf. [KLEBER 2000]):

- *Electrostatic-assisted high rotation bells* are mainly used for the serial varnishing of passenger cars and increasingly also for automotive parts as well as in other industrial sectors. Water-thinable paints can be processed. Material flows up to 1.000 ml/min can be achieved. A change of colour can be done within several seconds. The efficiency amounts up to 95 %. The application of the paint material takes place via electrostatic assisted high rotation atomisation (cf. Figure 2-4, chapter 2). The paint material is conducted to a rotating bell. Due to the centrifugal force, the material flows to the edge of the bell. Because of the stationary ambient air the material is atomised. The bells are energised with a direct voltage of 60.000 – 80.000 volt. Thus the paint particles follow the field lines of the electrostatic field to the grounded surface. Additionally air assistance is applied since atomisation takes place parallel to the surface of the workpiece. For processing of conductable (water-thinnable) paints, a galvanic insulation within the feed lines is essentially. If bells with a cantilever electrode are used, a galvanic insulation is not necessary (grounded feed lines). If special lacquers (metallic-paints) are applied a variance of the colour and also the surface quality may occur.

- *Electrostatic-assisted high rotating disks* atomise the paint material mechanically, such as high rotation bells. The process is suitable for almost all paint materials inclusively water based paints. Due to material flows up to 1.500 ml/min and a material efficiency of 95 % the process is eligible for universal industrial varnishing operations. Typical applications are varnishing of profiles and bicycle frames.

2.2.3 Electrostatic-assisted compressed-air-, airless- and ‚air-assisted Spraying

For electrostatic-assisted compressed-air-, airless- and ‚air-assisted[1]-spraying, the paint material atomisation is similar to regular compressed-air spraying except for the airless technique. There the atomisation is realised via the hydrostatic pressure of the material. Additionally the paint particles are electro-statically charged. Water-thinnable and conventional materials are processable. Compared to high rotating application devices the efficiency is lower (85 %).

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[1] Air assisted airless technique

Via compressed-air spraying complex geometries with depressions can be varnished. According to the application conditions, the material flows amount up to 1.000 ml/min. Airless or air-assisted airless technique are rather used for high material consumptions or high surface throughputs such as for example for the automated coating of furniture (workpieces with depressions), automated coating of window frames or manual coating of big workpieces. The material flows amount up to 3.000 ml/min. According to the implemented technique (only one pump or one pump for each colour) the time need for colour changes varies (cf. [KLEBER 2000]).

2.2.4 Electrostatic-assisted Processing of water-thinnable Paints

Since the atomisation via electric forces is not sufficient for water-thinnable paints, these materials are exclusively applied with high rotating application devices, or electrostatic-assisted compressed-air or airless (or air-assisted) spraying. The different technical for the electrostatic-assisted processing of water lacquers are in detail described in [KLEBER 2000].

2.2.5 Processing of Powder Coatings

During the processing of lacquer systems on powder basis, the coating material is applied in the form of thermosetting polymer or thermoplastic powders onto the workpieces surface. The powder is then merged into a closed film by heat impact. Due to the merging process an additionally cross linking takes place in thermosetting polymers. Two different processes can be differentiated:

- For *electrostatic-assisted powder coating*, the paint material is electro-statically charged and transported along the field lines to the grounded work piece. Due to the coulomb forces the powder particles adhere onto the surface. In the subsequent heating of the workpiece the paint layer is merged into the completed paint layer. The most widely applied process is the electrostatic powder spraying (ESP). In this process the powder is electrostatic-assisted sprayed onto the workpiece with compressed air. For small parts, the powder is applied via turbulent fluidised beds. Thereby the workpieces are not directly sprayed but coated in a closed chamber with the electrostatic charged powder.

- For *powder sintering* the workpieces are heated above melting temperature, before the coating material is applied. When the powder comes in contact with the surface, sintering and merging takes place. This principle is used for a number of coating operations. Most common is the fluidised bed coating.

Information about the configuration of these installations can be obtained from [STROHBECK 2000].

3 Separation resp. Recycling of Paint Overspray from Spray Applications

The deposition of overspray in the spray booth is either done by wet- or dry deposition by the aid of ventilation circuits. The determination of a suitable process depends on the type and amount of processed material, the application devices, the efficiency as well as economical aspects [KLEIN 2000].

3.1 Wet Separators

For wet separation of the overspray the air is extracted via exhaust air fans over the floor gate. The overspray enriched air is conducted to a wet separator, where it is absorbed by water. The generated paint sludge is constantly applied to the paint sludge separation. This process can be referred as state of the art. Thus the service life of the spray booth water is increased and the consumption of fresh water and generation of waste is thereby reduced. In general venturi scrubbers are utilised for separation of overspray. The paint sludge consists of 10 – 20 % solid material. For a reduction of disposal costs, the sludge needs to be drained via decanters or centrifugals.

The wet separation is suitable for a high paint input. Compared to dry separation no time-consuming paint stripping of baffels or changing of contaminated filters is necessary.

As state of the art, all spray booth parts, that come in contact with water, are made of stainless steel. Thus water-thinnable paints can be processed without a risk of corrosion. If solvent based paints and water-thinnable paints are processed within the same spray booth, problems of coagulation may occur [KLEIN 2000].

3.2 Dry Separation

Dry separation is generally used for spray booths with a small paint input. In some cases the combined spray booth and dryers are utilised. Advantages of the dry separation are:

- Absence of chemicals for a coagulation of separated paint particles,
- Low operating cost for small paint inputs.

Modern spray booths are generally equipped with heat exchangers for a reduction of energy demand for the heating of fresh air. The disposal of overspray is done by a paint stripping of baffles or the exchange of contaminated filters. The intake capacity of the filters amounts approx. 2,5 – 3,5 kg/m^2. Depending on the used paint material, the filters have to be disposed as waste or as hazardous waste [KLEIN 2000].

3.3 Paint recycling

The recycling of overspray is increasing. Such installations are mainly utilized for the industrial paint application for wood or timber products (e.g. furniture, window frames, door frames) or for the industrial varnishing of metal parts (e.g. supplier components for car manufacturers, shelves or parts for furniture).

For a reuse of overspray, the paint must be recyclable and reusable via addition of new paint materials or in applicable a different painting process. Thus the overspray must be sorted and also be available in sufficient amounts. Depending on the applied process and plant concepts, practical results show that approx. 60 to 97 % of the oversprays can be reused. Water-thinnable materials have the best conditions for a direct reuse of the overspray. Thereby the ovespray is absorbed in a curtain of paint material.

For detailed informations of plant concepts for overspray recycling confer [KLEIN 2000].

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[VDI 3462]

VEREIN DEUTSCHER INGENIEURE: *Emissionsminderung - Holzbearbeitung und -verarbeitung - Bearbeitung und Veredelung des Holzes und der Holzwerkstoffe (VDI 3462)*, Kommission Reinhaltung der Luft im VDI und DIN, in: VDI/DIN-Handbuch Reinhaltung der Luft, Band 3, Düsseldorf, Oktober 1996

Annex IV:

Drying

The transition from the liquid paint or powder into a solid state can be based on **physical drying** (netting of film forming agents due to the evaporation of organic solvents) or **chemical cross linking** of the film forming agents (via polymerisation, polycondensation or polyaddition). For drying the workpiece is either direct or indirectly heated. In the following the most widely spread drying processes for paints are listed [BROCK 1998]:

- Drying at room temperature (ambient temperature)
- Forced drying (up to approx. ca. 80 °C)
- Burning in (usually at temperatures from 100 to 200 °C) [1]
- Radiation curing (Infrared, ultraviolet or curing via electron beam)

1 Drying via circulating Air

In this process heated air transports heat to the workpiece via heat exchange. The energy demand heavily depends on heat losses of dryers. In general the additional costs for drying amount up to 2 – 5 % of the total energy costs of the painting line in the serial production of automobiles [ONDRATSCHEK 2002]. All available hot setting materials, such as solvent-thinnable and solvent free materials, can be dried via hot circulating air. Thereby the drying time depends on the applied paint material, the layer-thickness and the heat capacity of the workpiece.

All non heat sensitive workpieces can be dried via heated circulating air. Due to a potential risk of thermal deforming or damaging, the drying of workpieces that are made of wood or synthetics, are limited.

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[1] For a characterization of drying conditions the dryer temperature and the object temperature have to be stated. The weight and geometrie of the workpiece cause a difference of ambient temperature and object temperature.

Table IV-1:*Drying via heated air* [Ondratschek 2002]

Drying process	**Process description**	**Application**		
		Paint	**Workpiece**	**Plant**
Drying via heated, circulating air Convection dryer	Heat exchange via heated circulating air (approx.. 2 – 5 m/s)	Heat setting materials, solvent thinnable and solvent free paints No limitation according coating thickness or pigment content Drying time depends on utilized paints, coating thickness and heat capacity of the workpiece	All non-heat sensitive materials, limited use for heat sensitive workpieces that are made of wood or synthetics (thermal damaging and deformation might occur), suitable for all geometries	Big space request, long drying times Plant components: heating installations, filtering devices for fersh air and exhaust gases, air conditioning and where required, exhaust gas cleaning Partly air dehumifiers are applied in circulating air hydrex-dryers Energy demand: Approx. 2 – 5% of the total energy demand of the painting plant

For a drying of water-thinnable paints or a pre-drying of wet-on-wet layer constructions dehumified air is utilized (cf. [ORTLIEB 2000]). Therefore convectional dryers with an additional dehumification, so called **Hydrex-dryers,** can be used. Due to the intake of water, the drying times can be reduced significant.

Because of their universal field of applications, convectional dryers are utilized for drying of different shaped parts with different geometries. Due to the consistent heating, the risk of overheating (damaging of the paint layer or the surface of the workpieces) is low, even if short standstills of the conveyors occur [BROCK 1998].

Other than for drying of paints, dryers are also utilized for:

- Drying of retained water from pre-treatment or rinsing zones.
- For gelification and solidification of adhesives or underbody protection materials.
- For pre-heating of workpieces (against cold surfaces or trapped air in the laquer finishing of wood).

2 Ultra-red Radiation Curing

For ultra-red radiation curing the workpiece is heated via adsorption of infrared radiation. The intensity of the ultra-red radiation depends on the wavelength range and thus of the temperature of the radiator. The adsorption of the rays depends on the surface smoothness of the paint, its colour or lightness and its chemical composition.

Due to the radiant heat, also solvents are evaporated. Therefore, the exhaust gas has to be lead away and fresh air has to be supplied.

Table IV-2: *Drying via ultra-red radiation* [ONDRADSCHECK 2002]

Drying process	**Process description**	**Application**		
		Paint	**Workpiece**	**Plant**
Drying via ultrared radiation	Electromagnetic waves: λ=1µm – 1 mm, Adsorption of radiation from paint layer and potentially from the workpiece Drying from the inside to the surface	e.g. suitable for powder coatings and water-thinnable paints	Trouble-free drying of direct irradiatable surfaces Paint can be more heated than the raw material, lower heating of the workpiece and thus shorter cooling times and lower energy demand	Plant components: -Radiation dryer -exhaust gas extraction -plants with a continuous process

The advantages of the ultra-red curing are [BROCK 1998]:

- Fast heating of painted workpieces, since more energy can be transferred in a shorter time, compared to convectional dryers;
- faster cooling since the heat does not penetrate deeply into the raw material for short irradiation;
- lower energy demand;
- smaller thermal stress for the raw material;
- relatively low investments and technical expenditure;
- good controllability of object temperature via the intensity of radiation and;
- drying of the paint layer from the inside to the surface.

Besides the drying via heated circulating air, the drying with ultra-red radiation shows the widest range of applications. The ultra-red radiation curing is for e.g. utilized in the serial coating of passenger cars for the pre-drying of top coats that are applied by the wet-on-wet technique (cf. chapter 2, volume Paint Application).

Increasingly the ultra-red technique is also used for the drying of top coatings. For some materials the surface properties (such as brightness and blistering) can be influenced positively by an adjustment of temperature and drying time. Furthermore the ultra-red drying represents a technique that allows high heat transfers, contactless to the paint layer.

An increasing use of ultra-red drying for powder coatings is expected. Today already *powder coatings* are cured via near-infrared (NIR). Depending on the application the complete drying process of the coated workpiece takes 1 - 5 seconds. Thus the process is very suitable for heat sensitive Materials like plastic or wood.

Presently the NIR-technique is applied for the drying of water-thinnable paints used for the lacquer finish on wood.

For more detailed information about the ultra-red technique cf. e.g. [ORTLIEB 2000, WOLLENWEBER 2000].

3 UV- curing

As radiators for ultraviolet radiation (UV), for the UV-curing, the electrical discharge in gases are used. Mostly mercury-vapour lamps are utilized. The radiation starts a chemical cross linking within the paint layer. As film forming agents insatiate polyesters, epoxies, vinylether and acrylates are very suitable.

Table IV-3: *UV-curing* [ONDRADSCHECK 2002]

Drying process	**Process description**	**Application**		
		Paint	**Workpiece**	**Plant**
Drying via ultra red radiation	Absorption of UV-radiation, wave-length range: λ=0,32 – 0, 4 µm, photo-chemically decay reaction of photo initiators within the paint material and chain polymerization of the film forming agents (Curing within a few seconds)	e.g. insatiate polyesters, acrylates, thick film paints as clear coats or glazes	Curing only on direct irradiatable surfaces, low heating of work pieces	Plant components: - mercury-vapour lamps (80 – 240 W/cm²), - extraction of ozone

Advantageous is the very fast curing of UV-hardening paints onto plastics, metals, lumbers, glass and papers (cf. [GLASURIT 1984, GARRATT 1996]). Thereby polimerisations is started from the adsorption of the UV-radiation. In this way acrylates, unsaturated polyesters, melamine- or urea resins can be cured.

Curing takes place without a significant heating of the paint layer. Therefore a fast and energy efficient curing of paints onto heat sensitive materials can be obtained. Due to the high crosslink density a very good coating quality (hardness, abrasion resistance) can be archived. A further advantage of the UV-technique is the low space request, which amounts only approx. 20 % of convection dryers.

According to experiences, the energy cost can be reduced up to 70 % if UV-drying (of wet lacquers) is implemented instead of conventional dryers. At present no experiences for the serial application of UV-curing powder coatings for metal surfaces are available. However a reduction of the energy demand from approx. 30 – 50 % can be expected for the application of UV-curing of powder coatings [WIMSCHNEIDER 2000].

In Table IV-4 a comparison of conventional drying paints and UV-curing materials is given.

Table IV-4: *Comparison of conditions of conventional –drying paints and UV-curing wet lacquers and powder coatings* [WIMSCHNEIDER 2000]

Parameters	UV-wet lacquer	UV-powder coating	Water-thinnable paint	Powder coating
Drying temperatures	50°C	70°C - 130°C	At ambient temperatures	130°C to > 200°C
Drying temperatures	Very short (5 - 25 sec)	short (1 - 2 min)	long (10 min and more)	Long (5 min and more)
Material efficiency	Very high (up to 99 % for roller application)	Very high (up to 99 %)	Moderate to high losses from overspray	Very high (up to 99 %)
Energy demand	Very low	low	Moderate to high	Moderate to high
Corrosion protection	Good	Not stated	Good to very good	Good to very good
Chemical resistance	Good	Not stated	Good to very good	Good to very good
Plant engineering	Compact, uncomplicated, closed installation	Compact installations, little experiences for serial production	Conventional plant engineering, high efforts for drying, overspray losses	Conventional plant engineering, high efforts for netting
Field of application	Suitable for serial production and outside applications	Suitable for serial production and indoor applications	Universally	Universally

The disadvantages of this curing technology are slightly higher commodity prices compared to other paints, and high efforts for the labour protection (due to radiation and processed materials) [BROCK 1998]. For hardening of paints onto flat and two dimensional workpieces the UV-curing is uncomplicated. More complicated is the curing of three dimensional parts. At present also installations for the curing of powder coated three dimensional workpieces for plastic or wood raw materials are available on the market and produce good surface qualities [FUSION 2000].

Mainly UV-curing takes place for the coating of plastic or wooden workpieces with wet lacquers. UV-curing is suitable for the fast curing of bigger surfaces resp. bigger product quantities. It is not applicable for complex shaped workpieces that can not be completely irradiated directly. A lack of cross linking due to formation of shades can not be compensated by following storage or heat impact. The surface needs to be irradiatable directly. For pigmented paints the UV-curing can be disturbed by the adsorption of radiation by the pigments if bigger coating thickness is applied. A new area for UV-curing represents the powder coating of heat sensitive materials such as wood, chipboards and synthetics.

In general the applied powder is cross linked via ultra-red radiators and than cross linked with UV-radiation [BROCK 1998].

In many applications, solvent free UV-curing paints with a solids content of almost 100% are utilized. If these materials are applied via spray applications they have to be diluted for an adjustment of viscosity. Before curing takes place the dilutents (water or organic solvents) have to be removed via evaporation. Therefore the paint layer is heated up to at temperature 60 – 100°C. In table IV-5 an overview of present applications of UV-curing is given.

Table IV-5: *Applications of UV-curing*

Applications	Paint layers
Painting of eyeglasses and headlamp diffusers for automobiles made of polycarbonate	Clear coat
Coating of headlight reflectors made of several different plastics	Ground coat (before metallisation)
Coating of electro motors and aluminium rims	(powder coating)
Varnishing of mounting parts for passenger cars, made of various plastics	Clear coat
Varnishing in the wood- and furniture industry (e.g. floorings))	Not stated

For more detailed information's about the UV-technology cf. [KLEIN 2000].

4 Electron Beam Curing

In this process curing is initialised by an electron beam emitted from a hot-cathode tube. Polymerisation and thus hardening of the paint, is caused by the impact of electrons onto the monomers. That way unsaturated polyester, polyurethane, epoxy-resin, polyethylene, PVC and others are cured. Basically this process is suitable for all coated substrates and geometries. The achievable surface quality is high. This drying method requires a small floor space. Compared to conventional dryers, the investments are very high due to the technical equipment (hot-cathode tube, inert gas application, radiation protection and mainly labour protection). The energy demand is relatively low (cf. [ORTLIEB 2000])

5 Drying via Induction

In this process the metallic workpiece is heated via inducted eddy currents. All heat setting paints can be dried by this method. The technique is utilised for e.g. for the curing of adhesives in the production of passenger cars.

6 Drying via Microwaves

In this process the wet paint layer is heated via electromagnetic **microwaves** (high frequency-drying system). This technique is utilized for water-thinnable paints and non-metallic substrates (cf. [BROCK 1998, ORTLIEB 2000]) For microwave drying and high frequency-drying electromagnetic waves with different wave length and frequencies are used.

Due to the impact of these electromagnetic waves, the dipoles are oscillated and thus the electromagnetic energy is transferred into heat energy. Thus the contained water is evaporated rapidly. Both drying systems are only suitable for water-thinnable paints. The evaporated water must be extracted. Therefore these installations are always combinations oft radiators and suction units. In many cases flash off zones are used additionally. Since the efficiency depends on the amount of dipoles, water-thinnable paint systems have to be adjusted.
Due to the fast evaporation of the water, the caused surface roughness of wood surfaces is a lot smaller.

7 Summary

In Table IV-6 an overview of the different drying processes is given.

Tabelle IV-6: *Applications of different drying processes*

Drying process	**Applications**		**Installations**
	Paints	**Workpieces**	
Drying via heat carriers			
Heated circulating air	• Heatsetting materials, either solvent based or solvent free • No limitation of coating thickness or pigmentation • Drying time approx. 3 – 60 min • Drying time and drying temperature influence the surface quality. Risk of dust inclusions in the wet paint layer.	• All non-heat sensitive materials • Contingent usable for plastics and wood • Suitable for all geometries	• Long drying times • High energy demand due to isolation and opening losses and by heat discharge. • High level of automation possible, high flexibiliy
Drying via radiation			
Ultrared radiation	• Heat setting materials, solvent containing or solvent-free (the solvent composition has to be adjusted on the energy of the radiation), powder coatings • Fast heating and thus small cooling times. • No limitation of layer-thickness	• All non-heat sensitive materials • Contingent usable for transparent materials such as glass and partly plastics and also for wood • Formation of shades on edges and nitches • Paint can have higher temperatures than substrate	• Different radiators according to the utilized wave lenght. • Flow path or programm controlled installations according to drying and surface quality conditions
UV radiation	• insaturated polyesters, polyacrylates etc. • Clear Coats, glazes and thick-layer systems • Pigmented paints usually only as thinn-layers	• Drying only onto direct irradiatable surfaces (mainly flat workpieces) (vorwiegend Flachteile) • For wood and plasstics, a yellowing and also an embittlement is possible • widely applicated for paper and board	• Mercury-vapor lamps • Low required floor space and energy consumption • Low VOC-emissionens • Extraction of ozone is necessary

Drying process	**Applications**		**Installations**
	Paints	**Workpieces**	
Electron beam s	• insaturated polyesters, polyacrylates etc. • No limitation of layer-thickness or pigmentation • No photo initiators necessary	• All substrates, especially for paper, wood or foils, partly risk of embrittlement • Formation of shades	• Very low required floor space • Very high investments (radiationm protection and extraction of exhaust gas) • High level of automation • Only applicable for large surface throughputs
Drying via electrical processes			
Inductive drying	• heat-setting materials	• Ferromagnetc substartes	• Process used for special applications (e.g. hardening of structural bondings in the serial production of passenger cars)
Microwave drying	• water-thinnable materials	• non-metallic substrates	• Processes used for special applications (e.g. coating of wood)

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Annex V:

Secondary Emission Abatement Measures for Reduction of VOC Emissions

End-of-pipe technologies or so-called secondary emission reduction measures are used for the elimination of volatile organic compounds in exhaust gases. These processes are applied if a principal technique changeover to solvent-free products or to materials low in solvents cannot be realized due to technical or economical reasons or if a recovery and recycling of organic solvents is possible. In general two different categories of secondary emission reduction measures can be differentiated:

- Processes allowing a recovery of VOC from the exhaust gas and recycling as solvents
- Processes including the irreversible conversion of the VOC from exhaust gases into more environmentally-friendly products (e.g. post combustion methods or biological processes). These techniques also include measures for recovery of energy [KRILL 1996, BRUIJNES 1996].

In figure V-1 an overview of different secondary emission reduction measures is given. The following processes can be regarded as standard processes:

- thermal and catalytic post-combustion,
- absorption,
- adsorption
- biological processes

Besides these measures, **condensation** is used for emission reduction in exhaust gases.. However the condensation is no independent process, but it is used for a pre-separation of organic solvents in most applications and thus combined with further secondary emission abatement measures.

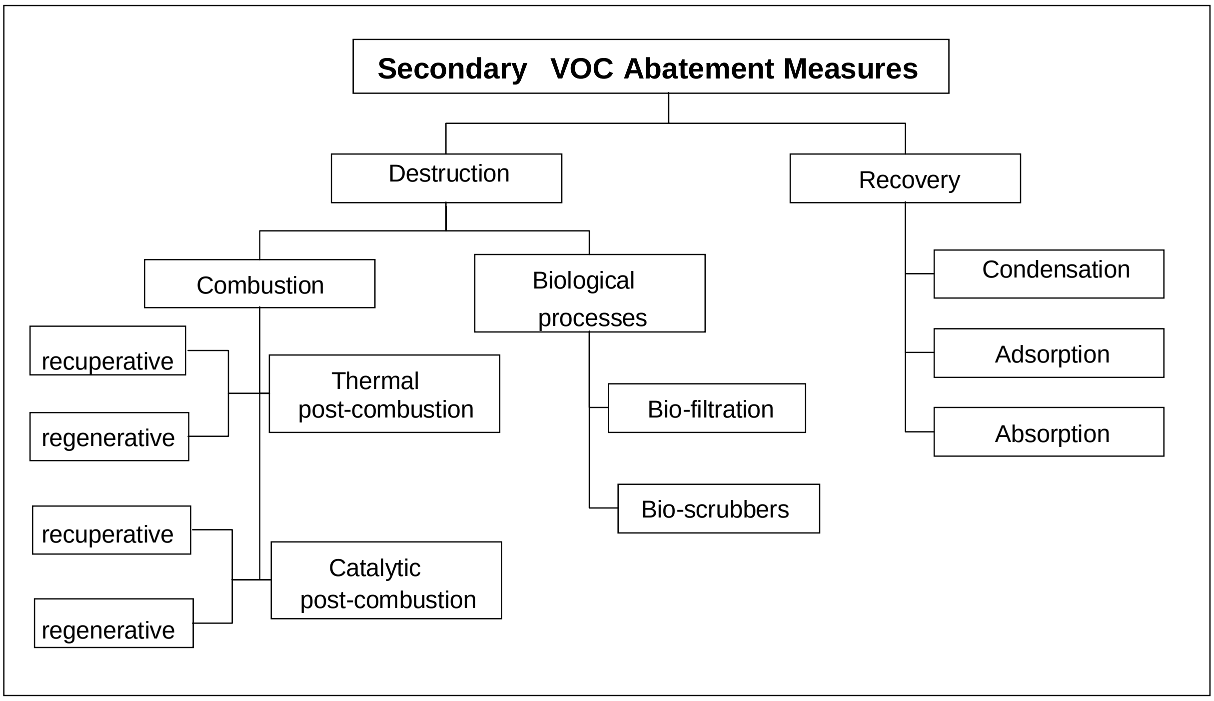

Figure V-1: *Secondary VOC Abatement Measures*

The secondary emission abatement measures illustrated in figure V-1 will be described in detail in the following. However especially for adsorption, absorption, condensation and biological oxidation methods, no generally valid cleaned gas concentrations[1] can be given due to varying efficiency factors. The efficiency factors of the techniques depend on the type of used solvents and the associated specific physical, chemical and biochemical properties of the materials and the respective installation technology (e.g. adsorption and absorption agents, desorption methods, operating temperatures and pressures or the population of microorganisms for biological techniques).

Criteria relevant for the applicability of the emission reduction measures will be described in the summary that can be found at the end of the chapter.

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[1] Exemplary values of exhaust gas cleaning installations can be found in the appropriate literature for the described installations

1. Exhaust Gas Cleaning by Thermal Oxidation

The thermal post-combustion is an experienced method in order to separate a wide variety of VOC by thermal oxidation. It is applied if a selective separation or/and a recycling by substance is not sensible in the production process or cannot be carried out [SCHULTES 1996]. The thermal oxidation transforms the contaminants far-reaching into carbon dioxide and water. The combustion process generates carbon monoxide and nitrogen oxides in low amounts. VOCs with nitrogen compounds (e.g. nitrogen containing solvents such as N-methyl pyrrolidone) also contribute to the formation of nitrogen oxides. If chlorinated hydrocarbons are oxidized, hydrogen chloride is generated that needs an additional exhaust gas treatment as a formation of dioxines can take place [CARLOWITZ 2001].

The thermal oxidation techniques can be classified into **thermal** and **catalytic** post-combustion methods. In Germany, about 60 to 70 % of the operating exhaust gas cleaning plants use the thermal post-combustion method. [MEHLIS 2001]. For both methods, the raw gas is pre-heated with the energy content of the cleaned gas via heat exchangers. Separation factors of 99.5 to 99.8 % of the supplied VOC are state-of-the-art [RENTZ 1999]. Depending on the type of heat exchanger, both methods can be separated into **regenerative** and **recuperative** technologies (see figure V-1). For achievement and maintenance of the reaction temperature, additional fuels are necessary in the non-autothermic operation mode. Their need can be reduced by pre-heating of the raw gas in the heat exchanger and depends on [VDI 2442]:

- Composition of the raw gas,
- proportion of flammable materials,
- pre-heating temperature of the raw gas,
- and the reaction temperature.

As additional fuel, fuel oil, natural gas or city gas are supplied. Also waste solvents are suitable as liquid fuels. In this case, the environmental laws concerning the disposal of solid and liquid wastes have to be considered. As the fuel can generate additional emissions, fuels with lower resulting emissions should be used if possible. [VDI 2242]. For a cleaning of solvent-loaded exhaust gas flows, predominantly thermal (reccuperative and regenerative) and catalytic (recuperative and regenerative) exhaust gas cleaning techniques are in use. However nowadays, the proportion of the thermal recuperative and catalytic post-combustion is decreasing in favour of the thermal regenerative post-combustion.) [CARLOWITZ 2001]. The techniques will be described in the following.

Heat recovery is state-of-the-art for the thermal techniques. Heat usage factors amount up to 80 to 90 %.

1.1 Thermal Post-combustion with Recuperative and Regenerative Pre-heating of the Waste Gas

1.1.1 Thermal Recuperative Post-combustion

For the thermal recuperative post-combustion, the raw gas is pre-heated by the hot cleaned gas via a tube bundle heat exchanger. Afterwards it is combusted at a temperature of 700 to 900°C generally including a fuel addition. (The combustion process may start already in the heat exchanger as so-called pre-burning) The remaining heat of the cleaned gas is often supplied to the production process via heat exchangers by thermal oils or hot water (see also figure V-2).

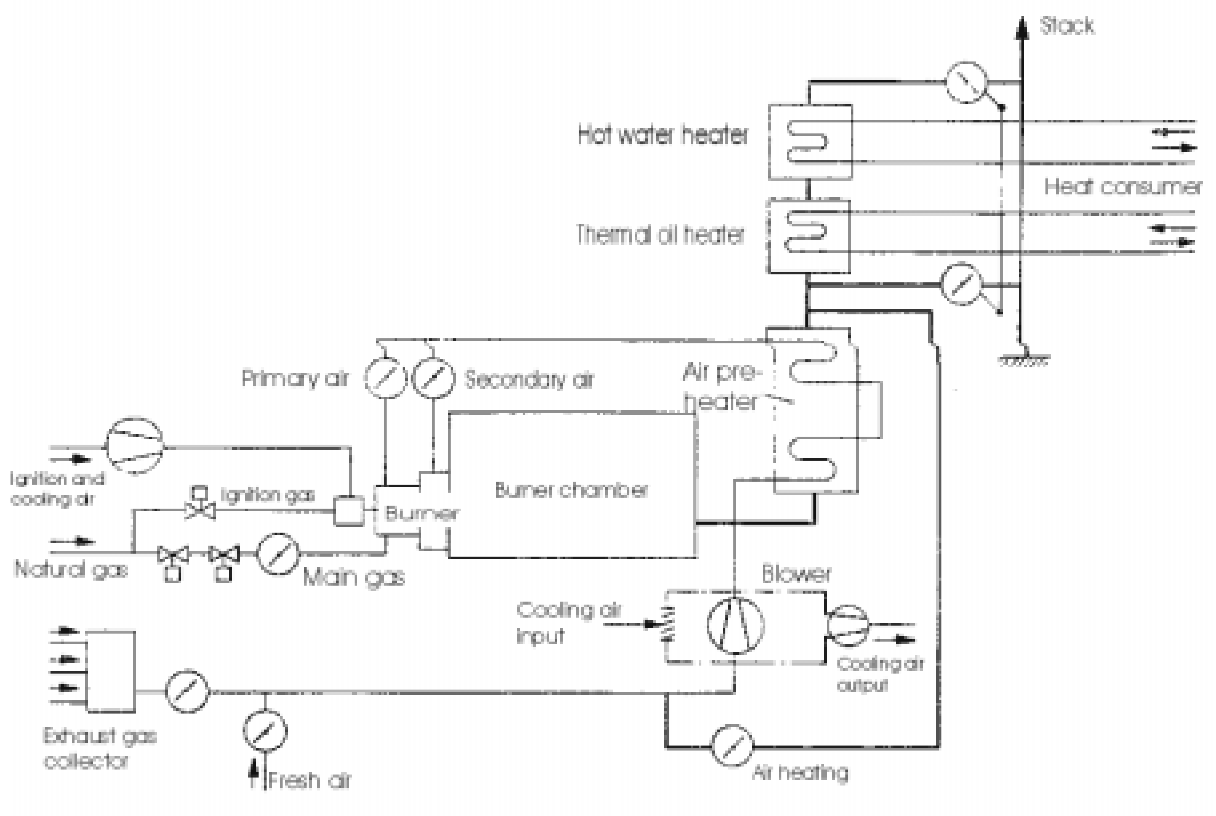

Figure V-2: *Thermal post-combustion with recuperative heat recovery* [BANK 1995]

1.1.1.1 Device Construction

A thermal recuperative post-combustion installation consists essentially of [RENTZ 1999]:

- Burner chamber with burner
- Heat exchanger for outgoing air (air pre-heater)
- Heat exchanger for recovery of heat from the cleaned gas

Burner

The burner heats the raw gas to be cleaned by addtive fuels at the reaction temperature (for non-aautothermic processes) whereas the operation depends on the VOC concentration in the raw gas. Flat, nozzle and swirl nozzle burners are in use [RENTZ 1999].

Burner Chamber

The VOC is oxidized in the burner chamber at a given reaction temperature and residence time. There are different designs and concepts of burner chambers, therefore there is a high variety in geometry, size ,flow conditions and materials. The high temperature oscillations the burner chamber is exposed to require whole-metal burner chambers and chamber with metal casing and fireproof brick lining. [RENTZ 1993]

Heat Exchanger

Heating of the raw gas is carried out via an indirect tube bundle heat exchanger with cooling of the hot cleaned gas at the same time. The energz efficiency factor amounts 70 % maximum so that a combustion of additive fuels is necessary in the non-autothermic operation mode in order to reach the reaction temperature in the subsequent burner chamber. As a pre-burning of the waste gas might occur within the heat exchanger, its material has to be resistant against the same temperature stresses as that of the burner chamber (forces initiated bz temperature differences and compensation of extension differences). If the waste gas is heated up to 500 to 600 °C , energy savings of up to 75% can be achived. The higher the VOC concentrations, the lower is the required use of primary energy.

The temperature of the cleaned gas is almost 200 to 400°C [SCHULTES 1996]. For these high exhaust gas temperatures, an additional heat recovery has to be provided such as the provision of process heat, e.g. for heating purposes in dryer installations.

1.1.1.2 Application

The recuperative thermal exhaust gas cleaning technique is for example used for cleaning of exhaust gas flows originating from dryer installations and partly spray booths for the varnishing of passenger cars, commercial cars, buses, large vehicles, plastic and metal workpieces as well as from coil coating processes. Often an adorption installation is upstream in order to concetrate the VOC.

The technique can clean exhaust gas flows of 5000 to 50.000 m³/h with a medium VOC loading (of up to 16 g/m³). As a result of the high temperatures of the cleaned gas (200 to 400°C), a recovery of the thermal energy and use in the production process is mandatory [RENTZ 1999, MEHLIS 2001]. The technique allows clean gas concentrations of up to 10 mg C/Nm³[2] .The combustion can be optimized in a way that the formation of NO_x and CO is limited to 100 mg /m³.

1.1.2 Thermal Regenerative Post-Combustion

The essential characteristic of regenerative post-combustion installations is the regenerative heat buffer: The heat energy of the cleaned gas is stored within a heat storage bulk that is located directly in the oxidation area. Hence it is directly available to the oxidation process. Regenrative heat storage bulk, typically a packed bed of ceramic bodies is used. The heat transfer efficiency amounts up to 95%. A higher efficiency factor would require higher storage mass that would generate a higher pressure loss and therefore would result in higher energy consumption. Autothermic operation is already feasible for very low VOC concentrations. If this concetration is not reached, the VOC are oxidized afterwards in the burner chamber. Then a burner is operated with additional fuels and guarantees achievement and maintenance of the reaction temperature in the burner chamber and the heat storage mass even for low contamination of the raw gas.

In the following, the differences in comparison with the thermal recuperative combustion will be explained. With respect to the design of the installations, single regenerator systems and compact regenerator systems have to be distinguished.

1.1.2.1 Device Construction

The installation of **single regenerator sytems** typically consists of three solid bed regenerators based on ceramics. These regenerators are switched cyclically.

Respective one bed pre-heats the exhaust gas up to the oxidation of VOC, the other cools the gas cleaned by oxidation while the third is washed for example by ambient air in order to remove hydrocarbon leftovers prior to the admission of cleaned gas. (The washer gas is

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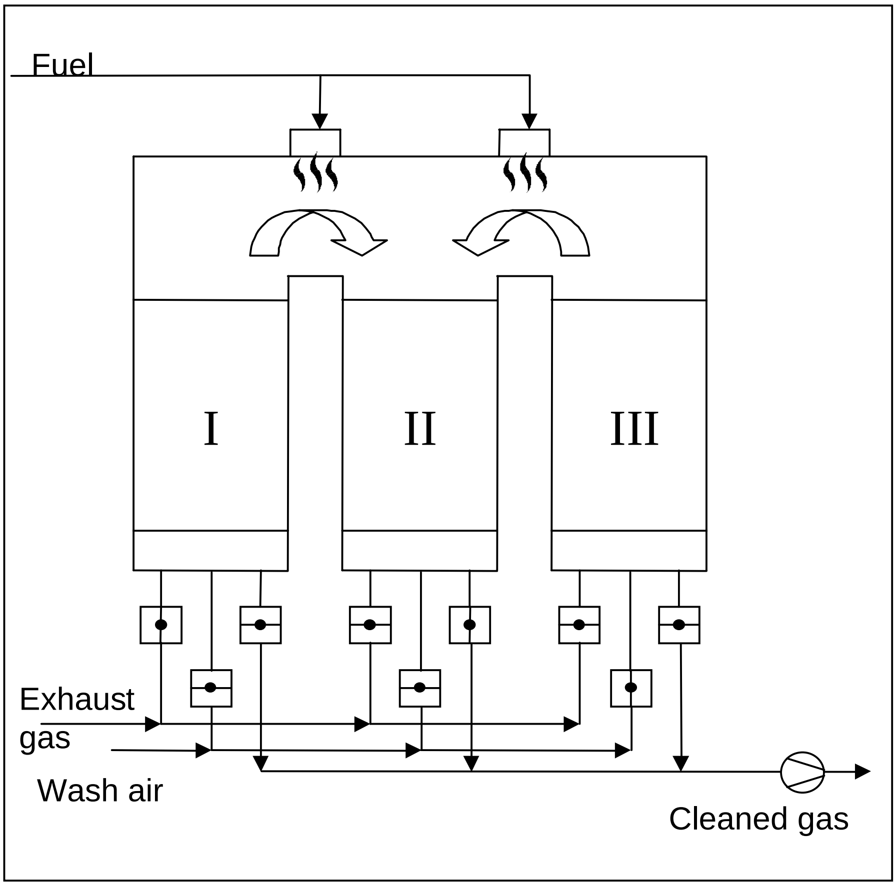
[2] Exemplary clean gas concentrations for varying contaminant mixtures, installation settings and residence times can be found in [VDI 2442].

oxidized within the first regenerator). The third regenerator is not necessary for especially low amounts of waste gas or very low VOC loadings in the exhaust gas [CARLOWITZ 1996].

Figure V-3: *Functional principle of a single regenerator system*



The heat buffer bulk of **compact regenerator systems** is separated into single segments. Alternately, one part of the packed bed serves as cooling unit and the other one as heating unit. Prior to the switch of a segment from heating of the exhaust gas to cooling of the cleaned gas, the packed bed is washed from exhaust gas by generated cleaned gas. The exhaust gas is supplied to the heat buffer bulk from the bottom to the top for heating reasons and it is pre-heated by the hot surface up to the oxidation of the contaminants. A burner chamber provides the energy necessary in order to maintain the required reaction temperature (of 750 to 820 °C). Afterwards the hot cleaned gas flows through the other part of the heat exchange bulk from the top to the bottom and hence heats the bulk. The flow through different segments is controlled by flaps or rotary valves or it is caused by a rotation of the regenerator (so-called rotation regenerators) [EISENMANN 2001].

For a minimization of the pressure loss, predominantly ceramic bed solids are used. Further also honeycomb bodies can be used as regenerator elements. The energy efficiency factor of regenerative heat exchangers amounts about 95 %, so that an autothermic operation is feasible already at VOC concentrations of 1 to 2 g/m^3. However this advantage can be used for continuous processes exclusively. In the case of autothermic operation, the oxidation of contaminants is carried out by pure oxidation of gas phases generating a small amount of nitrogen oxide, as the nitrogen oxide formation is reduced by the missing flame combustion [JAUNSS-SEYFRIED 1995].

1.1.1.2 Application

The regenerative post-combustion technology can be regarded as a standard for the reduction of VOC emissions for huge exhaust gas flows with low VOC loadings and a low need of process heat for the production. Cleaned gas concentrations of less than 10 mg/Nm^3 are achieved [JAUNS-SEYFRIED 1995, CARLOWITZ 1996, BANK 1996]. With this process, the CO and NO_X values can be limited to 50 mg/m³. The cleaning of huge amounts of waste gas with only low loadings together with a low energy consumption has allowed the distribution of the technology. A single reactor can process waste gas flows of up to 1000 to 45,000 Nm^3/h. For higher amounts of waste gas, a few reactors are used simultaneously [EISENMANN 2001]. The regenerative post-combustion method allows a very high heat recovery by heating of the raw gas, so that the temperature of the cleaned gas amounts 40 to 200°C when leaving the installation depending on the construction type of the installation. A further external use of the heat energy is therefore not necessary [EISENMANN 2001]. Special hot-gas bypass systems also allow the treatment of VOC concentrations of up to 12 g/Nm^3. An additional heat recovery in order to optimize energy needs can make sense for high VOC concentrations and autothermic operation [EISENMANN 2001].

For example the technique is used in the coating of beverage cans, passenger cars as well as for printing processes [VDI 2442 3455, 2587].

1.1.3 Properties of the Recuperative and the Regenerative Thermal Post-combustion Methods

Table V-1 shows a comparison of the regenerative and the recuperative post-combustion method.

Table V-1: *Comparison of thermal regenerative post-combustion and recuperative thermal oxidation* [Bank 1995]

	Regenerative post-combustion	**Recuperative thermal oxidation**	**Effects**
Type of heat exchanger	Packing	Tube bundle heat exchanger	Higher efficiency factor of the heat exchangers of the regenerative technique
Pre-heating, efficiency factor of heat exchanger	780 °C , about 90 – 98 %	500-600 °C about 70 – 80 %	Lower consumption of additive fuels for the regenerative technique
Cleaned gas temperature	about 40 – 200 °C	about 250 – 400 °C	Usage of process heat is sensible for the recuperative technique

In the following, the advantages and disadvantages of the thermal post-combustion are summarized:

- Wide range of applicability with respect to exhaust gas flows and the contaminants to be treated (Restrictions for nitrogen and halogenated VOC due to the formation of NO_x and hydrogen halide),
- low effort for maintenance as well as
- insensitiveness against changes in concentration.
- Recuperative systems quickly reach the working temperature and therefore allow abundant start-up processes
- **Installations with regenerative heat exchangers** are suitable for a continuous operation exclusively due to the high heat buffer mass. The high heat buffer also requires long start-up times [BANK 1995].
- **The combustion process is associated with a formation of NO_x and CO**

1.1.4 Parameters

The following technical parameters are critical for the percentage of burnable materials in the cleaned gas which determines the level of VOC emission reduction [VDI 2442, BANK 1995]:

- Reaction temperature in the combustion chamber
- Characteristics and type of flow
- VOC composition and concentration
- Mixing of the reaction agents
- Residence time in the burner chamber
- Oxygen content of the exhaust gas

Reaction Temperature

The level of chemical transformation of the VOC usually increases with higher reaction temperature and longer residence times; accordingly the remaining concentration of organic compounds in the cleaned gas decreases. For the determination of the reaction temperature, it has to be considered that also the NO_x formation increases with increasing temperature, so that shifted problems may result [BANK 1996].

1.1.5 Investments and Operation Costs

Investments especially depend on the waste gas flow that has to be cleaned and on the installations for heat recovery. Further the high temperatures result in high requirements for construction and materials of the burner chamber and the heat exchangers. Energy consumption essentially consists of [VDI 2242]:

- Thermal energy (additive fuel) for heating of the raw gas. The consumption depends on the composition of the raw gas, the content of flammable substances, the pre-heating temperature of the raw gas and the combustion temperature.

In general, the energy costs are lower for regenerative post-combustion than for thermal (for the same VOC loading of the raw gas), since the exhaust gas is pre-heated very efficiently.

1.1.6 Treatable Substances

A wide variety of VOC can be removed by the thermal post-combustion. It is the most versatile thermal oxidation technique with respect to the treatment of contaminant mixtures [BANK 1995]. Limitations exist for nitrogen and halogenated VOC caused by the formation of NO_x and hydrogen halide that would require a post-treatment of the cleaned gas. Substances forming ash (e.g. dust, varnish particles) may lead to errors in the heat exchangers and therefore have to be reduced by appropriate measures.

1.2 Catalytic Post-Combustion

The catalytic post-combustion is carried out at lower temperatures and therefore requires less primary energy than the thermal post-combustion. The catalytic post-combustion takes place with the support of catalysts at temperatures between 200 and 400° C depending on the contaminant’s type in the exhaust gas and the type of the catalyst [MACHEJ 1997]. As with the thermal post-combustion, the raw gas is heated by the hot cleaned gas. Both regenerative and recuperative heat exchangers are in use [JAUNS-SEYFRIED 1995].

The catalytic post-combustion has a low market share due to the restricted flexibility with respect to the substances being treated. [CARLOWITZ 2001]. The application range is restricted due to the possibility of catalyst deactivations due to certain ingredients of the gas to be cleaned (catalyst poisons such as halogens, silicones, heavy metal etc.). This is critical as the catalysts are the most expensive part of the installation.

1.2.1 Device Construction

The catalyst increases the reaction rate decreases the reaction temperature, so that the transformation of VOC is possible at lower temperatures than for the thermal post-combustion. In total, this leads to lower process temperatures of the system and to lower fuel consumption. A burner pre-heats the gas to be cleaned up to the reaction temperature of the catalyst. It also maintains the required working temperature of the catalyst bed with support of additive fuels if this is not guaranteed by combustion heat e.g. for low contaminant concentrations.

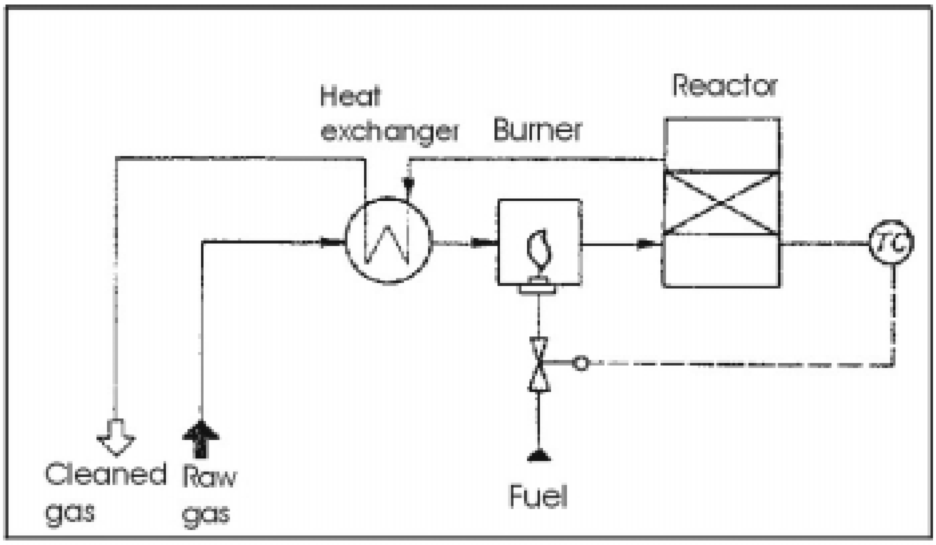


Figure V-4: *Catalytic recuperative post-combustion* [VDI 3476]

Catalysts for post-combustion are to meet the following requirements [BREITHOFER 1991, MCINNES 1995]:

- High activity at low temperature
- Thermal, chemical and mechanical stability
- Long service life

The following catalyst materials are used for catalytic post-combustion [VDI 3476, RENTZ 1999]:

- Precious metals (Pd, Pt, Ru) onto inorganic oxidizing substances
- Precious metals onto metal substrates
- Metal oxides (e.g. Mn) onto inorganic oxidizing substrates

Traditionally, the precious metals applied onto a solid layer have been used. The method of the solid layer has been progressively developed to a honeycomb-like base material that is typically processed of ceramics. Nowadays, especially packings of e.g. pellets materials are predominant for practical applications. These have the advantage of being readily exchangable and having a large surface. New catalysts have been developed that are more resistant against pollution as well as poisoning. For example, waste gas containing phosphorus, halogens and related materials can be cleaned catalytically. The catalysts generally consist of chromium and aluminum [McInnes 1995]. A detailed description of catalysts can be found in [VDI 3476].

Catalysts made of non-precious metals are the most resistant against poisoning. A lifetime of about 2 to 5 years is approximated (the lifetime depends on the working procedure of the system and on the waste gas to be treated). The effectiveness decreases with beginning sintering processes (reduction of the surface caused by high thermal stress) and with poisoning by impurities [RENTZ 1999]. Catalyst poisons include halogens, silicones and heavy metals [EISENMANN 2001].

Due to economical reasons, the exhaust gas is pre-heated by heat exchange with the hot cleaned gas similarly to the thermal post-combustion. The heat exchanger can be constructed according to either the regenerative or recuperative concept. Depending on the construction, **regenerative catalytic combustion** and **recuperative catalytic combustion** can be distinguished.

For the **regenerative catalytic combustion**, also ceramic packings are used as heat exchange media as in the regenerative post-combustion. They consist of filling bodies catalytically coated in the upper part of the packing. This technique can be operated already autothermic beginning with VOC concentrations of 1 to 2 g/Nm^3 .[JAUNS-SEYFRIED 1995]. The catalyst of the recuperative catalytic post-combustion can be designed either as solid bed packing or honeycomb-like.

1.2.2 Treatable Substances

This VOC reduction measure is especially appropriate if no dust or other catalyst poisons are present. The following substances can be degraded besides others: Alcohols, aldehydes, ethers, esters, ketones. The newest catalysts partly allow the removal of halogenated hydrocarbons. However during the combustion of these compounds, halogen hydrocarbons are formed that have to be separated afterwards in a subsequent washer. Further the installations have to be resistant against the corrosive effects of hydrocarbons [RENTZ 1999, KITTRELL 1991].

1.2.3 Parameters

The transformation of contaminants is predominantly influenced by the following non-independent parameters [BREIHOFER 1991]:

- Type and concentration of VOC in the exhaust gas
- Type of catalyst
- Temperature of the catalyst bed

- Space velocity

Similar to the thermal post-combustion, the VOC transformation efficiency increases with increasing temperature and decreasing space velocity. Further, the VOC composition, the concentration and the oxygen content of the exhaust gas influence the beginning and working temperatures as well as the chemical reaction [BREIHOFER 1991].

1.2.4 Application

The catalytic post-combustion method has minor significance. The technique is for example used in the can production and the varnish- and ink production [RENTZ 1999]. Descriptions of installations reducing emissions can be found in [VDI 3476, VDI 2587 page 3] e.g. for the production of composite foils.

The catalytic post-combustion is especially appropriate for high amounts of waste gas with a low content of organic compounds, even more if only a low use of the excess heat is possible. The reaction is autothermic for VOC concentrations of 1 to 3 g C/m^3 [RENTZ 1999]. For concentrations higher than 8 g/m^3 , the heat potential of the process rises strongly so that precious metal-based catalysts can be used exclusively. The cleaned gas concentrations that can be achieved are around 10 mg/Nm^3 depending on the velocity of the gas, the amount of catalyst and on the process temperature [RENTZ 1999]. At the same time, concentrations of the combustion products NO_x and CO do not exceed 50 mg/m^3 , respectively [VDI 2587 sheet 3].

Advantages of the catalytic post-combustion

- Suitable for different VOC mixtures,
- discontinuous processes as well as
- low VOC concentrations in the exhaust gas
- varying solvent concentrations and quality.
- Lower working temperatures if compared with the thermal post-combustion result in lower fuel consumption and hence comparably low energy costs; however additional operating costs caused by replacement of the catalyst have to be considered.
- Emissions of combustion products (e.g. NO_x) are principally lower than with the thermal combustion

Disadvantages of the catalytic post-combustion

- Smaller application range due to catalyst poisons (polymers, ash, halogens, silicone, phosphorus, sulfur, arsenic, zinc, mercury and other metals as well as their compounds) [MCINNES 1995]; particles and soot are to be separated prior to entering the catalytic exhaust gas cleaning installation;

- Halogen-hydrocarbons as well as sulfur and nitrogen-containing compounds require a subsequent additional exhaust gas cleaning step in order to remove the contaminants generated by the combustion such as HCl, SO_2, NO_X. Furthermore, a special catalyst is necessary for halogenated hydrocarbons.

- The aging of the catalyst requires a replacement of catalyst material;

- High thermal and mechanical stress damages the catalyst and therefore should be avoided [Rentz 1999, Mehlis 2001]. Hence the method is only suitable for maximum VOC raw gas concentrations of 15 g/Nm^3 [BANK 1995].

1.2.5 Investments and operating costs

The investments essentially depend on the exhaust gas volume flow that has to be cleaned and on the catalysts. The energy costs of catalytic post-combustion techniques are lower than for the thermal combustion (for an equivalent VOC loading), because lower temperatures are sufficient and therefore the fuel consumption is lower. Besides the energy costs, the operating costs also depend on the VOC loading of the exhaust gas, on the size and temperature of the heat exchanger, on the pre-heating temperatures as well as the replacement intervals of the catalyst. [RENTZ 1999]

2 Adsorption

Exhaust gas cleaning of VOC-loaded exhaust gas flows by adsorption is a widely used technique due to its flexibility. In this context, the adsorption is defined as the concentration of gases onto solid interfaces [Baumbach 1993]. The adsorbed substances have to be driven out in order to regenerate the adsorber. The VOC are not chemically changed and therefore they can be recovered. If a recovery is not sensible, the concentrated flows can be lead to a thermal post-combustion. Due to the concentration, an autothermic operation mode of these installations is possible.

2.1 Principle of the Technique

Single or some compounds are adsorbed selectively from the exhaust gas onto the surface of interfacial-active solids. The most common adsorbent for organic compounds is charcoal. Also other substances such as for example zeolithes are in use.

Both the adsorbed substances as well as the adsorbing solids can be re-used after desorption. If a recycling of the adsorbed products is not possible within the process, the desorption flow is leaded to a thermal post-combustion.

The most important steps of the technique are the following:

- *Adsorption*: The VOC-loaded exhaust gas flows through one or more adsorbers filled with adsorbing agent. The solid’s surface selectively adsorbs volatile organic compounds up to saturation (this means a depletion of the loading capacity). Prior to the reaching the saturation capacity, the flow way is switched to a regenerated adsorber or a regeneration is carried out, respectively.

- *Regeneration (desorption)*: The uptake cabability of the adsorbent has to be recovered by regeneration before the saturation is reached. The regeneration step desorbs the adsorbed VOC by an increase in temperature, by admission of steam or by pressure change techniques [EIGENBERGER 1988, BANK 1995].

2.1.1 Device Construction

In order to create a contact of the adsorbens with the exhaust gas to be cleaned in a suitable way and to allow a regeneration after loading, different adsorption techniques have been developed. The adsorbens is either a static or a dynamic layer. In the following, the most important techniques will be described. A more detailed illustration can be found in [VDI 3674].

Fixed-bed Adsorber

In 1988, fixed-bed adsorbers already had a market share of about 95 % [BANK 1995]. In new installations, rotation adsorbers are used increasingly. In a solid-bed adsorber, the exhaust gas flows through the porous adsorbens packing located in a container. This way, phases of loading and regeneration alternate. Hence at least two parallel installations are necessary for continuous operation with permanently generated gas flows, where one adsorber has to ready for an uptake of VOC at any time (see also figure V-7). Adsorbers working in a pulse mode are required for the continuous cleaning of exhaust gas [BANK 1995].

Moving Bed and Fluidized Bed Adsorbers

A continuous operation is achieved by moving bed and multi-step fluidized bed adsorption. Adsorption, desorption and cooling takes place in separated parts of the device. The adsorbent is leaded in circuitry in between. In a fluidized bed adsorber, a continuous replacement of the loaded adsorbent takes place. For a multi-step fluidized bed adsorber, the adsorbent is added at the top and moves in counterflow to the waste gas downwards. In comparison with fixed-bed adsorbers, the pressure loss is lower up to 50 % in moving bed and fluidized bed adsorbers [BANK 1995], however only lower loadings of the adsorbents can be achieved.

Rotation Adsorbers

Rotation adsorbers are especially used for continuous adsorption of large exhaust gas flows with a low VOC concentration [BANK 1995]. The exhaust gas flows through a rotor that is separated into segments and where the adsorbent is located between porous side walls or it is designed as a fiber package. Regeneration of the loaded adsorbent is carried out opposite to the adsorbing direction in a separated sector of the rotor. Every area is leaded through different zones (adsorption, desorption, drying and cooling zone) by a rotation of the rotor. Hence the exhaust gas is cleaned permanently and loaded adsorbent is regenerated for example with hot air. This way a highly concentrated exhaust gas flow is achieved that is further treated in order to fulfil the emission requirements. Typically the remaining treatment is carried out with thermal combustion or recovery techniques [BANK 1995, MEHLIS 2001]. Figure V-5 gives an overview over different variations of the cited adsorber types.

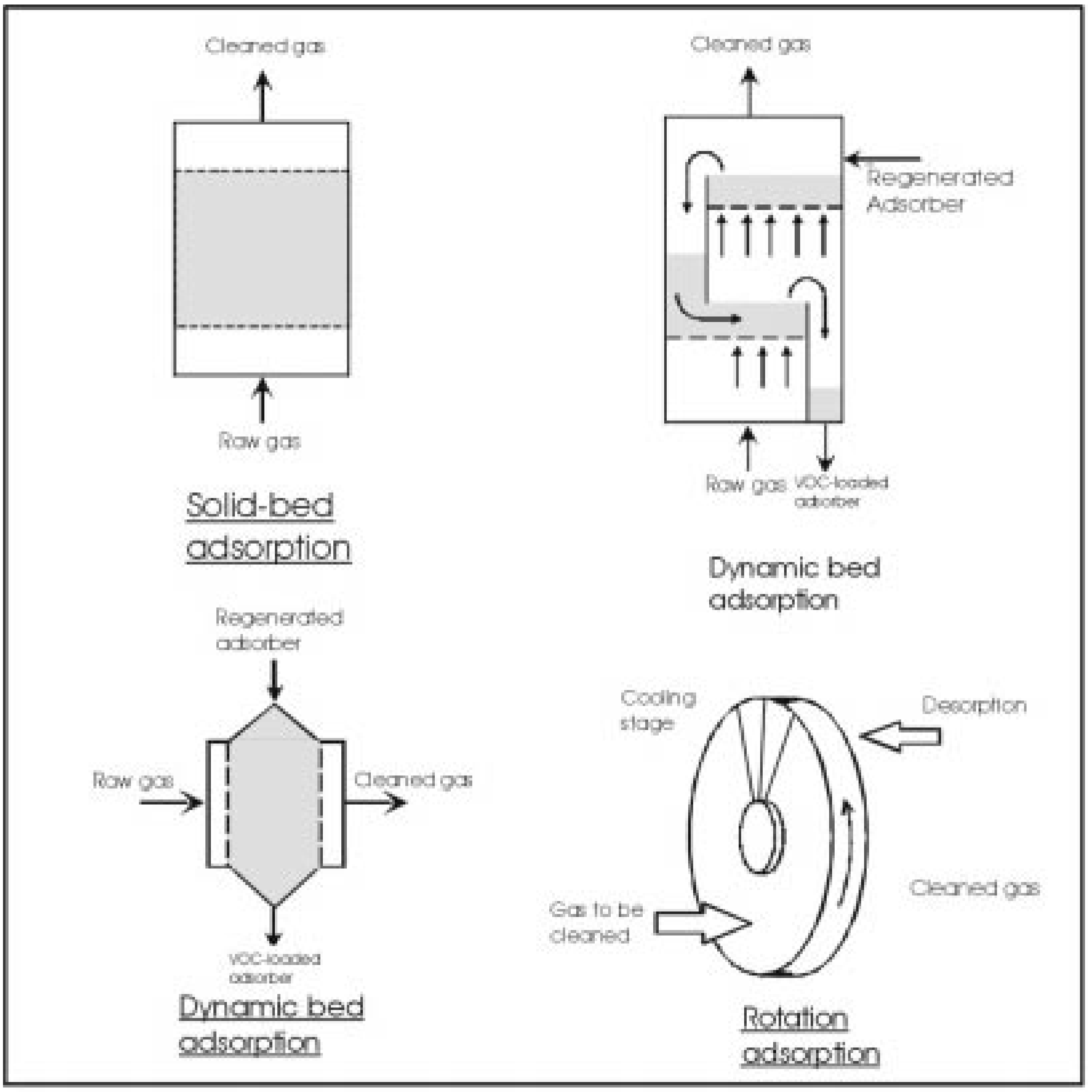


Figure V-5: *Technique variations of adsorption* [Ulrich 1990]

2.1.2 Desorption Techniques

Depending on the substance mixture and the selected working conditions, the following methods are used for desorption for adsorption methods in the solvent sector.

Steam Desorption

Steam desorption is carried out with water vapor at temperatures of 120 to 140 °C. The steam flows through the adsorbent and drives off the adsorbed substances in the gas phase (Figure V-7). The water-solvent gas mixture generated in this process is leaded into a phase separation container after liquidation in a condenser and possible cooling for water-insoluble solvents. For a separation of water-soluble solvents, a further reprocessing of the condensate by distillation or rectification is necessary (see also figure V-6). The charcoal has to be dried and cooled prior to the adsorption phase. In order to avoid the drying step, hot gas desorption is used. In new installations, the hot gas desorption is increasing at the expense of steam desorption [Mehlis 2001].

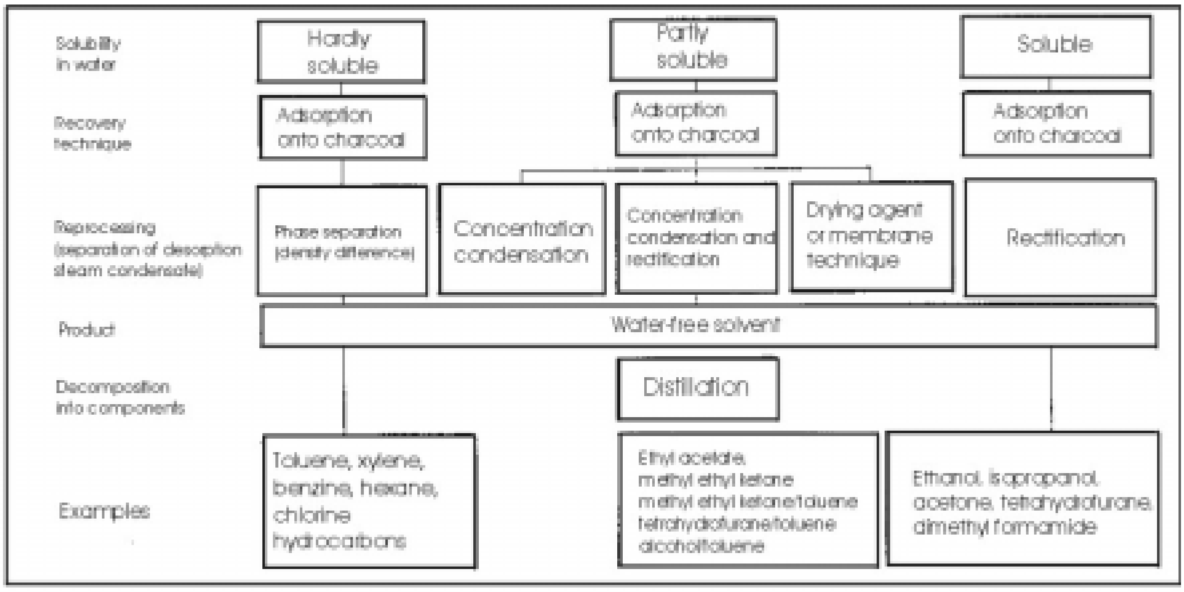


Figure V-6: *Possibilities for solvent recovery with steam desorption* [VDI 3674]

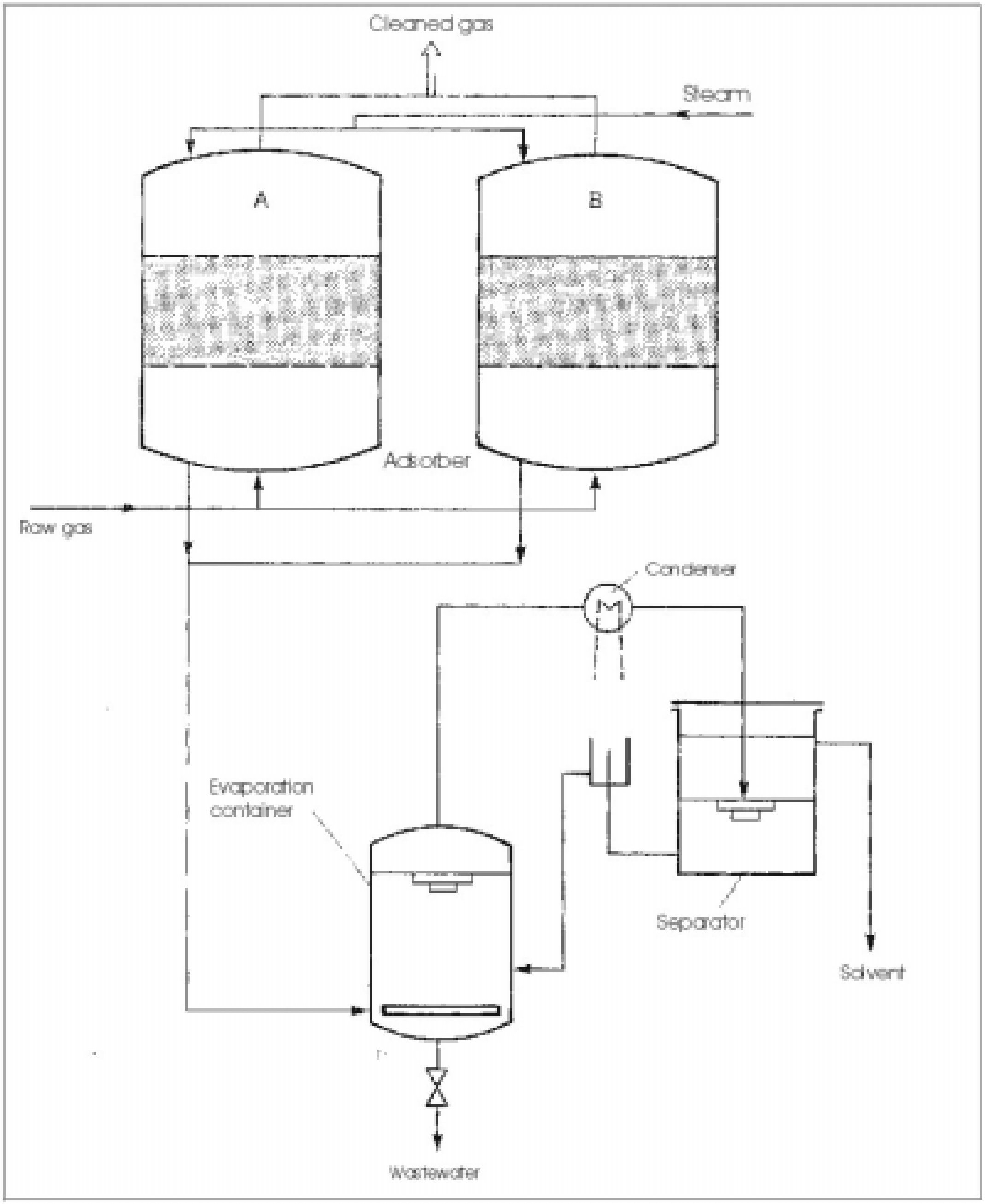


Figure V-7: *Installation scheme of the adsorption technique* [BAUMBACH 1993]

Hot Gas Desorption

With this technique, the solvents are driven out of the adsorbens with 150 to 350 °C hot gas. Both chemically inert gas (N2) as well as combustion air low in oxygen can be used. The hot gases are leaded in counterflow over the adsorbent. The VOC concentration in the desorption flow is by a multiple higher than in the exhaust gas. The desorption flow is either leaded to a thermal post-combustion or a solvent recovery (e.g. by condensation), especially if an application of the solvents in the production processes is possible [EISENMANN 2001].

2.1.3 Adsorbents

Essentially the separation level of an adsorption installation depends on the adsorbent used. Generally, these have to meet the following requirements:

- High adsorption capability (high specific inner surface, high proportion of mikro-porosities) ,
- high selectivity,
- advantageous adsorption properties: Good regeneration characteristics, low remaining loadings,
- temperature resistance,
- high abrasion resistance,
- low pressure loss.

Particle-like materials (cylinders, balls, broken grains and others) with a high specific surface of more than 600 m^2/g are used as adsorbents. Predominantly, granulated charcoal is used, however its application is limited if the solvent-containing exhaust gas has a temperature higher than 30 °C and more than 60% air humidity [MEHLIS 2001]. Due to these unavoidable disadvantages, new adsorbers such as zeolites, multi-layer polymers and charcoal fibers have been developed. [Ulrich 1990, VDI 2280, McInnes 1995]

The flow velocity of charcoal fiber pads is significantly higher than for the grain type, especially if combined with hot gas desorption. Especially for chlorinated solvents, special hydrophobic adsorber resins have been developed that allow a wastewater-free solvent recovery [RENTZ 1999].

A de-alumination technique for zeolithes causes hydrophobic behaviour, low catalytic activity and good acid resistance. Due to the hydrophobic behaviour, preferably non-polar compounds are adsorbed from humid exhaust gas flows. Zeolites can be thermally regenerated at temperatures of 600 to 700 °C.

2.2 Treatable Substances

A big variety of solvents is suitable for adsorptive exhaust gas cleaning, such as chlorinated hydrocarbons (possible with zeolites with higher efforts), alcohols, esters, ethers, and others [ARNOLD 1991]. However the adsorption onto charcoal is not appropriate due to catalytic oxidation for the following compounds: Di-acetone alcohol, cyclohexanone, higher molecular ketones, aldehydes, higher molecular fatty acids and aromatic amines. [MERSMANN 1990]

The adsorptiveness of organic compounds increases with increasing molecular weight and decreasing boiling point of the adsorptive. Further, the adsorbed amount increases with increasing concentration of the adsorptive up to the saturation of the adsorbent. The substances being adsorbed are to posess the following chemical properties:

- Not acidic,
- not polymer-forming
- not cracking
- not totally non-polar.

2.3 Critical Parameters

The following parameters are considered relevant for dimensioning of the adsorption technique:

- Variety of technique,
- type and properties of the adsorbent,
- type and concentration of the materials to be adsorbed,
- volume flow of the exhaust gas,
- adsorption temperature,
- simultaneous adsorption of other substances (e.g. water),
- remaining loading of the adsorbent.

2.4 Application

Adsorption techniques are for example used in order to concentrate exhaust gas flows of dryer installations in the serial varnishing of passenger cars (with thermal post-combusiton) or for solvent recovery in the adhesive tape production as well as for coating of ship parts.

The adsorption technique is especially economic if high exhaust gas volume flows (of up to 800,000 Nm^3/h) cannot be cleaned by other techniques such as thermal post-combustion. It is predominantly used for cleaning of low-loaded exhaust gas flows (< 5 to 20 g/Nm^3) with a temperature of less than 30 °C. [Rentz 1999] Higher loaded exhaust gas flows result in shorter adsorption cycles. The recovery varies between 95 to 99% depending on the method. Also often the adsorption is used as concentration step upstream to the thermal or catalytic post-combustion.[VDI 3674]

Dust in the exhaust gas has to be separated prior to adsorption by appropriate techniques.

Clean gas concentrations of 30 to 50 mg C/m³ or lower, can be achieved.

Advantages of the Adsorption

In general:

- Solvent recovery,
- The adsorption can be used for exhaust gas with varying VOC concentrations and for discontinuous processes,
- The adsorption is partly appropriate for chlorinated and fluorinated hydrocarbons that cannot be combusted.

Disadvantages of the Adsorption

In general:

- Limited application for some VOC (e.g. polymerizing substances such as styrene) [ALLEMAND 1990];
- Compounds with a boiling temperature higher than 200°C, with high polarity (e.g. methanol) or high reactivity (e.g. cyclohaxanone) are not to be treated.
- Dust and aerosols occlude the pores of the active material and hence have to be removed before.

2.5 Investments and Operating Costs

Investments depend on [ADEME 1997]:

- Technical outline,
- exhaust gas volume flow,
- type and diversity of the adsorbent,

- composition of the VOC mixture,
- required pre-treatment steps of the exhaust gas such as pre-filtering, removal of particles, and others,
- separation techniques for solvent recovery.

The operating costs mainly consist of costs for [ADEME 1997]:

- Energy consumption for: Cooling, steam or hot gas generation, conveyance of the raw gas (pressure loss within the adsorber packing), condensation (if VOC are recovered).
- Maintenance and replacement of the adsorbent material.

2.6 Side Effects

If the regeneration capability of the charcoal is exhausted, it has to be replaced. As the charcoal always has a remaining load, it has to be disposed of as waste. The best way of disposal is combustion [HOFMANN 1991].

3 Absorption

3.1 Description of the Technique

With absorption techniques, the solvents contained in the exhaust gas flow (absorptive) are taken up by a washer liquid (absorbent). Two technique variations can be distinguished:

- *Physical methods*: The compounds to be removed do not react with the washer liquid; a recovery is possible in principle.
- *Chemical methods*: The compounds to be removed take part in a chemical reaction with the washer liquid, so that a recovery is only possible for reversible reactions.

Mostly only physical absorption is suitable for the separation of organic compounds, as it allows recovery of the compounds without chemical changes. The absorption process is continuous by a combination of an absorbing part and a subsequent part where the loaded absorption agent is regenerated [PILHOFER 1990]. The solubility of a gas is strongly dependent on pressure and temperature: It decreases with rising temperature and decreasing pressure. Hence the absorbens can be regenerated at higher temperature or by decompression. [RENTZ 1990, 1993, ULRICH 1990]

3.1.1 Absorption

Typically the VOC-loaded gas is brought in contact with an absorption fluid in the reverse flow technique. The fluid takes up the organic compounds and the gas is cleaned. The process is carried out within an absorption column. Often washer towers filled with packing are in use (see also figure V-8). These installations combine a high specific absorber surface with low pressure losses and hence low energy consumption [PHILIPE 1997]. The washer fluid is nebulized in the upper part of the washer tower and trickles towards the exhaust gas via the packing. Due to the continuous discharge of washer liquid, a concentration gradient within the absorber is maintained. The loaded washer fluid is collected at the bottom of the absorber. It is pumped out of there, heated and leaded to the regenerator. A recuperator serves for heat recovery in between the cold absorbing solution and the hot desorption solution.

3.1.2 Regeneration (Desorption)

The heated and VOC-loaded absorption agent is continuously cleaned of the washed-out solvents by distillation in a desorber. Generally it is carried out under reduced pressure [BREIHOFER 1991, PHILIPPE 1997]. The separation is carried out at higher temperatures than the washing process. The solvents dissolved in the washer fluid can escape under vacuum conditions, before they are condensed and then re-supplied to the production process. The regenerated absorption fluid is cooled in a heat exchanger and pumped to the absorber [PILHOFER 1990, PHILIPPE 1997].

The absorption equipment consists of an absorption and a desorption column and of a heat exchanger [PILHOFER 1990]. Figure V-8 shows the principal construction of the absorption technology.

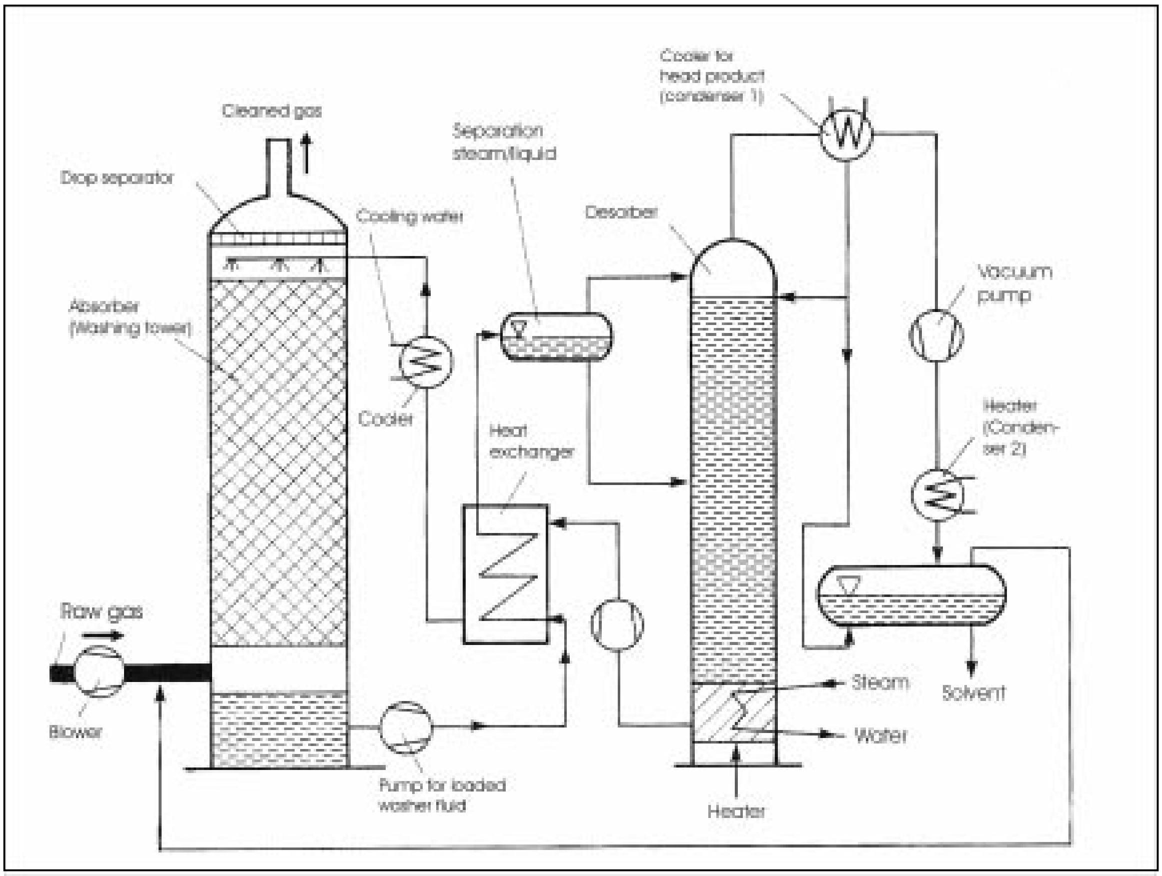


Figure V-8: *Scheme of the absorption technology including regeneration* [BAUMBACH 1993]

3.2 Treatable Substances

The technique is suitable for almost all solvents such as aromatics, alcohols, ketones, esters [BAUMBACH 1992, RENTZ 1999].

3.3 Absorbents

The absorbent has to meet the following requirements [RENTZ 1993]:

- Good solubility and high selectivity for the absorbed substance,
- low vapour pressure (loss of absorbent, pollution of the cleaned gas),
- low viscosity (high viscosity reduces the material exchange and require higher columns),
- good hydrolysis resistance,
- high ignition temperature,
- thermal and chemical stability,
- low toxicity,
- simple regeneration.

Various washer liquids meet these requirements. Also water can be considered for some solvents, e.g. methanol, acetone. Organic liquids are suitable for chlorinated hydrocarbons [ULRICH 1990]:

- N methyl pyrolydone,
- silicone oils,
- paraffin (e.g. di-iso propyl naphtalate),
- esters with high boiling points (e.g. dibutyl naphtalate),
- polyalkylene glycol ether.

3.4 Main Parameters

The following parameters influence the degree of separation of the absorbent [Rentz 1990, Pilhofer 1990]:

- Type and concentration of the substances to be absorbed (vapour pressure, solubility)
- Type of the absorbent (vapour pressure, solubility)
- Gas velocity
- Effective surface for the material exchange (distribution of the absorbent)
- Residence time
- Concentration gradient between the gas and the fluid phase
- Temperature and pressure

The VOC contained in the raw gas can be separated to up to 98 % [VDI 2587 sheet 3].

3.5 Application

The physical absorption is used for the recovery of complex, water-soluble solvent mixtures for high exhaust gas concentrations up to 50 g C/Nm^3 [RENTZ 1993, ADEME 1997].

The absorption technique is especially suitable for cleaning of small and medium exhaust gas flows with a high contaminant concentration. The use of a few absorbers is possible for higher exhaust gas flows. An advantage is that the technique also works reliably for variations in the exhaust gas volume, in the composition of the raw gas and in the VOC concentration. Furthermore, high moisture in the exhaust gas do not influence the cleaning effect. Clean gas concentrations of 30 to 100 mg/m^3 are achieved. Problems might arise for the use of multi-substance mixtures as this may cause displacement effects due to varying affinity to the absorbent. [Rentz 1993, 1999]. Some application data is given in table V-3.

Table V-2**:** *Dimensioning parameters of absorption installations*

Exhaust gas flow [m^3/h]	**Raw gas concentration [g C/Nm^3]**	**Cleaned gas concentration [mg C/Nm^3]**	**Efficiency factor [%]**
< 100.000	1 - 20	< 50	> 95

Advantages of the Absorption

- Solvent recovery
- Also suitable for highly loaded exhaust gas flows (> 20 g/m^3) and for mixtures of organic and inorganic compounds
- The technique is insensitive to varying contaminant loads
- No problems arise for the removal of polymerizable compounds
- Water-saturated exhaust gas does not cause operation errors

Disadvantages of the Absorption

- Complex installation technique and handling
- The design of the installation depends on the solvent, hence there is an increased adjustment effort for changes in processes [RENTZ 1993,1999, ALLEMAND 1990].

3.6 Investments and Operation Costs

The properties of the exhaust gas as well as the cleaned gas concentrations that have to be achieved determine the investment for the absorption installation. Operation costs are based on:

- Steam generation for heating of the desorption column,
- cooling agent for the condensers and the post-cooling of the absorption agent,
- electric current that is used predominantly for the vacuum pump and therefore it is directly influenced by the volume flow that has to be decompressed.

Besides that, the operation costs essentially depend on the efficiency of heat recovery between the hot, regenerated absorption agent and the cold, loaded absorption agent (efficiency factor of the heat exchanger).

4 Biological Processes

Besides the well-established technologies of waste gas cleaning like thermal combustion, absorption and adsorption, partly **biological processes** are applied (cf. figure V-9). Biological processes are inconsiderable for the investigated industrial installations and their use is mainly limited to a reduction of odour nuisance.

4.1 Bio-filters

In the investigated sectors, the bio-filtration is mainly used for the reduction of odorous substances. The market share of bio-filtration in Germany is very low (approx. 5 %). Some applications have to be noted for the investigated installations of the industrial paint and adhesive application.

4.1.1 Process Description

For the exhaust gas cleaning via bio-filters, hazardous- and odorous substances are metabolically decayed by microorganisms. End products generated of the metabolism are carbon dioxide, biomass and water for the ideal case. The pollutants are sorbed onto the surface of a carrier substance and are metabolised by microorganisms that are located in the aqueous phase (in the water film of the moistened filter particles) of the carrier substance. [VDI 3477]. The process is mainly suitable for solvents well water-soluble [BANK 1995]. The optimum existence and activity of the microorganisms can only be achieved if certain environmental conditions concerning the temperature, the nutrient content, the pH value and the oxygen content exist. Therefore the pollutant containing waste gas has to be pre-treated (if necessary) before it is lead into the filter [SCHNEIDER ET. AL. 1996, WINDSPERGER 1991, RENTZ 1999].

4.1.1.1 Device Construction

A bio-filter consists of:

- a preceding conditioning of the waste gas,
- a raw gas distribution for a regular approaching flow towards the filter,
- a substrate on which the filter material is homogenously distributed and
- a filter layer.

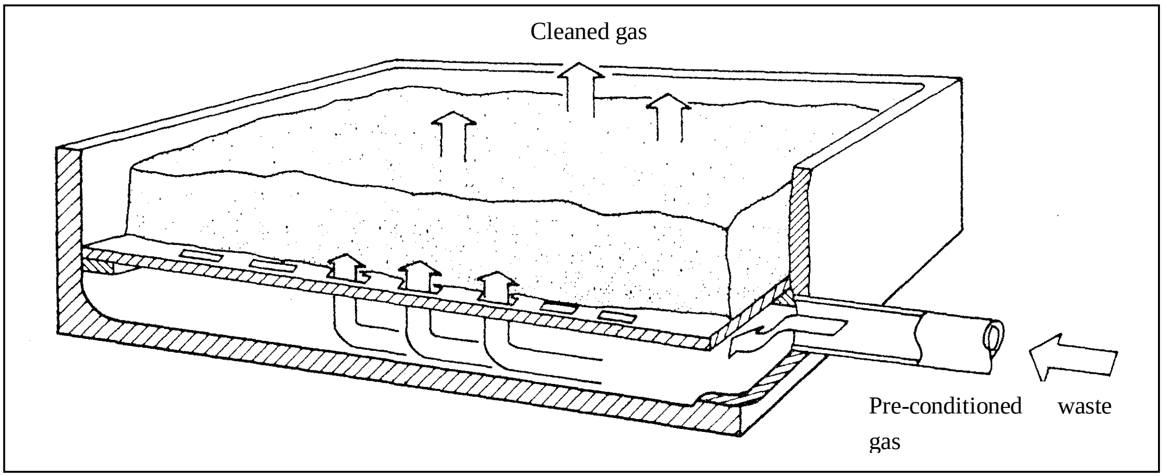
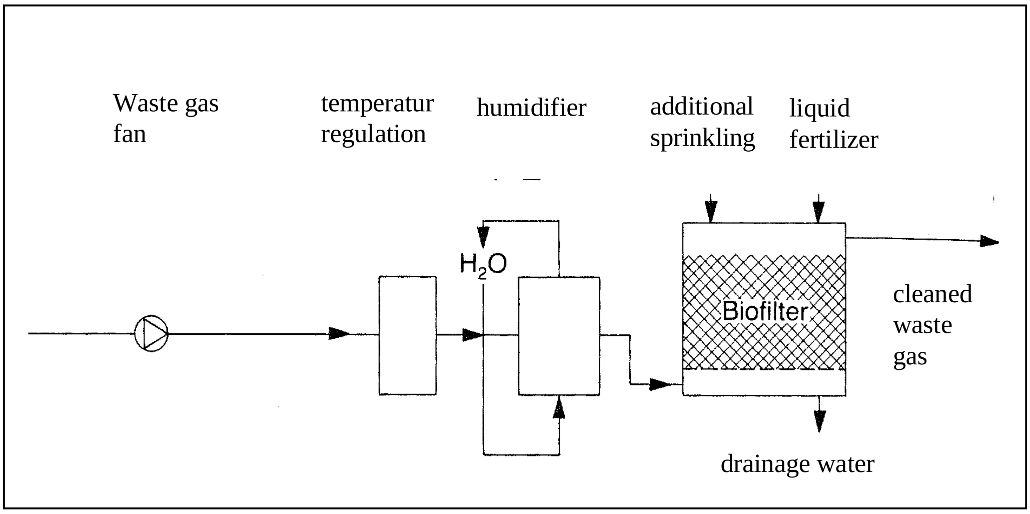


Figure V-9: *Principle of a bio-filter* [VDI 3477]

Waste Gas Conditioning

The waste gas has to have a temperature between 20 – 30°C and a relative humidity of more than 95% [BUCHNER 1990]. Therefore the waste gas is conditioned if necessary and conveyed to the filter by a ventilator. Depending on the waste gas characteristics, dust has to be removed and in the case of hot exhaust gases, heat exchangers have to be used in order to condition the waste gas (cf. figure V-10).



FigureV-10: *Waste gas conditioning before treatmen*t [BANK 1995]

Filter Materials

A prerequisite for the maintenance of the filter efficiency is a substrate that provides enough nutrients for the microorganisms. Therefore predominantly organic materials are utilized. If inert filter materials are used, an addition of liquid fertilizers is necessary:

- Peat soil and its by-products (e.g. fibrous peat),
- compost (e.g. bio-waste compost),
- bark,
- shredded wood,
- fibrous peat,
- mixtures of shredded wood and bark,
- inert materials (e.g. expanded clay, lava).

The materials are generally arranged in form of packed beds that are flown through by waste gases [LIEBE 1990, BREIHOFER 1991]. For the selection of filter materials the following factors have to be considered as they influence the efficiency and thus the investment and operational costs [LIEBE 1990], [ANGRICK 1991], [VDI 3477]:

- Pore structure and volume
- Pressure loss
- Share of organic substances (service life of the filter)
- Surface of the substrate (sufficient colonisation of microorganisms)
- pH-value of the substrate
- Water retention (constant humidity)
- odour of the filter material

A further important parameter is the pore size distribution of the filter material. An optimisation can be achieved by the intermixture of fractured, blazed expanded clay due to [BARDTKE 1991]:

- Increased water retention capacity,
- increased long-term stability,
- avoidance of critical effects such as the break through in border areas or the uncontrolled drying of filter material,
- lower pressure losses and hence higher flow velocities thus the required filter thickness can be reduced, possibly up to 1/5,
- the layer thickness can be increased up to 30 % and thus the space request for the bio-filter can be reduced.

The filter material is decomposed due to the biological activity. It may result in a compacting of the filter material and may create inhomogeneities in the filter and thus the pressure loss within the filter layer is increased. For maintenance of the filter efficiency, the material has to be replaced every 3 – 5 years [MCINNES 1995]. Plant stoppages of several weeks are possible. During this time, the organic filter material serves as nutrition for the microorganisms [LIEBE 1990]. After the start up or a change in the waste gas composition, an adaptation phase might be necessary for the microorganisms in order to get adapted to the different living conditions [BREIHOFER 1991, VDI 3477].

Table V-4 gives an overview of the characteristics of a few substrates. For further data concerning the filter efficiencies cf. [HERLITZIUS 1992].

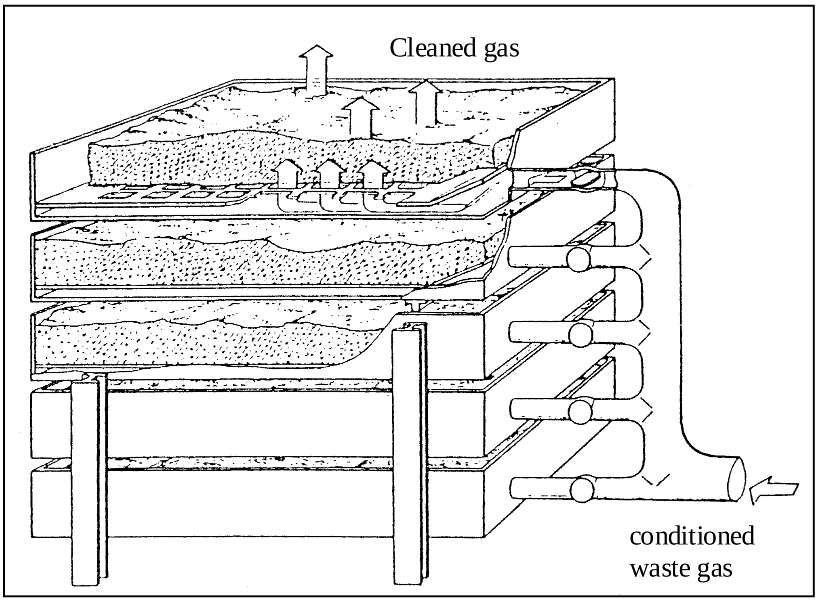
Table V-3**:** *Characteristics of filter materials* [HERLITZIUS 1992]

Filter material respective substrate	**Organic solvent to be treated**	**Moistening**	**Specific degradation performance [g/(m^3/h)]**	**Volume of filter/ air volume flow [m^3/(m^3/h)]**
Organic filter material	Toluene	Water	≈ 20	≈ 80
Inert substrate (rubber foam)	Toluene	Liquid fertilizer	≈ 80	≈ 400
Inert substrate (cellular glass)	Mixture of solvents	Water	≈ 20	≈ 300
Inert substrate (cellular glass) (without humidifier)	Mixture of solvents	Liquid fertilizer	≈ 80	≈ 300
Inert substrate (cellular glass) (without humidifier)	Toluene	Liquid fertilizer	≈ 50	≈ 200

Construction of Bio-filters

Surface filters are generally used if enough space is available (cf. figure V-10). In new installations, also surface filters in sublevel stoping construction are installed for a reduction of space request (cf. figure V-12) [VDI 3477].

Figure V-11: *Surface filter in sublevel stoping construction* [VDI 3477]



4.1.2 Treatable Substances

The bio-filtration is suitable for water soluble, bio-degradable organic compounds. This includes most of the strong-smelling hydrocarbons [FISCHER 1990A, ANTKOWIAK 1991]. In table V-5 the relative biodegradability of several VOC is listed.

Table V–4: *Biodegradability of selected* VOC [MCINNES 1995, VDI 3477]

Good biodegradability	Medium biodegradability	Low biodegradability
Toluene	Acetone	Dioxane
Xylene	Styrene	
Methanol	Benzene	Trichloroethylene
Butanol	Phenol	Tetrachloroethylene
Formaldehyde	Hexane	
	Methyl ethyl ketone	

The following parameters are critical for the degradation[3] of pollutants in bio-filters [LIEBE, 1990, VDI 3477]:

---

[3] For exemplary degradation efficiencies of existing installations it is referred to [VDI 3477].

- VOC degradability and concentration of VOC in the waste gas
- filter material,
- height of filter layer,
- flow rate within the filter layer,
- moisture and temperature,
- type, quantity and activity of microorganisms,
- concentration of oxygen
- pH value in the bio-filter.

Due to technical and economical aspects, biological processes are applied if the recovery of organic solvents is not ecologically reasonable or the VOC concentration of the exhaust gas is too low for a thermal utilization via combustion.

Therefore bio-filters are preferably applied for waste gases with low VOC contents (< 1g C/Nm³) with mostly odourus substances [BANK 1995]. For higher VOC concentrations in the waste gas, other emission reduction measures are applied because the space request for bio-filters would be too big.

For suitable conditions, efficiencies of up to 99 % can be achieved [ANTKOWIAK 1991]. The following operational criteria should be kept, in order to receive satisfying results:

- The relative humidity at the entrance of the filter has to be permanently above 95 %,
- the pollutants must be sorbable onto the filter substrate,
- the waste gas temperatures should be adjusted according to the population of microorganisms: Thermophilic 40-60 °C, mesophilic 20-40 °C, psycrophilic 5-20 °C,
- high concentrations of particles and aerosols has to be avoided,
- neither bases nor acids may be conducted into the filter system,
- for a sufficient oxygen supply a good ventilation is necessary,
- for inert filter materials a sufficient supply of mineral nutrients is necessary.

Advantages of the Bio-filtration

- Very suitable for cleaning of waste gases with a low VOC-content.
- Efficiencies of up to 99 % can be realized.

- Generally lower specific investments are necessary if compared to other emission reduction measures [RENTZ 1999].

Disadvantages of the Bio-filtration

- Large space request, except for surface filters in sublevel stoping
- Generation of anaerobic zones due to the lack of oxygen and nutrients.
- The microorganisms are adapted to special organic substances. Thus procedure conversions require adaptation time.
- Intermediates of the biological degradation have to be regarded.

4.1.3 Applications

The biofiltration is applied for the varnishing of wood (Firma Schimmel, Braunschweig) as well as for the production of rubbing linings and rubbing surfaces by the industrial installations of the solvent sector. A broad field of application represents the waste gas cleaning in the production of MDF fibreboard. The bio-filters are applied for a reduction of odour nuisance (VOC, phenol, etc.) [BAUMS 2000, WESSEL-UMWELTTECHNIK 2002].

4.1.4 Investments and Operating Costs

Investments depend on the waste gas volume flow, on the biodegradability and the VOC concentrations in the waste gas as well as on the volume and weight of the filter substrate.

Since the energy demand of bio-filters is comparatively small, the operational costs are relatively low. The operational costs arise with increasing (filter) layer thickness and thus increasing pressure loss within the layer. Besides the energy demand another important factor of the operational costs is the replacement of the filter material (average service life of approx. 3 - 5 years) [ADEME 1997]).

4.2 Bioscrubbers

Bioscrubbers are used for wastewater treatment, emission reduction of VOC and removal of odour nuisance [MEHLIS 2001]. The technical realization of the prerequisite absorption process takes place in absorbers, where the absorbent is brought in contact with the waste gas.

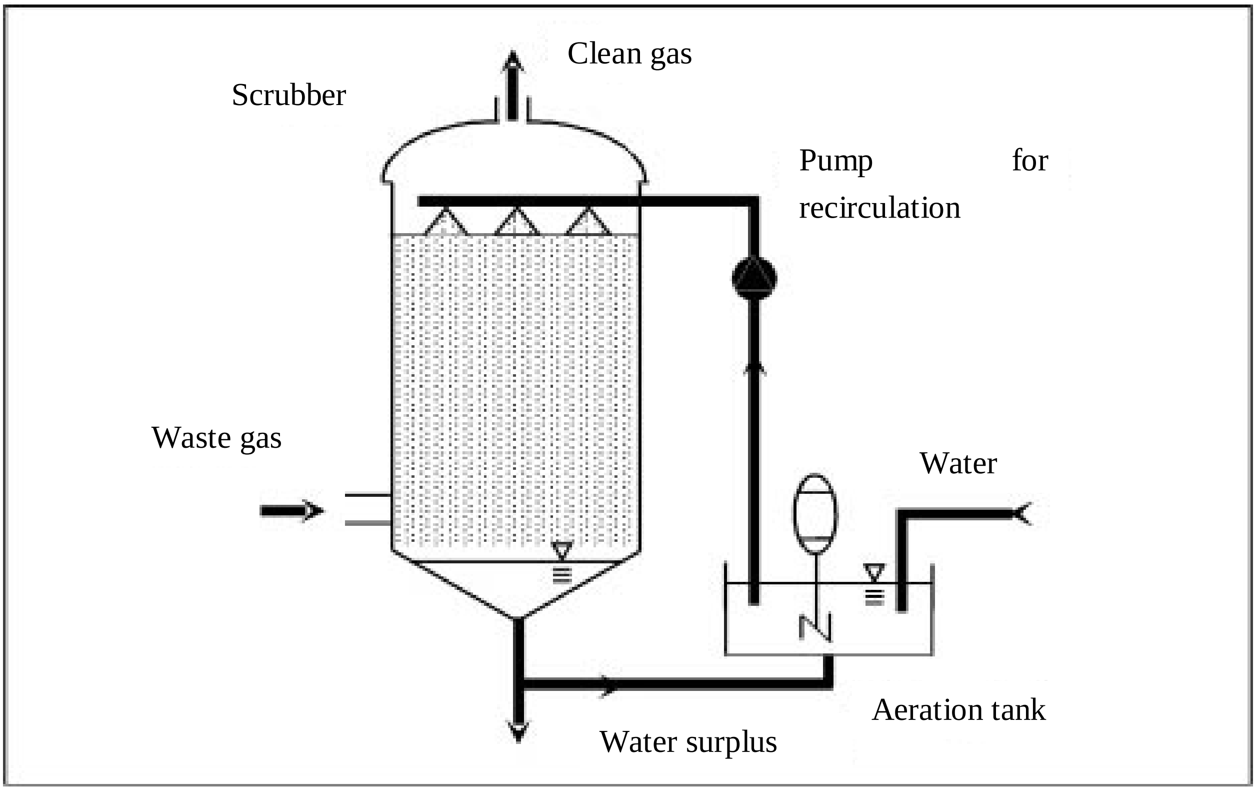
After absorption, the absorbed substances are metabolically degraded by microorganismns [VDI 3477].

4.2.1 Device Construction

For bioscrubbers, two methodical processes can be differentiated [VDI 3478]:

- In the **active-mud scrubber** the microorganismns are dispersed in the washing water. The waste gas is leaded into the scrubber in counter current flow to the suitable washing agent. Therefore the interface has to be as large as possible. Packed bed, gas bubble and plate columns as well as spraying and jet washers are utilized [BREIHOFER 1991]. The pollutants are ingested by the microorganismns that are present in the water and form the active mud. The washing liquid is regenerated in a aeration tank (cf. figure V-13). The active-mud-process is for example utilized, if the biodegradation is relatively slow. With this process, the regeneration step can be adjusted independently from the absorption step with regard to the pollutants and the degradation speed [BANK 1995].

Figure V-12**:** *Functionality of an active mud scrubber* [ADEME 1997]



For the **trickling filter scrubber** the microorganismns reside onto superstructions or packings (e.g. open porous rubber foam, based on polyurethane). The absorbent, running over the fixtures, provides nutrients for the microorganismns and is thus regenerated [BREIHOFER 1991]. For a detailed description of different biological waste gas treatments confer [SCHIRZ 1996, SCHNEIDER ET. AL. 1996]

4.2.2 Washing Agents

Within the circuit, the regenerated washing agent is pumped back to the washer. The secluded substances serve as nutritive substance for the microorgansimns. For the building of the cell substance, the washing agent has to contain nitrogen, phosphor as well as other trace elements besides carbon. Due to evaporation losses of the washing agent a salt enrichment occurs in general. A salt enrichment can be avoided by removal of absorbent and a supply of fresh water [VDI 3478]. For an improved efficiency factor, an adjustment of the pH value of the washing agent by addition of chemicals (such as sodium hydroxide or sulfuric acid) might be necessary. Depending on the waste gas composition, a two-step absorption might be necessary. Thereby one scrubber is adjusted alkaline (pH value of 7 – 9) and the other scrubber is adjusted acidic (pH value 4 – 7) [BREIHOFER 1991].

4.2.3 Treatable Substances

The following organic solvents and mixtures of these components can be treated via biodegradation:

- alcohols: Ethanol, isopropyl alcohol, methanol,
- phenols,
- glycols: Ethylene glycol,
- glycol ether,
- ester: Methyl acetate,
- ketones: Acetone, methyl ethyl ketone,
- aldehydes: Formaldehyde,
- Pollutants that are less soluble or toxic with regard to the microorganisms such as benzene, toluene, styrene, chlorinated solvents (only if a water-/ oil mixture is used as cleaning agent).

4.2.4 Parameters for the Applicability of Bioscrubbers

The degradation depends essentially on the following parameters:

- The pollutants have to be biodegradable.
- The pollutants of the waste gas have to be absorbable by water or a water/activated sludge mixture.
- VOC concentration in the waste gas,

- O_2 content, pH-value, temperature and phosphate/nitrogen ratio of the washing agent,
- VOC loading of the washing agent,
- Concentration of microorganismns and their adaption to the VOC to be transformed

4.2.5 Applications

Similarly to the bio-filtration, bioscrubbers were mainly used for the reduction of odour nuisance originally. Nowadays bioscrubbers are also applied for an emission reduction of painting processes [KOHLER 1990].

The typical application range of bioscrubbers and trickling filter scrubbers are waste gases with a VOC concentration of up to approximately 2 g / Nm³ [VDI 3478]. Bioscrubbers are especially suitable for large waste gas volume flows (up to 1 000 000 Nm³/h). VOC concentrations in the clean gas of 90 mg/m³ and less can be achieved [MCINNES 1995, SCHULZE 2002].

One bioscrubber (active mud scrubber) is utilized for the VOC emission reduction in the varnishing of beverage cans in the examined industrial installations of the paint and adhesive application. The installation is operated as a stand-by installation to replace the thermal combustion unit in case of failures. For exemplary data of bioscrubbers in the varnishing of beverage cans confer [VDI 3478].

4.2.6 Investments and Operating Costs

The costs caused by the consumption of operating materials (energy, water and chemicals) are significantly smaller in comparison to non-biological emission reduction measures. However due to the two-stage process, the investments and operating costs for bioscrubbers are higher than the ones for bio-filters.

5. Condensation

The condensation is no independent emission reduction measure and it is mostly applied as a pre- separation technique in combination with other subsequent emission reduction processes. In general, the condensation is not suitable for an adherence to legislative emission limits resulting of German and European law regulations, not even if low temperatures are used [BANK 1995]. Thus the condensation is therefore utilized as **pre-separation** of organic solvents out of waste gases e.g. if inert-gas dryers are applied. For fulfillment of the emission limits, installations with other exhaust gas treatment installations have to be used downstream [RINNER 2001].

5.1 Process Principle

The solvent-containing exhaust gases are cooled below the dew point of the organic solvents. The condensate is intercepted directly. For a separation of very volatile solvents, very low condensation temperatures are necessary. A specific problem of the condensation processes is the icing of the devices due to the water and other substances depending on the operation mode. Therefore the installations have to be equipped with defrosting devices. With a pre-conditioning of the waste gas by de-moistening, a contamination of recovered, water-soluble organic solvents can be prevented [BANK 1995, ULRICH 1990, RENTZ 1999]. For a more detailed description of installation designs confer [HERZOG, GRABHORN 1996].

The condensation process is only economical if the solvent concentrations in the exhaust gas / carrier gas are in the range of the saturation concentration and if the volume of carrier gas is as small as possible for energy reasons. A basic problem is that the solvent proportion may exceed the emission limits for the explosion prevention. Thus the installations are operated with inert gas (typically nitrogen) as carrier gas instead of air.

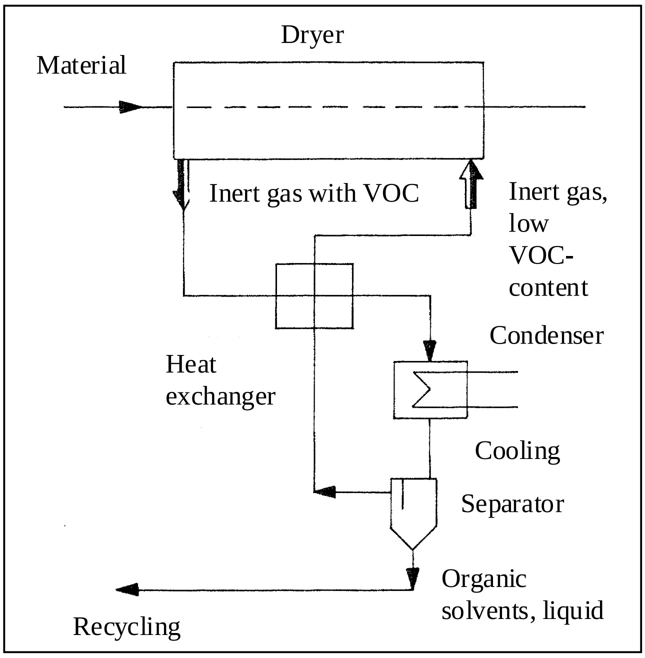


Figure V-13: *Indirect condensation techniques for solvent separation for the varnish drying in an inert-gas dryer* [BANK 1995]

In general, the **direct** and the **indirect condensation** are differentiated:

- For the **indirect condensation,** the condensation takes place at the surfaces onto heat sinks (cooled by water or coolants).
- For the **direct condensation,** the coolant is directly discharged into the exhaust gas stream.

5.2 Condensation Agents

As condensation agents for temperatures below 0 °C, mixtures of water and methanol or water and glycol (-15 °C to 5 °C), as well as KCl dissolved in water (-30 °C to 15 °C) are in use as coolants in cooling devices. For the so called cryo-condensation at very low temperatures, liquid nitrogen (boiling point: -196 °C) is utilized [BREIHOFER 1991, RINNER 2001].

5.3 Condensable Substances

The following parameters are relevant for the application of condensation:

- Type and concentration of components that have to be recovered
- Vapour pressure curves of the components
- Temperature of the exhaust gas
- Volume flow of exhaust gas
- Type of condensation process
- Temperature of the condenser
- Characteristics of the coolant

If the exhaust gas contains several components with similar vapour pressure curves, a selective separation of components is often not possible [SCHULTES 1996]. A limiting factor for the applicability of condensers is the energy demand that is necessary for reaching the dew point of the substances to be condensed.

5.4 Applications

Cryo-condensation is suitable for exhaust gases with a high content of expensive solvents. The cryo-condensation is utilized for the specialty chemistry and the pharmaceutic industry [TREMBLEY 1998].

Within the examined industrial solvent sectors, the condensation process is utilized for the pre-drying of adhesive coated tapes, where inert gas dryers are used with nitrogen as carrier gas. For a further recovery of VOC from the exhaust gas and for fulfillment of the legal requirements (German technical ordinance air), an adsorption installation is connected downstream.

Advantages of the Condensation

- The recovered solvents can be directly reused in the production process.
- In comparison to the indirect condensation, the direct condensation has the advantage of a quicker heat exchange. Also a more homogenous mixture of gas and steam is achieved with the coolant. Hence less coolants are necessary [BAUM 1988, SCHIFFBAUER 1990].

Disadvantages of Condensation

The condensation is not suitable, if [SCHIFFBAUER 1990]:

- The solvent concentration of the exhaust gas is low,
- Large volume flows have to be treated
- The exhaust gas contains components that interfere with the condensation process.

Further two significant disadvantages have to be observed:

- A selective condensation of components is often not possible.
- For the direct condensation an additional process step is necessary in order to separate the recovered solvents from the coolant.

5.5 Investments and Operating Costs

The investments depend on the heat exchangers and the cooling devices. Operating costs mainly depend on the energy demand and the consumption of coolants.

6 Criteria for the Selection of Emission Reduction Measures

For the applicability of the described emission reduction measures, the following technical parameters have to be regarded [RENTZ 1996, VDI 3476, VDI 3477]:

- Required efficiency of VOC emission reduction;
- characteristics of the waste gas: Composition of the waste gas, exhaust gas volume flow, VOC concentration in the exhaust gas;
- spatial considerations: space requirements for coupling of installations, for the implementation of a closed circuitry system, for re-fitting;
- technical-economic service live;
- additionally requested technical installations, e.g. for the production of water steam or nitrogen;
- quality requirements of recovered solvents.

In Table V-6, relevant criteria for the applicability of VOC emission reduction measures are shown.

Table V-5: *Overview of relevant parameters for the applicability of secondary emission reduction measures :*
[Koch, 2002, Schulze, Eisenmann 2001, Bank 1995, Schultes 1996, Baumbach 1993]

Parameter	Condensation as pre-separation only	Adsorption (4)	Absorption	Thermal recuperative combustion	Catalytic recuperative combustion	Thermal regenerative combustion	Catalytic regenerative combustion	Bio-filter	Bioscrubber
Concentration (L) [g C/Nm³]									
> 10	++	+	++	++	-	-	-	-	-
5 – 10	o	++	+	++	o	+	o	-	-
1 – 5	-	++[5]	+	+	++	++	++	o	++
< 1	-	++	0	0	o	0	+	++	++
Volume flow of exhaust gas [Nm³/h]									
50.000 – 100.000	-	++ ++)	++	+	-	+	+	+	++
5.000 to 50.000	o	+	++	++	++	++	++	++	++
up to 5000	++		+	++	++	+	++	++	+
Recovery of solvents	Possible	possible	possible	not possible	not possible	not possible	not possible	not possible	not possible

++ = very suitable + = suitable o = less suitable - = not suitable

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[4] For medium and large waste gas volume flows with VOC loadings of < 1 – 5 g/Nm³ , often the adsorption is used as a concentration step before thermal combustion [EISENMANN 2001, BANK 1995].

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Annex VI:

Case Studies

VI.1 Case study about the Serial Coating of Passenger Cars at the Volkswagen AG

Within the case study at the Volkswagen AG about the serial coating of passenger cars, the following installations were investigated:

- The ground coating plant F for pre-treatment / KTL[1] in hall 12 (plant Wolfsburg),
- the 5a process for top coating in hall 9 (plant Wolfsburg), and
- the ground coating plant for pre-treatment / KTL[1] in hall 17 (plant Emden)

An ongoing trend in the automobile industry is the further reduction of passenger car´s fuel consumption. This will lead to the production of more lightweight cars by the increasing use of plastic or aluminium parts. The layout of painting plants must therefore anticipate this development so that different materials can be pre-treated and coated. In this context, the varnishing of the model LUPO represents a good example.

Ground Coating Plant for the Pre-treatment/KTL1 in Hall 17 (Plant Emden)

This plant was built in 1996 and represents latest ecological and procedural aspects.

Ground Coating Plant F for the Pre-treatment/KTL1 in Hall 12 (Plant Wolfsburg)

The plant was constructed in 1978 and was significantly modified in 1998, according to new environmental and procedural aspects and was therefore partly new built.

In this plant, the car bodies of the LUPO are pre-treated. Their weight reduced construction (composite construction of steel/aluminium) causes high requirements to the pre-treatment and dip coating. It has to be noted that the phosphatization of aluminium surfaces is significantly more difficult for aluminium than for steel. Hence the phosphatization solution has to be adapted in order to meet the quality requirements.

Top Coat Plant, 5a-Process in Hall 9 (plant Wolfsburg)

This plant was new-built in 1996 for the top coating of LUPO car bodies.

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[1] KTL: cathodic immersion prime coating

VI.1.1 BASIC COATING PLANT Hall 17 (Pre-treatment/KTL) Volkswagen AG Plant Emden

General Information about the Plant

Name and location of the plant	Volkswagen AG, Plant Emden Pre-treatment/KTL installation
Annual capacity	330 000 vehicles/a (1998) capacity: 1 350 vehicles/day (plant layout) 1 100 vehicls/day (currently in use) (Source: Factory examination, 08.06.2000)
Annual consumption of solvents [t/a]	
Annual operation time	h/a days/a, 5 days per week, 3 shifts per day + 1 shift sunday night (Source: Factory examination 08.06.2000)
Year of commissioning	1996
Type and date of significant modifications	Filtration, degreasing
Brief description of the production process: Sequence of essential process steps	Pre-treatment Zone 1: Pre-heating and cleaning Zone 2: Spray degreasing Zone 3: Dip degreasing Zone 4: Spray rinsing Zone 5: Dip rinsing Zone 6: Dip phosphatization Zone 7: Spray rinsing Zone 8: Dip rinsing

	Zone 9: Dip reaction Zone 10: Rinsing Cataphoretic immersion prime coating (KTL) Zone 1: KTL immersion tank Zone 2: Recirculate Zone 3: Pure filtrate immersion application Zone 4: Rinsing with completely demineralized water
Car body	Surface to be coated: 90 m2 (Source: Factory examination, 08.06.2000)

Data for selected, applied measures

Ultrafiltration

- increased quality of immersion baths
- increased service life, higher installation availability

Ion exchanger

15 m^3 rinsing water, disinfection devices, gravel pits filter, 1 week service life, 2 production lines

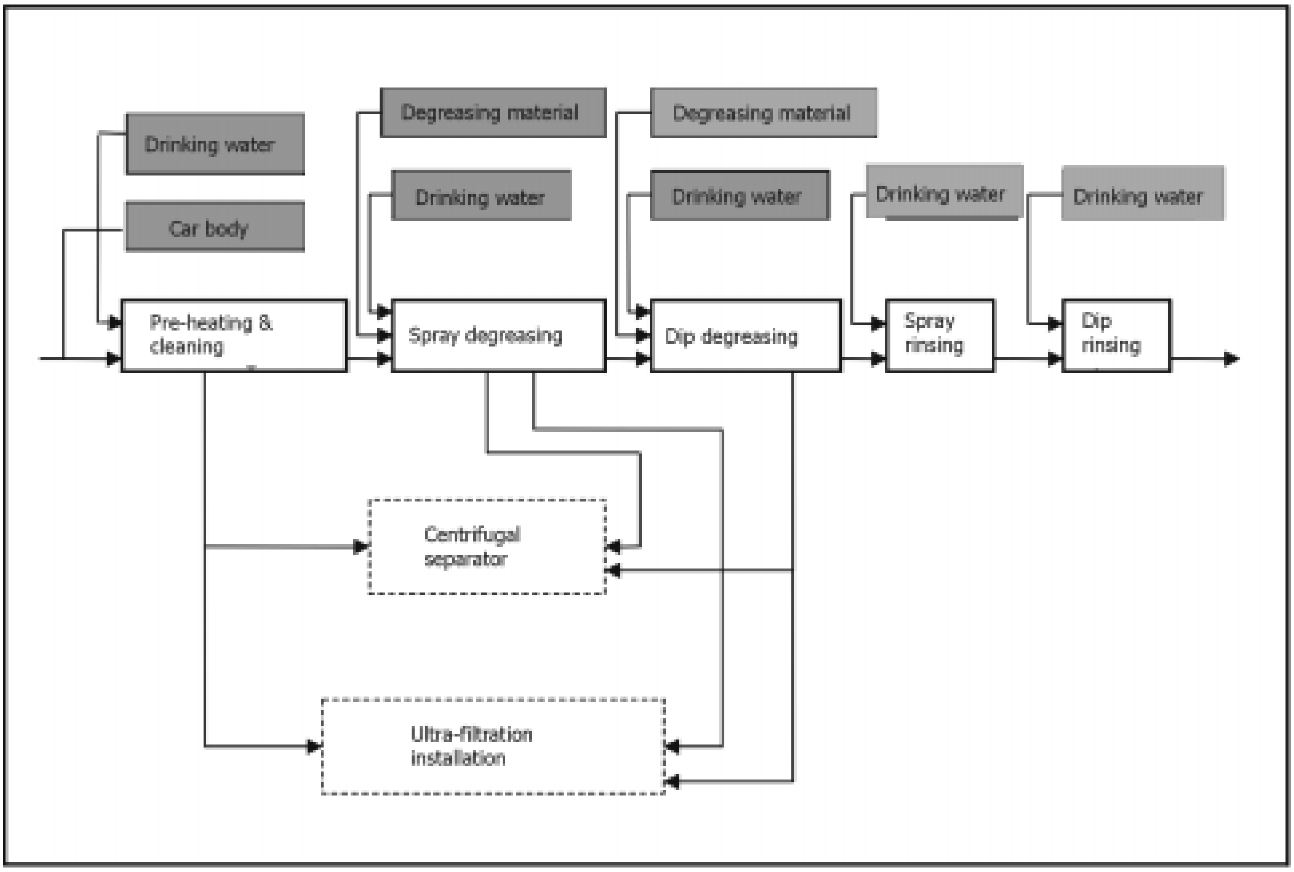
Central waste water treatment plant

Thermal combustion unit

50 % of energy recovery, utilization of recovered heat for pre-heating of the dryers

Base year for data: 1999, if not noted differently

1 Process Step: Degreasing and Activation



Comments:

- Dip rinsing is carried out for surface activation for the adhesion of chrome VI onto the surface
- Process step I is equipped with a separator for oil.
- It is intended to equip the spray rinsing installation with a recycling installation.
- *(Source: factory examination, 08.06.2000)*

Measures

Cascade arrangements and circuitry for process water (Source: factory examination, 08.06.2000)
Ultra-filtration devices (Source: Proposal for a modification permission, 1995)

Material Consumptions

Degreasing agent	0,85 litres/car body. *(Source: Proposal for a modification permission, 1995)*
Drinking water	5,5 m^3/h *(Source: Proposal for a modification of the permission, 1995)*
Demineralized water	1 m^3/h *(Source: Proposal for a modification of the permission, 1995)*
Procastination of water	500 litres of water/h *(Source: Factory examination, 08.06.2000)*
Evaporation losses	200 – 300 litres of water/h *(Source: Factory examination, 08.06.2000)*
Service life:	1 week *(Source: Factory examination, 08.06.2000)*
	Disposal after approx. 1,5 years *(Source: Factory examination, 08.06.2000)*
Degreasing tank:	
Share of degreasing agent / demineralized water	1: 9 *(Source: Factory examination, 08.06.2000)*
Consumption	5 m^3/h *(Source: Factory examination, 08.06.2000)*
Costs	3 EUR/m^3 *(Source: Factory examination, 08.06.2000)*

Environmental Aspects

Waste water: Central waste water treatment plant (→ sludge)

Waste: Degreasing sludge

Waste water:

1 m^3/h *(Source: Proposal for permission modification, 1995)*

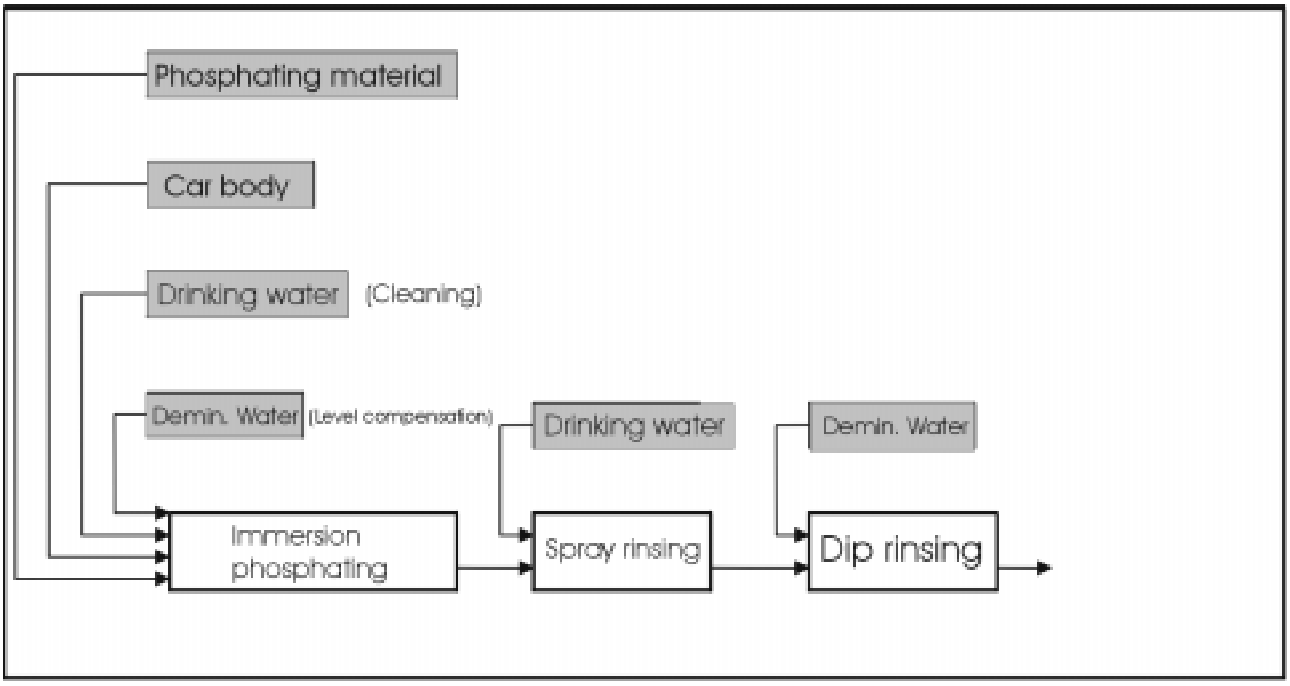
Waste

Hazardous waste:

Degreasing sludge (⇨ disposal site): 24 m^3/a
(Source: Proposal for permission modification, 1995)

Oil from separator (⇨ co-combustion in power plants): 18 t per quarter year
(Source: Factory examination, 08.06.2000)

2 Process Step: Phosphatization



Due to a low iron content and thus a low generation of paint sludge, a filter press is not required.
(Source: Factory examination, 08.06.2000)

Measures

Cascade technique (Source: Factory examination, 08.06.2000)
Ion exchanger (Source: Proposal for permission modification, 1995)

Consumptions

Phosphatization material:	1,3 litres/car body
Ion exchanger:	
Demineralized water	4 m^3/h
HCl	5-12,5 Litre/h
NaOH	14 Litre/h

(Source: Proposal for permission modification, 1995)

Environmental Aspects

Wastewater: Central waste water treatment plant (→ sludge)

Waste: Sludge from phosphatization

Wastewater:

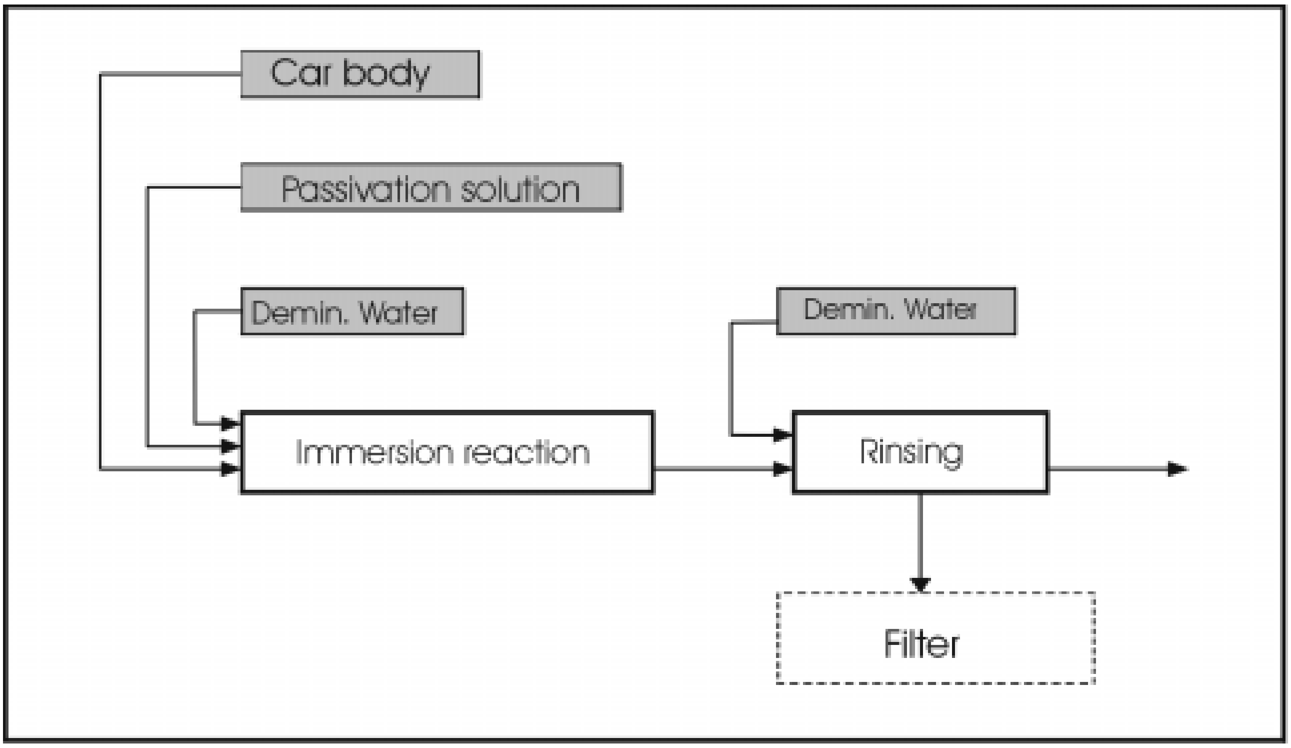
8 m^3/h *(Source: Proposal for permission modification, 1995)*

Waste:

Hazardous wastes:

Sludges (material recycling): 283 t/a
(Source: Proposal for permission modification, 1995)

3 Process Step: Passivation



Measures

Ion exchanger (Source: Proposal for permission modification, 1995)

Consumptions

Passivation agent (chromate):	0,025 kg/car body
Ion exchanger:	
Demineralized water	2,5 m^3/h
Regular salt	2000 litres/h
$NaHSO_3$	9-12,5 litres/h
NaOH	10-24,5 litres/h
HCl	10-25 litres/h

(Source: Proposal for permission modification, 1995)

Environmental Aspects

Waste water: Central waste water treatment plant (→ Sludge)

Waste: Contaminated filters

Waste water:

2,5 m^3/h *(Source: Proposal for permission modification, 1995)*

Waste:

Non-monitoring-needy waste:
Filters ⇨ municipal solid waste

4 Process Step: Cataphoretic immersion prime coating + drying

Measures

Ultrafiltration plant, cleaning of waste gases from dryers (2 thermal combustion units) *(Source: Proposal for permission modification, 1995)*, lead-free dip coating solution *(Source: Factory examination, 08.06.2000)*

Consumptions

Material for electro-coating:	
Solvent content	4.35 weight per cent
Solids content	Not stated
Material consumption	8 kg / Car body
Demineralized water:	7 m^3/h
Energy:	Not stated
Ultrafiltration:	
Al-SO4	9 kg/h

(Source: Proposal for permission modification, 1995)

Environmental Aspects

Waste gas: VOC-Emissions

Wastewater: Central wastewater treatment plant (→ Sludge)

Waste: Paint sludge (negligible amounts), filters

Waste gas:

Amount of waste gas:	22 000 Nm^3/h (dryer)
Emissions:	
VOC (KTL)	1.66 g/m^2
VOC (dryer)	0.09 g/m^2
C_{total} (dryer)	50 mg/m^3

(Source: Proposal for permission modification, 1995)

Waste water:

5,5 m^3/h *(Source: Proposal for permission modification, 1995)*

Waste:

Hazardous waste
Electro-coating sludge (⇨ waste site): 20 t/a *(Source: Factory examination, 08.06.2000)*

VI.1.2 Ground coating line F, hall 12 (Pre-treatment/cathodic immersion prime coating)

Volkswagen AG Plant Wolfsburg

General Information about the Plant

Name and location of the plant	Volkswagen AG, Plant Wolfsburg Hall 12: Pre-treatment installation / cathodic immersion prime coating
Annual capacity	11 500 vehicles / y capacity: 250 vehicles/day (plant layout) 50 vehicles/day (current production) *(Source: Factory examination, 02.-04.05.2000)*
Annual solvent consumption [t/y]	5 t/y
Annual operational time	3 680 h/y 230 days/y, 5 days/week, 2 shifts/day
Year of comissioning	1978
Type and date of significant modifications	Conversion of the complete pre-treatment plant in 1998
Announcements according to § 15 BImSchG	Reconstruction and subsequent re-comissioning
Short description of the production process: Sequence of essential process steps	*Pre-treatment* Zone 1: Spray cleaning I Zone 2: Spray cleaning II Zone 3: Degreasing via dipping / activation Zone 6: Rinsing via dipping Zone 7: Phosphatization via dipping Zone 8: Rinsing via dipping Zone 9: Passivation via dipping Zone 10: Spray rinsing *Cataphoretic immersion prime coating* Zone 1.0: dip-coating tank cathodic immersion

	coating Zone 2.0: Recirculate Zone 3.0: Dipping in pure filtrate Zone 4.0: Rinsing with demineralized water

Data of Selected Applied Measures

Solid separator (Hydrocyclone) + Ultrafiltration - in test stage

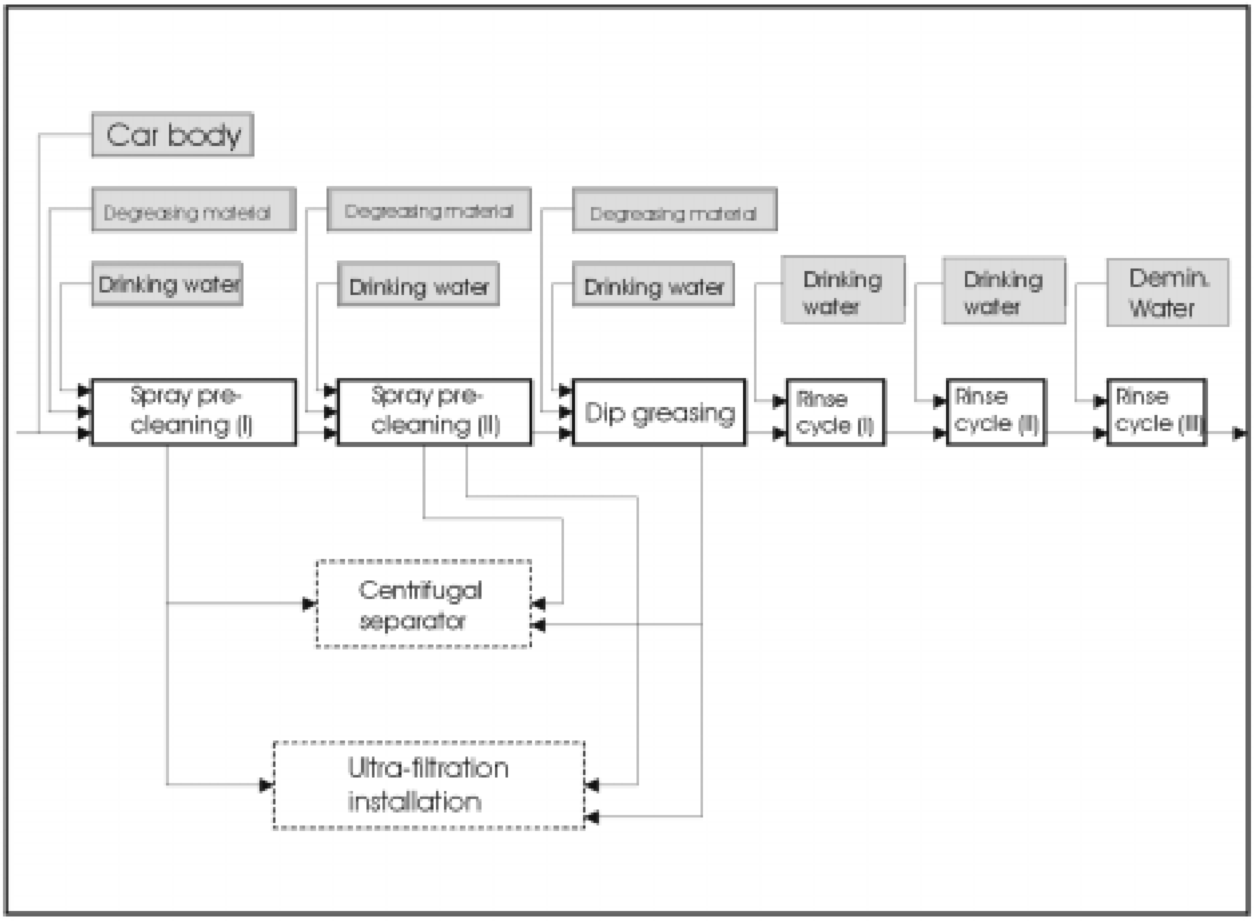
- Higher Quality of the degreasing agent
- Longer service live, better equipment availability

Thermal post-combustion unit

50 % energy recovery, utilization of recovered heat for heating of dryers input air

Base year of data: 1999, (if not noted differently)

1 Process Step: Degreasing and Activation



Measures

Circuitry of degreasing agent, cascade rinse technique, centrifugal separator, bandpass filter, ultra-filtration installation

Consumptions

Degreasing agent:	No data available
Drinking water:	0.3 m^3/car body
Demineralized water:	0.6 m^3/car body

Environmental Aspects

Waste water: Central waste water treatment plant (→ Hydroxyl sludge)

Waste: Sludge from degreasing, emulsions of waste oil, filter

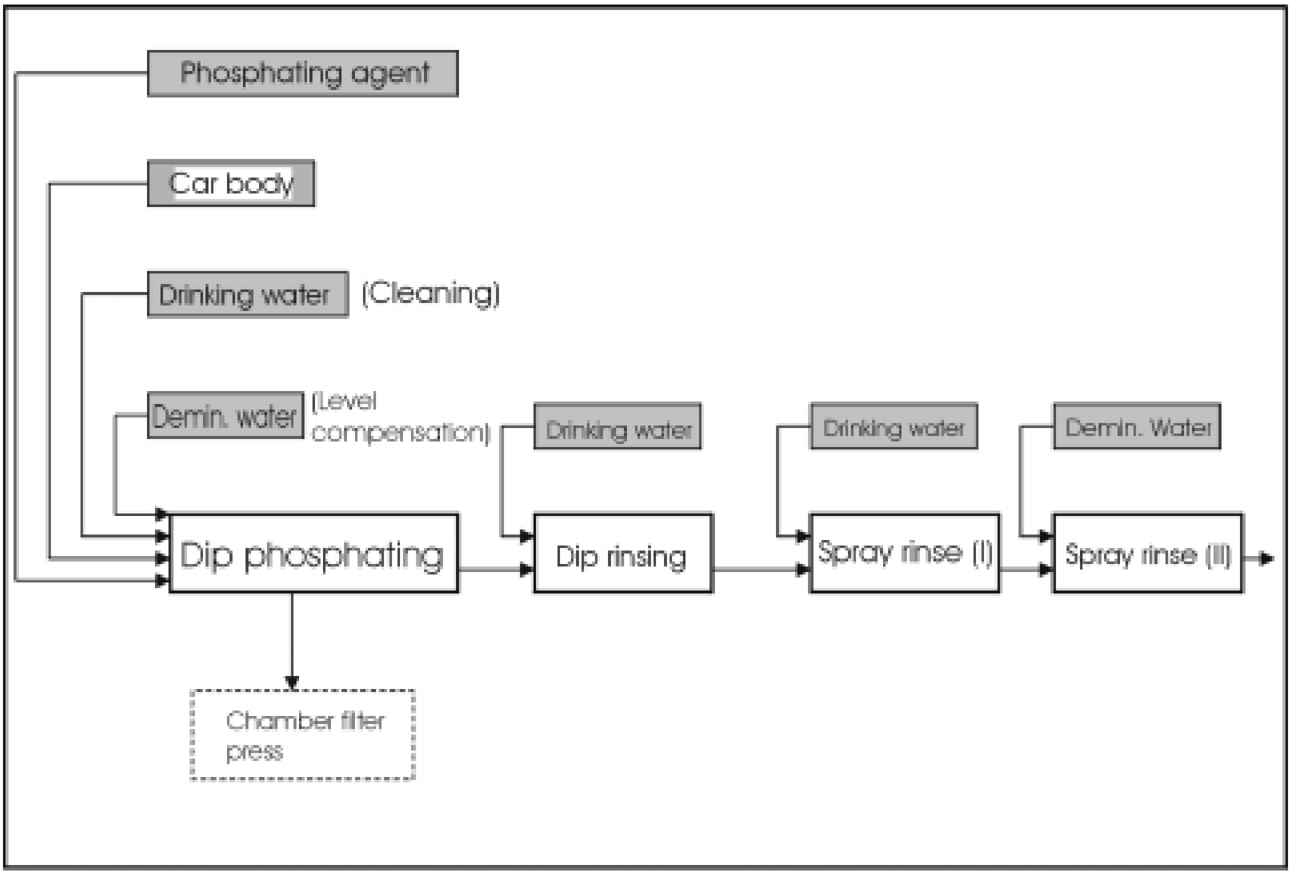
Waste water:

0.78 m^3/car body *(source: flow chart hall 12)*

Waste:

Hazardous waste:		
Sludge from degreasing	1,25 kg/car body	disposed
Emulsion of waste oil	No data available	
Hydroxyschlamm	No data available	Waste site
Contaminated filters	1 filter/10 car bodies (for total pre-treatment)	disposed

2 Process Step: Phosphatization



Measures

(Ni, Cu, Mn) Tri-cation-phosphating agent, circuitry of phosphating agent, cascade rinse technique, chamber filter press

Consumptions

Phosphatization material	No data available
Drinking water	0.85 m^3/car body
Demineralized water	0.06 m^3/car body

Environmental Aspects

Waste water: Central waste water treatment plant (→ Hydroxyl sludge)

Waste: Phosphating sludge

Waste water:

0.85 m^3/car body *(Source: flow chart hall 12)*

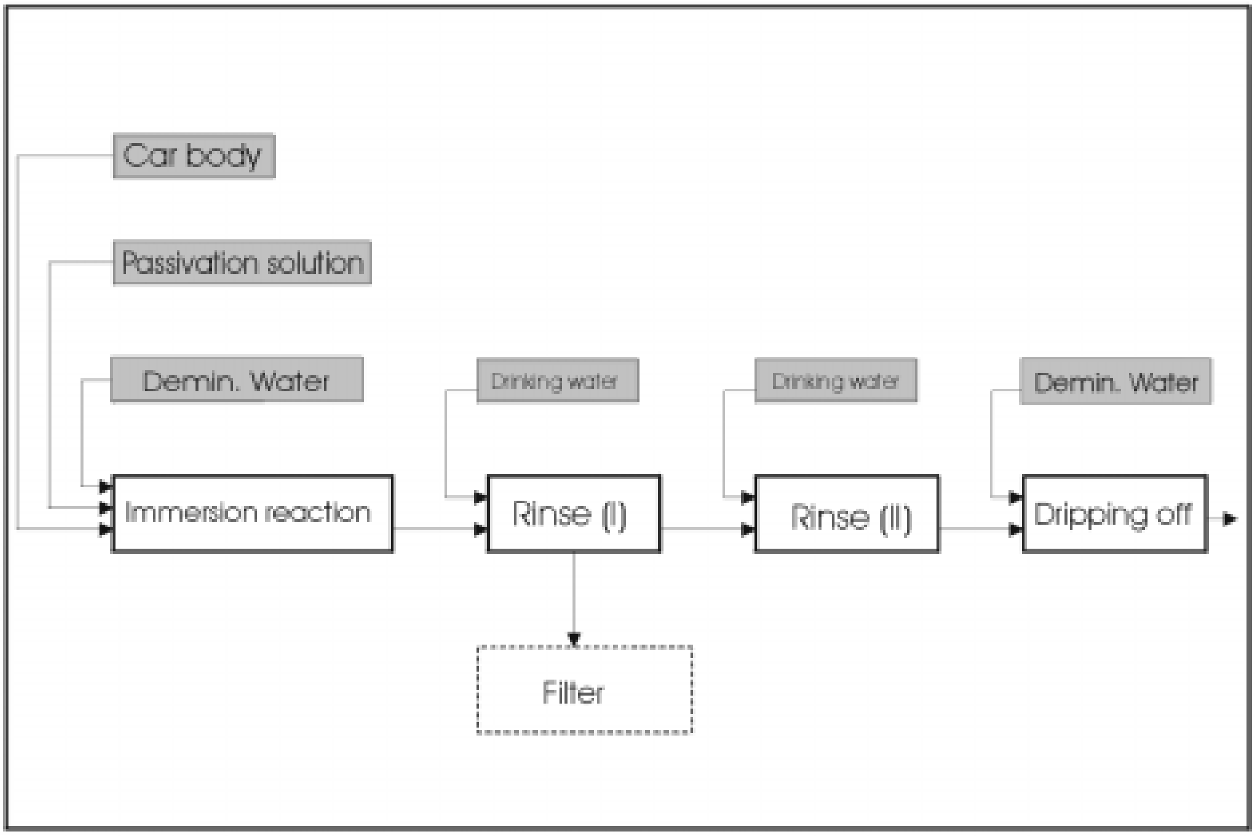
Waste :

Hazardous wastes:

Sludge from phosphatization (waste site): 0.005 m^3/car body

Hydroxyl sludge (waste site): No data available

3 Process Step: Passivation



Measures

Chromate-free passivation solution, application of cascade technique, filters

Consumptions

Passivation agent: No data available

Demineralized water: 0.26 m^3/car body

Environmental Aspects

Waste water: Central waste water treatment plant (→ Hydroxyl sludge)

Waste: Sludge, filters

Waste water:

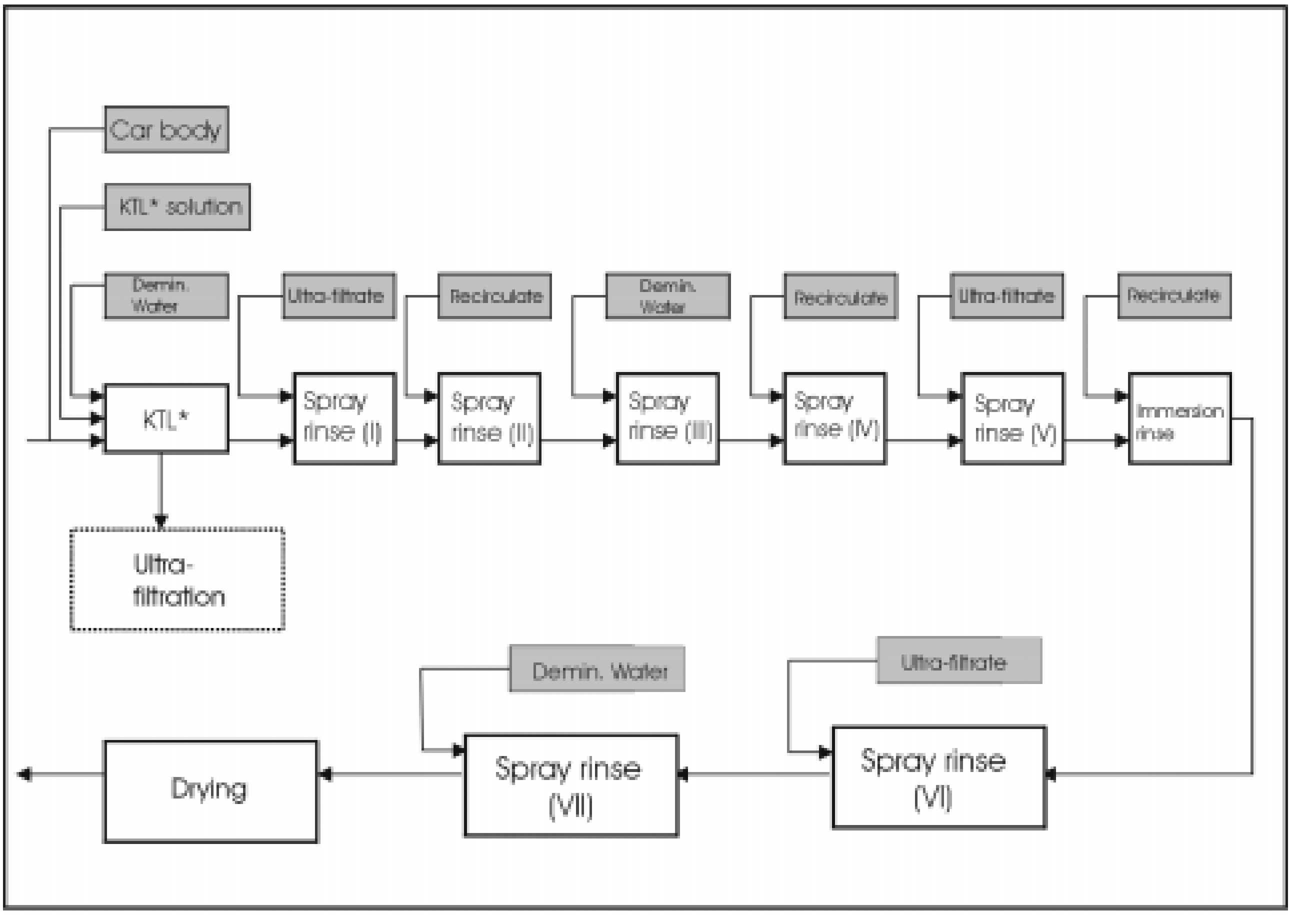
0.26 m^3/car body

Waste :

hazardous waste

Hydroxy sludge (Waste site):	No data available
Contaminated filters (disposed):	1 filter/10 car bodies (for total pre-cleaning)

4 Process Step: Cathodic Immersion Prime Coating + Drying



KTL*: cathodic immersion prime coating

Measures

Ultra-filtration for the recycling of material and demineralized water, filter; utilization of paint sludge, waste gas-cleaning from dryers via thermal combustion

Material Consumption

Electro dip coat:

Content of organic solvents:	3 - 4 weight per cent
Solids content:	45 weight per cent
Consumption:	75 g/m^2 *(Source: Umweltschutzbericht, 1999)*

Demineralized water:	0.5 m^3/car body
Energy:	No data available

Environmental aspects

Waste gas: VOC emissions, emissions of heavy metals (lead)

Waste water: Central waste water treatment plant(→ Hydroxyl sludge)

Waste: Paint sludge (negligible amounts), filter

Waste gas:

Waste gas volume:	10 000 – 20 000 Nm^3/h (dryer)
Emission values:	
VOC	2,5 g / m^2
Heavy metals (lead)	Negligible amounts

(Source: Environmental protection report, 1999)

Waste water:

0.5 m3/car body

Waste:

hazardous waste

Hydroxyl sludge (waste site):	No data available
Contaminated filters (disposed):	1 filter/10 car bodies (complete pre-treatment)
Paint sludge (energy recycling):	1 t/y

VI.1.3 Top Coating Line (5a process, hall 9)

Volkswagen AG Plant Wolfsburg

General Information about The Plant

Name and location of the plant	Volkswagen AG, Plant Wolfsburg Hall 9: Varnish installation
Annual capacity	138 000 vehicles /y capacity: 720 vehicles/day (plant layout) 600 vehicles/day (present production)
Annual consumption of solvents [t/y]	160 t/y *(Source: Emission measurement)*
Annual operation time	4 600 h/y 230 days/y, 5 days/week, 2.5 shifts per day
Year of commissioning	New installation,1996
Announcements according to § 15 BImSchG	Reduced application of PVC and filler onto the underbody of the LUPO car bodies ,1999
Description of relevant process steps	Underbody protection, seam sealing ↓ Filler application, drying (thermal post-combustion of waste gas from dryer) ↓ Base coat application, drying (thermal post-combustion of waste gas from dryer) ↓ Clear coat application, drying (thermal post-combustion of waste gas from dryer) ↓ Cavity sealing
Car body	Surface to be coated: 69 m^2 (LUPO) Outside area / interior: 80 / 20 %

Data of Selected Applied Measures

Thermal combustion unit

50 % energy recovery, utilization of recovered energy for heating of dryers' air

Electrostatic spray application

- Application efficiency factor of 85 % (regular spray application: 50 %)
- Reduction of costs by a reduction of material consumption by approx. 30 % (from 13 to 9 kg/car body for the coating system filler up to clear coat)
- Reduction of paint sludge (from 5.5 to 4 kg/car body)

Paint sludge utilization

Generation of paint sludge: approx. 4 kg/car body
Consumption of materials for coagulation: Approx. 0.47 kg/car body
(Source: Dr. GRUBER, personal report, Mai 2000)

Scraper-technology

Reduction of material consumption by application with scrapers:
300 g/car body for top coating
150 g/car body for fillers

Base year for data: 1999 (if not stated differently)

1 Process Step: Underbody Protection and Seam Sealing

Technique:

Application: Automated or manual

- 90 % of the vehicles are coated with 100 % PVC
- < 10 % of the vehicles (approx. 50 vehicles/day, Lupo, 3-liter car) are coated partly with PVC, partly with fillers,

Measures

PVC reduction, application onto the turned car body (rotation of 180°) [a] (for a reduction of overspray and better ergonomics for employees due to the avoidance of overhead work)

---

[a] a special construction of the car body is necessary.

Consumption

Majority of produced vehicles:	
PVC	8,5 kg / car body
3 litre cars:	
PVC	6,5 - 7 kg / car body
Filler	100 g / car body
Solvent content of filler	7 weight per cent
Reduction of PVC	1,5 - 2 kg / car body

(Source: Dr. Gruber, May 2000)

Energy demand: No data available

Environmental aspects

Waste gas: Low emission (measure: Filter for protection of employees)

Waste:: PVC, contaminated PVC masking materials, masking paper, cellulose cloth, paint brushes, gloves

Waste gas:

Waste gas volume:	100 000 Nm^3/h (spray booth)
Emission values:	
Dust	0.4 g / car body
VOC	0.19 g / m^2

(Source: Report of Emission measurement for the year 1998)

Waste :

Hazardous waste:		
PVC	66 t / a (approx. 480 g / car body)	Disposed
PVC masking materials	247 t / a (approx. 1,8 kg / car body)	Disposed
Other waste:		
Masking paper	No data available	→ Waste site
Cellulose cloth	No data available	→ Waste site
Paint brush	No data available	→ Waste site

Gloves	No data available	→ Waste site

2 Process Step: Wet Cleaning via Washers and Subsequent Drying

Process

(If necessary: wet sanding), wet cleaning with demineralized water (circuitry), drying

Consumption

Demineralized water: No data available

Energy consumption of dryers: No data available

3 Process step: Application of Filler and Subsequent Drying

Process

(1) Application of filler onto sills by two robots (spray-application)
(2) Outside areas: Electrostatically assisted spray application (ESTA)
{(3) If a yellowish coloring is applied: manual spray application with compressed air for quality testing reasons}

Measures

Water-thinnable fillers, electrostatic spray application, interception of cleaning solvents, scrapable ring circuits, utilization of paint sludge, waste gas cleaning from dryers via thermal combustion.

Material Consumption

Filler:

Content of organic solvents:	7 weight per cent
Solids content:	69 weight per cent
Material consumption:	2.8 kg filler/car body

(Source: Dr. Gruber, personal report, July 2000)

Water:

5 m^3 /day (approx. 8 liter / car body)

Energy:

Filler line:	Electricity: Heat (heating of intake air):	25 kWh / car body 150 kWh / car body
Dryer with cooling zone:	Electricity: Natural gas (thermal combustion):	33 kWh / car body 7 kWh / car body

(Source: 5a Process)

Cleaning solvents:

Solvent content: 10 weight per cent

Consumption: Approx. 0,8 kg / car body

(Source: Dr. Gruber, personal report, July 2000)

Volume of intake air:

Sluice	20 000 m^3/h
Manual application	160 000 m^3/h
ESTA	40 000 m^3/h
Inspection, flashing off	70 000 m^3/h
Flashing off	30 000 m^3/h
Sum	*320 000 m^3/h*

(Source: 5a Process)

Auxiliary materials:

Coagulation agent:

Material Consumption: Approx. 75,5 g / car body

Flocculation agent:

Material consumption: Approx. 13,4 g / car body (filler , base and clear-coat application)

Anti-foaming agent:

Material consumption: Approx. 190,3 g / car body (filler , base and clear-coat application)

(Source: Dr. Gruber, personal report, July 2000)

Environmental Aspects

Waste gas: VOC, Particles (Application); CO, CO_2, NO_x, Total C (dryer/ thermal post-combustion)

Waste: Paint sludge, paint containing cleaning agents, cellulose cloth, solid varnish leftovers, paper filter, (painting gloves, suits, etc.)

Waste gas:

Waste gas volume	100 000 Nm^3/h (Spray booth) 10 000 Nm^3/h (Dryer)
Emissions:	
Dust	0.6 g / car body
VOC	0.84 g / m^2
CO	9 g / car body
NO_x	33 g / car body

(Source: Measuring report (Emissions) for 1998)

Waste :

Hazardous waste:		
Paint and varnish sludge	208 t / a (Filler, base and clear-coat)	Energy recovery
Varnish-containing cleaning solvents	No data available	disposed
Cellulose cloth	No data available	
Non-hazardous waste: **Domestic / industrial waste**		
Solid varnish leftovers	No data available	→ Waste site
Paper filters	No data available	→ Waste site
Painting gloves and suits	No data available	→ Waste site

(Source: Environmental protection report, 1999)

4 Process Step: Application of Base coat, Intermediate Drying (infrared radiation dryer)

Process

(1) Automated Spray application with compressed air (2 robots) for the interior (20 %)

(2) Electrostatic application (ESTA-process) for the exterior (80 %)

(3) In case of metallic paints / pearl effects: Automated spray application with compressed air ("spraymate")

Measures

Water-thinnable base coats, electrostatic application, interception of cleaning solvents, scrapable ring-circuits, utilization of paint sludge, cleaning of waste gas from dryers with thermal combustion

Consumption

Base coats:

Solvent content	10 - 20 weight per cent
Solids content	19 - 25 weight per cent
Material consumption	5,47 kg /ca body (uni-coloured base coat and metallic-paint)

(Source: Dr. Gruber, personal report, July 2000)

Water:

10 m^3 / day (approx. 17 liter / car body)

Energy:

Base coat spray booth:		
	Electricity:	31 kWh / car body
	Heat (heating of intake air)	160 kWh / car body
Intermediate dryer:		
	Electricity:	10 kWh / car body
	Natural gas (thermal combustion:	3 kWh / car body
	Refrigerating power:	15 kWh / car body

(Source: 5a Process)

Cleaning solvent:

Solvent content : 8 weight per cent

Consumption; Approx. 1,8 kg / car body

(Source: Dr. Gruber, personal report, July 2000)

volume of intake air:

Application of base coat:	
Sluice	20 000 m^3/h
Manual application	160 000 m^3/h

ESTA	40 000 m^3/h
Flashing off	20 000 m^3/h
Spraymate	45 000 m^3/h
Inspection	55 000 m^3/h
Flashing off	5 000 m^3/h
Sum	*345 000 m^3/h*
Intermediate drying:	
Sluice + intermediate flashing off	30 000 m^3/h
Cooling zonee	45 000 m^3/h

(Source: 5a Process)

Auxiliary materials:

Coagulation agent:

Material consumption: Approx. 74,9 g / car body

Flocculating substance:

Material consumption: Approx. 13,4 g / car body (Filler , Base and clear-coat application)

Anti-foaming agent:

Material consumption: Approx. 190,3 g / car body (Filler , Base and clear-coat application)

(Source: Dr. Gruber, personal report, July 2000)

Environmental aspects

Waste gas: VOC, particles (application); CO, CO_2, NO_x, total carbon (dryer / thermal combustion unit)

Waste: Paint sludge, paint-containing cleaning solvents, cellulose cloth, varnish solid leftovers, paper filters, (painting gloves, and suits etc.)

Waste gas:

Waste gas volume:	260 000 Nm^3/h (spray booth) 10 000 Nm^3/h (dryer)
Emission values:	
Dust	4.2 g / car body
VOC	2.16 g / m^2
CO	9 g / car body
NOx	33 g / car body

(Source: Measuring report (Emissions) for 1998)

Waste :

hazardous waste:		
Paint sludge	208 t / a (Filler , base and clear-coat application)	Energy recycling
Paint containing cleaning solvents	No data available	Disposed
Cellulose cloth	No data available	
Non-hazardous wastes: **Domestic-/industrial waste**		
Solid varnish leftovers	No data available	→ Waste site
Paper filter	No data available	→ Waste site
Painting gloves and suits	No data available	→ Waste site

(Source: Environmental protection report,, 1999)

5 Process step: Application of Clear Coat and Subsequent Drying

Process

(1) Spray application with compressed air by 2 robots onto interior surfaces (20 %)

(2) Electrostatic application onto exterior surfaces (80 %)

Measures

Electrostatic application, interception of cleaning solvents, scrapable pipelines, utilization of paint sludge, cleaning of waste gas from dryers (thermal combustion)

Consumption

Clear coat:

Solvent content	40 weight per cent
Solids content	60 weight per cent
Consumption	
Master laquer	2,3 kg /car body
Hardener	0,8 kg /car body

(Source: Dr. Gruber, personal report, July 2000)

Water:

7-8 m^3 / day (approx. 12,5 liter / car body)

Energy:

Clear coat booth:		
	Electricity:	27 kWh / car body
	Heat (heating of intake air)	143 kWh / car body
Dryer with cooling zone:		
	Electricity:	28 kWh / car body
	Natural gas (thermal combustion)	7 kWh / car body
	Refrigerating power:	13 kWh / car body

(Source: 5a Process)

Cleaning solvent:

100 % organic solvent

Material consumption: Approx. 1 kg / car body

(Source: Dr. Gruber, personal report, July 2000)

Volume of intake air:

Sluice	13 000 m^3/h
Manual	160 000 m^3/h
ESTA	40 000 m^3/h
Inspection	70 000 m^3/h
Flashing off	17 000 m^3/h
Sum	*300 000 m^3/h*

(Source: 5a Process)

Auxiliary materials:

Coagulant:

Material consumption: Approx. 184,3 g / car body

Flocculant:

Material consumption: Approx. 13,4 g / car body (filler , base and clear-coat application)

Anti-foaming agent:

Material consumption: approx. 190,3 g / car body (filler , base , and clear-coat application)

(Source: Dr. Gruber, personal report, July 2000)

Environmental Aspects

Waste gas: VOC, particles (application); CO, CO_2, NO_x, total C (dryer/ thermal combustion unit)

Waste: Paint and varnish sludge, paint-containing cleaning solvents, cellulose cloth, solid varnish leftovers, paper filters, (painting gloves, and suits etc.)

Waste gas:

Waste gas volume:	210 000 Nm^3/h (spray booth) 10 000 Nm^3/h (dryer)
Emissions:	
Dust	2.1 g / car body
VOC	15.46 g / m^2
CO	20 g / Car body
NO_x	33 g / Car body

(Source: Measuring report (Emissions) 1998)

Waste:

Hazardous waste:		
Paint sludge	208 t / a (filler, base , and clear-coat)	Energy recycling
Paint-containing cleaning solvents	No data available	Recycling: Distillation
Cellulose cloth	No data available	
Non-hazardous wastes: **Domestic /industrial waste**		
Solid varnish leftovers	No data available	→ Waste site
Paper filter	No data available	→ Waste site
Painting gloves and suits	No data available	→ Waste site

(Source: Report of environmental protection, 1999)

6 Process Step: Cavity Sealing

Process

(1) heating of the solvent-free paraffin and the car body

(2) Application

Measures

Solvent-free material for cavity sealing

Consumption

Cavity sealing paraffin :

Solids content: 100 weight per cent

Material consumption: No data available

Energy: No data available

VI.2 Case Study at the BMW AG

Plant Dingolfing

General Informations about the plant

Complete plant:

Number of employees:	20 000
Produced vehicles per year:	285 000
Production lines:	Press shop, car body construction, varnishing plant, assembly, spare part production, production of components for transmission and chassis

Varnishing plant:

Number of employees:	1 500
Coated vehicles per day:	Up to 1 200 and more
Produced models:	3 series, 5 series, 7 series, Z8
Processing time:	7 hours
Surface of car body (interior and exterior):	92 m^2
Number of serial applied colorings / special colorings:	41 / 210

Informations about the varnishing process

Pre-treatment:

Until 2001, a 25 years old pre-treatment plant was in operation. There the car bodys were transported vertically through the pre-treatment washings. (the so-called VERTAK-Process). A new pre-treatment plant was built in 2001. In this installation, the car bodys are dipped into the different washing tanks in a rotational process. In all wasshings, the car body is dipped verttically, and turned 360 °within the washing tank. Since the carbody is dipped and reemerged vertically and not lowered transversally, no additional intake and discharge ranges are necessary. Thus a significant reduction of required floor space is achieved. Due to the turning of the car body within the tanks, a uniformly distribution of the chemicals onto the car body is ensured. Thus an improved quality of pre-treatment and coating can be achieved.
In comparison to the former installation a reduction of the material consumption of approx. 50 % is expected. Also the amounts of generated waste water and will be reduced by the same factor. Also extended service life and a lower procrastination is expected.

Cataphoric dipp coating:

The cataphoric dip coating installation is a conventional plant, where the car body is transported horizontal through the tank. The exhaust gases from the dryer are treated via thermal combustion.

Underbody protection:

The underbody is coated conventional with PVC and for a reduction of weight partly with an underbody protection paint, based on polyurethane.

Filler:

The BMW AG is using chromophore fillers since several years. Therefore the application of a base- and clear coat onto interior surfaces (such as trunk, doors, engine compartment) is not necessary.

For outside surfaces, four fillers and for interior surfaces sixteen fillers are applied. The exterior fillers are recycled external. The fillers are completely applied via the ESTA-process.
At present all fillers are solvent based. For the future, water-thinnable products will be applied, together with a reduction of process steps.

Base coat:

As base coat a water-thinnable material is applied via a combination of the ESTA-process via high rotation bells and compressed air spraying, which represents the state of the art.

Powder Coating Plant

General informations about the plant

Name and location of the plant	BMW AG, plant Dingolfing Powder coating plant
Annually capacity	200 000 vehicles /a capacity: 900 vehicles / day (plant layout) 905 vehicles / day (present output)
Annually solvent consumption [t/a]	no solvent consumption
Annually operation time	3.536 h/a (2-shifts, 221 working days)
Year of commissioning	1998
Announcements according § 15 BImSchG	The installations were requested according to §16
Description of the process	After an intermediate drying of the base coat (applied via the ESTA-process), the doors and door entries are coated with powder clear coat via the ESTA-process. (4 robots, a spray

	gun apiece). Subsequently the horizontal surfaces and the vertical surfaces are coated via the ESTA-process. (10 and 12 spray guns). Eventually the clear coat layer is burned in. Therefore the car body is heated for about 6 minutes and the paint layer is cured for 24 minutes.
Car body (model: 3. 5. 7.)	Surface to be coated: 13,5 m^2 (mean value)

Base year for data: 1999, (if not noted differently)

Technical Parameters of the Powder Coating Plant

Lenght of spray booth:	40 m
Air speed:	0,2 m/s
Temperature:	20 ± 2 °C
Relative humidity:	45 ± 5 %
Speed (of car body):	4 m/min
Total air volume:	227 000 m^3/h
Intake air volume:	50 000 m^3/h

Selected and Applied Measures

1. Powder clear coat, based on acrylate, 100 % solids content
2. Recycling of powder clear coats

The overspray is collected and recycled in the coating process. The efficiency amounts 95 %.

3. The generated fine grain is reextruded (at the paint manufacturer)
4. 80 % of the cabin´s air are cycled.
5. Heat recovery via rotating air-to-air heat exchanges

Consumption

Consumption of powder coatings per car body:	1,63 kg/car body (2001: 1,45 kg/Car body)
Annual consumption:	343 t
Water:	No water required
Auxiliary materials:	Non
Energy:	In comparison to a conventional 2-component plant, 12 % of energy can be saved

Environmental impacts

VOC:	-

Dust:	< 0,1 mg/m^3
Other pollutants:	non; baking losses (< 1%) are burned in the thermal combustion unit ⇨ total-C < 1 mg/m^3
Wastes:	
Hazardous wastes:	17 t/a; 102 g/car body (partly used in the production of bricks or partly used for energy recycling)

VI.3 Case Study for the Serial Varnishing of of Passenger Cars at the DaimlerChrysler AG

Plant Rastatt

For this case study, the plant for pre-treatment, dipp-coating and top coating for the varnishing of the model „A-Klasse“ was examined at the DaimlerChrysler AG plant, in Rastatt. The implementation of the painting process was realized by a co-operation of DaimlerChrysler, BASF Coatings Dürr Systems (industrial engineering).

General Informations about the Plant

Name and location of the plant	DaimlerChrysler AG, plant Rastatt coating of the model „A-Klasse“
Annually capacity	Plant layout: 200 000 vehicles/a produced vehicles: 192 769 in 1999
Annually operation time	5 460 h/a 105 h/week
Year of commissioning	1997
Description of the production process:	Pre-treatment Degreasing and activation ↓ phosphatization ↓ dipp coating (KTL) and drying Top coating Application 1. Base coat and intermediate drying ↓ Application 2. Base coat and intermediate drying ↓ Application of clear coat and drying
Car body	Surface to be coated: 70 m^2

Data of slected and applied Measures

Pre-treatment without nickel-compounds, nitrite, chromate

Lead-free cataphoric dipp coating materials

Shuttle haulage

Outside of the washing tanks

⇨ Avoidance of contamination of the car bodys

Electrostatic assisted spray-application

- increased efficiency
- reduction of overspray (of approx. 20 %)
- reduction of generated paint sludge

Underbody paneling instead of the application of a underbody protection material

- no costs for application and drying
- reduction of energy demand and manpower

(Process: Instead of the application of a underbody protection material, the underbody is paneled with formed components, made of plastic. Thus a reduced air resistance and a splash guard is achieved. Together with the organically coated sheet metals of the car body, a good corrosion protection is obtained.

In-Line coating of plastic fenders

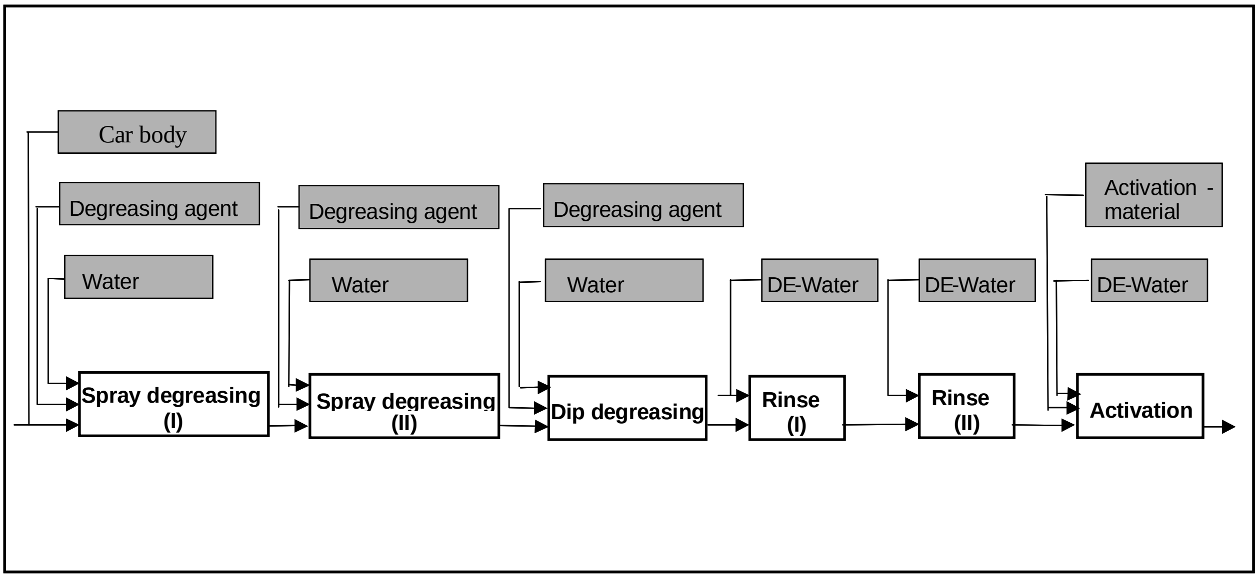
Exactly the same colouring of fenders and car body has to be achieve.

Abdication of wax-cavity sealing and underbody protection

This is achieved by the processing of organically pre-coated sheet metals.

Base year of data: 1999

1 Process step: Degreasing and activation



DE: Demineralized water

Measures

Hydrozyclone, belt filter, Ultrafiltration

Consumption

Material for pre-treatment: 2,6 kg / car body
(degreasing, activation and phosphatisation)

Drinking water / Demineralized water

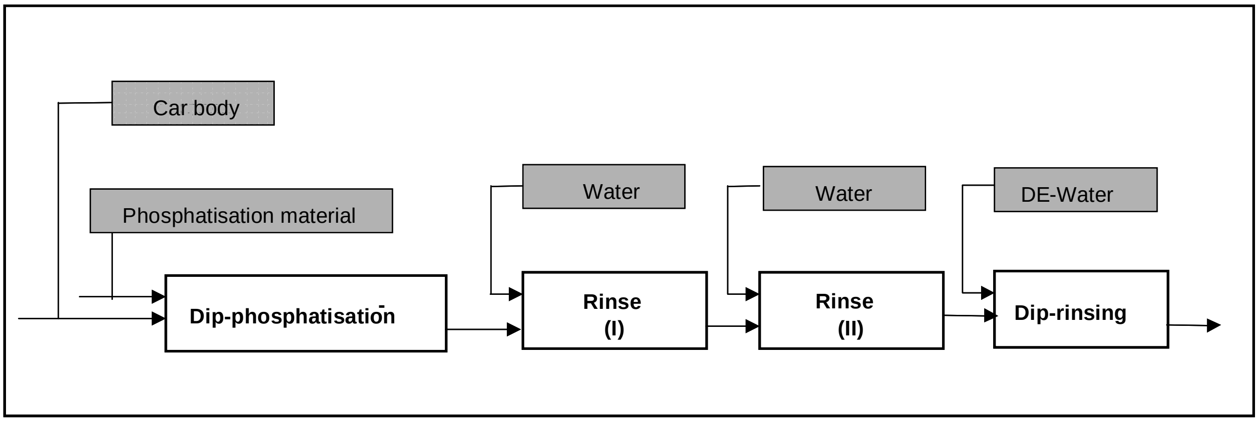
Environmental aspects

Waste: Oil-water mixture, contaminated filters, metal hydroxide, wastewater

Waste:

Oil-water mixture (⇨ utilization): 153,1 t - 0,77 kg / car body
Filter (⇨utilization)

2 Process step: Phosphatization



Measures

Phosphatization without nickel-components and nitrate, filter press

Consumptions

Material for pre-treatment: 2,6 kg / car body
(Degreasing, activation and phosphatization)

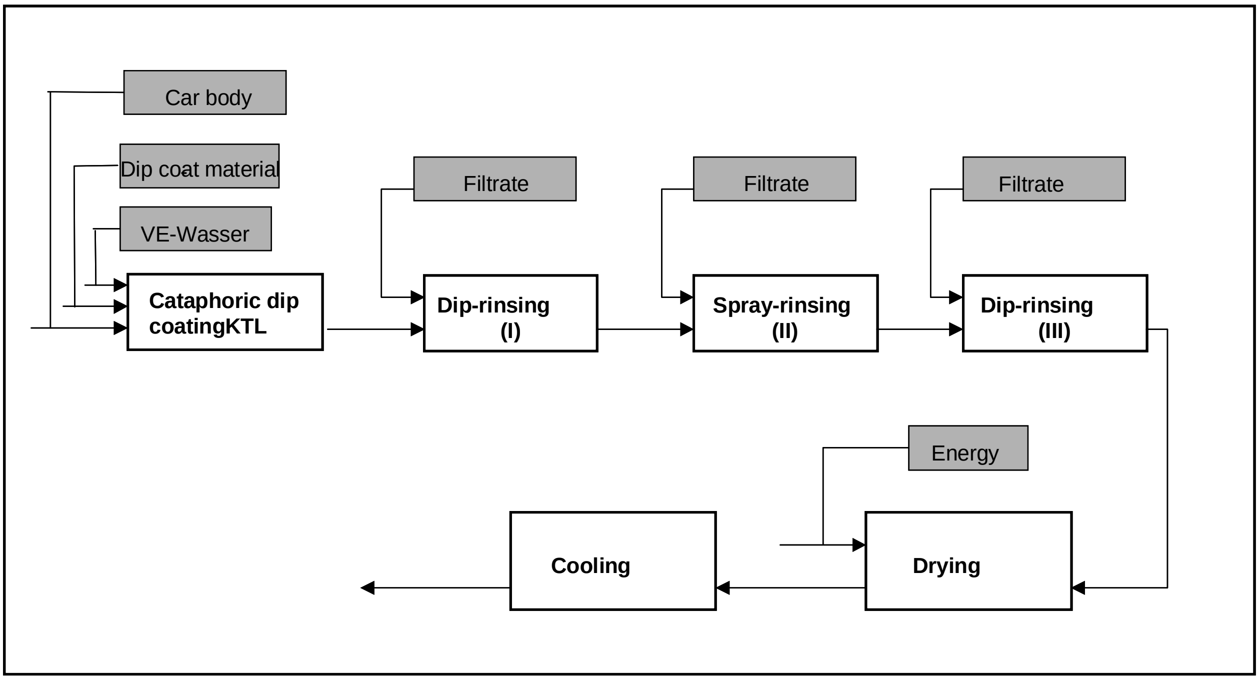
Environmental aspects

Waste and wastewater: Sludge from phosphatization,

Waste :

sludge from phosphatization (⇨ utilization: metallurgical processes for smelting of iron and steel): 89,5 t - 0,5 kg / car body

3 Process step: Electro Dipp Copating (KTL) and drying



Measures

Lead-free dip coating varnishes, thermal combustion for waste gases from dryer, reverse osmosis

Consumptions

Electro coat:

Solvent content:	< 1 weight per cent
Solids content:	No data available
Material consumption:	5,3 kg / car body

Environmental aspects

Waste gas: VOC, SO_2, NO_x, CO (drying and thermal combustion)

Waste water

Waste: Sludge from dip coating (KTL)

Waste gas:

10 000 Nm^3/h (dip coating)
12 000 Nm^3/h (dryer)
100 000 Nm^3/h (cooling zone)

Waste:

Sludge from dip coating process (⇨ utilization, disposal in exeptional cases): 23,7 t/a - 123 g/car body

4 Process step: Application and intermediate drying of base coat 1

Process

1. Dust removal via air nozzles (automated), subsequently cleaning via feather rollers (emu-zone) in case of malefunction: Mannually)
2. Application of base coat 1, ESTA (exterior)
3. Flashing off, intermediate drying via dehydrated circulating air, cooling

Measures

Base coat 1, water-thinnable (inclusive properties of a filler), electrostatic application

Consumption

Base coat 1:

Solvent content: 10,5 weight per cent (depending on the colouring)

Solids content: 33 weight per cent

Material consumption: 1,1 kg / car body

Environmental aspects

Waste gas: VOC

Waste: Paint sludge, rinsing agent

Waste gas:

Waste gas volume: 198 000 Nm^3/h (spray booth for water-thinnable base coat 1 and 2)

Waste :

- hazardous waste: Cleaning agent
- non-hazardous wastes: Paint sludge, domestic-/industrial waste

5 Process step: Application and intermediate drying of base coat 2

Process

1. Application base coat 2, automated application, (interior)
2. Application base coat 2, ESTA (outside surfaces)
3. Flashing off, intermediate drying and cooling

Measures

Base coat 2, water-thinnable, electrostatic assisted application

Consumptions

Base coat 2:

Solvent content: Approx. 6,5 weight per cent (depending on the colouring)

Solids content: 29 weight per cent

Material consumption: 2,7 kg /car body

Environmental aspects

Waste gas: VOC

Waste: Paint sludge, rinsing agent

Waste gas:
Waste gas volume: 198 000 Nm^3/h (spray booth base coat 1, 2)

Waste:

- hazardous waste: Cleaning agent
- non-hazardous wastes: Paint sludge, domestic-/industrial waste

6 Process step: Application of Clear Coat and Drying

Process

1. Application of clear coat, automated (interior)
2. Application of clear coat, ESTA (outside surfaces)
3. Drying and cooling

Measures

Pulver-Slurry, electrostatic-assisted application, waste gas cleaning from dryers via thermal combustion

Consumptions

Cleat coat:

Solvent content:	< 1 weight per cent
Solids content:	No data available
Material consumption:	3,1 kg / car body

Environmental aspects

Waste gas: VOC, SO_2, NO_x, CO

Waste: Paint sludge, cleaning agent

Waste gas:

Waste gas volume: 161 000 Nm^3/h (spray booth), 9 500 Nm^3/h (dryer for top coating)

Waste:

- hazardous waste: Cleaning agent
- non hazardous waste: Paint sludge, domestic-/industrial waste

7 Process step: Seam Sealing

Process

Automated application (in case of malfunction: Manual)

Consumptions

Seam sealant (solvent-free): PUR

Material consumption: 0,8 kg/car body (only the amount applied in the varnishing plant, the bigger amount is applied in the car body construction)

Environmental aspects

Waste gas

Waste: Adhesive waste

Material Consumptions and environmental related data for the complete process

Energy demand and material consumptions

Painting process: 47 622 MWh/a

Painting plant building: 5 706 MWh/a

Cooling energy: 4 198 MWh/a

Cleaning agent

Solvent content: 5 to 20 % (Application concentration)

Consumption: 1,2 kg/Car body (concentrate)

Emissions (complete production plant)

Organic solvents: 60,3 t/a - 313 g/car body - 4,5 g/m^2

Sulfur dioxide: 1,5 t/a

Nitrogen oxide: 15,0 t/a

Carbon monoxide: 6,7 t/a

Dust: No data available

Waste

Paint sludge for reuse (Top coat): 327 t/a - 1,7 kg/car body

Solvents and cleaning agents for disposal: 1 118,1 t/a - 5,8 kg/Car body

Metal hydroxide- and sludge from phosphatization: 640 t- 3,3 kg/Car body

Waste water from pre-treatment

Waste water: 44 600 m^3/a - 230 Liter/car body

Water consumption for the total process

Drinking water and demineralized water: 87 000 m^3 - 450 liters/car body

VI.4 Case Studie at the Dynamit Nobel Kunststoff GmbH

Plant Sterbfritz

Table 1: General Informations about the installation

Name and location of the plant	Dynamit Nobel Kunststoff GmbH, plant Sterbfritz
Workpieces to be coated	Bumpers and side skirts
Type of material	Formed components made of thermoplastic synthetics and polyurethane
Size of workpieces	1,2 - 1,4 m^2 (bumpers)
Required surface quality	Very high (automobile industry)
Frequenzy of colour changes	80 – 90 per day
Annually solvent consumption	240 t/a
Annually operation time	4 389 h/a (3-shift operation)
Year of commissioning	1996
Type and date of significant changes	1998: • Water-thinnable paints • Laydown room / mixing booth for varnishes • Steam boiler and thermal combustion unit
Description of the varnishing process	Pre-treatment Degreasing, Rinsing, drying ↓ Flame treatment ↓ Ground coat application Top coating Base coat application and drying ↓ Clear coat application and drying

(Base year of data 1999)

Description of the Varnishing Process

First the plastic workpieces are mounted onto a link assembly conveyor and thus transported through the different zones (power-wash-unit, flame treatment, spray booths, masking cabin, evaporation- and drying zones).

Per-treatment:

The plastic workpieces are wet-cleaned from dust, grease and other impurities (from the production process) and subsequently dried. The process consist of five different steps:

1) Degreasing 1 with a aqueous cleaning agent at a temperature of approx. 70 °C
2) Rinsing 1 with water
3) Degreasing 2 with a aqueous cleaning agent at a temperature of 70 °C
4) Rinsing 2 with water
5) Rinsing with demineralized water

In all five zones the cleaning and rinsing is carried out via spray application. The generated waste water is treated in a biological sewage treatment plant

After cleaning and rinsing, the workpieces are dried and cooled subsequently. Partly the parts are flame treated for an improved adhesion of the paint. For parts made of polyurethane, no flammig is necessary. The parts are therefore separated by an automated article identification system. For flaming, two robots are used. The surface of the workpiece is thereby heated with a flame up to a temperatuer of maximum 70 °C. For flaming natural gas is utilized. Approx. 4,5 m³ / h are consumed. During the combustion CO, NOx and SO_2 are generated in very low amounts.

Ground coat application:

The workpieces are either grounded manually or automated by robots. In the case of malfunction of a robot, manual application is utilized. The overaspray amounts approx. 70 % for the manual application and approx. 50 % for automated application. The applied ground coats are water-thinnable 1- and 2-component materials. At present almost 100 % of the workpieces are grounded with these water-thinnable materials. The ground coat material is provided to the spray booth via ring lines. The paint material that is not consumed, is piped back to the reservoir.

The spray booth is equipped with a wet separation: Intake air is aerated from the top of the cabine. Thus the generated overspray is lead to the ventury system, located underneath the cabin´s floor. There the overspray is washed out. The washing water is collected in a tank where the coagulation takes place. The grounded workpieces are transported to a flashing off zone and are subsequently dryed in a convectional dryer and then cooled down to ambient temperature.

Inspection and masking (if necessary) :

The customers request for two colored or multicoloured coatings is increasing. For these lacquerings a masking with adhesive foil of parts of the surface, is necessary.

Top coating:

The base coat is applied within two spray booths. The application techniques as well as the separation of overspray is the same as for the application of ground coat. The varnish application is carried out manually or automated, depending on the demand. For the separation of the overspray, the spray booths are equipped with a venturi-washer. As base coat 1-component paints (either solvent based or water thinnable) are applied.
If possible, car bodies with the same color are coated serial. After the paint application, flashing off, drying (at 70 °C) in a convectional dryer and cooling of the coated workpieces take place. The waste gas from the dryer is treated via thermal combustion.

Clear coating

After the top coat, a clear coat is applied in similar process. As clear coats a 2-component paint material is utilized. After the paint application, flashing off and drying (at 90°C) takes place. Then the workpieces are cooled down to ambient temperature.

Quality inspection and intermediate storage (if necessary)

Finally a quality inspection of the varnished workpieces takes place. Then the parts are taken from the belt conveyor and intermediate stored, until the delivery to the ordering customer takes place. From the conveyor equipment, the paint material is removed in regular intervals.

Table 2: Emissions into the Atmosphere

Source of data	Operation data from the buying department and disposal of paints and solvents
Base year of data	2000

Table 2a: Applied emission reduction measures:
Integrated measures for emission reduction

Measures	Process step	Further informations
Application via robots	Ground coat Base coat Clear coat	Share of approx. 50 %
Increased application of water-thinnable paints	Ground coat Base coat	Almost 100 % water-thinnable ground coats, approx. 45 % water-thinnable base coats
Paint supply via closed circular pipelines (circuit)	Ground coat Base coat Clear coat	Reduction of material consumption
Supply of paints in large containers	Ground coat Base coat Clear coat	Reduction of material consumption
Recycling of cleaning solvents	Ground coat Base coat Clear coat	Reduction of material consumption

Tabelle 2b: Applied emission reduction measures:
End-of-the-pipe measures for an emission reduction

Measures	Process step
Venturi-washer for separation of overspray	Ground coat Base coat Clear coat
Thermal combustion for waste gases from dryers	Ground coat Base coat Clear coat

Table 2c: Data of waste gas and clean gas

Process step	Waste gas volume flow [Nm^3/h]
Ground coat application Base coat application Clear coat application	295 000
Dryer	2 500

Table 2d: Emission values- clean gas (after waste gas cleaning)

Parameter	Volume flow [kg/h]	Volume flow [kg/a]	Source of emissions
VOC	46,8	205 500	
Total-C [1]	0,070	307	Flashing off zone, drying zone
Dust	0,145	637,28	
	0,13	570,57	

[1] after thermal combustion unit

Table 2e: Emission values- diffuse emissions (derivation from gates and doors)

Parameter	Amount of emissions
VOC	1,5 kg/h - 6 600 kg/a

Table 3: Waste water

Source of Data	Internal protocols
Base year of data	2000

Table 3a: Measures for a reduction of the water consumption

Measures	Process step	Achieved efficiency
Replacement of the retangular coagulation tank by a round tank	Top coating	Increases service live of water
Application of heat exchange via (heat wheels), planned for the future	Grounding Base coat application Clear coat application	At present: 1,7 m^3/h In the future: 1,3 m^3/h of fresh water
Cascade technique	Degreasing, rinsing	

Table 3b: Applied measures for waste water treatment

Measures	Achieved efficiency
Biological waste water treatment plant	COD-intake: Approx. 4 500 mg/l CSB-outlet: Approx. 250 mg/l
Neutralisation	
Precipitation	

Table 3c: Waste water

Waste water	Value [mg/l]
	COD
Treated waste water (incl. waste water from recycling of mineralized water)	250 mg/l

Table 4: Wastes

Source of data	Waste report 2000
Base year of data	2000

Table 4a: Applied measures for waste water reduction and recycling of process water

Measures	Process step	Achieved efficiency
Robot application	Ground coat application Base coat application Clear coat application	Reduction of overspray and thus paint sludge
- closed circular pipelines (circuit) for the paint supply - Utilization of reusable containers - material recycling of old paints (external) - (external) distillation of contaminated cleaning solvents	Ground coat application Base coat application Clear coat application	Reduction of wastes
Squeezing machine for containers made of sheet metal and disposal as discarded metal	Ground coat application Base coat application Clear coat application	Reduction of costs

Table 4b: Amounts of waste and their disposal / recycling

Waste	Waste key number (EAK)	Waste	Unit	Disposal- or recycling process	Characteritics / Comments	Waste art
Paint sludge	080107	315	t/a	Material recycling	Water content: Approx. 50 % Heat value > 11 000 kJ/kg	hazardous waste
Old varnishes	080102	12	t/a	Material recycling	-	hazardous waste
Residual substances from distillation	070304	-	-	Material recycling	Approx. 35 % Waste	hazardous waste

Table 5: Consumption of materials and energy demand

Process step:	**material**	**Material consumption**	**Unit**	**Solvent content [weight per cent]**
Ground coat application	solvent based material	450	kg/month	50
	water-based primer	10 200	kg/month	15
Base coat application	solvent based material	10 000	kg/month	50
	water-based	8 200	kg/month	15
Clear coat application	solvent based material	8 100	kg/month	50
Hardener	solvent based material	4 500	kg/month	30
Verdünnungen	Butylacetate	6 500	kg/month	100
	Mixture of solvents	7 800	kg/month	10

Process step:	Auxiliary materials	Material consumption	unit	Characteristics
Ground coat application Base coat application Clear coat application	- Coagulant - hydrocloric acid 30 % - sodium hydroxide 45 % - Flocculant - Anti-foaming agent	-		Neutralisation Neutralisation Neutralisation

Process/installation:	Characteristics
Energy demand	No data available

Table 6: Costs

Measures for a reduction of environmental impacts	Heat exchangers
Investments:	Approx. 0,92 Mio. EUR
Measures	Modification of coagulation tank
Investments:	approx. 30.685 EUR

VI.5 Case Study for the Varnishing of Beverage Cans

For the varnishing of beverage cans in the plants A, B, C a data collection was carried out. Data were also provided by the Verband Metallverpackungen (union)

Plant A

Table 1: General Information about the plant

Name and location of the plant	Plant A
Contact person for queries: Address: phone: fax: e-mail:	Claudia Weber Verband Metallverpackungen e.V. (VMV) Düsseldorf Kaiserswertherstr.137 40474 Düsseldorf 0211/45 46 525 0211/45 46 531 cweber@metallverpackungen.de
Workpieces to be coated	Beverage cans
Material	Tin plate
Size and geometry of workpieces	33 / 50 cl
Requirements	Requirements of the food law
Frequency of colour changes	Approx. 500 Decoration changes per year for the production of 33 cl. cans and 1.100 for 50 cl cans
Annually capacity for the base year 2000	Approx. 120.000.000 m²
Solvent consumption	Maximal 0,0072 kg of solvents/m² (maximal 864 t)
Annually operation time	6.500 - 8.400 h
Year of commissioning	1978
Type and date of significant modifications	Modernization and reconstruction of two high speed production lines, 1999 installation of a regenerative thermal combustion unit, 1995 modernization
Announcements according § 15 BImSchG	Painting plant with paint store house, dust filters with adsorption installation and regenerative thermal combustion unit for treatment of waste gases

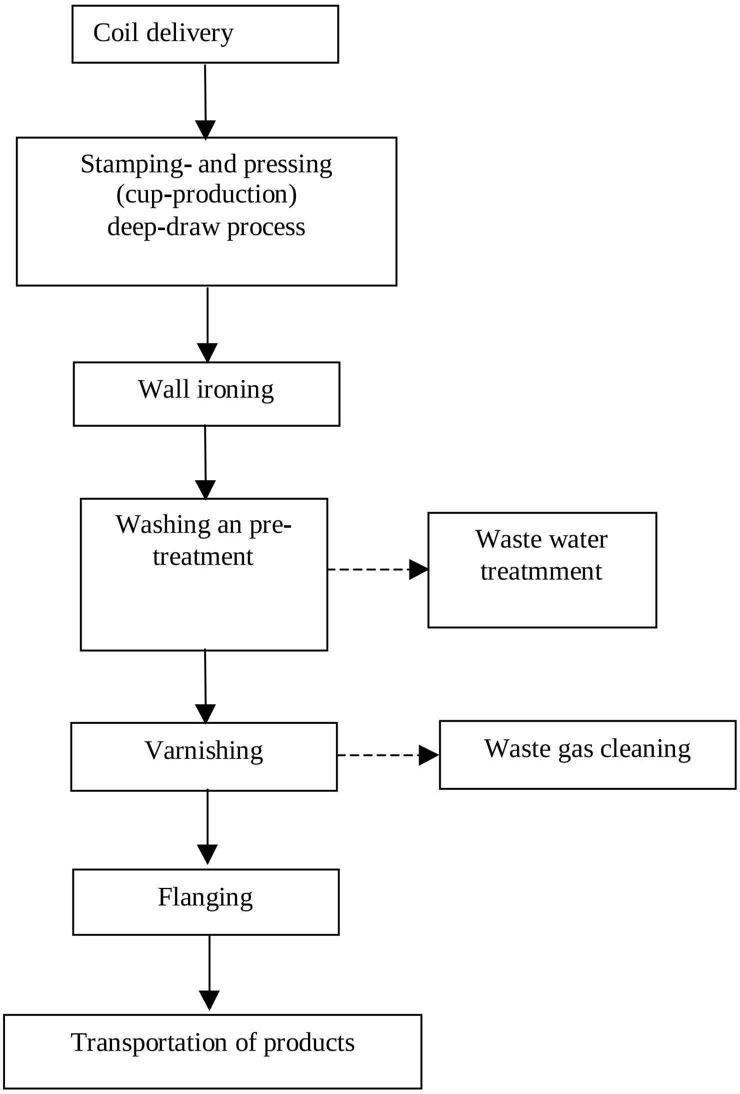
Description of production process	**Simplified flow sheet of the production process of beverage cans** 

Table 2: Emissions in the Atmosphere

Source of data*	Product data sheets, offering memorandum, measuring report
Base year of data	2000

Table 2a: Applied emission reduction measures:
Integrated emission reduction measures

Measures	Process step
Water-thinnable paints	Base coat, varnish for inside lack, printing inks
Reduction of material consumption for the spray application on the internal can	Interior coating
Reduction of application weight	Complete varnishing process
Recycling of overspray	Inside coating and bottom coating
Recycling of cleaning solvents	Complete process

Table 2b: Applied emission reduction measures:
end-of-pipe measures for emission reduction

Measure	Process step	Obtained efficiency
Regenerative thermal combustion unit, asorption installation for a concentration of VOC from waste	Waste gas cleaning	> 99 %

Table 2c: Data about the waste gas cleaning and clean gas

Process step	Waste gas volume flow [Nm^3/h]
Thermo-Reactor, measuring 2000	76 000 from two production lines
Adsorption wheel, measuring 2000	90 000 from two production lines

Table 2d: Emission values- clean gas after waste gas cleaning

Parameter	Mass flow [kg/h]	Mass flow [kg/a]	Comments
VOC	No data	No data	
Total-C **1)**	0,61	5.075	After thermo-reactor
	1,2	10.080	After Adsorption wheel
Dust	0,00015	1,27	After thermo-reactor
CO	1,37	11.400	After thermo-reactor
NO_x	1,52	12.600	After thermo-reactor

Table 3: Waste water

Source of data	Environmental report, balance sheet, water works, journal
Base year	2000

Table 3a: Measures for a reduction of the water consumption

Measures	Process step
Reduction of overflow from washers Optimisation of the washers, cascades, nozzles Closed circuit	Washing

Table 3c: Data about the waste water mass flow

Waste water	Value [mg/l]				
Origin :	Sn	MKW	AOX	PH	Temp.
▪ Untreated waste water after machines				6,5-9	<30^C
▪ Treated waste water (neutralisation)	4,0	< 20	0,5	6,5-9	<35^C

(data represent legal threshold values)

Table 4: Wastes

Source of data*	Waste bilance, refuse economy concept
Base year	2000

Table 4a: Applied measures for waste avoidance and recycling

Measures	Process step
Re-usable containers (paints, oils, grease) Reduction of material consumption	All processes

Tabelle 4b: Waste

Waste	Waste-key number EAK	amount [t]	Applied material [g/m^2]
Organic solvents, washing agent and alcaline solution (overspray)	*70304*	*56,79*	*0,473*
Sludges from paint removal	*080107*	*2,95*	*0,025*
Solvents and solvent mixtures	*140103*	*42,15*	*0,351*
Contaminated filter materials, cleaning cloths, protective clothing,)	*150299D1*	*61,66*	*0,514*

Table 5: Consumption of materials and energy demand (Plant A)

Process-step	Material	Material consumption [t/a]	Material consumption [g/m²]	Solvent content [%]	Solids content [%]
Varnishing of inside- and outside surface	Paints (complete)	1.200	10	15-45	35-60 %
	Inside varnish	2.300	19,17	10-15	20-22 %
	Printing ink	60	0,5	18-38	62-82 %

Process-step	Materials	amount[1)]	Unit
Energy demand	Natural gas,	67.000	MWh
	electricity,	43.000	MWh
	energetically utilized waste heat	4.000	MWh

1) Total volume for the whole plant

Table 6: Costs

Measures for a reduction of the environmental impact	1. Water: a. Installation of a reverse osmosis 2. Paints a. Recycling of overspray for inside coating b. Increased use of water-thinnable paints 3. Metal a. reduction of the cans wall thickness 4. ISO 14001 5. Reduction of work traffic
Investments:	1: Approx. 255.754 EURR 3: Approx. 767.000 – 1.023.000 Mio EUR 4: approx. 76726 EUR 5: Approx. 409.207 EUR
Base year	2000

Plant B

Table 1: General information about the installation

Name and location of the plant	Plant B
Contact person for queries: Adress: telefon: Fax: e-mail:	Claudia Weber Verband Metallverpackungen e.V. (VMV) Düsseldorf Kaiserswertherstr.137 40474 Düsseldorf 0211/45 46 525 0211/45 46 531 cweber@metallverpackungen.de
Workpieces to be coated	Beverage cans
Material	Tinplate
Size	33 / 50 cl
Requirements	Requirements according the food law
Frequency of color changes	Approx. 400 decoration changes per year and production line
Annually capacity in the base year 2000	Approx. 100.000.000 m^2
Consumption of solvents	Maximal 0,0067 kg LM/m² ***Maximal 670 t***
Annually operation time	6500-8400 h
Year of commissioning	1984
Type and kind of essential changes, relevant for the following data	Installation of a 3. Production line 1991 Installation of a regenerative thermal combustion unit 1991
Announcements according § 15 BImSchG	Activated charcoal filter Installation of a third production line, installation of suction hoods at the dryers for the inside coating

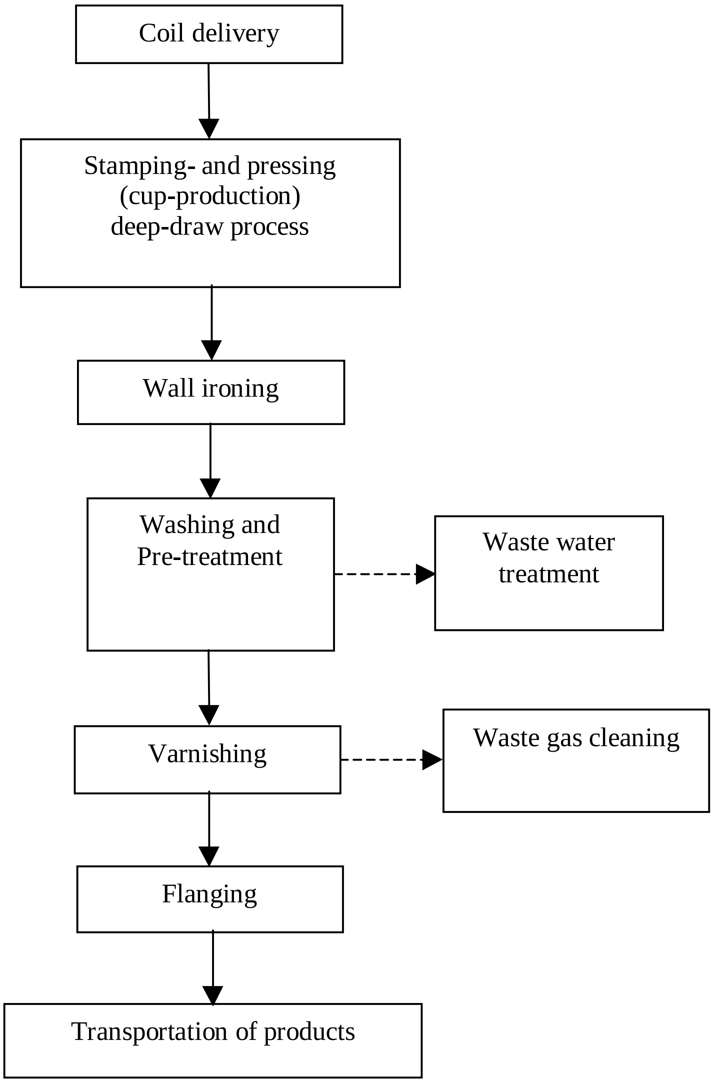
Description of the production process	**Flow sheet of the production process of beverage cans** 

Table 2: Emissions into the atmosphere

Source of data	Product data sheets, emission report, measuring report
Base year	1999 / 2000

Table 2a: Applied Emission reduction measures: Integrated measures

Measure	Process step
Water-thinable lacquers	Base coat, inside coating, printing inks
Installation of suction hoods at the dryers for the inside coating	Innenlackierung
Reduction of material consumption for the inside coating	Inside coating
Reduction of application weight, application gravure roll	Painting process
Production in overvarnish-design	Protection of printing inks
Recycling of cleaning solvents	Complete coating process

Table 2b: Applied emission reduction measures: End-of-pipe technologies

Measures	Process step	Efficiency
Thermal combustion unit, Bioscubber, deposition of overspray	Waste gas cleaning waste gas cleaning	> 99%

Tabelle 2c: Data about waste gas

Process step	Volume flow of waste gas [Nm^3/h]
Dryer, thermal combustion unit, measuring 1998	71.240 for 3 production lines
Biowäscher , Messung 1999	31.820 for 2 production lines

Tabelle 2d: Emission values – clean gas after waste gas cleaning

Parameter	Volume flow [kg/h]	Volume flow [kg/a]	Waste gas cleaning
VOC	No data available	No data available	
Total-C [1)]	1,19	6.764	After thermal combustion
	0,3	252	After Bioscrubber
Dust	0,03	202	After thermal combustion
CO	0,69	3.929	After thermal combustion
NO_x	1,71	9.721	After thermal combustion

Table 3: waste water

Source of data	Environmental report, balance sheet, water works, journal
Base year	2000

Table 3a: Measures for a reduction of water consumption

Measure	Process step
Reduction of overflow at the washers Optimization of the washing process To Washer III- optimization of the cascade technique Optimization of nozzles Implementation of a closed circuit	Washing

Table 3b: Applied measures for waste water treatment

Measures	Process step
At present installation of a precipitation- and flocculation plant	Waste water treatment

Table 3c: Waste water mass flow

Waste water	value [mg/l]				
	Sn	Hydrocarbons	AOX	pH	Temp.
Precipitation and flocculation plant	< 2	<20	<1	6,5-10	<30°C

Parameters meet legal requirements (Ortssatzung).

Tabelle 4: Amounts of waste in 2000

Waste stoff	**Key number** **EAK**	**Amount** **[t]**	Amount per surface **[g/m²]**
Lacquer filters	*150201*	*6*	0,06
Paint sludges	*080108*	*87,00*	0,87
Packagings with dangerous contaminations	*150199 D1*	*8*	0,08
Filter materials, wiping cloths and protective clothing with harmful impurities	*150299D1*	*43*	0,43

Table 5: Consumption of materials and energy demand

Process step	Materials	Consumption [t/a]	Consumption [g/m^2]	Solvent content [%]	Solids content [%]
Paint application	Paints (total)	1.200	12,00	15-45	35-60 %
	Inside coating	2.200	22,00	10-15	20-22 %
	Printing ink	74	0,74	18-38	62-82 %

Process-step	Material	Consumption[1)] [MWh]
Energy demand	Natural gas Electricity	60.000 55.000

1) total amount for the whole plant

Table 6: Costs

Techniques and measures for a reduction of environmental impacts	1.Water: b. Washer II to Washer III c. Waste water treatment 2. Paints c. Overvarnish 3.Emissions / odour a. Extraction hoods at the dryers for inside paint 4.Metall a. reduction of the cans wall thickness 5. ISO 14001
Investments:	1.: approx. 1.023.017 EUR 2.: approx. 56.265 EUR 3: approx. 153.452 EUR 4.: approx. 767.263 – 1.023.000 EUR 5.: approx. 51.150 – 76726 EUR
Base year	2000/01

Plant C

Table 1: General information about the installation

Name and location of the plant	Plant C
Contact person for queries: Address: phone: fax: e-mail:	Claudia Weber Verband Metallverpackungen e.V. (VMV) Düsseldorf Kaiserswertherstr.137 40474 Düsseldorf 0211/45 46 525 0211/45 46 531 cweber@metallverpackungen.de
Workpieces to be coated	Beverage cans
Material	Aluminum
Size	0,15-; 0,20-; 0,25-; 0,296-; 0,33-; 0,35 l cans
Required surface quality	Food law
Frequency of color changes	Decoration changes: 2.200 in 1999
Annually capacity in the base year*	Production: 1.453.000.000 beverage cans; Coated surface: 72.090.000 m^2
Annually solvent consumption [t/a] base year 1999	0,0032 Kg / m², 250 – 300 t/a
Annually operation time in base year 1999 [h/a]	8.300
Year of comissioning	1968
Type and date of significant modifications,	Installation of a new thermal combustion unit in combination with adsorption wheels 1993
Announcements according § 15 BImSchG	Notifiable: Waste gas cleaning plant, Washer; modification of the tank farm and filling place for inside coating

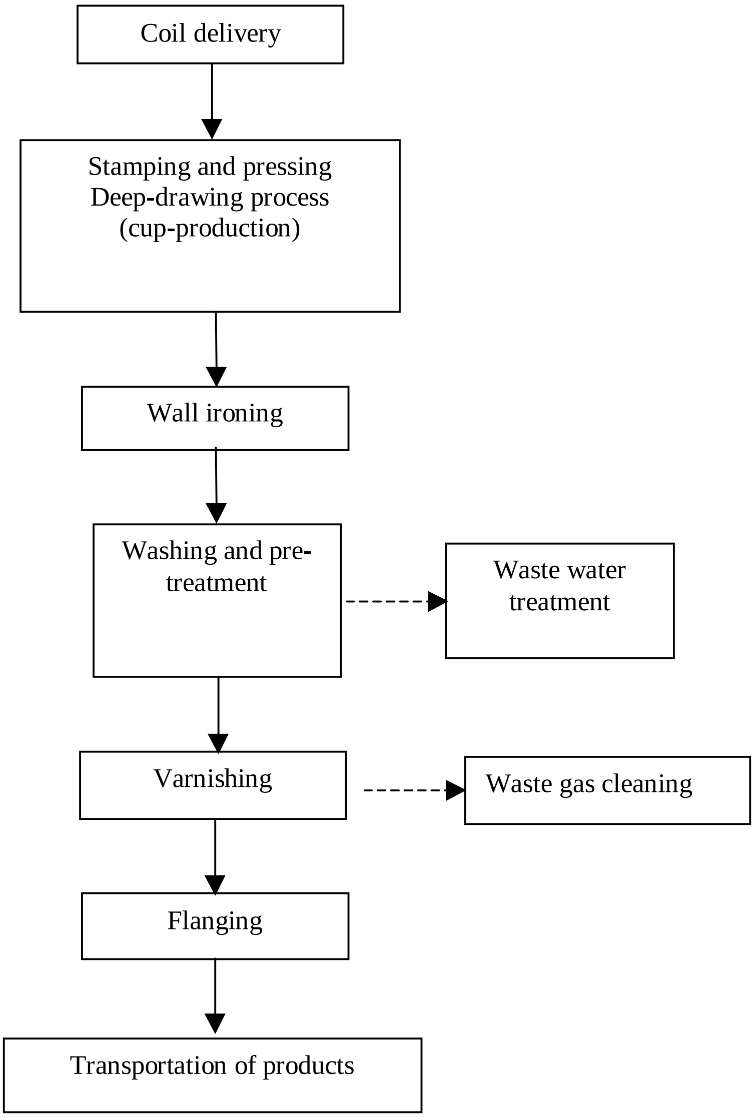
Description of the production process	**Flow chart of the production process**
	

Table 2: Emissions into the atmosphere

Source of data	S: Estimated values, roughly calculative acuired M: Measured values by independent Institut
Base year	1999 (considered interval 1990 – 2000)

Table 2a: Applied emission reduction measures:
Integrated measures

Measure	Process step	Achieved efficiency
Replacement by water-thinnable paints (1994)	Paint application	Approx. 50 % reduction of solvent content
Reduction of application weights by an improved nozzle adjustment for application of inside varnish (1993 – 1999)	Inside varnish	10 to 20 % reduction of material consumption
Replacement of base coat by overvarnish (from 1995 on)	Exterior varnish	Reduction of approx. 30 % solvents (lacquers) and fall away of a base coat dryer
Application via gravure rollers for overvarnish and base coat (1996)	Paint application	Reduction of approx. 50 % solvents (paint)

Table 2b: Applied emission reduction measures:
End-of-pipe-technologies

Measure	Process step	Obtained efficiency
Thermal combustion unit	Drying	99,9 %
Adsorption wheel (adsorption on activated char coal)	Ground coat Top coat	54,4 % for Buthoxyethanol 16,7 % for Dibutylaminoethanol

Table 2c: Waste gas before waste gas cleaning

Process step	Waste gas volume flow [Nm^3/h]
Ground coat application	Cf. Adsorption wheel / thermal combustion
Top coat application	Cf. Adsorption wheel / thermal combustion
Drying	Cf. thermal combustion
Thermal combustion (dryers)	30.000 m^3/h
Thermal combustion unit (concentrated waste gas from adsorption unit)	5.000 m^3/h
Thermal combustion unit (clean gas)	35.000 m^3/h
Adsorption wheel (from machines, cleaned waste gas flow)	35.000 m^3/h
Waste gas from hall (extraction)	138.000 m^3/h
Waste gas from hall (Colt-fan, no ventilators)	Approx. 12.000 m^3/h depending on thermal

Table 2d: Emission values – clean gas after waste gas cleaning according emission report

Parameter	**Mass flow [kg/h]**	**Mass flow[kg/ a]**	**Areas / plant components with collected emissions**
C_{total}	1,75 kg / h (50mg / m^3)	14.525 kg / a	Adsorption wheel (8.300 h / a, 35.000 m^3 / h)
	<0,07 kg / h (<2 mg/m^3)	581 kg / a	Thermal combustion unit(8.300 h / a, 35.000 m^3 / h)
CO	2,55 kg / h (73mg/m3)	21.206 kg / a	Thermal combustion unit
CO_2		8.290 kg/a	Thermal combustion unit and dryers
NO_x	2,8 kg/h (80mg*m3)	23.240 kg/a	Thermal combustion unit

Table 2e: Emission values for diffuse emissions and discharge via chimmneys without waste gas cleaning

Parameter	**Estimated emissions**	**Areas / plant components with collected emissions**
VOC	34.700	Total plant
Dust	No data available	

Table 3: Waste water

Source of data	Measuring of the Emschergenossenschaft
Base year	1999

Table 3a: Measures for a reduction of water consumption

Measures	Process step	Achieved efficiency*
Cascade technique, implemented 1994)	Acid cleaning Washing	
Optimization of nozzles	Acid cleaning Washing	
Optimization of chemical dosage	Acid cleaning Washing	A total of approx. 60,3 % from 1994 to 1999

Table 3b: Applied measures for waste water treatment

Measures	Process step
Precipitation and flocculation, deposition, neutralization, dewatering	Washing

Tabelle 3c: Waste water flow

Waste water	Wert [mg/l]			
	COD	TOC	AOX	Carbo-hydrogen index
Untreated waste water			< 0,5	
Treated waste water	350		< 0,5	0,5-2,0
Direct coolant			< 0,5	

Table 4: Waste

Source of data	Waste balance
Base year of data	1999

Table 4b: Waste amounts and disposal and recycling options

Waste	Waste –key number (EAK)	Amount [t / a]	Options for disposal or recycling	Type of waste
Mixture of solvents	140303	8 t (0,11 g/m^2)	Energy recycling	Hazardous waste
Paint sludges	080107	32 t (0,40 g/m^2)	Energy recycling, disposal	Hazardous waste
Sludge from cleaning of tank	160706	11 t (0,15 g/m^2)	Disposal via combustion	Hazardous waste
Filter papers from filtration of emulsion	150299D1	2,4 t (0,03 g/m^2)	Disposal via combustion	Hazardous waste
Oil filter	150299D1	1,4 t (0,02 g/m^2)	Disposal via combustion	Hazardous waste
Oil-contaminated operation resources (gloves, cleaning cloths, etc)	150299D1	1,4 t (0,02 g/m^2)	Disposal via combustion	Hazardous waste
Oil residues	130202	12,4 t (0,17 g/m^2)	Recycling, disposal	Hazardous waste
Lime sludge	190804	316 t (4,0 g/m^2)	90 % utilization	Hazardous waste
Mixed industrial wastes	200301	53 t	utilization	Hazardous waste
Aluminum scrap (raw material)		3,63 t (3,879 t 2000)	utilization	

2) amount of waste [t/a]

Table 5: Consumption of materials and energy demand

Process step	Material	Consumption 1)	Comments
Ground coating	Base coat	127 t	12,5 % (weight per cent) solvent content
Printing	Printing inks	58 t	15 % (weight per cent) solvent content
Overvarnish	Overvarnish	257 t	16 % (weight per cent) solvent content

Bottom varnish (roller application)	Bottom Rimcoat	19 t	33,5 % (weight per cent) solvent content
Inside coating	Inside coating	1.050 t	15 % (Weight per cent) solvent content
Complete varnishing process	Cleaning agents, solvents	26 t	
Total process	Water	135 t	
Wash process	Ridoline 124	172 t	Sulfuric acid, tensides
Wash process	Alodine 404	55,4 t	Nitric acid, phosphoric acid, hydrofluoric acid
Surface treatment	Ridoline 120	53 t	Hydrofluoric acid
Surface treatment	ME 50	24 t	Improvement of mobility

Process step:	Auxiliary materials	Material consumption [t/a]
Waste gas cleaning: Absorption wheel	Activated charcoal	2 t
Waste water treatment	Lime	82,3 t
Waste water treatment	Anti-foaming agent	2,1 t
Waste water treatment	Flocculant Poly aluminium chloride	2,54 t
Waste water treatment	Flocculant Polyelektrolyte	2,54 t
Waste water treatment	Break down agent (Ferroline)	12,1 t
Waste water treatment	Break down agent (Ferroline)	14,4 t
Waste water treatment	Caustic soda	35,1
Waste water treatment	Hydrochloric acid	34,5 t
Waste water treatment	Sulfuric acid	5,78 t

Process:	**Material /energy**	**Material consumption per year**
Energy demand	inert gas energy	50.919 m^3 22.23 kWh
Measures for a reduction of environmental impacts		**Costs**
Investments:		
Thermal combustion unit, adsorption wheel, heat exchanger		1.148.810 EUR(1993-1996)
		102.890 EUR (1998-2000)
Oil mist separator		35.805 EUR (2001)
Renewal of tank farm for inside coating, gas pendulum		12.787 EUR (2000)
Restraint system for fire fighting water		51.150 EUR (2000)
Renewal of tank farm for transmission oil / emulsion oil		

Operational costs: (thermal combustion, adsorption wheel, filter, extraction system)	1996: 900255 EUR 1997: 685933 EUR 1998: 722.762 EUR 1999: 728388 EUR
Costs for waste water	1996: 1.047.570 EUR 1997: 929.411 EUR 1998: 1.043.989 EUR 1999: 951.406 EUR
Noise abatement	1996: 60.869 EUR 1997: 97.186 EUR 1998: 226.086 EUR 1999: 179.539 EUR

Annex VI.I:

Data for the Varnishing of Steel Furniture

In the following data for the varnishing of steel furniture, shelves, household appliances, control cabinets and windshield whipers are listed. In the course of the study from Harsch, varnishing concepts have been investigated with the method of integrated balancing. In doing so, the balancing software GaBi and the database Lacky have been used. Hence for the basic data, data sources and assumptions for the calculations confer [Harsch 1999] (cf. chapter 4).

Varnishing of Steel Furniture

Table VI.I-1: *Consumption- and emission values, investments and material costs for three different coating systems for steel furniture* [Harsch 1996].

Parameter	**Unit**	**Conventional paint 1)**	**Water based paint2)**	**Powder coating3)**
Solids content	Weight per cent	62	20	100
Solvents content	Weight per cent	38	1	0
Content of water	Weight per cent	0	79	0
Layer-thickness	µm	40	25	50
Material efficiency	%	60	98	90
Paint consumption	kg/a	213 000	176 000 4) 7 700 5)	55 000
Energy demand	MJ/m^2			
Electricity		2,7	2,4 4) 6,3 5)	3,7
Hot water		2,60	1,37	1,37
Natural gas		13,8	6,1	6,5
CO$_2$-Emissions	kg/m^2	1,27	0,86 4) 1,51 5)	1,0
VOC-Emissions	g/m^2	72,9	1,86	0,3
Investments	•	2,6 Mio.	1,43 Mio. 4) 0,81 Mio 5)	1,68 Mio.
Material costs	•/kg	3,19	1	6,39

1) solvent containig paint, electroststic assisted spraying
2) Cataphoric dipp coating
3) Automatic powder coating (manuall application for rework)
4) Cataphoric dipp-coating TL-continous coating
5) cataophoric dipp-block coating

Coating of Shelves

Table VI.I - 2*:* Parameter for the varnishing of shelfs for three different concepts [Harsch 1996].

Parameter	**Unit**	**Solvent based paint**	**Water based paint**	**Powder coating**
Layer-construction	-	1-layer	1-layer	1-layer
Pre-treatment	-	Fe-phosphatization	Fe-phosphatization	Fe-phosphatization
Solids content	Gew.-%	57	52	100
Solvents content	Gew.-%	43	5	0
Content of water	Gew.-%	0	43	0
Application	-	ESTA	ESTA	ESTA
Layer-thickness	µm	Approx. 30	Approx. 30	70 – 90
Paint consumption	g/m^2	Approx. 100	Approx. 110	110 – 140
Drying	-	15 min at 150 °C	15 min at 150 °C	15 min at 180 °C
Energy demand				
Energy demand for application	MJ/m^2	10,5	10,5	14,5
Thermal energy	MJ/m^2	4,0	4,0	4,5
Electrical energy	MJ/m^2	1,8	1,8	2,8
CO_2-emissions (paint application)	kg/m^2	540	540	735
VOC-emissions (paint application)	g/m^2	43	5,1	0,2
Costs				
Application/spray booth, drying	• / m^2	Approx. 0,1	Approx. 0,1	Approx. 0,15
Disposal, cleaning of spray booth	• / m^2	Approx. 0,026	Approx. 0,026	Negligible

Table VI.I - 3*:* Data for three different coating concepts for shelves [Harsch 1996]

Parameter	**Unit**	**Solvent based paint**	**Powder coating (white)**	**Powder coating (Special colours)**
Layer construction	-	1-layer system	1-layer system	1-layer system
Pre-treatment	-	Alkaline aqueous degreasing	non	Fe-phosphatization
Application	-	Dipping	Spraying	Spraying
Efficiency	%	99	95*	95*
Layer-thickness	µm	25 – 35	50 – 70	100
Paint consumption	g/m^2	75	80	111
Energy demand				
Primary energy (paint-application)	MJ/m^2	7,8	8,1	9,3
Thermal energy	MJ/m^2	3,8	0	5,1
Electric energy	MJ/m^2	1,0	2,3	1,0
CO_2-Emissionen (paint-application)	g/m^2	480	400	590
VOC-emissionen (paint-application)	g/m^2	0,7	0,05	1,0

Parameter	Unit	Solvent based paint	Powder coating (white)	Powder coating (Special colours)
SO_2-emissions (paint-application)	g/m^2	0,5	0,4	0,7
NO_x-emissions (paint application)	g/m^2	1,3	0,6	1,6
Dust emmission (paint application)	g/m^2	0,1	0,2	0,15
Ammount of waste water	l/m^2	5,6	0	0,1
Emissions in water**	Mg/m^2	375	-	65
Waste***	g/m^2	0,02	< 0,005	0,01

* by overspray recovery and reuse of the powder

** total solids

*** Waste oil, paint- and hydroxid sludge

Table VI.I - 4***:*** Results of a qualitativ comparison of two painting concepts for shelfes *[HARSCH 1996]*

Parameter	Solventz based paint, dipp-coating	Powder coating, spray application
Quality	1	2
Capacity	1	1,5
State of technology	3	2
Potential for optimation	2	1
Automation	3	1

1 (very good resp.very high) to 5 (very low, very poor)

Varnishing of household appliances

Table VI.I - 5*: Parameters for two different coating concepts household appliances [HARSCH 1996].*

Parameter	Unit	Conventional paint	Powder coating
Layer construction	-	Dipp coating + 2K-base coat	Dipp coating + powder coating
Pre-treatment	-	Zn-phospatisation	Zn-phosphatisation
Solids content	Weight per cent	71	100
Solvent content	Weight per cent	29	0
Application	-	ESTA	ESTA
Layer-thickness	µm	Approx. 20	Approx. 70
Efficiency	%	Approx. 85	Approx. 95
Paint consumption	g/m^2	Approx. 60	Approx. 125
Drying	-	6 min at 190 °C	15 min at 200 °C
Energy demand			
Thermal energy	MJ/m^2	3,6	4,05
Electrical energy	MJ/m^2	1,35	1,71
CO_2-emissions (paint application)	g/m^2	437	525
VOC-emissions (paint application)	g/m^2	17	0,2
Costs			
Application/spray booth, drying	• / m^2	0,09	0,12
Disposal, cleaning of spray booth	• / m^2	0,015	Negilible

Coating of Control Cabinets

Table VI.I -6*:* Parameters for three different coating concepts for control cabinets *[HARSCH 1996].*

Parameter	Unit	Solvent based paint	Water based paint	Powder coating
Layer-construction	-	KTL + 2K-Decklack	KTL + 2K-Decklack	KTL + Pulverlack
Pre-treatment	-	Zn-Phosphatierung	Zn-Phosphatierung	Zn-Phosphatierung
Solids content	Gew.-%	62	56	100
Solvent content	Gew.-%	38	4	0
Water content	Gew.-%	0	40	0
Application	-	ESTA	ESTA	ESTA
Layer-thickness	µm	Approx. 40	Approx. 40	Approx. 80
Paint consumption	g/m^2	Approx. 160	Approx. 190	Approx. 130
Drying	-	20 min at 130 °C	20 min at 130 °C	15 min at 180 °C
Energy demand				

Primary energy (application)	MJ/m^2	Approx. 57	Approx. 57	Approx. 38
Thermal energy	MJ/m^2	Approx. 29	Approx. 29	Approx. 18
Electrical energy	MJ/m^2	Approx. 8	Approx. 8	Approx. 5,5
CO_2-emissions (paint application)	kg/m^2	Approx. 3,0	Approx. 3,0	Approx. 2,0
VOC-emissions (paint application)	g/m^2	60	7,0	0,7
Costs				
Application/spray booth, drying	• / m^2	0,5	0,5	0,3
Disposal, Cleaning of spray booth	• / m^2	0,15	0,15	Negilible

Varnishing of Windshield Wipers

Table VI.I - 7***:*** Consumption and emission-values, investments and material prices for three coating concepts for windshild wipers *[HARSCH 1999]*

Parameter	**Unit**	**Water based paint 1 1)**	**Water based paint 2 2)**	**Powder coating 3)**
Application efficiency	%	70	50	50
Material efficiency	%	70	90	90
Energy demand 3)	KW/h			
Electricity		100	120	110
Hot water		380	380	100
Natural gas		325	325	390
VOC-emissions	g/Ww	0,65	0,5	0,05
CO_2-emissions	g/Ww	35	38	28
Paint residues				
Paint sludge	g/Ww	1,1	0	0
Waste paints	g/Ww	0	0,3	0
Waste powder	g/Ww	0	0	0,3 - 0,4
Material prices	•/kg	3,68 – 5,21	3,68 – 5,21	6,13 – 7,67

1) Application via automated spray application with high rotation bells and wet deposition of overspray ;
Ww: windshield wiper

2) Application via automated elektrostatic assisted HVLP-spraying, ultrafiltration for recovery of overspray
3) for spray booth, evaporation zone, dryer and cooling zone

Table VI.I - 8**:** *Results of a technical assesment of two different coating concepts for windshield wipers* [HARSCH 1999]

Parameter	**Water-thinnable paint**	**Powder coating**
State of technology	5	3
Potential for optimatization	4,5	3
Automatisation	4,5	4,5
Rework	4	4
Reduction of layer-thickness	4,5	3
Accuracy of assembly	5	2

1 (poor, very low) to 5 (very good resp. very high)

Annex VII:

Questionnaire for Data Retrieval

Audi AG
Plant Ingolstadt

Table 1: General Informations about the plant

Name and location of the plant	Varnishing plant of the AUDI AG, plant Ingolstad
Contact person for inquiries: Address: phone: fax: e-mail:	Mr. Kerschenlohr , Abt.: I/PI/U 85045 Ingolstadt Tel.: 0841 / 89 31 001 0841 / 89 31 682 Josef.Kerschenlohr@audi.de
Annual capacity in the base year	100 car bodies / h resp. 405.000 car bodies / a (capacity according to the permission from 1997) 1999: 441 000 car bodies
Annual solvent consumption [t/a] in base year	1 727 t in 1999
Annually operating hours [h/a]	Approx. 6 200
Year of commissioning	1998 trial run, from 1.1.1999 serial production
Announcements according § 15 BImSchG	1999: 441 000 car bodies varnished

Description of the production process

The plant for the application of base coat was built in 1996 - 1998 (Building NR. 56). Besides this varnishing plant (which consists of four autonomous segments, an other plant (built 19996 – 1998) for the coating of components is in operation.

After the pre-treatment, cataphoric dip coating and subsequent drying, seam sealants and the underbody protection material are applied. After an intermediate storage in the colour sort buffer, sanding, application of the water-thinnable filler, flashing off and drying takes place.

Before the wate-thinnable, chromopore base coat is applied, sanding takes place if necessary. After flashing off, a solvent based 2-component clear coat is applied and dried.

Between the applications, the application devices are cleaned with a cleaning agent. After an inspection the car bodies can be exfiltrated to the spot repair booth for reworking, and then transfered back to the production

As a surface protection during the car´s assembly and transportation, a spray foil (water-thinnable material) will be applied in the future. Subsequently the sills are varnished and dried.

Before the assembly process takes place the car body´s cavities are sealed via flooding with wax.

The following emission values are determined by the permission (issued by the city of Ingolstadt, June 1997, Az. Vll/68.1):

- Sum of VOC-emissions (without reworking of finished vehicles and transport conservation 35 g / m² car body.
- Concentration of organic solvents in the coating of assembly: 150mg/m^3
- Particle emissions in the spray booths´s waste gas (coating of car bodies and assembly parts) may not exceed 3 mg/m^3
- Emissions from dryers of the varnishing of car bodies and components may not exceed 50 mg/m^3 (total-C).

Also the applied paints may not contain substances of the category I Nr. 3.1.7 of the German TA Luft.

Emissions into the atmosphere from dip coat application- and drying

Source of emissions	**Application and drying of dip coat**
Source of data	Measuring
Base year of data	1999

Applied emission reduction measures

Measure	Process step	Reached efficiency
Integrated measure for an emission reduction	Utilisation of a cataphoric dip coat, water-thinnable, 6 % of organic solvents	-
Measures for a reduction of diffuse emissions	Complete housing / routing of air flow	100 %
End-of-pipe-measures	Thermal combustion unit for the dryer of dip coat*	Approx. 95 % via thermal combustion (measured in 1987)

* two production lines with 2 thermal combustion units

Data about waste gas

Volume flow	Dip coating and underbody protection are centralised in booths Dryer: 12 977 Nm^3/h (with thermal combustion unit)
O_2-content of the waste gas	21 % (waste gas from paint application) 18 % (thermal combustion unit, waste gases from dryer)

Table 2c: Emission values– drying of dip coating

Parameter	**Measured concentration**	**Unit**	**Time**	**Mass flow**	**Comments**
Waste gas from dryer:					
C_{total}	4	Mg/m^3	1/2 h	0,06 kg/h	
CO					No data available
NOx					No data available

Emissions into the atmosphere: Underbody protection, application and drying

Source of emission	**Application and drying of underbody protection**
Source of data	Measuring 1999
Base year of data	1999

Applied emission reduction measures

Integrated measures for emission reduction	Underbody protection with a low VOC-content (3%)
Measures for a reduction of diffuse emissions (obtained emission reduction)	Housing and routing of flows (100%)
End-of-pipe-measures	Particle filter, thermal combustion unit for dryer of underbody protection*
Achieved efficiency	approx. 97% via thermal combustion unit after dryer (Measuring from 1993)

*2 lines with 2 thermal combustion units

Data about waste gas

Waste gas volume flow	Dip coating and underbody protection are centralised in booths dryer: Underbody protection 1: 6 433 Nm^3/(h (THERMAL COMBUSTION UNIT) Underbody protection 2: 10 742 Nm^3 /h (THERMAL COMBUSTION UNIT)
O_2-content of waste gas	21 % (exhaust air from installation) 18,5% (Underbody protection, dryer 1) 19,1 % (Underbody protection 2)

Emission-values for dryer of underbody protection

Parameters	Measured concentration	unit	Time	Mass flow	comments
Waste gas from underbody protection, dryer 1					
C_{total}	24	Mg/m^3	1/2 h	0,15 kg/h	
CO				1	No data available
NO_x					No data available
Waste gas from underbody protection, dryer 2:					
C_{total}	29	Mg/m3	1/2 h	0,31 kg/h	
CO					No data available
NO_x					No data available

Emission values of combined dip coating- and underbody protection booth

Parameter	**Measured concentration [C_{total}]**	**Unit**	**Time**	**Mass flow of VOC**
Chimney 1N	Volume flow: 103 762 Nm^3/h			
Organic substances	12	mg/m^3	1,5h	2,87 kg/h
Dust	0,2			0,03 kg/h
Chimney 2N	Volume flow: 106 294 Nm^3/h			
Organic substances	5	mg/m^3	1,5h	1,22 kg/h
Dust	0,5			0,05 kg/h
Chimney 3N	Volume flow: 95 193 Nm^3/h			
Organic substances	3	mg/m^3	1,5 h	0,66 kg/h
Dust	0,8			0,06 kg/h

The conversion from total C to organic solvents is done with the following response factors: FID: 0,75, total C – organic solvent: 1,7

Diffuse Emissions

Diffuse Emissions	**Amount of VOC**
VOC	Non

Supplements: Emissions from underbody protection and dip coating 0,9 g VOC / m^2

Emission into the atmosphere: Filler application and drying

Source of emission	**3.** Filler application and drying
Source of data	Measuring report 1999
Base year of data	1999

Applied Emission reduction measures

Integrated measures Measures for a emission reduction (Achieved emission reduction)	Water-thinnable filler with a low content of organic solvents (approx. 6%)
Measures for a reduction of diffuse emissions (Achieved emission reduction)	Housing and air guiding (100%)
En-of-pipe-techniques for waste gas cleaning Achieved emission reduction	Particle separation (Washer) for spray application thermal combustion unit for dryer (filler)* 72 % by thermal combustion of dryer waste gases

* 4 production lines with 4 thermal combustion units

Waste gas

Waste gas volume flow	Spray application of filler and clear coat are carried out in combined booth Dryers: Filler 1: 4 406 Nm^3 / h (thermal combustion unit) Filler 2: 4 522 Nm^3/h (thermal combustion unit) Filler 3: 5 295 Nm^3/h (thermal combustion unit) Filler 4: 5 111 Nm^3/h (thermal combustion unit) Cooling zone: Sum of line 1-4 approx. 224 000 m^3/h
O_2-content of waste gases	21 % (plants exhaust air), 19,3 –19,8 % (Filler-dryer)

Emission values filler-dryer

Parameter	Measured concentration	Unit	Time	Mass-flow	Comments
Thermal combustion unit, filler-dryer 1:					
C_{total}	34	Mg/m^3	1,5h	0,15kg/h	
CO	475	ppm	1,5 h	—	
NO_x					Not measured
Thermal combustion unit, filler-dryer 2:					
C_{total}	50	mg/m^3	1,5 h	0,23 kg/h	
CO	600	ppm	1,5 h	—	
NO_x					Not measured
Thermal combustion unit, filler-dryer 3:					
C_{total}	39	mg/m^3	1,5h	0,21 kg/h	
CO	450	PPM	1,5 h	—	
NOx					Not measured
Thermal combustion unit, dryer 4 for filler:					
C_{total}	35	mg/m^3	1,5 h	0,18 kg/h	
CO	320	PPM	1,5 h		
NO_x					Not measured

Diffuse Emissions

Diffuse Emissions	Amount of emissions
Organic substances	Non

Emissions in the air: 4. Base coat

Source of emission	**4. Base coating**
Source of data	Measuring 1999
Base year	1999

Applied emission reduction measures

Integrated measures for an emission reduction (Achieved emission reduction)	Water-thinnable base coat with a solvents content of approx. 12% (uni) up to 18% (metallic)
Measures for a reduction of diffuse emissions (Achieved emission reduction)	Housing and air guiding (100%)
Downstream Waste gas cleaning	Separation of particles (Washer) for spray application

Waste gas

Waste gas volume	Spray booths: Sum of line 1-4: 1 566 551 Nm^3/h
O_2-contentof waste gases	21% (plant exhaust air, base coating)

Emission values base coat, spray booth

Parameter	**measured concentration C_{total}**	**Unit**	**Time**	**Mass flow of VOC**	**Comments**
Base coat 1 Volume flow: 411. 515 Nm3/h					
Organic substances dust	9 0,7	mg/m^3	1,5h	8,38 kg/h 0,27 kg/h	
Base coat 2 Volume flow: 389.993 Nm3/h					
Organic substances dust	4 1,1	mg/m^3	1,5 h	3,82 kg/h 0,42 kg/h	
Base coat 3 Volume flow: 384.000 Nm3/h					
Organic substances dust	10 0,8	mg/m^3	1,5 h	8,38 kg/h 0,32 kg/	
Base coat 4 Volume flow: 381.043 Nm3/h					
Organic substances dust	6 0,6	mg/m^3	1,5h	5,18 kg/h 0,24 kg/h	

The transversion of C_{total} to organic solvents was carried out with the following factors: Response factor FID: 0,75, C_{total} - solvents: 1,7

Diffuse Emissions

Diffuse Emissions	**Amount of emissions**
organic substances	non

Comments: Average emissions from the application of base coating: 3,7 g/m^{2}car body

Emissions in the air 5: Clear coat-booth and top coat-dryer

Source of emission	**5. Clear coat-booth and top coat-dryer**
Source of data	Measuring 1999
Base year	1999

Applied measures for emission reduction

Integrated measures for emission reduction (Achieved emission reduction)	2K-Clear coat with a lower content of organic solvents (approx. 45 %)
Measures for a reduction of diffuse emissions (Achieved emission reduction)	Housing and air guiding (100%)
Downstream waste gas cleaning Achieved emission reduction	Particle-separation (Washer) for spray booth, thermal combustion unit for waste gases from dryer* 98 % via thermal combustion of waste gases from dryer

* 4 Lines with 4 thermal combustion units

Waste gas

Waste gas flow	Spray-booth: Filler and clear coat cabins are combined Dryer: Top coat 1: 4 332 Nm^3/h (thermal combustion unit) Top coat 2: 5 120 Nm^3/h (thermal combustion unit) Top coat 3: 8 278 Nm^3/h (thermal combustion unit) Top coat 4: 5 538 Nm^3/h (thermal combustion unit) cooling zone: Sum line 1-4 approx. 256 000 m/h
O2-content of waste gas	21 % (plant exhaust air, clear coat) 18,9 -19,7 % (top coat-dryer)

Emission values: Top coat-dryer

Parameter	Measured concentration	Unit	Time	Mass flow	comments
Thermal combustion unit: Top coat-dryer1					
C_{total}	39	mg/m^3	1,5 h	0,17 kg/h	
CO	600	PPM	1,5 h		
NOx					Not measured
Thermal combustion unit: Top coat-dryer 2					
C_{total}	32	Mg/m^3	1,5 h	0,16 kg/h	
CO	740	PPM	1,5 h		
NO_x					Not measured
Thermal combustion unit: Top coat-dryer 3					
C_{total}	33	Mg/m^3	1,5 h	0,27 kg/h	
CO	640	PPM	1,5 h		
NO_x					Not measured
Thermal combustion unit: Top coat-dryer 4					
C_{total}	27	Mg/m^3	1,5h	0,15kg/h	
CO	340	PPM	1,5 h		
NO_x					Not measured

Emission values of the combined booth for filler and clear coat

Parameter	Measured concentration [C_{total}]	Unit	Time	Mass flow of solvents	Comments
Filler / CC1	Volume flow:	567. 675	Nm^3/h		
Organic substances Dust	28 0,6	Mg/m^3	1,5h	30,9 kg/h 0,35 kg/h	

Parameter	**Measured concentration** **$[C_{total}]$**	**Unit**	**Time**	**Mass flow of solvents**	**Comments**
Filler / CC 2	Volume flow:	514.675	Nm^3/h		
Organic substances Dust	37 1,1	Mg/m^3	1,5h »	36,6 kg/h 0,54 kg/h	
Filler/CC 3	Volume flow:	542 750	Nm^3/h		
Organic substances Dust	52 0,6	Mg/m^3	1,5 h	53,6 kg/h 0,31 kg/h	
Filler/CC 4	Volume flow:	462 738	Nm^3/h		
Organic substances Dust	27 0,6	Mg/m^3	1,5 h	28,2 kg/h 0,27 kg/h	

The transformation of C_{total} to organic solvents was carried out with the following factors: response factor FID:0,75, C_{total} – solvents: 1,4 : 1,4 (weighted mean value of both painting systems)

Diffuse Emissions

Diffuse Emissions	**Amount of emissions**
organic substances	non

Comments: Mean total emission of filler and clear coat and base coat in Sum:
21,8 g/m^2 car body

Emissions in the air: 6. Spray booth and dryer for coating of sills

Source of emission	6. Spray booth and dryer for sills
Source of data	Measuring 1999
Base year	1999

Applied emission reduction measures

Integrated measures for a reduction of emissions, achieved emission reduction	2K-paint for sills with approx. 40 % organic solvents 1K-paint for seat slides with approx. 68 % organic solvents
Measures for a reduction of diffuse emissions Achieved emission reduction	Housing and air guiding 100 %
Downstream emission reduction measures	Particle filter for spray booth

Waste gas

Waste gas volume flow	4 ventilation plants with 354 798 Nm^3/h over-all
O2-content of waste gas	21 %

Emission values

Parameter	Measured concentration	Unit	Time	Mass flow
Decor line 1				
Plant 4 Organic substances Dust	46 <0,1	mg/m^3	1,5h	10,1 kg/h
Plant 4-1 Organic substances Dust	<3 <0,1	mg/m^3	1,5 h	0,6 kg/h
Decor line 2				
Plant 5 Organic substances Dust	6 <0,1	mg/m^3	1,5h	1,2 kg/h
Plant 5-1 Organic substances Dust	7 <0,1	mg/m^3	1,5h	1,3 kg/h

Diffuse Emissions

Diffuse Emissions	Amount of emissions
Organic substances	Non

Comments: Total emissions from sills and seat slides: 1,6g LM / m^2 car body

Summary

Emissions according VDI-Directive 3455

Pre-treatment/ dip coating/ Underbody protection:	0,9	g/m^2
Filler / Clear coat:	21,8	g/m^2
Base coat:	3,7	g/m^2
Siller:	1.6	g/m^2
Sum:	**28,0**	**g/m^2**

Opel Eisenach GmbH

General informations about the plant

Name and location of the plant	Opel Eisenach GmbH, painting plant, building E30 Adam-Opelstr. 100, 99817 Eisenach
Contact person for quiries: Address: Phone: Fax: E-mail:	 Jürgen Heilwagen, Technischer Service 03691 / 66 16 11 03691 / 66 11 22 juergen.heilwagen@de.opel.com
Workpieces to be coated	Car bodys
Type of material	Metal (galvanized sheet metal)
Size	60 - 85 m^2
Required surface quality	Corrosion protection (12 years), optical effects
Frequency of colour changes	range: 10 colours
Annually capacity in 2000	Type Corsa II: 52 161 car bodies Type Corsa III: 30 144 car bodies Type Astra: 62 838 car bodies
Annually solvent consumption [t/a] in base year	318
Annually operational time in base year [h/a]	1 830
Year of commissioning	1992
Type and date of significant modifications	Recycling of ground coating, 1996
Reports according to § 15 BImSchG	Extension of the colour palette, introduction of coloured base coat in 1997

Description of the varnishing process

The car bodies are transported to the wash- and phosphatisation installation via a roller belt. After cleaning, phosphatisation and passivation, the car bodys are coated electrophoretic via dip coating for a steady corrosion protection.

Afterwards sanding takes place and the PVC-underbody protection material is applied via robots. Subsequently the seams are sealed. After that the exterior surfaces and the rear and front are coated with a water-thinnable ground coat via electrostatic spray application with rotation atomisers. The material contains only 9 % of organic solvents, the efficiency amounts up to 90 %. After coating and drying the surface quality is inspected and imperfections are repaired. Then the car bodies are furnished with protection strips and are intermediate stored.

In the painting plant of the Opel Eisenach GmbH, special environmental sound processes are applied. Exclusively only water-thinnable paints are processed. The emission value of the German technical ordinance Air (TA-Luft) of 35 g VOC-emissions per coated m² of car body are undershoot by approx. 40 %. For electrophoric dip coating, filer, base coat and also clear coat, water is utilized as main solvent. The water-thinnabel dip coat contains less than 5 % of organic solvents. The top coatings have an average content of organic solvents of approx. 15%. The water-thinnable clear coat was applied first worldwide at the Opel Eisenach GmbH. Thus the content of organic solvents could be reduced from 50 % to 20 %. Also the clear coat meets the same quality standards than conventional clear coats.

For an increasing flexibility, the colour mixing area was enlarged by approx. 250 m2. Also three additional ground coat systems were installed for an adjustment of the grounding to the top coat colour for better optical appearance in the case of surface damages by chipping. Also eight further top coat colours were implemented to better suit the customers demand. By the implementation of systems for a reduction of water consumption and reuse of water, the fresh water demand could be reduced from 13 – 7 liters to 3 liters per coated surface of the car body."1

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[1] From: Opel Eisenach GmbH (Hrsg.), 2000, S. 12-13

Emissions in the atmosphere

Source of data	Environmental information system
Base year	2000

Applied emission reduction measures
Integrated measures

Measure	Process step	Efficiency
Water based paints	☑ Ground coat ☑ Top coat	30 % of the organic solvents were replaced by water
Electrostatic assisted application	☑ Ground coat ☑ Top coat	Reduction of the overspray by 50 %

Applied emission reduction measures:
Downstream measures

Measure	Process step	Obtained efficiency
Absorption of overspray via water films and coagulation and flotation, dehydration of the paint clot via a decanter, and external feedstock recycling (Methanol synthesis)	☑ grounding ☑ top coat application	90 % less particle emissions
Thermal combustion of waste gas from dryers	☑ drying ☐	20 % reduction of VOC-emissions from coating processes
Heat exchangers intake air / waste gas	☑ drying ☑ total plant	Reduction of 8 000 t/a fuel oil for heating of intake air

Waste gas before treatment or discharge via chimney

Process step	Waste gas flow [Nm^3/h]
Pre-treatment (degreasing, phosphatiezation, passivation)	17 180
Pre-treatment (electrophoric dip coating)	30 900
varnishing (ground coat, PVC, top coat)	1 739 000
Dryers and cooling zones (electrophoric dip coating, ground coat, top coat)	244 050

Emission values – clean gas after waste gas cleaning

Parameter	Mass flow in [kg/h]	Mass flow in [kg/a]	Source of emissions
C_{total}	0,085	410,6	Pre-treatment (degreasing, phosphatisation, passivation)
	0,613	2 960,8	Pre-treatment (electrophoric dipp coating)
	18,463	89 176,3	Varnishing
	0,903	4 361,5	Dryers, cooling zones
Dust	0,014	67,6	Pre-treatment (degreasing, phosphatisation, passivation)
	1,420	6 858,6	Pre-treatment (electrophoric dipp coating)
	0,117	565,1	Drying, cooling zones
CO	7,95	38 400	Drying
CO_2			
NO_x	3,954	19 100	Drying

Emission values - diffuse emission and discharged gases without waste gas cleaning

Parameter	Amount of emissions	Source of emissions
C_{total}	diffuse emissions: 30 % (estimated)	Ventilation of installation, complete varnishing plant

Comments: Solvent emissions and material consumption of the painting plant of Opel Eisenach in the year 2000,

Installation	Material	Total consumption [kg/a]	Content of solvents [%]	Content of solvents [kg/a]	Reduction via thermal combustion or refeed [kg/a]**	Remaining emissions [kg/a]
Pre-treatment	Cleaning agent	34 250		0,0		0,0
	Tenside	10 100		0,0		0,0
	Activator	8 900		0,0		0,0
	Phos.A-solution	15 670		0,0		0,0
	Phos.-E-solution	101 730		0,0		0,0
	Caustic soda	3 907		0,0		0,0
	accelerator cleaning	37 750		0,0		0,0
	acid	5 000		0,0		0,0
	Passivation sol. I	2 170		0,0		0,0
	Passivation sol. II	1 495		0,0		0,0
	Sum:	**220 972**		**0,0**		**0,0**
Electrophoric dip coating	Binding agents	823 205	1,05	8 643,7	1 728,7305	
	Pigment paste	158 595	11,5	18 238,4	3 647,685	
	Acetic acid	11 950	25	2 987,5	597,5	
	Phenoxy propanol	400	100	400,0	80	
	Butyl glycole	2 600	100	2 600,0	520	
	Sum:	**996 750**		**32 869,6**	**6 573,9**	**26 295,7**
PVC-booth	Underbody/Sealing	1 547 000	3	46 410	9282	
	seams siller	86 000	3	2 580 1	516	
	protection	38 500	3	155	231	
	Sum:	**1 671 500**		**50 145**	**10 029**	**40 116**

Installation	Material	Total consumption [kg/a]	Content of solvents		Reduction via thermal combustion or reefed [kg/a]**	Remaining emissions [kg/a]
			[%]	[kg/a]		
Varnishing process	Ground coat	252 000	7	17 640,0	3 528,0	
	Base coat, uni	115 671	14	16 193,9	3 238,8	
	Base coat, metallic	330 758	15	49 613,7	9 922,7	
	Clear coat	276 000	19,3	53 268,0	10 653,6	
	Sum;	**974 429**		**136 715,6**	**27 343,1**	**109 372,5**
Solvents	Rinsing solvent	54 400	100	54 400	27 200	
	Butyl glycol	32 160	100	32 160	16 080	
	N-propane	11 764	100	11 764	5 882	
	Sum:	**98 324**		**98 324**	**49 162**	**49 162**
Dispersion (ESKA)	Peptizers	4 190	0	0	-	
	Anti-foaming agent	4 900	0	0	-	
	PH-adjustment agent	1 225	0	0	-	
	Sum:	**10 315**		**0**	**-**	**0**
Coagulation (ESKA)	Anti adhesive agent	14 200	0	0	-	
	pH- adjustment agent	3 800	0	0		
	Flocculent	5 350	0	0		
	Anti-foaming agent	16 200	0	0		
	Sum:	**39 550**		**0**		**0**
					Sum:	**224 946,2**

	m^2/car body	**Car bodies/a**	**Coated surface m^2/a**
Total surface of car body, type Corsa (old model),	65,0	52 161	3 390 465,0
Total surface of car body, type Corsa (new model),	77,1	30 144	2 324 102,4
Total surface of car body, type Astra	85,3	62 838	5 360 081,4
		Sum:	**11074648,8**
Solvent emissions per year	**Emissions per year kg/a**	**Surface m^2/a**	**Solvent emissions g/m^2**
	224 946,2	11 074 648,8	**20,31**

Production time:	**21 h/d**
Working days:	**230 d/a**
Production time:	**4830 h/a**
Solvent consumption:	**318054,2 kg/a**
Emissions:	**224946,2 kg/a**
Emission rate:	**46,57 kg/h**

*) mean value from utilised paints

**) 20 % Reduction via thermal combustion unit, recycling of cleaning solvents 50%

Waste water

Source of data	Data recording via the environmental information system
Base year	2000

Measures for a reduction of the water consumption

Measures	Process step	Obtained efficiency
Circuitry, activated charcoal filter and ion exchanger	☑ Phosphatisation ☑ Passivation	70% Reduction fresh water content
Ultrafiltration: Rinsing water after dip coating	☑ electrophoric dip coating	10% less material consumption

Waste water treatment

Measures	Process step	Obtained efficiency*
Ultrafiltration precipitation / flocculation Neutralisation Selective ion exchanger	☑ Pre-treatment / degreasing	
Precipitation / flocculation Neutralisation Selective ion exchanger	☑ Pre-treatment, Phosphatierung, Passivation	
Coagulierung Precipitation / flocculation Neutralisation Selective ion exchanger	☑ Pre-treatment KTL	
Coagulation Flotation Decanter	☑ ground coat ☑ Top coating	100 % circuitry

Waste water volume flow

Waste water	Value [mg/l]			
	COB	AOX	Carbon-hydrogen-index	VOC
▪ Untreated waste water*	5 000	0,590	5,2	< 0,001
▪ Treated waste water	1 064	0,220	0,16	< 0,001
▪ Cooling water		0,182		
▪ Waste water from waste water treatment	15	0,031		

* Mean value from all waste water flows

Wastes

Source of data	Data recording by the environmental information system
Base year	2000

Applied measures for a reduction of wastes

Measures	Process step	Obtained efficiency*
Decanter	☑ Ground coat ☑ Top coat	Raise of solids content in the coagulated paint sludge of about 40 % Raise of solids content by 80 %

Amounts of waste, disposal or recycling options

Waste	Waste key-number (EAK) [1)]	Amount [2)]	Disposal / recycling	Characteristics[3)]	Type of waste
Contaminated hydro cleaning solvent	070304	491,46	Distillation	10% Solids 10 % Solvents 80 % Water	Hazardous waste
Paint sludge	080108	196,79	Methanol synthesis	20 % Water 80 % Paint sludge	Hazardous waste
Contaminated cleaning acid	110105	26,13	Chemical-physical treatment	10 % Sulphuric acid heavy metals	Hazardous waste
Waste oil	130202	22,64	Thermal combustion	95 % conservation oils	Hazardous waste
Metal hydroxide sludge	190201	193,64	Waste side	Lime Heavy metals 40 % Water	Hazardous waste
Cleaning cloth and filters	150299D1	60,4	Energy recycling	Paint and solvent residues	Hazardous waste
Paper / paperboard	150101	80 *	Waste paper recycling		Non hazardous waste
Plastic	150102	20 *	Recycling		Non hazardous waste
Mixed materials	150106	3*	Recycling	Packagings	Non hazardous waste

* estimated amount

Consumption of materials and energy demand

Installation	Material	Consumption [kg/a]	Organic solvents [%]	Solids content	Water hazard class	Comments
Pre-treatment						
	Cleaning agent	34 250	0	0	1	
	Tenside	10 100	0	0	2	
	Activator	8 900	0	0	1	
	Phos.-A-sol.	15 670	0	0	1	
	Phos.-E-sol.	101 730	0	0	1	
	Caustic soda	3 907	0	0	1	
	Accelerator	37 750	0	0	1	
	Cleaning acid	5 000	0	0	1	
	Pass.-sol. I	2 170	0	0	2	
	Pass.-sol. II	1 495	0	0	1	
Electrophoric dip coating	Binding agents	823 205	1,05	35	1	Pb-free product is tested
	Pigments	158 595	11,5	52	1	
	Acetic acid	11 950	25	0	1	
	Phenoxy propanol	400	100	0	1	
	Butyl glycol	2 600	100	0	1	
PVC-spray booth						
	Underbody protection/Sealing	1 547 000	3	97	1	
	Flanged seams	86 000	3	97	1	
	Side sill protection	38 500	3	97	1	

Installation	Material	Consumption [kg/a]	Organic solvents [%]	Solids content [%]	Water hazard class	Comments
Painting process	Ground coat	252 000	7	50	1	Water based
	Base coat Uni	115 671	14	25	1	Water based
	Base coat Metallic	330 758	15	25	1	Water based
	Clear coat	276 000	19,3	23	1	Water based
Solvents	Cleaning agent	54 400	100	0	1	
	Butyl glycol	32 160	100	0	1	
	N-propane	11 764	100	0	1	
Dispersion: ESKA	Dispersions	4 190	0	0	1	Process discontinued in 2001, only coagulation
	Anti-foaming agents	4 900	0	0	1	
	pH-correction	1 225	0	0	1	
Coagulation: ESKA	Anti-adhesive	14 200	0	0	1	
	pH-Corrector	3 800	0	0	1	
	Flocculation agent	5 350	0	0	1	
	Anti-foaming agents	16 200	0	0	1	

Installation	Material	Consumption [kg/a]	Organic solvents [%]	Solids content [%]	Water hazard class	Comments
Complete varnishing plant	Demineralized water	48 747	0	0	*	
	Water	27 316	0	0		
	Total energy	103 515MWh				Natural gas + electricity + cooling + heating
Fresh water- and waste water treatment						
	Caustic soda	68 500	0	50	1	
	Lime water	98 750	0	40	1	
	Ferric chloride (III)	13 320	0	40	1	
	Hydrochloric acid	133 852	0	31	1	
	Amio sulfon acid	500	0	100	1	
	Sodium bisulphate	17 261	0	40	1	
	Hydrogen peroxide	3 900	0	100	1	
	Sodium hypochlorid	1 800	0	13	1	
	Trisodium phosphate	1 800	0	100	1	

HFP Bandstahl GmbH & Co KG

Table 1: general informations about the plant

Name and location of the plant	Bandlackieranlage (Coil coating) HFP Bandstahl GmbH & Co KG Bad Salzungen
Contact person for queries: Address: phone: Fax: E-mail:	Herr Dr. Sameith Schäfergasse, 36433 Bad Salzungen 03695 / 663-248 03695 / 663-241 d.sameith@hfp-bandstahl.de
Workpieces	Coils, metal bands
Material	Metal (Fe, Va, Al,)
Size and geometry	width: max. 600 mm thickness: 0,15 - 1,5 mm
Required surface qualities	Decorative and technical surfaces
Frequency of colour changes	700 / a
Annually capacity in the base year*	Approx. 17 000 t (15 000.000 m²)
Annually solvent consumption in the base year [t/a]	285
Annually operating hours [h/a]	8 488
Year of commissioning	1974 – 1996 (Stages of development)
Date and type of significant modifications, relevant for the following data	1992: Degreasing-and neutralisation plant 1993: Thermal combustion unit 1995: Primer application + oven + thermal combustion unit1996 electrolytic galvanisation, waste water treatment plant, evaporator 1997 4-shift system 7 days / week
Announcements according § 15 BImSchG	1991, 1995, 1996, 1998

Process description

The company HFP laminates coils with metallic and organic coatings. Therefore the coils are cleaned in a flow path, galvanised, alodined and varnished via two painting plants. According to the customers request, the coated coils are cut to size and coiled

Process

The metal band runs from the looper through the cleaning installation. There degreasing, brushing, electrolytic cleaning, rinsing and drying (via a blower) takes place. Then the band is galvanised. Therefore the coil´s surface is pickled with thinned sulphuric acid and rinsed three times with distillate from the vaporiser.
The galvanised band is than coated in a no-rinse-coater with chromate (5-10 mg/m2) via a rubber roll. This layer is subsequently dried with heat recovered by a heat exchanger from the painting plant 2. Then the band runs through painting plant 1, painting plant 2 and is finally coiled.

Cleaning of the coil

In the cleaning installation the band is cleaned from corrosion protection oils, greases and other impurities. Thus an pre-cleaning is carried out via the spray application of a cleaning agent and subsequently cleaning by rotating brushes. By the electrolytic degreasing a pure surface is obtained.

Via the third rinsing cascade all cleaning agents are removed via rinsing with demineralized water. Before galvanisation the band is dried. The amount of approx. 500 l/h demineralized water which is fed to the rinsing cascades, is piped as waste water to the neutralisation zone 1. The chamber filter press generates lime sludge as filter cake. The material can be disposed in the same manner than domestic waste. In a baffle plate thickener, the wastewater is cleaned from suspended particles and is then piped to the final pH-test. If necessary the pH-value is adjusted.

Galvanisation

In the galvanisation plant, the cleaned metal band is pickled with thinned sulphuric acid and rinsed (rinse 1) with condensate, which is recovered from the galvanisation solution via vacuum evaporation. Subsequently the band is then treated in five galvanisation cells, where the zinc is deposited. Afterwards the band is rinsed in the rinse 2 with condensate. The condensate is recovered from the electrolyte by vacuum evaporation via the vaporiser.

Then the band´s surface is dried and transported to the no-rinse chromating. By the circuitry of the auxiliary materials, only low amounts of heavy metal containing wastewater are generated in the galvanisation. During the pickling, iron is released which deposits within the tank. For an avoidance of a accumulation, the iron (in form of iron sulphate) is removed from the solution by freeze desalination. The crystalline iron sulphate is external reused. The electrolyte is constantly filtered via a by pass system. The rewind of the therefore used settling filter is carried out with electrolyte. By this split-off ratio an accumulation of heavy metals within the electrolyte is prevented.

The zinc-contaminated wastewater is piped to the neutralisation zone 2, where a standard neutralisation with caustic soda is carried out.

The precipitated zinc hydroxide is concentrated by the chamber filter press as filter cake with a zinc content of approx. 40 % and is utilised as a raw material for zinc smelting processes. The wastewater (approx. 0,5 m3/week) from the chamber filter press is piped to the neutralisation zone 1 for conditioning.

Varnishing plants

The application of varnishes is carried out in two installations via rubber rolls simultaneously from the topside and the bottom side or optional only from one side. For the cleaning of the devices in the case of colour changes, organic solvents are utilised. Contaminated solvents and paint residues are intercepted and recycled externally.

The applied layer thickness is within the micrometer range. The coated band is dried in a flotation dryer. The dryer is heated via exhaust heat from the clean gas (750 °C) from the painting installation 1. The dryer´s waste gas is heated in a heat exchanger to 450°C and treated via thermal combustion (at 750 °C). The maximum VOC-content in the dryer amounts 9,3 g/m^3, maximal 23 % of the lower explosion limit (LFL) which amounts 40 g/m^3. The hot clean gas is lead through a heat exchanger and discharged into the atmosphere. The recovered heat is utilised for heating of the dryer´s intake air.

The band leaves the dryer at a temperature of 350°C and is cooled down to 150°C in a cooling zone via fresh air. The heated air is also lead through a heat exchanger before discharged. Then the band is further cooled by the application of demineralized water. After drying, the band is transported into the second varnishing plant, where similar processes are applied for the further varnishing. In the second painting installation, the dryer´s VOC concentration limit amounts 8,75 g/m^3, (21,88 % of the LFL).

Table 2: Emissions in the atmosphere

Source of data	Emission report 2000
Base year	2000

Table 2a: Applied emission reduction measures: Integrated measures

Measure	Process step	Obtained efficiency
Recycling of cleaning solvents	☑ Ground coat ☑Top coat	Very high
Processes with no solvent consumption	☑ bleaching ☑ degreasing	

Table 2b: Applied emission reduction measures: Downstream measures

Measures	Process step	Obtained efficiency
Thermal combustion unit, dryer 1	☑ Ground coat ☑ Drying	Almost 100 %
Thermal combustion unit, dryer 2	☑ Top coat ☑ Drying	Almost 100 %

Table 2c: Waste gas without cleaning or before direct discharge

Process step	Waste gas volume flow [Nm^3/h]
☑ Ground coat / drying	6.000
☑ Top coat / drying	8.000

Table 2d: Emission values – clean gas (after waste gas cleaning)

Parameter	Mass flow in [kg/h]	Mass flow in [kg/a]
VOC		
Thermal combustion unit 1	544	
Thermal combustion unit 2	612	
CO		
Thermal combustion unit 1	0,664	5.664
Thermal combustion unit 2	0,510	4.335
NO_x		
Thermal combustion unit 1	0,544	4.624
Thermal combustion unit 1	0,552	4.692

Table 3: Waste water

Source of data	Operation data
Base year	2000

Table 3a: Measures for a reduction of the water consumption

Measures	Process step	Obtained efficiency*
Cascade technique	☑ degreasing	
Evaporator technique	☑ pickling	approx. 90 %
Evaporator technique	☑ pickling ☑ galvanisation	approx. 90 %

Table 3b: Applied measures for waste water treatment

Measures	Process step	Comments
Neutralisation + Precipitation / Flocculation	☑ degreasing	New installation
Evaporation + Freeze desalination + Discharge of $FeSO_4$	☑ pickling	New installation
Precipitation + Filtration + Drying of $Zn(OH)_2$	☑ galvanisation	New installation

Table 3c: Waste water volume flow

Waste water	Value [mg/l]
	COD
▪ Waste water after treatment	20 - 60 mg/l

Table 4: Wastes

Source of data	Operation data
Base year	2000

Table 4a: Applied measures for a reduction and recycling of wastes

Measures	Process step	Obtained efficiency*
Distillation of cleaning solvents	☑ Ground coat ☑ Top coat	
Precipitation + Filtration + Drying of Zn $(OH)_2$ And external utilisation for smelting	☑ galvanisation	100 %
Reuse of H_2SO_4 for pickling after freeze desalination of $FeSO_4$	☑ pickling	approx. 90 %
Collection of scrap metals	☑ total production process	

Comments: A waste treatment is undertaken by dehydration of $ZN(OH)_2$-sludges

Table 4b: Amount of waste and utilisation

Waste	Waste key-number (EAK) [1]	Amount [kg / a]	Recycling / disposal	Characteristics	Comments
$FeSO_4$	06 03 03	4.000	Raw material for smelting		Hazardous waste
$Zn(OH)_2$	11 02 02	7.000	Raw material for smelting	Zn-content > 50%	Hazardous waste
Solvents	14 01 03	7.000	Distillation		Hazardous waste

1) EAK-classification or according to BestüVAbfV 10.09.1996

Table 5: Material consumption and energy demand

Process step:	Materials	Consumption	Unit	Characteristics	Comments
Ground coat, Top coat	Paints	450.000	kg/a	Solvents content 50 - 80 %	Solvent based
Degreasing	Cleaning agent	6.000	kg/a	Aqueous, alkaline cleaning agent	
Pickling	$H_2 SO_4$	7.000	kg/a	96 %	During galvanisation
Waste water treatment	Lime HCl NaOH	7.000 34.000 25.000	kg/a kg/a kg/a	Solid 33 % 30 %	Precipitation and Flocculation of wastewater from cleaning Precipitation of $Zn(OH)_2$
Varnishing	Paints	450.000	kg/a	Solvent based	Coil coating

Process	Water hazardous substances	Consumption	Unit	Water hazard class
Degreasing	Cleaning agent	6.000	kg/a	1
Pickling	H_2SO_4	7.000	kg/a	1
Waste water	Lime	7.000	kg/a	1
	HCl	34.000	kg/a	1
	NaOH	25.000	kg/a	1
Varnishing	Paints	450.000	kg/a	2

Further comments

The waste water from the wash-out is piped into the coagulation tank. There the separation of water and solids takes place. The solid material is discharged and utilised for an external energy recovery via combustion. The painting installation is supplied with paint materials via a closed circular pipeline.

Plastic Omnium Automotive Components GmbH

Table 1: General informations about the plant

Name and location of the installation	Varnishing plant PO in Großenlupnitz Plastic Omnium Automotive Components GmbH Essener Straße 99819 Großenlupnitz
Contact person for queries: Address: phone: fax: e-mail:	Herr Baum Essener Straße, 99819 Großenlupnitz 036920 / 85 19 04 035920 / 85 14 38
Workpieces to be coated	Bumpers, hubcaps
Material	Plastic
Size and geometry	0,93 m^2/ bumper (1,58 m x 0,59 m)
Required surface quality	VW standard TL 211 and Opel standard GME 00010
Frequency of colour changes	70 changes / d
Annually capacity in the base year 2000	1.937.920
Solvent consumption in 2000	316 t/a
Operating time in 2000	6.400 h/a
Year of commissioning	1996
Type and date of significant changes of the installations	/

Description of the process

First the workpieces (made of polypropylen) are mounted onto skids. From there the parts are transported into the cleaning cabin. Contaminations of the workpiece´s surface are removed manually with cleaning agents (mixture of water and isopropyl). For a removal of electrostatic charge, subsequently an ionisation is carried out with manually operated pistols.
After a quality inspection the surface is activated via flaming (natural gas / air) by two robots. Then a primer (2-component polyurethane) is applied from two robots via compressed air spraying. After flashing off for approx. 10 minutes, the base coat is applied in the base coat spray booth. All colourings are applied manually in form of 1-component paints via manual electrostatic assisted spray application. The base coat cabin consists of two working stations, operated by 4 employees. After flashing off for approx. 10 minutes the clear coat is applied via electrostatic assisted spray application manually by two employees and also automated by two robots. After flashing off, all applied paint layers are dried for approx. 45min at a temperature of 100°C. After cooling, the coated parts are removed from the skids.

The spray booths are climatized. For tempering of the required 320000 m^3 / h intake air, two hot water boilers, each 4,55 MW, are installed. The heat for drying is generated by the thermal combustion of waste gases 8at 750 °C) from dryers. The overspray is separated via wet separators.

Table 2: Emissions into the atmosphere

Source of data	Product data sheets, emission measurement
Base year	1999, 2000

Table 2a: Applied emission reduction measures: <u>Integrated measures</u>

Measure	Process step	Obtained efficiency
Materials High-Solid-paints Solids content: 20 % Solvent content: 80 %	☑ Ground coat	30 %
Application		
HVLP	☑ Primer (Ground coat)	45 %
	☑ Base coat (chromophore)	45 %
Electrostatic assisted spray application	☑ Primer (Ground coat)	55 %
	☑ Base coat (chromophore)	55 %
	☑ Clear coat (Top coat)	55 %
Other measures Recycling of cleaning solvents	☑ Primer (Ground coat)	96 %
	☑ Base coat (chromophore)	96 %
	☑ Clear coat (Top coat)	96 %

Table 2b: Applied emission reduction measures:
Downstream located measures

Measures	Process step	Obtained efficiency
Overspray separation	☑ Primer (Ground coat)	99 %
	☑ Base coat (chromophore)	99%
	☑ Clear coat (Top coat)	90 %
Thermal combustion	☑ Primer (flashing off)	99 %
	☑ Base coat (flashing off)	99 %
	☑ Clear coat (flashing off)	99 %
	☑ Dryer	99 %

Table 2c: Waste gas

Process step	Waste gas flow [Nm^3/h]
Cleaning Ionisation	6.000 m^3/h
Flaming	19.000 m^3/h
Primer (Ground coat)	64.000 m^3/h
Primer (flashing off)	1.000 m^3/h
Base coat (chromophore)	124.000 m^3/h
Base coat (flashing off)	1.000 m^3/h
Clear coat (Top coat)	84.000 m^3/h
Clear coat (flashing off)	1.000 m^3/h
Dryer	2.550 m^3/h

Table 2d: Emission values – clean gas after waste gas cleaning)

Parameter	Mass flow [kg/h]	Mass flow [kg/a]	Source
VOC			Flashing off: Primer Flashing off: Base coat Flashing off: Clear coat Drying
Total-C	0,02	128	
Dust	0,01	64	
CO	0,22	1.408	
NO_x	0,57	3.648	

Table 2e: Emission values - diffuse Emissions and discharges via chimneys without waste gas cleaning

Parameter	Amount of emissions		Source
VOC	49,37kg/h	(calculated)	Cleaning Primer- ground coat, base coat- and clear coat application
Dust	0,9 kg/h	measured	

Table 3: Waste water

Source of data	Product data sheets
Base year	2000

Table 3a: Measures for a reduction of the water consumption

Measure	Process step	Obtained efficiency
Closed circuit	☑ Ground coat ☑ Base coat ☑ Top coat	90 %

Table 3b: **Waste water treatment**

Measure	Process step	Obtained efficiency*
Flotation, Sedimentation	☑ Ground coat ☑ Base coat ☑ Top coat	100 %

Table 4: Waste

Source of data	Waste balance
Base year	2000

Table 4a: Applied measures for reduction and recycling of waste

Measure	Process step	Obtained efficiency
Reusable containers	☑ Ground coat ☑ Base coat ☑ Top coat	49 %
Distillation of contaminated cleaning solvents	☑ Ground coat ☑ Base coat ☑ Top coat	94 %

Table 4b: Amounts of waste and waste treatment

Waste	Waste key-number (EAK)	Amount [t / a]	Disposal, utilization	Characteristics	Type
Paint sludge	80108	170	Drying, energy recycling	40 % water content	Non hazardous waste
Hardened paint residues	80102	2,1	Waste side	solid	Non hazardous waste
Water from coagulation	80108	32	Recycling	Liquid	Non hazardous waste
Cleaning solvent	70104	17,8	External recycling by the producer	Liquid	Non hazardous waste

Table 5: Consumption of materials and energy demand

Process step:	**Material / Energy**	**Consumption**	**Unit**
Painting plant	Natural gas	57.336 026	MJ/a
	Propane gas	891.018	MJ/a
	Electricity	4.967.081	kWh
	Water	14.860	m^3

Process	**Material / Energy**	**Consumption**	**Unit**	**Specific energy demand**
Energy demand	Natural gas	680.000	Nm^3 /a	10 kWh/Nm^3
	Thermal combustion unit ½	720.000	Nm^3 / a	10 kWh/Nm^3
	Electricity	2.250.000 1.400.000	KWh/a kWh/a	9 kWh/kg
	Solvents from paints	285.000	Kg / a	

Table 6: Costs

Techniques for a reduction of environmental impacts	1. Thermal combustion unit 2. Evaporator 3. Waste water treatment for degreasing and galvanisation
Investments	1. approx. 0,5 Mio. EU 2. approx. 205.000 EU 3. approx. 205.000 EU
- Base year	2000
- capacity	coating of approx. 15 Mio. m²