VOC Emission Abatement Techniques – Surface Cleaning

IAMC Toolkit

Innovative Approaches for the Sound Management of Chemicals and Chemical Waste

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Introduction

This presentation gives an overview of surface cleaning techniques, methods and requirements in the chemical industry with a particular focus on the role of solvents.

It introduces the reader to the potential of abatement of solvent use due to the introduction of improved cleaning technologies, including solvent recovery systems.

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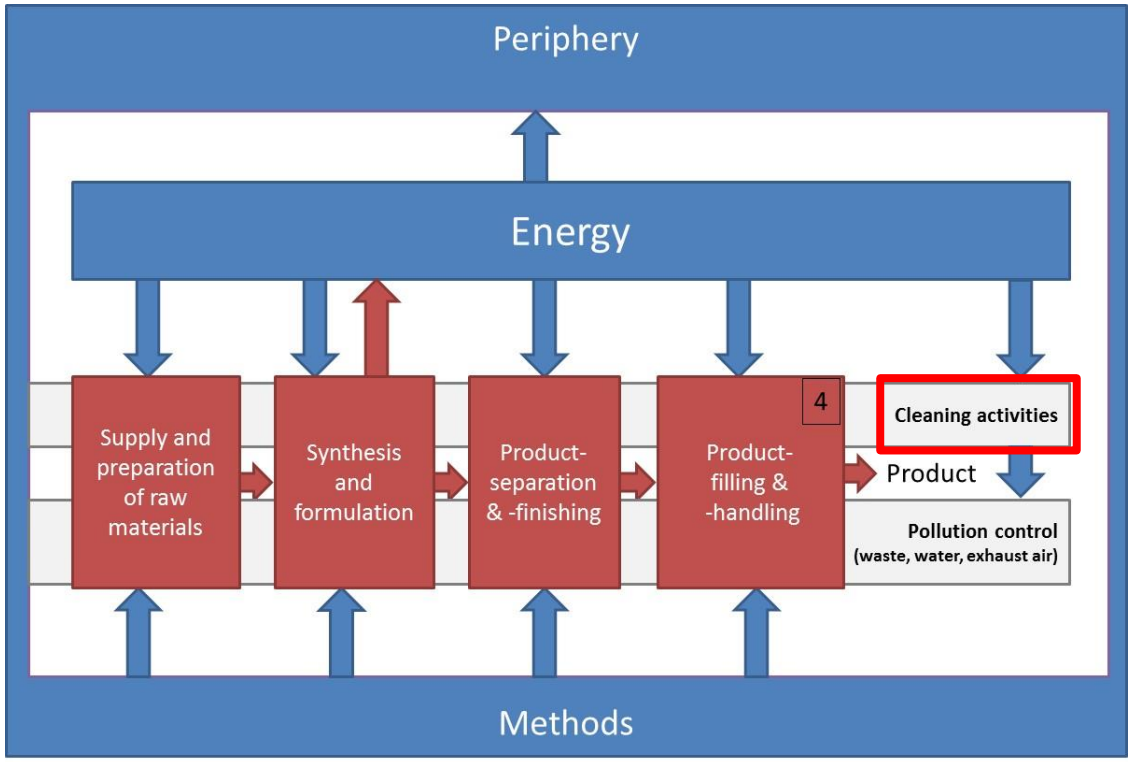
1. Solvent Use, Emissions and Environmental Impact
2. Surface Cleaning: VOC Abatement Techniques
   - Use of cleaning machines
   - Enclosed cleaning machines
   - Solvent-based cleaning forms
   - Best practices and further process improvements
3. Good Practice Examples

Solvent Use, Emissions and Environmental Impact

Importance of Cleaning Substances and Costs

Cleaning is mandatory, it is directly related to production efficiency and quality.



Large amounts of energy, time and personnel resources are allocated to cleaning activities.

Cleaning procedures are often delicate (associated with risks for staff).

The company image is improved when using less harmful substances or methods.

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Solvent Use: VOCs With Specific R-Phrases (GHS: H-Phrases)

- The use of CMR substances (carcinogenic, mutagenic or toxic to reproduction) or halogenated solvents is subject to specific requirements

- Halogenated solvents:
  - Excellent cleaning properties
  - High solvency power for a large variety of substances
  - Low surface tension
  - Non-flammability
  - Rapid and residue-free evaporation
  - Good recyclability
  - Suitable for a wide range of materials

Examples of halogenated solvents:

- Perchloroethylene (PER): used for industrial surface cleaning of aluminium, magnesium, zinc, brass, etc.
- Dichloromethane: used for paint stripping
- Trichloromethane: used for vapour and cold cleaning
- N-propyl bromide: used to remove solder flux, wax, oil, grease from electronic parts, metals and other materials

Solvent Use: VOCs Without Specific R-Phrases

- **Solvents used for surface cleaning:**
  - Alkanes (isododecane, iso-paraffins, kerosene)
  - Alicyclics (cyclohexane)
  - Alcohols (isopropanol, 1-butoxypropan-2-ol)
  - Polar aprotics (N-methylpyrrolidon)
  - Ketones (acetone, diketone)
  - Esters (N-butyl acetate)
  - Ethers (glycol ether)

Solvent Consumption and Emission Levels

- Chlorinated solvent consumption has declined over recent years in Europe due to the following reasons:
  - Increased number of closed systems and improved process management (emission control, solvent recycling systems, better management of waste)
  - Legal restrictions
  - Shift from chlorinated solvents to alternative solvents
  - More stringent carcinogenicity classification of trichloroethylene

Key Environmental and Health Issues

VOC with specific R-phrases

- Main environmental and health issues with CMR labelled solvents: carcinogenic, mutagenic, toxic to reproduction
- Perchloroethylene and trichloroethylene are toxic/harmful to aquatic organisms
- Halogenated solvents are toxic to the aquatic environment

VOC without specific R-phrases

- 1-butoxypropan-2-ol, isopropanol, cyclohexane, N-methylpyrrolidon, acetone: harmful and may cause irritation to eyes and skin
- Cyclohexane: highly toxic to the aquatic environment
- Most organic solvents are highly flammable

Key Environmental and Health Issues

VOC emissions to air, water, soil and groundwater occur during:

- Storage of solvents
- Cleaning processes
- Spills and leakages

- **Waste** generated by the processes containing **solvents** needs to be disposed of in a way that **prevents the emissions** of VOC to air, water and soil.

Surface Cleaning
VOC Abatement Techniques

- Use of cleaning machines
- Enclosed cleaning machines
- Solvent-based cleaning forms
- Best practices and further process improvements

A: Use of Cleaning Machines

Applications

Cleaning machines are used in many industries to avoid health and environmental hazards arising from production processes and to maintain the production line.

Examples:

- Printing industry
- Degreasing metal parts
- Brewing industry
- Polymer industry
- Paints manufacturing

A: Why are Cleaning Machines Important?

By using cleaning machines, hazards can be controlled and prevented.

- Flammability
- Explosivity
- Toxicity
- Carcinogens
- Tissue damage
- Hazardous air pollutants

A: Use of Cleaning Machines

Different types of cleaning machines:

- Open, solvent not heated
- Open-top, solvent heated, using vapour degreasers
- Airless, enclosed degreasers at an ambient pressure
- Vacuum, reduction of boiling point by reducing the pressure
- Cosolvent, twin solvent aggregation

Open and open-top systems do not allow controlling the outgoing vapours/gases.

Enclosed systems prevent the release of vapours/gases and operate at ambient pressure.

Closed systems prevent the release of vapours or gases and allow the adjustment of pressure (sealed).

Note: The definition of “closed/enclosed “can vary by country or industrial sector.

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B. Enclosed Cleaning Systems

- Using enclosed/closed systems is a highly effective way of reducing VOC emissions.
- Example: results achieved by using sealed chamber systems:
  - Reduction in direct solvent emissions by over 90% compared to open systems
  - Reduction in solvent consumption by 60-80%
- The reduction in solvent consumption depends on the solvent content of the waste conveyed to external recycling.

B. Enclosed and Closed Cleaning Systems

- Differences between technologies for surface cleaning

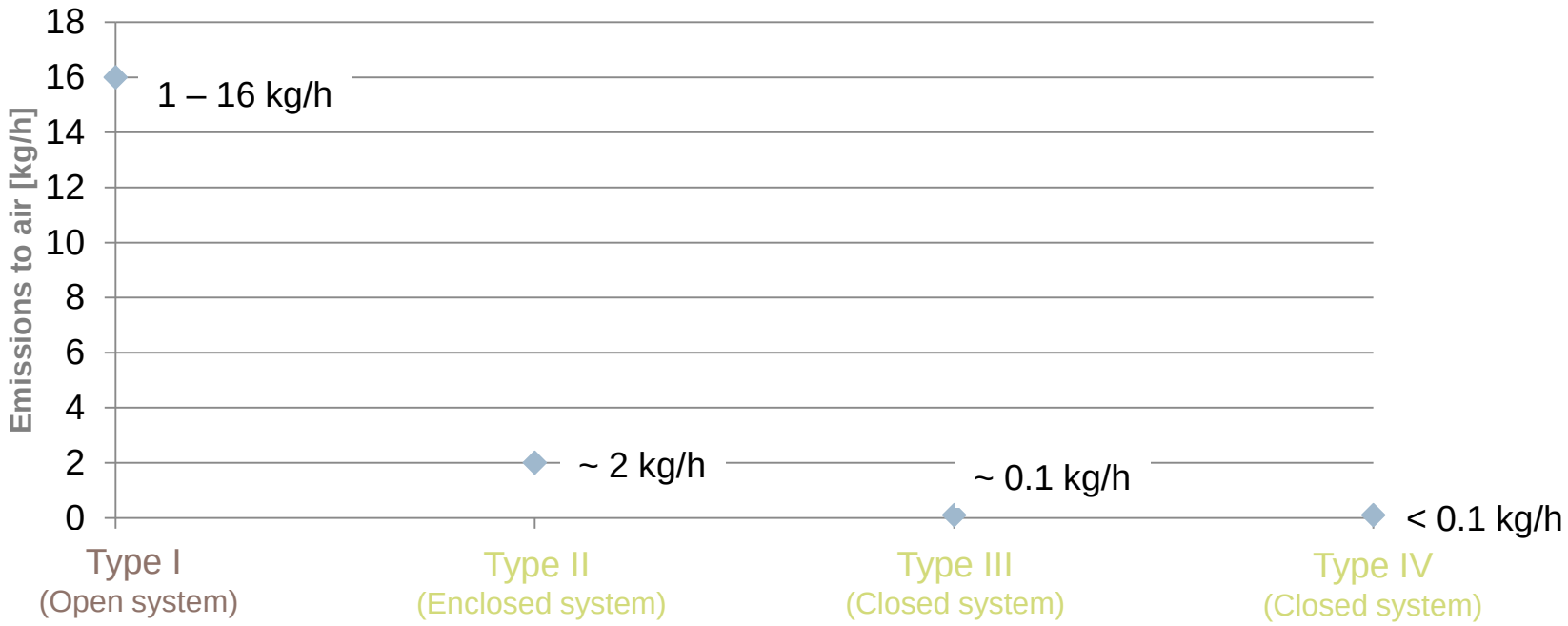
Technology generation	Construction type	Closed loop drying with refrigeration	Solvent recycling	Vapour extraction	Activated carbon
Type I	Open top	No	External	No	No
Type II	Enclosed	No	External	Yes	No/Yes
Type III	Closed (sealed)	Yes	Integrated	Yes	Yes
Type IV	Closed (sealed)	Yes	Integrated	No	Yes

Open systems

Closed systems

Source: based on European Commission

B. Differences Between Open and Closed Systems



Source: based on European Commission

The types of open/closed systems illustrated in this graph are presented in more detail in the next slide.

B. Closed Systems – Technology Generations

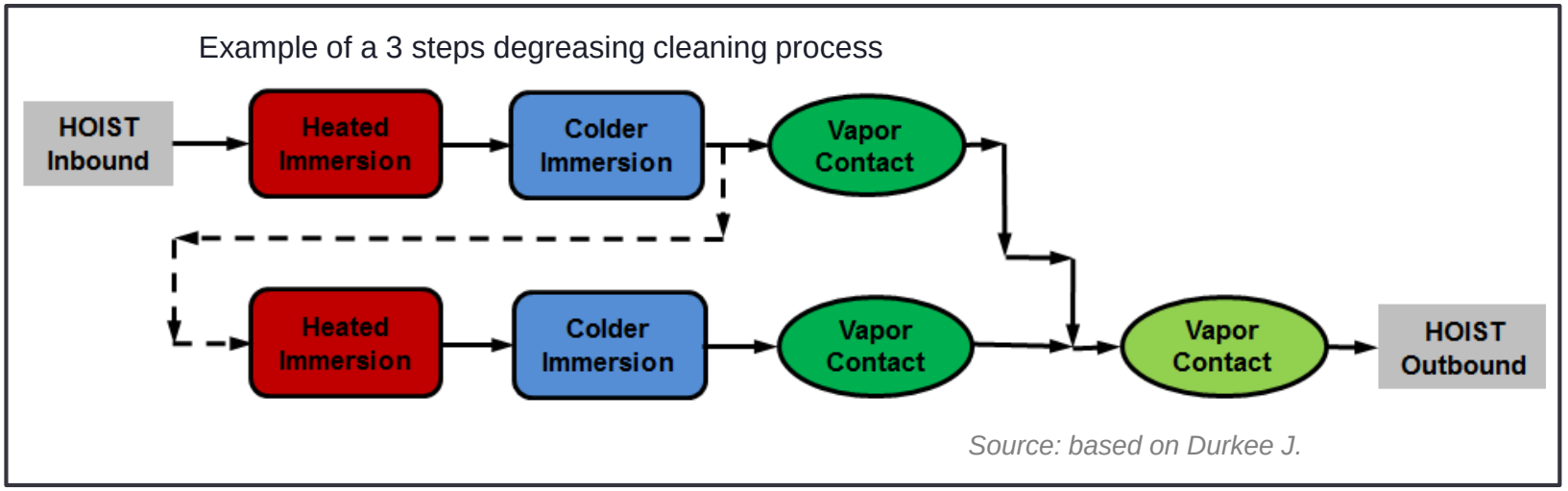
- **Type I:**
  - Open installations with no specific VOC control measures
  - Use in industry declined due to environmental and health concerns
  - Very high solvent consumption with associated costs
- **Type II:**
  - Installations similar to Type I but enclosed
  - Widely used type of installation
- **Type III:**
  - Closed loop systems with integrated solvent recycling
  - VOC emissions significantly reduced (approx. 0.1-0.2 kg/h)
- **Type IV:**
  - Closed loop systems with vacuum technology
  - Significant reduction in VOC emissions (min. 0.001 kg/h)

The latest generation of closed systems (Types III and IV) achieve high reductions in VOC consumption and air emissions.

B. Introduction to Cleaning Processes

An appropriate process has to be selected for a given machine type!

Cleaning processes are selected sequences of steps: immersion in liquid/vapour contact/liquid spray under pressure



Surface Cleaning
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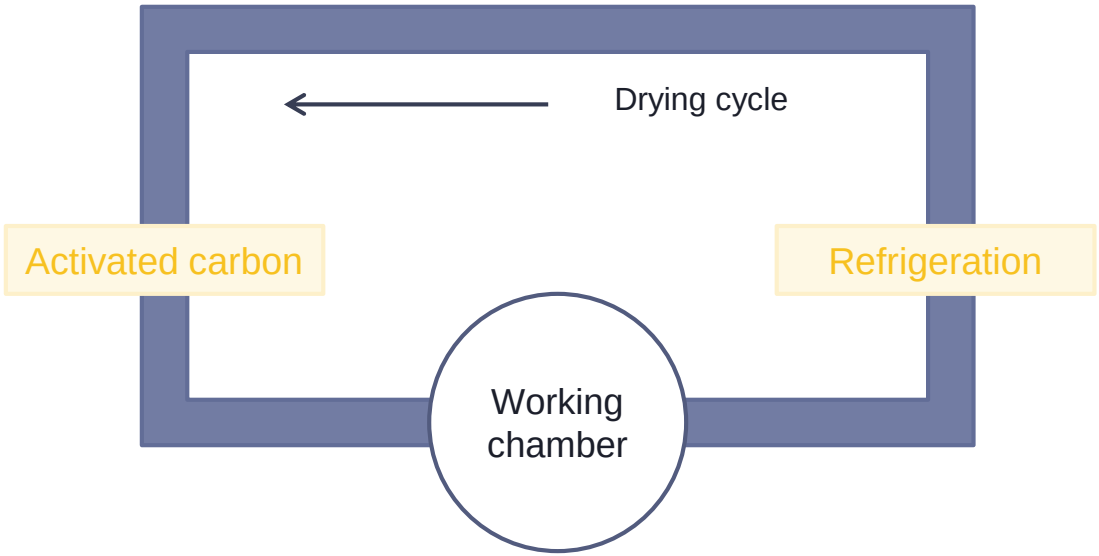
C. Solvent-Based Forms of Cleaning

Vapour phase cleaning or degreasing	Liquid phase cleaning	Manual cleaning
Solvent vapours condense on the surfaces of the product.	*Contaminants are soaked/immersed in solvent.*	*Liquid or aerosol solvents are applied using wipes and brushes.*
Example: chamber systems	Example: cold cleaning	

Source: based on UN GHS, 2013

C. Vapour Phase Cleaning: Chamber Systems

- **Chamber system with vacuum**

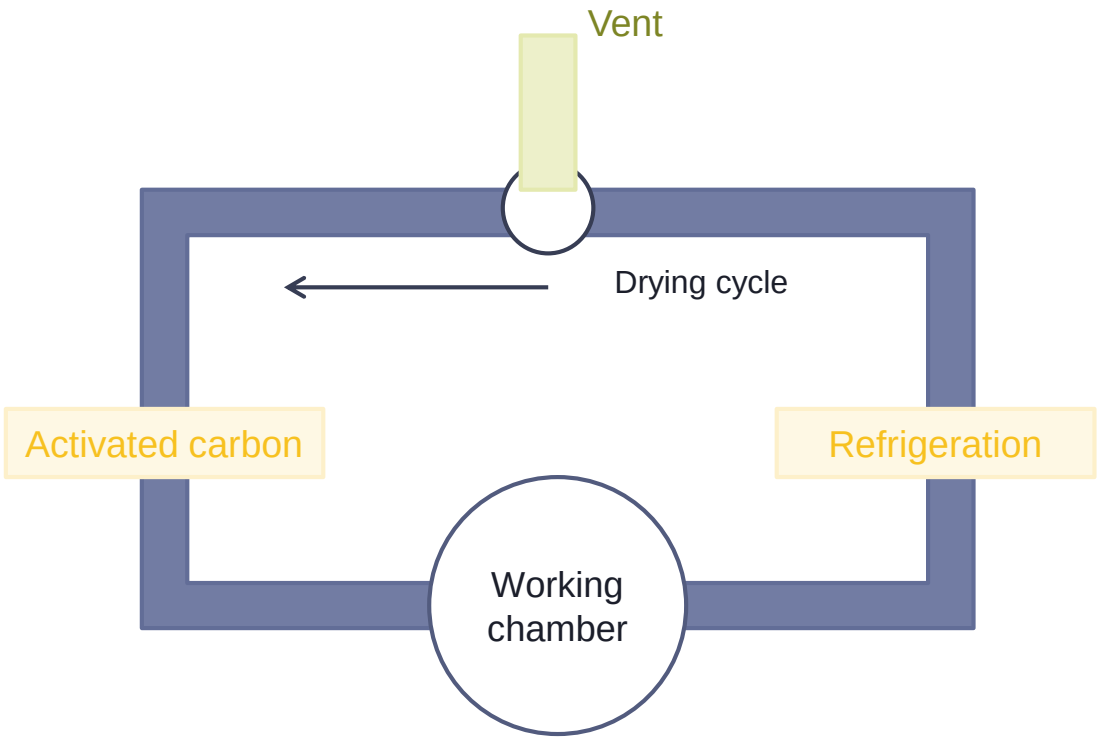


Source: based on European Commission

- System offering the highest standards of surface cleaning and emission reduction
- All processes where solvent emissions may occur are enclosed in a sealed casing
- System working with chlorinated solvents and hydrocarbon solvents with a flash point higher than 55 °C

C. Vapour Phase Cleaning: Chamber Systems

- **Chamber system without vacuum**

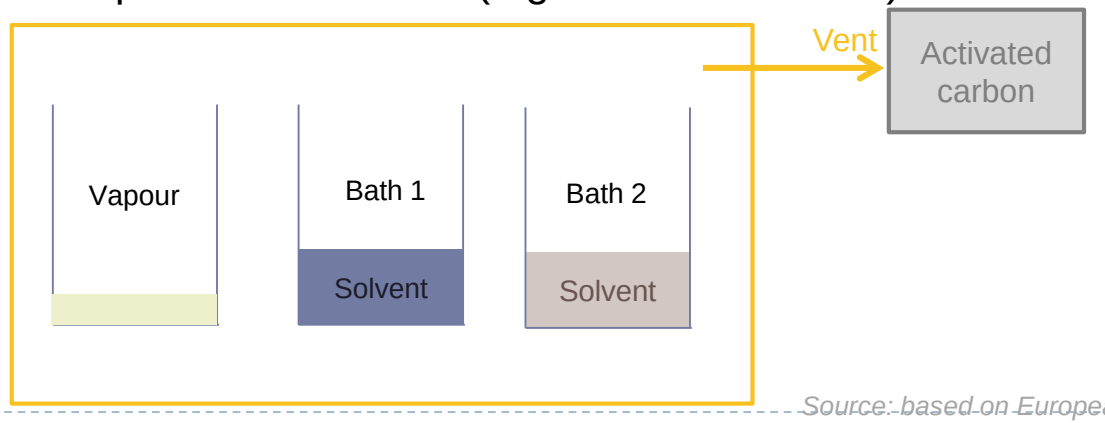


Source: based on European Commission

- Technique preventing the direct emission of solvents by a series of interlocks combined with a vapour extraction and/or refrigeration system
- Vapour is recycled back into the solvent tank
- System evacuates gas
- Very high degree of solvent containment and reduction in emissions
- System works with chlorinated and non-flammable solvents

C. Vapour Phase Cleaning: Open-Top Vapour System

- Typical open-top vapour degreaser:
  - Sump containing a heater to generate solvent vapour
  - Parts to be cleaned are immersed in the vapour zone, vapour condenses on the work piece until heated up to vapour temperature
  - Immersion of the parts to be cleaned in liquid solvent baths is often used to supplement the cleaning action
- Reducing VOC emissions and protecting workers:
  - Open-top systems should be enclosed.
  - Vapour should be captured and treated (e.g. activated carbon).



Source: based on European Commission

C. Liquid Phase Cleaning – Cold Cleaners

- **Cold cleaners:**
  - Commonly used for maintenance and manufacturing activities
  - Batch loaded and solvent degreasers with higher boiling point used
- **Cleaning efficiency** is often increased by manual pre-cleaning (spraying) before soaking the parts in the tank.
- **After cleaning**, the parts are hung up to drain over the tank. The drained solvent is reused.
- **VOC emissions** arise from the open tank and from the cleaning process.

  Solution: Use a tightly fitting cover to close the unit.

C. Manual Cleaning – Paint Stripping

- Procedures used for paint stripping: dipping process or spraying
- Solvent bath temperature: 80-90 °C
- Choice of stripping chemical depends on the material to be treated:
  - Pure solvents for light and non-ferrous metals
  - Mixture of solvents or aqueous solutions for steel

Surface Cleaning
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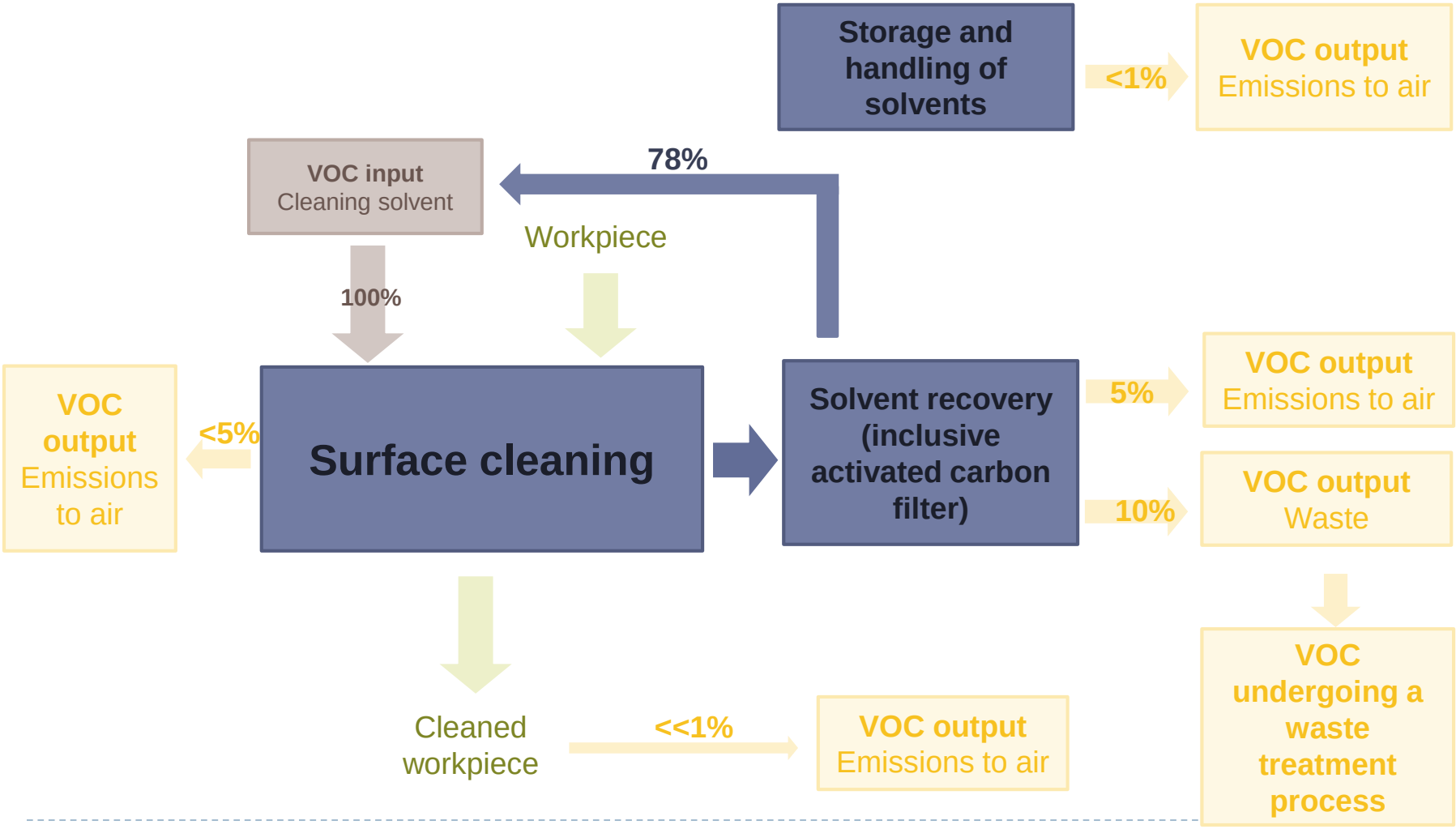
D. Typical Cleaning Process in an Enclosed System and Associated VOC Emission Flows

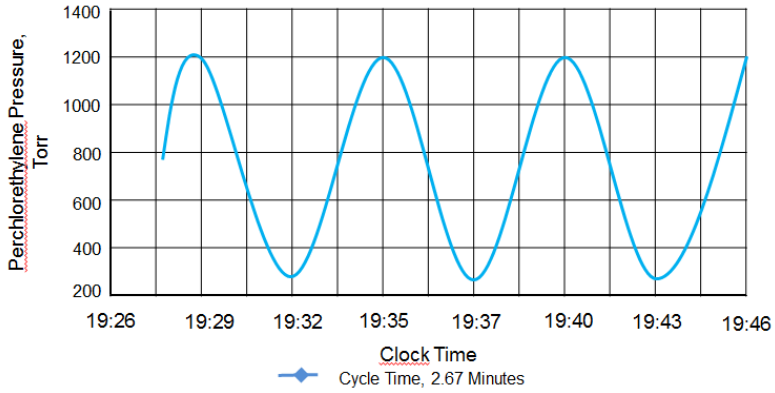


D. Best Practices in Closed/Enclosed Cleaning Machines

Enclosed cleaning tank = pressure-sealed cleaning tank to contain emissions

Processes:

- Vacuum cavitational streaming (VCS)
  - Cyclic pressure/temperature change
  - 1-40 seconds per cycle
  - Controlled formation and collapse of bubbles
- Solvent recycling and recovery by distillation:
  - Up to 99.9% of the solvent recovered
  - Reduced environmental impact and solvent consumption



Source: based on Durkee J.

Source: ISSPPRO

D. Best Practices in Closed/Enclosed Cleaning Machines

Optimization (1):

- Vacuum management: vacuum pump dimensioning
  - Management of temperature reduction due to the vacuum (stream of hot air/water to protect the chamber)

- Selection of operating temperatures:
  - Determine the optimum temperature by taking into account the reduction in product viscosity if the temperature is increased and the reduction in product fragility if the temperature is decreased.
  - Use the Antoine equation to calculate the operating vapour pressure.

- Vessels for enclosed machines:
  - Wall thickness, dimensioning (must sustain required pressure or vacuum)

D. Best Practices in Closed/Enclosed Cleaning Machines

Optimization (2):

Solvent storage

At least two solvent vessels required (loading and unloading in batches)

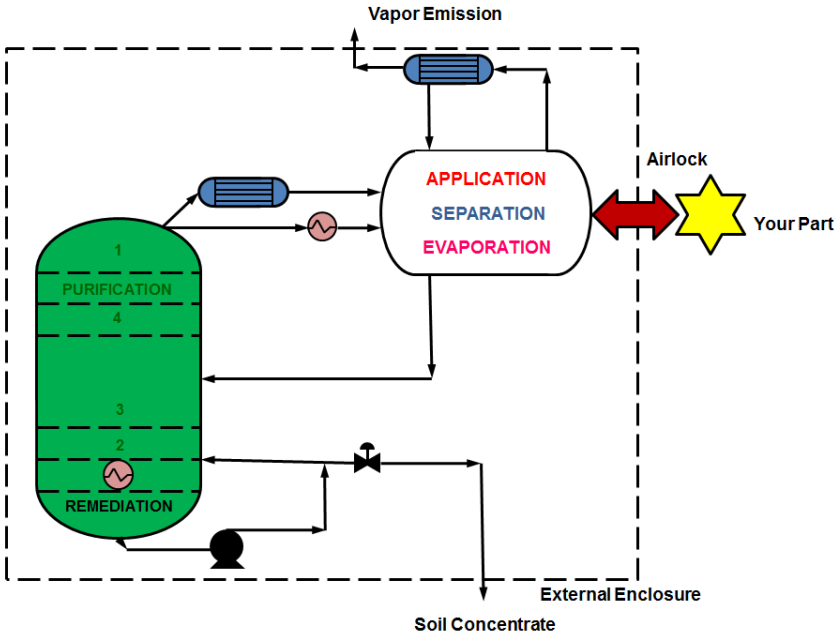
Removal of solvent vapour from the work chamber:

1. Chamber filled with solvent gas atmosphere
2. Vacuum removes 98.7% of the atmosphere
3. Chamber filled with air/inert gas (nitrogen)
4. Vacuum removes 98.7% of the atmosphere
5. Chamber finally filled with dry air

D. Best Practices in Closed/Enclosed Cleaning Machines

Optimization (3):

- Solvent management
  - Application of clean solvent on dir parts
  - Separation of dirty solvent from cleaned parts
  - Evaporation of cleaned solvent fro cleaned parts
  - Purification of dirty solvent
  - Remediation of soil materials



Source: based on Durkee J.

Source: UN GHS, 2013

D. Best Practices in Closed/Enclosed Cleaning Machines

Overview of the cleaning cycle

Steps are detailed and monitored

Repetition of Cleaning Steps to Achieve a High Level of Soil Removal		
Elapsed Time	**Actions**	**Comments**
0:01	Parts loaded in racks in chamber	
0:15	Chamber sealed. Cycle started	
2:15	Air removed by vacuum pump-down to 1 Torr absolute	
1:30	Cold parts immersed in condensed hot solvent	Parts are made cold by evaporation of solvent during vacuum operation
3:00	After draining, parts sprayed with hot solvent vapor	This step removed volatile soil components, leaving only non-volatile ones to be removed by repeated rinse steps
2:00	Solvent vapors are removed by vacuum	
1:30	Cold parts immersed in condensed hot solvent	Rinse step #1
2:00	Solvent vapors are removed by vacuum	
1:30	Cold parts immersed in condensed hot solvent	Rinse step #2
2:00	Solvent vapors are removed by vacuum	
1:30	Cold parts immersed in condensed hot solvent	Rinse step #3
2:00	**Solvent vapors are removed by vacuum**	
1:00	**Chamber filled and flushed with air**	
2:00	**Solvent vapors are removed by vacuum**	
1:00	**Chamber filled and flushed with air**	
0:15	**Cycle complete. Chamber unsealed automatically**	

Source: based on Durkee J.

D. Further Process Improvements

- Use of spraying to enhance cold soaking and vapour degreasing:
  - Spraying can increase the cleaning efficiency
  - Low-pressure spraying
- Improved containment achieved by better covers:
  - Evaporation control by using a cover
- Improved handling of solvents:
  - Solvents stored in separate safety containers (fresh/used solvents)
  - Dry-break couplings
  - Covers for containers

D. Further Process Improvements

- Product/process design to reduce the need for cleaning:
  - Identification of causes of contamination
  - Elimination/modification of interim cleaning processes
  - Time reduction between cleaning and the next process
  - Pre-cleaning
  - Counter-current cleaning

- Optimized cleaning by matching technology and products to the cleaning requirements:
  - Type of surface
  - Geometry of the surface to be cleaned
  - Variety of parts to be cleaned
  - Required cleanliness of the surface
  - Contaminants present
  - Process technologies associated
  - Quantity parts to be cleaned
  - Continuous or batch process

Advantages and Limitations of Closed/Enclosed Cleaning Machines

- **Advantages of enclosed cleaning machines:**
  - Cleaning solvent selection to match soil characteristics
  - Implementation of cleaning steps at any pressure
  - No solvent substitution
  - High level of solvent recovery through distillation
  - Ideally providing an emission-free environment

- **Advantages of different machines:**
  - **Externally sealed enclosed machines:** solvents with low flash points or exposure limits can be used
  - **Airless enclosed vapour degreaser:** solvents unstable in air can be used, no solvent degradation
  - **Airtight enclosed vapour degreasers:** higher temperatures possible

- **Limitations of enclosed cleaning machines:**
  - Price
  - Require continuous processes (at least two vessels needed)
  - Heating/cooling medium necessary

Good Practice Examples

Good Practice Examples

- A car manufacturer uses a sealed single-chamber cleaning installation with vacuum applying **PER as cleaning agent** for the cleaning of parts for fuel tank filler necks (Type IV installation which recycles the used solvents).

- With the new installation, the company has reduced its VOC consumption by more than 99% compared to Type I conventional systems.

If the company's VOC consumption is 180 kg/year with the Type IV installation, what was the VOC consumption when using a Type I conventional system?

Answer: 18,000 kg/year

Good Practice Example (2)

- An automotive and electro-tool company cleans steel, stainless steel and aluminium parts contaminated with emulsions or oils.
- The company replaced one of its closed single chamber systems (Type III) by a vacuum system (Type IV).
- With the new vacuum system, the company needs to purchase 6,000 to 8,000 litres of solvents per year to compensate for VOC losses.
- With the old system, the company had to purchase between 13,950 and 18,900 l of solvents annually.

What is the reduction in solvent consumption achieved by switching from a Type III to a Type IV installation?

Answer: 57% reduction in solvent consumption

Source: ISSPPRO

Key messages

- Large amounts of energy, time and personnel resources are allocated to cleaning activities.
- Cleaning procedures are often delicate (associated with risks for staff and environment).
- Abatement techniques are available for surface cleaning, as (enclosed) cleaning machines, solvent-based cleaning forms and other practices and further process improvements.
- Optimal abatement option should be studied according to the cleaning needs and the solvent use of each company.

Source: ISSPPRO

Sources

Sources

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