< Chemical process improvement>

VOC Emission Substitution Techniques – Surface Cleaning

IAMC Toolkit

Innovative approaches for the Sound Management of Chemicals and Chemical Waste

Introduction

This presentation gives an overview of 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 substitution of VOC solvent use due to the introduction of improved cleaning technologies, including solvent recovery systems.

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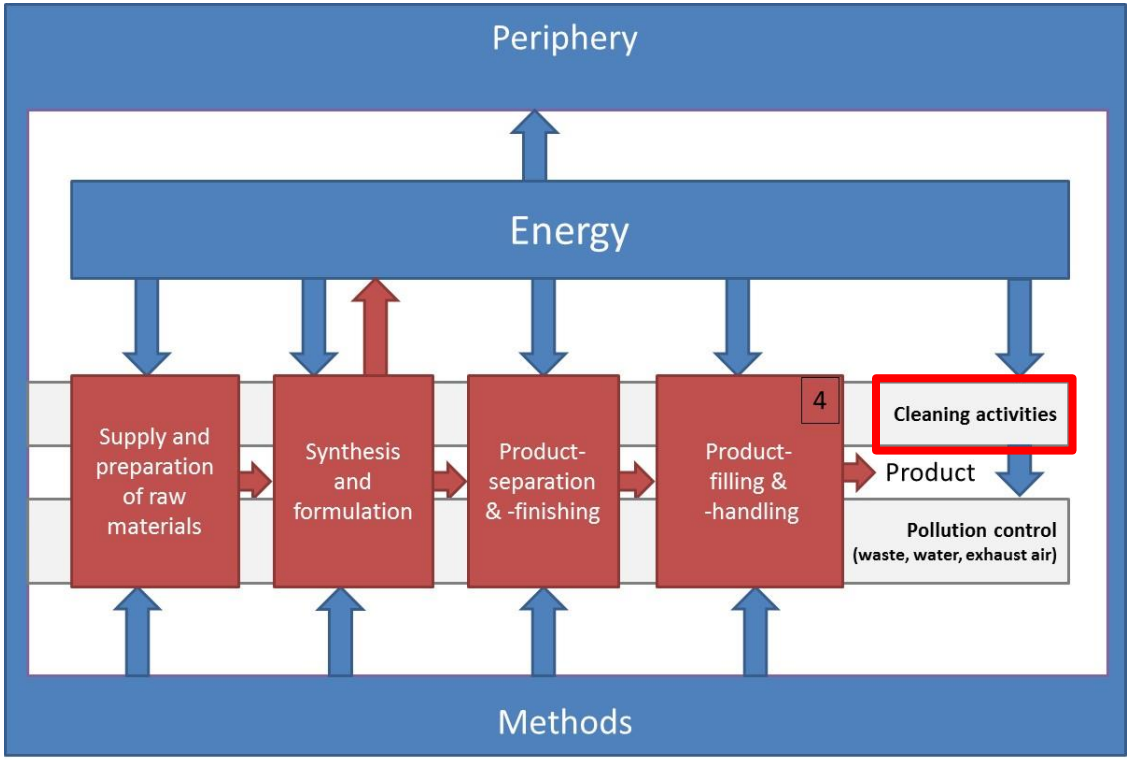
Solvent Use, Emissions and Environmental Impact

Importance of Cleaning Substances and Costs

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



Large amounts of solvents are required ("Better more than less" approach)

Expensive and often highly hazardous substances

Company image is improved if less harmful substances/ methods are used

Solvents Used: VOC **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 and suitable for a wide range of materials
  - High solvency power for a large variety of substances
  - Low surface tension
  - Non-flammability
  - Rapid and residue-free evaporation, good recyclability

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

Solvent Use: VOC **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 in a way that prevents the emissions of VOC to air, water and soil.

Surface Cleaning: Substitution Techniques

- Water-based cleaning systems
- Carbon dioxide cleaning
- Plasma technology
- UV cleaning
- Laser cleaning
- Thermal paint stripping

VOC-Free Systems

Substitution of VOC solvents with water-based cleaning systems

Carbon dioxide cleaning

Plasma technology

UV cleaning

Laser cleaning

Thermal paint stripping

Substitution of VOC Solvents with Water-Based Cleaning Systems

- Aqueous solutions of acid, alkali or neutral cleaners can **replace halogenated and non-halogenated solvents** in the industrial cleaning of hard surfaces:
  - Steel
  - Aluminum
  - Magnesium
  - Copper
  - Plastics
  - Coated surfaces
  - Glass
  - Electronic components
- **Neutral pH cleaners are used for intermediate and final cleaning.**
- **Strongly alkaline cleaners** are used to obtain very clean surfaces, e.g. before coating processes.
- **Acidic solutions** are used to clean metals (e.g. to remove metal oxides).

Substitution of VOC Solvents with Water-Based Cleaning Systems

- Investment costs for water-based installations:
  - 50% lower than solvent-based systems (enclosed systems with air extraction)
- Operational costs:
  - Depending on the cleaning medium and requirements for bath maintenance
  - May be more energy intensive than solvent-based cleaning (need for drying stage, final cleaning with deionized water)
  - May have to be maintained/replaced more regularly
- Efficiency of water-based cleaning can be enhanced by:
  - Ultrasonic or megasonic cleaning systems
- Aqueous systems vary in character and need to be adapted to the product and production cycle under consideration to achieve the required cleanliness.

Carbon Dioxide Cleaning

- CO_2 can be used as solvent to remove oil, grease and other organic contaminants.
- Technique:
  - Pressurized air (300m/s) is used to blow pellets of dry ice onto the surface to be cleaned.
- Technique suitable for:
  - Removing small amounts of organic contaminants
  - Cleaning electrical components and sensitive parts in situ
- High degree of cleanliness
- Costs:
  - Machine: €9,000-€14,000
  - Dry ice: €0.6/kg (machine consumption: 30-50 kg of dry ice per hour)

Plasma Technology

- Use/Application:
  - Removing grease, oxides, oils, silicones in the automotive and electronics industries (before industrial painting or for pre-treatment before gluing or soldering)
  - Removing thin films of organic contaminants (< 1µm)

  Remark: Plasma technology is ineffective when inorganic materials are present.

- Technique:
  - Ion bombardment
  - Two techniques available: low-pressure plasma system (LPPS) and atmospheric pressure plasma system (APPS)
  - Process gas: argon or oxygen (the choice of the process gas depends on the material to be cleaned and the composition of the contaminant)
  - Leaves no residues on the surface – no need for rinsing

Plasma Technology

- Often combined with a pre-cleaning step (water-based or semi-aqueous pre-cleaning)

- Investment costs:
  - Depending on the size of the installation (2-13,000 l): €8,000-€400,000

- Operational costs:
  - Very low, no specific chemical required

UV Cleaning

- Used to remove organic contaminants from the surface of substrates (e.g. photoresists, semiconductors)
  - Cleaning agents: oxygen-free radicals that decompose organic contaminants
  - Best results achieved with thin layers of organic contaminants
- Pre-cleaning step may be required
- Ozone is produced during the cleaning process
- Cleaning time can be short (5 to 10 minutes)
- Common technology (same principle applied in other industrial sectors, e.g. water treatment)

Laser Cleaning

- Applicable to high-quality surfaces in the automotive, aviation or electronics industries
  - A laser heats and vaporizes the contaminants (vapour filters required).
- Small areas of a part can be cleaned (rather than the entire piece).
- Technique:
  - Laser radiation pulsed to remove organic protective layers or coatings
  - No additional chemical needed
  - Suitable for paints, adhesives, coatings, rubber residues, plastics, oxide layers
  - Contaminant needs to be known to calibrate the laser frequency
- High investment costs but low operational costs

Thermal Paint Stripping

- Used for thermo-resistant materials (e.g. steel, aluminium, etc.)

- Technique:
  - Process takes place in an oven at 250-430 °C and takes 3 to 12 hours
  - Sandblasting or high-pressure water washing are used to remove the remaining ash
  - Not suitable for wood and plastics (degradation of the materials)
  - Exhaust gases need to be treated by thermal oxidation

VOC-Reduced Systems

- If the complete substitution of organic solvents is not possible, one can switch to systems with reduced VOC content.

- The use of **products with very low VOC content** can replace systems with higher solvent content:
  - Semi-aqueous cleaning systems (e.g. micro phase cleaning system (MPC) with a VOC concentration of 10%)

C12_Substitution of chemicals

Good practice example

Good Practice Example

Good Practice Example

- A company decided to switch to plasma cleaning technology to degrease and activate the surface of plastic parts.

The new system has the following operational characteristics:

- Cleaning volume per process: 20-40 l
- Process duration: 15-20 min
- Oxygen consumption: approx. 0.1 l/min → 1.5 l/process
- Oxygen costs: approx. €4 for 1,000 l
- Electrical power: approx. 2.5 kWh → 0.83 kWh/process
- Maintenance: approx. €2,000 per year

What are the company's VOC consumption and emissions ?

Answer: By using the plasma cleaning technology, the VOC consumption and emissions can be reduced to zero.

Key messages

- The volatile proprieties of VOC solvents induce a high percent losses.
- Several solvent substitution technique with less harmful substances or technologies are available.
- The initial financial and personnel training investment needs to be balanced with the long term saves in terms of solvent consumption and emissions.

Sources

Sources

- CSD Engineers, Switzerland/ISSPPRO, Germany, 2015
- European Commission - DG Environment: Guidance on VOC Substitution and Reduction for Activities Covered by the VOC Solvents Emissions Directive (Directive 1999/13/EC), Europe, 2009.

Images

- CSD Engineers, Switzerland, 2015

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