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ENVIRONMENTAL TECHNOLOGY MONITOR

1994
(Introductory number)



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Vienna 1994

**ENVIRONMENTAL TECHNOLOGY
MONITOR**

1994 (Introductory number)

This number: *Technology Updates*

Future Coverage:

Country news

Legislation

Market trends

News and events

Patents

Publications

Research

Software products

Standards

Technology updates

Training

This is the first number of UNIDO's *Environmental Technology Monitor* and represents the latest title in the long-established *Industrial Technology Monitor Series* of the Organization. As some readers may know, the *Monitor Series* was established as a mechanism of current awareness—through monitoring areas of industrial technological development—for governments, industry and academia, located primarily in developing countries.

Other titles in the series are:

- *Advances in Materials;*
- *Genetic Engineering and Biotechnology;*
- *High Technology Spin-offs;*
- *Marine Industrial Technology;*
- *Microelectronics.*

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TO OUR READERS

This is the first number of a new title in the long-established *Monitor Series*. The first *Monitor* was released in December 1981 and covered the subject of microelectronics. This was closely followed, in February 1982, by the *Biotechnology Monitor* and later by the other 2 titles currently in the *Series*, namely *Advances in Materials* and *Marine Industrial Technology*. The *Series* is aimed at industry, government and the scientific/technological community in developing countries.

The main objective of the *Monitor Series* is to act as a vehicle for current awareness of and sensitization to the various aspects of industrial technology—as such, the information is presented without evaluation or recommendation. Presenting awareness of the potential (and limitations) of technological advances is part of a broader UNIDO programme which assists developing countries to strengthen their technological capabilities.

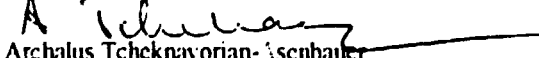
The concept of monitoring technological advances stems from the Vienna Conference on Science and Technology for Development, held in the summer of 1979 and subsequently endorsed by the governing body of UNIDO.

This title in the *Series* will cover industrial 'environmental technology'—which has come centre-stage in the world consciousness since the preparations for and holding of the United Nations Conference on Environment and Development (UNCED), commonly known as the Earth Summit, in June 1992. As readers may know, UNCED resulted in a wide-ranging programme for action by the world community—Agenda 21—which has (rightly) also been called an agenda for information. Each of the 40 chapters recommends that information be collected, stored, analysed and disseminated for their respective subject areas. Three of these chapters exclusively address issues that are relevant to this publication—technology transfer, industry and information. Many of the other chapters are also relevant and will feature in future numbers of the *Series*.

This first number of the *Series* is a special issue. The full range of subject headings will not be utilized, rather, fifty-five 'generic' (as opposed to process-specific) waste management/treatment technologies are described in some detail. In this case, one may wish to refer to Chapters 20 and 21 of Agenda 21, as these technologies are commonly-used for managing hazardous as well as solid wastes/sewage. These technologies are equally important when considering other chapters dealing with the protection of: the atmosphere (Chapter 9); water resources (Chapters 17 and 18); and human health (Chapter 6).

Each technology description has been presented with the following headers: the principal of the process (general description); the aim of the processing—the pollution/waste streams concerned; the technological preconditions—including several sub-headings such as temperature, pressure, concentration of influents, additives required, capacity; the performance evaluation—including *inter alia* rates of removal, effluent concentration, energy consumption, emissions and bottlenecks; costs—investment and operation; range of applications; and practical experiences.

We owe our thanks to the National Institute of Public Health and Environmental Protection (RIVM) of the Netherlands, for allowing us to prepare these fifty-five technology descriptions, which are based on their research and publication series *Monografieën informatiesysteem technieken*, issued in 1992. It was also RIVM that recommended the structure for describing the technologies, allowing us to present each in a consistent and concise manner, providing much more than the more commonly-used, standard bibliographic references.


Archalus Tcheknavorian-Asenbauer
Managing Director, Industrial Sectors and Environment Division

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INTRODUCTION

RIVM, the Dutch National Institute of Public Health and Environmental Protection, is a centre of information and know-how, whose task it is to supply the government with the information required for its health and environmental policies. Because research lies at the heart of all RIVM's activities "Research for man and environment" is how RIVM describes its work.

The Laboratory for Waste Materials and Emissions (LAE) is one of the laboratories within the Environmental Research Division of the RIVM. The remit of LAE is to support government policy on waste materials and emissions. To this end, studies on the origin and amount of waste materials, and on emissions to water, soil and air, are carried out. Ways of preventing emissions and wastes, and of reusing or disposing of existent wastes are investigated.

Besides reporting on the present situation, LAE is future-oriented in its studies on the effects of preventive and abatement measures for different scenarios. It is concerned with gaining insight into social processes, particularly those applying to production and consumption, and the resulting burden to the environment.

Collecting information, and building up and interpreting knowledge to be used in advising on policy and environmental forecasts are important focal points of LAE activities. This is done in cooperation with various other (government) institutions and research agencies.

As technology plays an important role in solving environmental problems, the Directorate General of Environment of the Dutch Ministry of Housing, Physical Planning and Environment (VROM) commissioned RIVM/LAE to start with the development of the Environmental Technology System (IT) in 1987. The aim of IT, for internal use only, is to collect scattered knowledge on environmental technology and make it available in a user-friendly way.

The first version of the system has been operational since July 1989 and the second, a more user-friendly version, since April 1992. Both are in Dutch.

The system is based on monographs --descriptions of a technique-- consisting of 15 to 25 pages each. The monographs are drawn up using a standard format consisting of several sections. At the moment IT contains 55 monographs written by the Netherlands Organization for Applied Scientific Research (TNO) and RIVM during the period 1989-1992. These monographs have also been published in a series of four reports.

Since 1992 UNIDO and RIVM/LAE have been cooperating informally on the exchange of environmental technology information.

In 1993 UNIDO made English-language Environmental Technology Factsheets of the IT monographs to be used in their database. A factsheet is 1 to 2 pages in length and consists of the following sections:

Principle of the process

- Aim of processing, pollution, waste stream(s)
- Technological preconditions
- Performance
- Costs
- Range of applications
- Practical experience

RIVM/LAE developed the format of the Environmental Technology Factsheets and UNIDO translated and prepared them.

As a means of dissemination of knowledge on the factsheets, UNIDO and RIVM/LAE decided in 1994 to include the 55 Environmental Technology Factsheets in this quarterly publication of UNIDO.

1. BIOFILTRATION

Principle of the process

Biofiltration is the aerobic conversion of air-borne impurities into non-polluting components (primarily CO₂, H₂O and inorganic salts). The polluted gas is passed through a filter consisting of biologically active material such as compost, containing naturally occurring microorganisms which can decompose the contaminants.

Aim of processing, pollution(s), waste stream(s)

To remove impurities and odours from waste gases. Impurities are mainly organic, with some inorganic components (H₂S, NH₃, CS₂) being suitable.

Technological preconditions

Influent concentration

0.001–4 g/m³ (usually < 1 g/m³) depending on impurity.

Temperature

10–40° C

Pressure

Atmospheric

Additives

Filter material, compost, turf etc. sometimes mixed with coarser, inert fraction e.g. bark, plastic, lava. Potassium of calcium phosphates to speed reaction if necessary. C:N:P = 200:10:1. Insoluble alkaline material (lime, marl) if necessary.

Capacity

1–200 g/m³/h

Others

Dry matter content < 20–50 mg/m³. Moisture content > 95%. In some cases 99%. Filter must be leakproof for gas and fluid. Air load on filter < 600 m³/m²/h to keep energy costs low.

Performance

Removal rate

Depends on filter design.

Effluent concentration

Usually 1–10% of influent concentration

Volume-flux

1–200 g/m³/h

Energy consumption

Electrical energy required for ventilator. Only substantial if air load > 600 m³/m²/h

Emissions

Microorganisms in exhaust gas (max 10⁴ CFU/m³). Some emission of impurity or reaction products to water may occur. After 2–5 years filter is replaced, producing waste with usually the same composition as original filling (compostable). Additives are usually recyclable.

Bottlenecks

Process is sensitive to high and low temperatures, excessive concentrations, and discontinuities in emissions.

Costs

Investment

Installation Dfl 500–7500/m² filter surface. Filter material Dfl 75–40 /m³

Operation

Dfl 0.50–5/1000 m³ gas.

Range of applications

Treatment of biodegradable waste gases from odour-emitting industries.

Practical experience

Used in a variety of industries, including sewage treatment, tar distillation, slaughterhouses, meat and fish treatment, food processing, plastics, animal breeding, animal feedstuffs, paint, medicines, destruction processes, oil refining and compost processes.

2. BIOSCRUBBING

Principle of the process

Impurities in waste gases are adsorbed by water in a scrubbing column and decomposed by microorganisms contained either in the column (trickling filter) or in a separate reservoir (activated sludge installation) to produce harmless components, primarily H₂O and CO₂. A sludge is produced, some of which must be removed in order to guarantee continuous operation. The purified water can be recirculated.

Aim of processing, pollution(s), waste stream(s)

To separate and destroy biodegradable pollutants such as organic matter, NH₃, odour components from waste gases.

Technological preconditions

Influent concentration

0.001–20 g/m³

ph-range

6–8

Temperature

10–40° C

Pressure

Atmospheric

Additives

Nutrients from microflora—ratio C:N:P=200:10:1. Acidification must sometimes be compensated by addition of e.g. NaOH.

Capacity

1–200 g/m³/h

Others

Particle content 20–50 mg/m³. Air load 600 m³/m²/h.

Performance

Removal rate

50–90%

Effluent concentration

1–10% of influent concentration.

Energy consumption

1.6–3 kWh/1000 m³ treated gas.

Emissions

Residual emission of contaminants determined by process. Sludge emitted via waste water contains PO₄, decomposition products etc.

Bottlenecks

Sensitive to excessive temperatures and impurity concentrations, and fluctuations in impurity concentrations. Dry particles can cause blockages.

Costs

Investment

Capacity 30–130 m³/h, Dfl 0.55–2.5 x 10⁶

Operation

Capacity 30–130 m³/h, Dfl 11–66/h

Range of applications

Odour removal, treatment of hydrocarbons.

Practical experience

At laboratory and pilot-plant stage. Examples include removal of: dichloromethane—capacity 200 g/m³/h (70%); dichloroethane—capacity 80 g/m³/h (70%); odour components in cocoa industry (65%), pigsties (50–90%), fat processing (75%), foundries (60%), solvents (90%), NH₃, amines, phenols, etc. in various industries.

3. DRY FLUE GAS PURIFICATION BY MEANS OF CHEMICAL CONVERSION

Principle of the process

Flue gas impurities react with chemical to form solid salts of the acidic components or are oxidized or reduced with the help of a catalyst. Solid reaction products are separated before emission of the purified gas. In some cases the reactor is integrated in the combustion installation.

Aim of processing, pollution(s), waste stream(s)

To neutralise acidic contaminants from flue gases using basic additives (adsorbents) to form solid salts and to convert them catalytically into harmless gases.

Technological preconditions

Influent concentration

100–10000 mg/Nm³ (1–100 mg/Nm³ for HF)

Temperature

300–1100 depending on impurity

Pressure

Usually atmospheric. For pressurized fluidised bed combustion 10 bar.

Additives

Neutralizing agent—usually CaCO₃, Ca(OH)₂, CaCO₃, MgCO₃. Catalyst material—usually oxides of vanadium or tungsten, on titanium carrier. NH₃ for reduction of NO_x—0.5 kg per kg NO_x.

Capacity

1000–2000000 Nm³/h.

Performance

Removal rate

50–90%

Effluent concentration

SO₂, HCl, NO_x: 50–1000 mg/Nm³, HF < 1 mg/Nm³

Energy consumption

10–20 kWh/ton waste (2–3 kWh/1000 Nm³ flue gas) for neutralisation of acid components in waste incineration. 1 kWh/kg NO_x (0.6 kWh/1000 Nm³ gas) in NO_x reduction.

Emissions

Non-chemically-bonded acid components emitted to air. Solid reaction products and non-converted additives, often

mixed with fly ash. In NO_x reduction—old catalytic material renewed after 5 years, treated as waste. Max. ca. $5 \text{ mg/Nm}^3 \text{ NH}_3$ escapes to air.

Bottlenecks

Blockages by powdery additives in dosing/transport system. Presence of fly ash can block catalyst and packed beds.

Costs

Integrated system

Total costs ca. Dfl 1/kg SO_2 or HCl, of which investment less than half

Secondary processes

ca. Dfl 1–10/kg acid component.

Range of applications

Treatment of flue gases from combustion of coal and waste. Catalytic reduction of NO_x .

Practical experience

Fluidized bed combustion of coal using limestone for SO_2 : AKZO (90 MW th). Pneumatic injection of $\text{Ca}(\text{OH})_2$ used in waste incineration to reduce HCl emission to below 5000 mg/Nm^3 . Also examples of other additives based on Ca, Mg and Na used. Selective catalytic reduction: widely used in Germany and Japan. Coal-fired power station at Nijmegen—half of flue gas treated. Secondary system for HCl removal in waste incineration and HF removal in glass, mineral and aluminium works, Germany and Sweden.

4 . E L E C T R O F I L T R A T I O N

Principle of the process

The gas stream is passed through an electric field whereupon an electric charge is induced in solid and liquid particles in the gas. These charged particles are precipitated on the positive collector electrode, and removed. The impurities can be reused if desired.

Aim of processing, pollution(s), waste stream(s)

To concentrate/remove particulate matter (organic, inorganic, metallic) from a gas stream (usually N_2 , O_2 , CO_2 , H_2O).

Technological preconditions

Influent concentration

< 50 g/m^3 . For higher concentrations pre-separation is necessary—e.g. gas cyclone.

Temperature

Up to 400°C at atmospheric pressure. Up to 900°C at high pressure.

Pressure

Usually atmospheric.

Additives

For wet electrofilters with water-misting, ca. 0.6 l water/m^3 gas occasionally SO_3 (15–20 ppm) added to improve efficiency if particles have high resistivity.

Capacity

200–> $100000 \text{ m}^3/\text{h}$

Others

High moisture content increases separation efficiency. Resistivity 102–2108 ohm meters on collector electrode deposits. Regular removal of deposits necessary, by tapping collector plates. Deposit thickness 1–10 mm. Electrical charge 20–115 kW.

Performance

Removal rate

95–99.99%

Volume flux

0.5–2 m/s

Effluent concentration

Less than 5 mg/m^3

Energy consumption

0.3–1 kWh/ 1000 m^3 gas

Emissions

Particulate impurities—may be recovered for reuse. In wet filters—waste water emissions must be treated. Ozone—production limited by use of two-stage system.

Bottlenecks

Deposit thickness too great, disturbance of current or tapping mechanism, blockage of collector funnel.

Costs

Investment

Dfl < $5\text{--}150/\text{m}^3/\text{h}$

Operation

Dfl 0.5–3/ 1000m^3

Range of applications

Treatment of industrial waste gases. Air purification.

Practical experience

Treatment of industrial waste gases—used in coal and oil-fired power station, steel, coke, non-ferrous metal, cement, chemical and fibreglass industries. Flue gas purification in waste incineration and wastewater purification. Two-stage system used in

work-place air purification (recirculation), and in small-scale gas decontamination, e.g. grinding processes, food industries, softeners in textile and plastics industry.

5. GAS CYCLONES

Principle of the process

Gas is blown or sucked through the cyclone, separating into an upper and lower stream according to the difference in particle size and specific mass.

Aim of processing, pollution(s), waste stream(s)

To remove/concentrate impurities by separating solid particles and/or liquid droplets with a specified particle size, from the gas phase. The separated particles may be wholly, partially or not polluted.

Technological preconditions

Influent concentration

0.001–1 kg dry matter/m³ gas, 0.02–0.5 g/m³ for droplet separation.

Temperature

Up to 1000° C

Pressure

No effect on process.

Additives

Water sometimes sprinkled in the cyclone to increase efficiency by causing agglomeration.

Capacity

Average 10000 m³ gas/hour

Others

Particle size > 200 µm require pre-separation. Constant input gas speed and particle concentration for maximum efficiency. Volatile impurities unsuitable.

Performance

Removal rate

80–99%, less if particle size < 2 µm

Volume-flux

Input air 6–15 m/s

Energy consumption

0.25–1.5 kWh/1000 m³

Emissions

Can occur depending on cyclone efficiency.

Bottlenecks

Blockages can occur, often due to too high moisture content or partially smolten particles.

Costs

Investment

Capacity 9000 m³/h—Dfl 9000

Operation

Dfl 0.10–0.30/1000 m³ air

Range of applications

Separation of solid matter from gas stream.

Practical experience

Many examples, including fly ash, non-metallic minerals, steel, chemical process and petroleum industries, incinerators (household waste), carbon treatment (thermal drying), general industrial applications.

6. ACTIVATED CARBON ADSORPTION IN AIR PURIFICATION

Principle of the process

Impurities are adsorbed by activated carbon in granular or fibrous form, the impurity being eventually concentrated in the activated carbon, in a condensate stream or gas stream. At a certain degree of saturation, the activated carbon is either replaced or regenerated using steam, hot gas, air or vacuum.

Aim of processing, pollution(s), waste stream(s)

To separate and concentrate organic matter (usually volatile organic substances), H₂S, SO₂, CS₂ from waste gases.

Technological preconditions

Influent concentration

Without activated carbon regeneration < 10mg/m³ gas.
With activated carbon regeneration 10mg–1000g/m³.

Temperature

0–40° C

Additives

Activated carbon—in separation of VOS, with regeneration of carbon, 0.5–1 kg/ton solvent. In odour removal, without regeneration, 2–5 kg/kg odour component.

Capacity

< 5000 → 20000 m³/h

Others

Non-explosive matter. Moisture content 0–70%.

Performance

Removal rate

95–> 99%

Volume-flux

350–1500 m³/h/m² absorber surface

Effluent concentration

For odour removal < 1 mg/m³. For volatile organic substances < 20–100 mg/m³.

Energy consumption

100–200 kWh/ton VOS

Emissions

To water if steam desorption used and separated impurity is water soluble. Condensate from regeneration, or waste carbon.

Bottlenecks

Non-desorbable impurities. Volatility > 70% lowers adsorption capacity. Heat of chemical reactions can cause adsorber burning.

Costs

For odour removal, without activated carbon regeneration. Investment

Carbon grains Dfl 4/kg. Installation Dfl 1000 - 3000 for gas stream of 1000 m³/h

Operation

Dfl 1–2/1000 m³ gas

For separation of VOS, with regeneration.

Investment

Dfl 10–150/m³ gas

Operation

Dfl 1.50–6.80/1000 m³ gas

Range of applications

Deodorization of waste gases. Reclamation of volatile organic substances from waste gases.

Practical experience

Deodorization: removal of amines, ammonia, alcohols, mercaptans, etc in chemical, foodstuff and pharmaceutical industries, bio-industry, air-conditioning, kitchens, etc. Reclamation of VOS: used in production of films, fibres and lacquer, chemical cleaning, chemical industry, etc.

**7 . F L U E G A S
S C R U B B I N G**

Principle of the process

Impurities in flue gas are absorbed in a watery solution or suspension. Depending on the composition of the solution, neutralisation or oxidation can take place. In some cases the added chemicals can be regenerated and reused.

Aim of processing, pollution(s), waste stream(s)

To separate and destroy or concentrate acid components, SO₂, HCl, HF and NO_x from flue gases.

Technological preconditions

Influent concentration

1000–10 000 mg/m³

Temperature

< 100° C, usually 40–80° C

Pressure

Atmospheric

Additives

CaCO₃, CaO (Ca(OH)₂) for neutralisation

Capacity

< 50000–2000000 m³/h

Performance

Removal rate

85–90%. In waste incineration (HCl, HF) > 90%.

Volume-flux

104–2106 m³/h

Energy consumption

20 kWh/ton waste (3kWh/1000 Nm³ flue gas)

Emissions

Reaction products (solid), waste water from scrubber, non-chemically-bounded acid components may be emitted to air.

Bottlenecks

Corrosion and erosion of equipment, deposits in sprinklers, and heat exchangers.

Costs

For flue gas desulphurisation

Operation

0.5–1 ct/kWh (Dfl 1/kg SO₂)

For HCl removal from waste incineration

Operation

Dfl 30–45/ton waste (5–1/1000 m³ flue gas).

Range of applications

Household, chemical and industrial waste incineration. Desulphurisation in coal-fired power stations and oil fired industrial plants.

Practical experience

Flue gas desulphurisation in electrical power stations: 6 plants in the Netherlands capacity 300–640 MWe. Wellman-Lord desulphurisation plants: 33 plants in operation. Used in oil-fired industrial plants. Wet scrubbers predominantly used in coal-fired installations

8. GAS SCRUBBING

Principle of the process

The impurity is dissolved (absorbed) and concentrated in the scrubbing liquid. The liquid is then treated by thermal desorption, rectification, pressure reduction or stripping, to remove the impurity, and can be reused. Additives may be needed to improve the solubility of the impurity (chemical scrubbing).

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate contaminants including organic substances, SO₂, NO_x, HCl, HF, NH₃, Cl₂, H₂S, SiF₄, Br₂, CO and CO₂ from waste gas.

Technological preconditions

Influent concentration

< 1 mg/m³–100 g/m³

pH-range

Acid, neutral or alkaline liquids used according to the impurity to be removed.

Temperature

Up to > 100° C, usually 20–40° C.

Pressure

Usually atmospheric.

Additives

Scrubbing liquid—water or organic liquids e.g. glycols, paraffin oils. For chemical scrubbing, solutions of bases, acids, ammonia in water. Chemicals to improve solubility of impurity.

Capacity

< 10 000–> 100 000 m³/h.

Others

Impurity must be highly soluble in scrubbing liquid, e.g. Henry coefficient < 0.1 x 10³.

Performance

Removal rate

75–99%

Volume-flux

0.3–2.5 m/s.

Effluent concentration

< 10 mg/m³.

Energy consumption

Electricity—0.1–10 kWh/1000 m³ gas. Heat—up to 5 m³ natural gas/1000 m³ gas.

Emissions

Polluted scrubbing liquid and vapours.

Bottlenecks

Blockages in scrubbing liquid recirculation process. Gas containing sticky particles.

Costs

Investment

System without recovery Dfl 10–30 m³ gas. System with recovery Dfl 30–200/m³ gas.

Operation

Dfl 0.5–> 5/1000 m³ gas.

Range of applications

Purification of industrial waste gases.

Practical experience

Used in the chemical, mining, paper, fertiliser, metal working, food and leisure industries, laboratories, incinerators, sulphuric acid manufacture, and odour removal.

9. THERMAL AFTERBURNING

Principle of the process

Combustible components in waste gases react with oxygen at high temperatures to produce CO₂, H₂O and other products. The output gas is passed through a heat exchanger to partially preheat incoming gas.

Aim of processing, pollution(s), waste stream(s)

To destroy components such as organic substances, H₂S, CO, NH₃, COS, CS₂, H₂ and HCN in waste gases. In principle all gaseous compounds containing C, H, N or S which react with oxygen at 600–2000° C can be treated.

Technological preconditions

Influent concentration

Max. concentration of combustible components 25% of lower explosion limit, i.e. for hydrocarbons 10–2-gC/m³ gas.

Temperature

Input gas usually < 300° C, raised to 500° C in heat exchanger, 600–1200° C in combustion chamber.

Pressure

Atmospheric.

Additives

Fuel to produce 0–2000 kJ/m³ gas. Combustion air 10 m³/m³ natural gas or kg oil.

Capacity

< 5000–> 20000 m³/h.

Others

Oxygen content 10–100% higher than necessary for combustion of the contaminant.

Performance

Removal rate

> 99%.

Effluent concentration

CO < 100–1000 mg/m³. Hydrocarbons < 20–50 mg C/m³. NO_x < 40–200 mg/m³.

Energy consumption

Electricity 0.001–0.003 kWh/m³ gas. Fuel 0–2000 kJ/m³ gas depending on degree of heat exchanger use.

Emissions

Exhaust gas treatment necessary to prevent excessive amounts of organic compounds, Co, NO_x, SO₂, HCl, HF, CO₂ etc.

Bottlenecks

Inert and combustible solid particles (dust, soot and coke).

Costs

Investment

Capacity 5000 m³/h, Dfl 60–150/m³/h. Capacity 20000 m³/h, Dfl 25–70/m³/h.

Operation

Dfl 2.5–25/1000 m³ gas.

Range of applications

Treatment of industrial waste gases.

Practical experience

Used in chemical, petrochemical and refining processes, surface treatment processes, solvent processes, food and leisure industry, treatment of household, industrial, slaughterhouse waste, soil cleaning, etc. Thermal afterburning of vapour/gas mixtures emitted from storage and transport operation for pumping of toxic volatile organic compounds (acrylonitrile, ethylene dichloride, benzene).

Pump capacity 1,000 m³ fluid/h.

Investment

Dfl 6 900 000 (1986)

Operation

Dfl 1–5/m³ fluid.

10. CATALYTIC AFTERBURNING

Principle of the process

Oxidation of contaminants is speeded up by the use of a catalyst, so that the reaction can take place at a reduced temperature. The reactants are adsorbed onto the catalyst surface, oxidation takes

place at the phase boundary, and the catalyst surface is free for further oxidation.

Aim of processing, pollution(s), waste stream(s)

To destroy harmful components found in waste gases. Contaminants include organic substances, CO₂, H₂S, CS₂, COS, SO₂, H₂, O₃, HCN, NH₃, and NO_x.

Technological preconditions

Influent concentration

Maximum generally 10–20 gC/m³ gas.

Temperature

Maximum 900° C for alumino-silicate catalysts. Maximum 600° C for gamma-aluminium oxide.

Pressure

In afterburner usually atmospheric. Pressure drop in catalyser 0.1–0.5 kPa.

Additives

Fuel—air for combustion ca. 10 m³/m³ fuel gas. Catalyst—active components metals from platinum series and oxides of less inert metals. For selective catalytic reduction of NO_x approx. 0.65 kg NH₃/kg NO_x.

Capacity

< 2000–> 20000 m³/h.

Others

Calorific value of waste < 750 kJ/m³ (ca. 35% of LEL). Remove particles by pretreatment (filtration) if more than 2g/m³ gas.

Performance

Removal rate

90–99.9%.

Effluent concentration

Hydrocarbons < 200 mgC/m³. CO negligible.

Energy consumption

Electricity 0.001–0.002 kWh/m³ gas. Fuel 0–1000 kJ/m³ gas (depends on degree of heat recovery and calorific value of contaminants).

Emissions

NO_x < 15 ppm, CO₂, solid residue containing (heavy) metals.

Bottlenecks

Blockages by dust, fibres, highly-polymerised; organic compounds, soot, ash and metal oxides. Efficiency is reduced as catalyst ages (replacement) necessary after 2–5 years.

Costs

Investment

Catalytic afterburner Dfl 30–60/m³/h. Catalyst material Dfl 3–35/m³/h.

Operation

Dfl 2.50–20/1000 m³ gas.

Range of applications

Treatment of waste process gases, and emissions from combustion engines.

Practical experience

Used in treating waste gases from solvent processing industries, sludge processing, food and leisure industries, desulphurisation works (Claus units), treatment of hydrocarbons, combustion engines, incinerators and chemical industries.

11. FABRIC FILTRATION

Principle of the process

Waste gases are passed through woven or felt-type fabric filters, trapping solid particles. Filter operation is based on the tendency of particles to adhere to filter fibres and other particles. The particles are then removed from the filter fabric and can often be reused.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate and recover solid particles from waste gases. Particles may be organic, inorganic or metallic.

Technological preconditions

Influent concentration

Up to 200 g/m³. At concentrations > 50 g/m³ mechanical separation techniques are used first.

Temperature

Up to 450° C depending on filter material.

Pressure

Usually atmospheric. Pressure drop across filter 0.5– 2 kPa.

Additives

Filter fabric, precoating material if necessary (e.g. calcium, aluminium oxide, pulverised coal).

Capacity

< 1000–> 100000 m³/h.

Others

Particle diameter > 0.01 µm.

Performance

Removal rate

95–99%.

Effluent concentration

1–75 mg/m³.

Energy consumption

0.5–2.0 kWh/1000 m³ gas.

Emissions

Solid residue of trapped particles—often recovered for reuse.

Bottlenecks

Filter blockage by sticky, hygroscopic, strongly agglomerated and/or small particles or at temperatures around the dew point. (e.g. at process start-up).

Costs

Investment

Dfl 3–25/m³ gas/h. Higher if system is thermally insulated in stainless steel, or if special fabric filter required.

Operation

Dfl 0.50–3/1000 m³ gas.

Range of applications

Treatment of gases from industrial processes and incineration.

Practical experience

Widely used.

12. SELECTIVE CATALYTIC REDUCTION (for NO_x control in combustion processes)

Principle of the process

Ammonia, usually in solution, reacts with nitrogen oxides to produce molecular nitrogen and water vapour, as follows: 4NO + 4NH₃ + O₂ implies 4N₂ + 6H₂O 6NO₂ + 8NH₃ implies 7N₂ + 12H₂O. In the presence of a metallic oxide catalyst, e.g. vanadium pentoxide or tungsten trioxide, the reaction takes place at a lower temperature (250–400° C).

Aim of processing, pollution(s), waste stream(s)

To convert NO and NO₂ in flue gases into N₂ and H₂O.

Technological preconditions

Influent concentration

No strict limits, but in practice: NO_x 600–2000 mg/m³ (at 2.5% O₂); SO₂ 700–2600 mg/m³ (at 2.5% O₂); high dust 5–25 g/m³; low dust 0.01 g/m³.

Temperature

250–400° C. Low temperature units (180° C) under construction.

Pressure

Usually atmospheric or slight over pressure (tenths of bar).

Additives

Ammonia (gas) ca. 0.37 ton/ton NO_x. 25% ammonia (solution) ca. 1.1 ton/ton NO_x. Catalyst ca. 11-12 ton/year.

Capacity

Power stations up to 2000000 m³/h. Waste incineration 100-130 m³/h.

Performance

Removal rate

75-90%.

Effluent concentration

Existing installations 100-200 mg/m³ NO_x. New installations 70 mg/m³. Pilot plants 20-70 mg/m³.

Energy consumption

6000-10000 kWh/ton NO_x. Estimate for low-dust installation in waste incineration 1400 kWh/h incl. 3-6 t/h steam.

Emissions

N, H₂O plus N₂O if reaction temperature too high. Ammonia max. 5 mg/m³. Solid residues—ammonium sulphate and bisulphate. Fly ash. Spent catalyst.

Bottlenecks

Irregular distribution of NO_x in flue gas. Deposition of ammonium salts or fly ash in pipes. Blockage of catalyst pores. Equipment erosion in high-dust units.

Costs

Power stations

Investment

DM 66.3/kW

Operation

DM 100-170/kW.

Waste incineration

Investment (estimated)

Dfl 8000 - 13000/ton NO_x removed (Dfl 6000 for activated carbon catalytic reduction).

Range of applications

Treatment of flue gas from power stations and waste incineration installations.

Practical experience

Power stations—used in Germany, Switzerland, Austria, Japan, Netherlands. EPON (Nijmegen)—coal-fired power station, manufacturer ESTS, 65MW, flue gas consumption 210000 nm³/h, honeycomb catalyst, removal rate 76% (planned 80%). Waste incineration plant: Vienna-Spittelau in operation since

1990, also DSM (acrylonitrile works), others planned or under construction.

13. COMPOSTING

Principle of the process

Composting is the aerobic biological degradation of organic waste resulting in a usable product (compost).

Aim of processing, pollution(s), waste stream(s)

To obtain an organic compost, reduce the volume of waste and destroy weeds and disease germs in organic waste.

Technological preconditions

pH range

Initially 5-5.5, rising to 9 then falling to 7-8.

Temperature

Rises to 55-80° C during heating phase.

Additives

Depending on consistency of waste—dry matter, bulk (e.g. wood shavings), straw and paper.

Capacity

Examples of closed system: DANO-system 30-90 ton/day; Thyssen Engineering max. 300 ton/day.

Others

C/N ratio < 30 depending on composition of waste. Size of heap up to 4-5 m high. Oxygen required for microbial activity. Dry matter content at least 40%. Moisture content 30-70% (average 40-50%). 20-80% organic material in waste.

Performance

Compost yield

40-50% of starting material.

Emissions

CO₂ and H₂O from degradation process. Waste paper etc may be blown by wind. Heavy metals and non-biodegradable compounds leached into soil and percolation water. Ammonia gas emission, sometimes H₂S and mercaptans if anaerobic zones are formed.

Bottlenecks

Porosity too low. Insufficient aeration.

Costs

Operation

Household waste Dfl 30-1100/ton; vegetable, fruit and garden waste Dfl 140/ton; closed rotary drum method Dfl 100/ton.

Range of applications

Reduction of organic household and garden waste.

Practical experience

Open system—heaps e.g. Beltsville, Rutgers University. Closed systems cell systems—Kneer reactor, household waste and slurry, 10 - 14 days & 8 weeks maturing. Drum systems—e.g. DANO small capacity, 3-6 days. Multifloor systems—e.g. Multibacto and Carel-Fouche, 2-6 days.

14. ELECTROLYTIC SEPARATION OF METALS

Principle of the process

Using two electrodes connected to a direct voltage source, an electric current is passed through the waste water. Electrochemical reactions occur at the electrodes whereby at the anode chemical substances are oxidised and at the cathode metal ions are reduced as metal.

Aim of processing, pollution(s), waste stream(s)

Removal of impurities and concentration of impurities from polluted water, liquid waste and slurry. Metals, metalloids and their compounds may be separated.

Technological preconditions

Influent concentration

≥ 0.1 mg/l. Upper limit depends on solubility of metal.

pH range

> 5.

Additives

Sometimes necessary to alter pH

Capacity

1-10 m³/h.

Others

Presence of salts for good conductivity.

Performance

Removal rate

> 99.9%.

Volume-flux

1-3 m³/h

Effluent concentration

< 0.1 ppm-100 ppm.

Factor concentration (i.e. concentrate concentration influent)

1-10.

Energy consumption

10.1-10 kWh/m³.

Emissions

Salts, acids present in waste water. Hydrogen, oxygen and chlorine depending on waste content.

Costs

Investment

Capacity 1 m³/h Dfl 100000

Operation

10 m³/day wastewater containing 100ppm Cu(II) purified to 1 ppm Dfl 3.00-Dfl 5.50.

Benefits

Some metals, e.g. silver in photographic industry, can be reused.

Range of applications

Obtaining metals from raw materials, surface treatment of metals and reclaiming metals.

Practical experience

Obtaining metals from raw materials: electrorefining of Al, Na, Li, Mg from molten salts; Cu, Zn and others from solutions in water. Surface treatment: metals in galvanic industry; layers of pure metals, alloys and composites (metals containing PTFE or WC2). Reclaiming metals: Hg, Cd from batteries; Ni, Pt etc. from catalyats; Au, Pt, Ag from precious metal working and photographic industry; Cu, Ni, Zn, Cd, Pb and Co from rinsing water from galvanic industry.

15. LEACHING WITH ACID/ALKALI/ COMPLEXING AGENTS (dissolving)

Principle of the process

Impurities are dissolved from solid waste using water, acid, alkali, complexing or oxidising solvents. They can then be removed from the solvent and both impurities and purified solid may be reused.

Aim of processing, pollution(s), waste stream(s)

To remove/concentrate impurities from solid waste in powder, granular or pellet form, generally inorganic, metallic and not inert. In principle all inorganic compounds, and certain organic salts, acids and bases can be removed.

Technological preconditions

Influent concentration

No upper or lower limits.

pH range

No limits set.

16. SOLVENT EXTRACTION

Temperature

Generally room temperature, 20° C. Can be raised to boiling point of solvent. In pressure-suspension system, temperatures of 90–250° C are used.

Pressure

For percolation and suspension systems—atmospheric. For pressure-suspension systems—up to 2000 kPa.

Additives

Solvent depending on compound to be dissolved. Acid, alkali, complexing agent, water, oxidising solvents may be used.

Capacity

Ranges from grams to hundreds of tons per hour.

Others

Fluid content must be reduced if suspension or slurry is to be processed.

Performance

Removal rate

95%.

Effluent concentration

Optimally a few ppm.

Energy consumption

Low unless carried out at high temperature.

Emissions

Some harmful gas may be produced in pressure-suspension system.

Costs

Depend on type and quantity of chemicals used. Example: removing Al from fluidized bed from coal-combustion:

Investments:

Dfl 270 k

Operation

Dfl 70,581 k/year (Dfl 441.13/ton ash).

Benefits

Reuse of sulphuric acid reduces costs.

Range of applications

Obtaining metals from ores and waste.

Practical experience

Obtaining metals from ore: widely used. Recovery of metals from waste: Hoboken-Overpelt Co. Ni, Cu, Cd, Zn, etc. Metal waste from metal-working industries. Hydroxide sludge. Research into treatment of coal ash, spent catalyst, batteries & electronic waste.

Principle of the process

Impurities, mainly metal ions, are separated from a water phase and concentrated. The result of the solvent extraction process is a second stream of water containing the extracted component(s). After treatment of this stream to separate the desired components, the fluid can be reused.

Aim of processing, pollution(s), waste stream(s)

To remove/concentrate metals and their compounds (excluding alkali (earth) metals) metalloids and their compounds and acids from wastewater and liquid waste.

Technological preconditions

Influent concentration

No limits in principle

pH range

< 0 -> 10 depending on extractant used.

Temperature

Generally 20–60° C.

Pressure

Atmospheric.

Additives

Extractant, solvent and additives comprising the organic phase acids, bases or salts for regenerating extraction medium. Oxidising or reducing agents or complexing agents to extract the separated impurities.

Capacity

Mixer-settler combination 0.2–2000 m³/hour. Separators and centrifugal extractors 1–180 m³/hour. Column extractors 0.1–6000 m³/hour.

Performance

Removal rate

60–99%.

Effluent concentrations:

ppm level.

Energy consumption

Centrifugal extractor 0.25–9 kW/m³. Column extractor 0.1–0.3 kW/m³. Mixer-settler combination 0.2–0.8 kW/m³.

Emissions

Treated fluid and regeneration fluid.

Bottlenecks

Suspended particles, precipitation of e.g. iron hydroxide, calcium sulphate and manganese oxide.

Explicit plus-points

High selectivity possible.

Costs

Depend greatly on apparatus type, extractant and process conditions.

Investment

US\$ 60–200k (1974).

Operation

US\$ 1000–2000/1000 m³ water (1974).

Range of applications

Extraction of metals, recovery of metals from waste water, ash, spent catalysts and batteries.

Practical experience

Extraction of metals such as copper and gold. Recovery of metals from waste: from metalworking operations, galvanisation and metallurgical industries. Separation of zinc from rayon manufacture waste: AKZO (Fibre and Polymer Division), capacity 40 m³/hour, Zn concentration influent 800 mg/l, effluent 15–20 mg/l. Solvent Solvesso 15 and extractant DEHPA.

17. PRECIPITATION

Principle of the process

A chemical process in which components are separated from waste water by forming an insoluble compound with an additive.

Aim of processing, pollution(s), waste stream(s)

To remove/concentrate substances such as alkaline earth metals, heavy metals, semi-precious and precious metals, other metals, metalloids and their compounds from waste water.

Technological preconditions

Influent concentration

No limits specified.

pH range

Depends on the effect of pH on compound solubility. Generally not acid.

Temperature:

Usually 0–25° C.

Pressure

Not applicable.

Additives

Substance required to form insoluble compound with desired impurity. Others may be required to alter pH or break down sequestering agents.

Capacity

Can be carried out on any scale.

Performance

Removal rate

Over 99.5%.

Process time

< 1 min. to several hours depending on distribution of solids.

Effluent concentration

A few mg/l (depending on treatment process).

Energy consumption

Low.

Emissions

Besides precipitated substances, emissions to air can occur depending on chemicals used.

Bottlenecks

Pipework blockages, e.g. by calcium deposits, formation of undesired insoluble products.

Costs

Depend on technique, chemicals used and waste concentration. Examples:

For waste water containing 113 mg/l Zn.

Investment

Dfl 200k (1978)

Operation

Dfl 0.29/m³

For concentrated chemical waste.

Operation

Dfl 100–3000/ton waste (1989). Dfl 300–400/ton on the average

Range of applications

Separation and recovery of metals and metalloids from waste water and liquid waste.

Practical experience

Treatment of waste water containing metals from metals and surface treatment industries. Separation of cadmium from

waste water. Water purification—reducing hardness of drinking water and removal of phosphates. Precipitation of gold by reduction with Fe(II) sulphate solution. Cementation of copper or lead with iron.

18. IMMOBILISATION

Principle of the process

Immobilisation is the solidification of liquid waste products by physical confinement, often preceded by chemical stabilisation of the impurities.

Aim of processing, pollution(s), waste stream(s)

To solidify impurities with a view to removing or reusing waste products. Impurities are generally inorganic and ionogenic such as metal and metalloid compounds and inorganic salts, acids and bases. Soil, slurry, silt and solid or liquid waste can be treated.

Technological preconditions

Influent concentration

Too low to be otherwise recovered but too high to be safely dumped.

pH range

6–11.

Temperature

Physical confinement 10–20° C. Chemical stabilisation up to 50° C.

Pressure

Atmospheric.

Additives

Binding agents such as lime, cement and fly ash 100 to 1000 kg/ton. Chemical stabilisers such as acids, bases, oxidising reducing or precipitation agents are in the region of kg per ton.

Capacity

10–400 m³/hour.

Others

Minimal moisture content desired (usually 10–50%) but liquid waste can be immobilised if extra binding agents are used. Concentration of organic components is < 20–30%.

Performance

Affluent concentrations

Similar to influent concentration

Energy consumption

Max. 3kWh/ton for capacity 100 ton waste/day.

Emissions

In some cases small amounts of volatile organic components.

Bottlenecks

Blockages in transport system.

Process time

Mixing time 2–5 minutes, hardening time several days to several weeks.

Costs

For capacity of 20000 ton waste/year

Investment

Dfl 10 M.

Operation

Dfl 205/ton waste (Dfl 4,100 k/year)

Dumping costs

Dfl 100–350/ton immobilisate

Range of applications

Treatment of industrial waste. Water purification.

Practical experience

Treatment of soil containing heavy metals, cyanide or oils; solid matter such as spent catalysts, fly ash, asbestos waste; slurries, silts and filter beds including harbour silt, hydroxide silt, waste from pharmaceutical, printing and dye industries and water purification installations; liquid waste, mainly containing acids and metal (ions). Capacities range from 10000 to 100000 tons/year.

19. GRINDING / SIZE REDUCTION

Principle of the process

Reduction of the particle size of solid materials, to enable optimal suitability for further processing and lowering of transport costs. The term grinding is used for particle reduction to a size of < 5 mm.

Aim of processing, pollution(s), waste stream(s)

To reduce the particle size of a solid, non-elastic, low ductility material, with starting size over 10 mm.

Technological preconditions

Influent concentration

Not applicable as components not separated.

Additives

Water if wet grinding is required. Graphite, oily liquids, volatile substances and water vapour among others.

Capacity

Up to 250 ton/h.

Others

Damp/wet material preferred.

Performance

Reduction ratio

4:1 to 100:1 depending on process. Final particle size: 1 cm to < 10 µm

Energy consumption

0.5–10 kWh/ton (higher for ultrafine reduction)

Emissions

Sometimes vapour and dust.

Bottlenecks

Blockage of mill grating.

Costs

Investment

Capacity 5 ton/h Dfl 500 k. Capacity 200 ton/h Dfl 1000.

Operation

Capacity 5 ton/h Dfl 15.03/ton. Capacity 200 ton/h Dfl 1.10/ton.

Benefits

Lower transport costs of waste.

Range of applications

Reduction of waste prior to recycling

Practical experience

Waste from building and demolition work, car breaking, household waste, packaging, hospital waste, wood, vehicle tyres. Research into use in recycling of batteries.

20. PYROLYSIS

Principle of the process

Pyrolysis is the thermal splitting of organic materials in the absence of oxygen. With the rise in temperature, water and organic matter is evaporated, followed by the splitting of higher hydrocarbons into lower hydrocarbons.

Aim of processing, pollution(s), waste stream(s)

To remove impurities from solid, liquid, chemical or sil/slurry waste. This can lead to a reduction in dumping volume, and the production of energy carriers in the form of pyrolysis gas and cokes, and (petro) chemical raw materials (pyrolysis oil/tar).

Technological preconditions

Influent concentration

Varies by substance, e.g. maximum hydrocarbons 100%, maximum Cl, S, N, F < 1%.

Temperature

500–1000° C.

Pressure

Autoclave processes 10–100 bar, other processes atmospheric.

Additives

Sometimes fuel, air, additional material to prevent sintering cleaning agents.

Capacity

< 20000–>100000 ton/year.

Performance

Removal rate

> 99%

Effluent concentration

Depends on composition of waste and varies by substance.

Energy consumption

5–20 KWe/MWth of waste.

Process time

Up to 120 minutes depending on reactor type

Emissions

Pyrolysis gases, rinsing water.

Bottlenecks

Blockages and corrosion by deposits. Sintering at high temperatures.

Costs

Varies according to reactor type and capacity. Example: fluidized bed reactor, capacity 15000 ton/year.

Operation

Dfl 356/ton

Benefits

Dfl 404/ton.

Range of applications

Treatment of organic waste.

Practical experience

Treatment of household, industrial, hospital, agricultural and forestry waste including tyres and plastics

21. THERMAL PROCESSING IN ROTARY DRUM KILN

Principle of the process

As waste matter is heated in a rotary drum kiln to temperatures of up to 1200° C water and organic matter is evaporated. Further organic matter and solid carbon burn in the kiln and the post-combustion chamber, and the non-combustible components (sand, ash, slag) remain in solid form.

Aim of processing, pollution(s), waste stream(s)

To remove or destroy harmful or unusable organic impurities in polluted soil, solid or liquid waste, sludge and slurries, thus reducing the volume of solid residue. In some cases the released energy can be utilised. Impurities may include pesticides, dioxins, oils and benzene. Waste includes metal components, tyres, and filter cake.

Technological preconditions

Impurity concentration

Polluted soil/water < 1%. Solid and liquid waste including slurry > 50 - > 99%. Limits on certain substances.

Temperature

900-1300° C.

Pressure

Atmospheric.

Additives

Fuels, air and cleaning agents.

Capacity

< 3- > 12 tons/hour.

Others

No explosive or radioactive material. Certain other substances limited.

Performance

Removal rate

99.999%.

Process time

Volatile substances 5 seconds in rotary kiln and post-combustion chamber. Solid substances 30- 90 minutes in rotary kiln and post-combustion chamber.

Effluent concentration

Depends on substance.

Energy consumption

3-4 KWe/MWth.

Emissions

Besides solid residue, concentrations of emissions to water, air and soil are less than the AVR recommended maximum. Treatment of combustion gas is necessary.

Bottlenecks

Inert and combustible solids (dust, soot, coke).

Explicit plus-points

Energy can be recovered in some cases. No pre-treatment of waste necessary. No strict requirements for waste.

Costs

Depend on installation size.

Investment

Dfl 8-60 M.

Operation

Dfl 60-270/ton waste (lowest at higher capacity).

Benefits

Dfl 0-210/ton.

Range of applications

Treatment of industrial waste with chemical impurity content.

Practical experience

Example: AVR Chemie capacity 6 ton/hour

Investment

Dfl 80 M.

Net costs

Dfl 500/ton.

22. DRYING

Principle of the process

Air is heated, then passed through paper and plastic waste, removing the water content in the form of vapour.

Aim of processing, pollution(s), waste stream(s)

To remove the moisture content of paper and plastic layers from household waste. This reduces the potential for micro-organism development, and the solid residue may be used as refuse derived fuel.

Technological preconditions

Moisture content

Paper 50-55%. Plastic 20-25%

Temperature:

Air input 350-400° C for paper in drum dryer. 100° C for plastic in belt dryer.

Pressure

Atmospheric.

Additives

None.

Capacity

Drum dryer 100 kg/h to 300 ton/h. Usual capacity for paper fraction is 4 ton/h.

Performance

Removal rate

100%.

Drying time

5-10 minutes.

Final moisture content

Plastic 0%. Paper usually dried to normal 10% moisture content.

Energy consumption

Per ton dried paper—115 m³ natural gas, 30 kWh electricity (125 m³ natural gas equivalent). No data available for plastics.

Emissions

Water vapour and dust.

Bottlenecks

Accidental combustion caused by sparks.

Costs

Investment

Capacity 4 ton/h drum dryer Dfl 460000.

Operation

Dfl 56 per ton.

Range of applications

Treatment of household waste.

Practical experience

Treatment of household waste: drying paper waste in drum dryer, capacity 4 ton/h, process time 30 minutes; drying plastic foil waste in belt dryer, capacity 0.4 ton/h, drying time 70 minutes.

2 3 . D I S T I L L A T I O N

Principle of the process

Distillation is a method of separating two or more components with different boiling points/volatility. The mixture is heated until one component evaporates and can be removed and condensed. The process can be repeated as different fractions are released from the mixture.

Aim of processing, pollution(s), waste stream(s)

To separate organic compounds or mixtures of organic compounds and water, from organic fluid waste and polluted water.

Technological preconditions

Influent concentration

Depend on differences in boiling points of fractions.

pH range

Only significant in connection with corrosion degree of apparatus.

Temperature

Generally 35-300° C, depending on boiling point of least volatile component.

Pressure

0.01-2 bar.

Additives

Used in azeotropic and extractive distillation only.

Capacity

1000 to 10000 ton/year.

Others

Material should be thermally stable.

Performance

Removal rate

< 75%—> 90%.

Effluent concentration

0.01% or ppm region achievable, depending on differences in boiling points of fractions.

Energy consumption

Depends on type and concentration of components.

Emissions

Besides recovered components and residue, none.

Bottlenecks

Presence of solid matter, viscous or solid residue, polymerisation of components.

Costs

Operation

Dfl 400-600/ton.

Treatment of residue

Dfl 400-700/ton.

Range of applications

Treatment of organic waste. Water purification.

Practical experience

Treatment of organic waste: halogenated hydrocarbons used as degreasing agents or solvents, non-chlorinated solvents such as alcohols and esters, oils such as motor oils. Purification of water from production of dichloromethane, chloroform, freon 113, 1,2-dichloropropane, etc., using steam stripping.

24. SIEVING OF WASTE MATTER (DRY)

Principle of the process

Particles are separated according to size by passing through a sieve, while the particles are moving in relation to the sieve.

Aim of processing, pollution(s), waste stream(s)

To separate particles according to size, in order to remove impurities from solid waste, to concentrate particle size fractions for further processing or to fabricate fractions according to specifications.

Technological preconditions*Particle size*

0.5 mm to 0.5 m.

Moisture content

Material should not be wet, but up to 40% moisture is possible in naturally moist matter e.g. household waste.

Capacity

Up to 150 ton/h depending on type of material and particle size.

Performance*Volume reduction*

70-90% for construction waste.

Energy consumption

Flat sieve ca. 0.5 kWh/ton. Drum sieve 1-3 kWh/ton.

Emissions

Dust may be produced in addition to sieved matter.

Bottlenecks

Blockages in sieve mesh

Costs*Investment*

Dfl 40-700 k

Operation

Flat sieve capacity 100 ton/h Dfl 1 000/ton. Drum sieve capacity 25 ton/h Dfl 2 32/ton.

Range of applications

Separation and concentration of organic and inorganic fractions from solid waste

Practical experience

Used in treatment of household, construction and demolition, wood, industrial, shredder and industrial waste, compost and combustion residue, e.g. household waste, particle size 10-250 mm, capacity 10-15 ton/h.

25. HYDROCYCLONES

Principle of the process

A stream of matter in suspension enters the conical or cylindrical hydrocyclone tangentially, and centrifugal force causes heavier particles to gravitate downwards while lighter particles are separated upwards.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate solid impurities in suspension from polluted soil, water, sludge or slurry.

Technological preconditions*Influent concentration*

5-25% wt suspended matter

pH-range

Depends on material.

Pressure

Maximum 3 bar.

Additives

Water for dilution

Capacity

Depends on separation diameter. Diameter 10 μm , capacity 1 m³/h. Diameter 5 μm , capacity 100 m³/h.

Moisture content

Minimum 75%.

Others

Sieving necessary to prevent blockages. Separation diameter 5-250 μm at 2700 kg/m³ suspended matter.

Performance*Effluent concentration*

Dry matter content of upper stream 1-15%. Dry matter content of lower stream 60-85%.

Energy consumption

0.2-0.07 kWh/m³

Emissions

Washing water, slurry fractions (in some cases).

Bottlenecks

Blockages, wear of cyclone wall

Costs

Capacity 100 m³/hr.

Investment

Dfl. 400 - 500.

Operation

Dfl. 120-150/m³.

Capacity 1000 m³/hr.

Investment

Dfl. 1000-1600.

Operation

Dfl. 320-380/m³.

Range of applications

Water/liquid waste purification. Sand extraction. Sludge processing.

Practical experience

Used in: sand extraction, clay processing, food and processing industries; extractive soil purification (capacity tens of m³/hr); processing dredged sludge (capacity hundreds of m³/hr); waste-water purification; sewage sludge processing.

26. SIEVING OF SOIL

Principle of the process

Particles of different sizes are separated in a gravitational field using a sieve, sometimes with shaking or vibration of the sieve. Wet or dry methods are possible.

Aim of processing, pollution(s), waste stream(s)

To separate waste stream into two or more parts with different particle size distribution. Reasons include the removal of (large) particles which cause blockages or cannot be processed, separation of heavily polluted particles, optimal processing treatments and achieving desired product specifications.

Technological preconditions

Influent concentration

Unlimited for non-fluid impurities.

Additives

Some processes require water or air. Wet sieving 5-20 m³ water/m³ solid material. Other methods 1-5 m³ water/m³ solid material.

Capacity

1-50 m³/hr/m² sieve surface. For slurry maximum 100 m³/hr/m width of sieve.

Others

Avoid material which will 'stick' due to moisture, humus, tar, etc. content.

Performance

Sieve efficiency

90-95%. Wet sieving 95-99%.

Volume-flux

For slurry 3m³/s.

Effluent concentration

Depends on impurity distribution over different particle sizes.

Energy consumption

< 1 kWh/t soil (often < 0.1 kWh/t). Static sieving uses no energy.

Emissions

Particles of dust to air, soluble impurities to water.

Bottlenecks

Blockage of mesh by fibrous or adhesive particles, high moisture or clay content.

Costs

Investment

Up to Dfl. 25k/m² sieve surface.

Operation

Dry sieving, capacity 25 t/hr, Dfl. 0.99/t. Slurry sieving, capacity 60 m³ slurry/hr, Dfl. 0.13/m³.

Range of applications

Soil cleaning and separation of polluted particles.

Practical experience

Soil cleaning—particle size 100-300 mm using static or vibrating mesh sieves 40-100 mm using rod sieves, 5-40 mm using oscillating sieves. Separation of oil and sand in coastal pollution—influent concentration 5-30% wt. oil effluent concentration 0.25% wt. oil.

27. PROCESS - MODERATED EXTRACTIVE SOIL PURIFICATION

Principle of the process

The highly polluted fine fraction of the soil (diameter < 0.050 mm) is dissolved or dispersed in an extraction medium, which can then be separated by sedimentation or in a hydrocyclone. The extraction medium can be purified for reuse.

Aim of processing, pollution(s), waste stream(s)

To remove impurities such as heavy metals, cyanide, aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons and pesticides from sandy soil or sand containing peat or loam with a fine particle content of < 30%.

Technological preconditions**Influent concentration**

Content of fine particles (< 0.050 mm) 30%. Impurity content theoretically unlimited.

pH-range

For uncoated installation minimum pH 5 for coated installation minimum pH 2.

Temperature

0–100° C.

Pressure

Atmospheric. In high pressure water jet process 150–200 bar.

Additives

Releasing agents (e.g. soaps); pH regulator (e.g. HCL, FeCl₃); emulsifiers/demulsifiers (e.g. NaOH); coagulants (e.g. FeCl₃); flocculants (e.g. polyelectrolytes); 40–500 g NaOH/ton soil.

Capacity

< 10–> 20 ton/hr.

Others

Moisture content < 20% for clay soils.

Performance**Removal rate**

50–99%.

Effluent concentration

No limits set.

Energy consumption

20–30 kWh/ton soil. For thermocoil installations ca. 200 kWh/ton.

Emissions

Sometimes volatile components to air; water with high concentration of dissolved salts (ca. 200 g/m³, mostly sulphates).

Bottlenecks

Too much coarse matter can cause blockages; too much fine material can lengthen processing time.

Costs**Investment**

DN 2530–3950 K per year (88–101/ton).

Operation

DN 29.50–139/ton.

Range of applications

Purification of polluted soil and sand

Practical experience

High pressure water jet installation (Bodemsanering Nederland BV), capacity 150 t/day for oil, heavy metal, organochloride compounds and cyanide. Thermocoil installation (Ecotechniek)—cleaning fuel oil from coastal sand. Alkali extraction (Heymans Milicutechniek BV, Hollandse Wegerbouw Zanen BV). NaOH solution used. Acid extraction (Heymans).

28. FLOTATION OF CONTAMINATED SOIL**Principle of the process**

Contaminated soil is mixed with water to form a slurry with dry matter content 20–30%. Surface-active chemicals are added to develop differences in surface properties so that impurities will adsorb air. Air bubbles are passed through the mixture and the impurities adhere to the bubbles to form a foam layer which is then removed.

Aim of processing, pollution(s), waste stream(s)

In principle all types of components can be separated. In soil purification, has been used for removing Pb, Cu, cyanides, certain aromatic compounds, polycyclic hydrocarbons, chlorinated hydrocarbons and mineral oils.

Technological preconditions**Influent concentration**

No limits.

pH-range

3–11.

Temperature

Environmental temperature. If outdoors no more than a few degrees of frost.

Additives

Air as flotation gas; water 15%; chemicals (0.05–0.5 kg)—collectors; regulating reagents; frothers.

Capacity

15–30 ton/hr.

Others

Dry matter content 20–30%. Impurity grain diameter 0.5–1 mm, depending on grain density.

Performance**Removal rate**

Maximum 95–99%.

Effluent concentration

Depends on influent concentration and type of material, e.g.: cyanide 5 mg/kg; lead 50–150 mg/kg; oil 50 mg/kg.

Energy consumption
10-15 kWh/ton soil.

Emissions
Volatile impurities may be emitted to air.

Bottlenecks
Blockages can occur in pipes and sieves.

Costs
Depend on capacity and degree of difficulty, e.g. capacity 120,000 ton/yr (40 ton/hr)

Investment
Dfl. 6840.

Operation
Dfl. 100/ton.

Range of applications
Decontamination of soil.

Practical experience
Mosmans Mineraaltechniek BV—installation capacity 15 ton/hr plus pilot plant 0.5 ton/hr. Heidemij Uitvoering BV milieutechniek - two flotation installations with capacity 15-30 ton/hr. Jaartsveld & Groen Milieutechniek—no information.

29. THERMAL TREATMENT OF SOIL IN INCINERATORS

Principle of the process
After sieving (if necessary) soil is heated to 300-700 ° C, whereby cyanides and organic compounds are separated and evaporated, the vapour then being treated in an afterburner.

Aim of processing, pollution(s), waste stream(s)
To remove contaminants such as complex cyanides, oils, aromatic hydrocarbons, polycyclic aromatic hydrocarbons, phenols and alkylated benzenes from soil.

Technological preconditions
Influent concentration
Maximum a few %.

Temperature
300-700° C (usually 500-650° C)

Pressure
1 bar.

Additives
Fuels (oil, gas)

Capacity
5-50 ton/yr.

Moisture content
Maximum 35%.

Performance
Removal rate
> 99%.

Effluent concentration
A-values achieved for all components.

Energy consumption
3.1-70 liters oil/ton soil.

Emissions
CO₂, H₂O, sometimes HCl, SO₂, NO_x and other toxic components if chlorinated hydrocarbons present.

Costs
Operation
Dfl. 75-250/ton soil.

Range of applications
Cleaning of soil contaminated by chemical spillages or waste.

Practical experience
Cleaning of soil from around gas works, petrol stations from sites of leaky fuel tanks and soil contaminated with non-chlorinated pesticides. Use of rotary drum kilns with indirect, direct and combined direct and indirect heating. Fluidised bed method used in pilot plant (no longer operational).

30. SECONDARY COMBUSTION OF FLUE GAS IN SOIL DECONTAMINATION

Principle of the process
Gases produced during the thermal treatment of soil together with fuel (if necessary) and air are mixed together in the afterburner and heated to ignition. During combustion, harmful components are destroyed. If necessary, particle separation using cyclones or filters and gas scrubbing to remove remaining impurities, are undertaken before the gas is emitted.

Aim of processing, pollution(s), waste stream(s)
To convert harmful components remaining in flue gas after the thermal treatment of soil into non-harmful or less-harmful products. Impurities include aliphatic compounds, aromatic compounds, polycyclic hydrocarbons and chlorinated compounds.

Technological preconditions

Influent concentration

Must be between upper and lower explosion limits for the particular substance.

Temperature

For non-chlorinated pollutants 700° C or higher. For compounds difficult to decompose or toxic compounds > 1200° C.

Pressure

Atmospheric.

Additives

Fuel (oil or gas); air for combustion; caustic soda or calcium for gas scrubber.

Capacity

< 5000–> 20,000 m³/hr.

Others

Oxygen content 1–10%.

Performance

Removal rate

99–99.9999%.

Residence time

(in burner) 0.2–2 seconds

Effluent concentration

Very low concentrations possible.

Energy consumption

Fuel 0–2000 kJ/m³ gas depending on concentration of combustible components. Electricity 0.001–0.003 kWh/m³ gas.

Emissions

Exhaust gases; calcium or water from scrubbing, if used; and solid noncombustible particles.

Bottlenecks

Blockages may be caused by inert, non-combustible particles (dust, soot).

Costs

Investment

Dfl 45–70/m³ gas.

Operation

Dfl. 10–25/1000 m³ gas

Range of applications

Treatment of gases produced from thermal combustion of contaminated soil.

Practical experience

Used in treatment of soil contaminated with oil, polycyclic aromatic hydrocarbons, cyanides and non-chlorinated substances.

31. STEAM STRIPPING

Principle of the process

Contaminated soil is heated by contact with steam, either in-situ or ex-situ, whereby contaminants which are relatively volatile at about 100° C transfer to the vapour phase and are discharged together with the steam. The contaminants are then removed by condensation.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate volatile impurities, usually organic but also some inorganic e.g. NH₃, H₂S and Hg from soil.

Technological preconditions

Influent concentration

Theoretically no limits but other techniques more cost effective over 5% wt. concentrations.

Temperature

100° C (in-situ)–200° C (ex-situ), depending on pressure.

Pressure

In-situ: overpressure ca. 30 kPa, underpressure < 20 kPa. Ex-situ depends on equipment and material.

Additives

Steam e.g.: 0.1 kg/kg soil contaminated with perchloroethylene; 0.25 kg/kg soil contaminated with kerosene. Cooling medium (15–50 m³ water/ton steam).

Capacity

1–20 m³ soil/hr.

Others

In-situ process minimum depth 1–2 m. Unsuitable for clay soils or water-saturated soils.

Performance

Removal rate

Up to > 99% possible, often much less.

Effluent concentration

0.1 mg/kg–tens of mg/kg.

Energy consumption

3000 MJ to generate 1 ton steam. Actual consumption 10–20% higher.

Emissions

Condensate: emitted air can contain pollutants so purification necessary. In-situ methods potential percolation of polluted condensate.

Bottlenecks

Blockage by particles carried with steam; fatty components in cold parts of system e.g. condenser.

Costs

In-situ capacity 5 m³/hr

Investment

Dfl. 1380k.

Operation

Dfl. 143/m³

Ex-situ capacity 5 m³/hr

Investment

Dfl 2000k

Operation

Dfl. 216/m³

Range of applications

Purification of contaminated soil. Theoretically also solid, liquid and slurry waste.

Practical experience

Only in development and pilot-plant stage at present. In-situ: stratified soil with layers of cinders, clay, peat and sand. Lighter aromatic compounds 95-99% separated in sand and cinder layers, other pollutants 50-90% separation. 20-70% separation in peat and clay layers. Ex-situ: 40 kg batches of soil contaminated with perchloroethylene or kerosene, ca. 90% separation.

**3 2 . S U P E R C R I T I C A L
O X I D A T I O N**

Principle of the process

At high temperatures (500-700° C) and pressure (> 221 bar), organic materials are oxidised to form H₂O, CO₂ and other products. Inorganic salts and oxides are separated as sediment and other inorganic components such as sulphides and phosphor are converted to acids then deposited as salts.

Aim of processing, pollution(s), waste stream(s)

To convert toxic organic compounds found in chemical waste water, e.g. PCBs, DDT, lindane, dioxins to less harmful substances.

Technological preconditions

Influent concentration

Chemical oxygen consumption of material 110-310 g/l.

pH-range

Not important for process. Limited by material of reactor and heat exchanger.

Temperature

500-700° C.

Pressure

250 bar.

Additives

Oxygen/air, NHO₃ (for sediment separation), NaOH (to raise pH, prevent sediment formation).

Capacity

Only pilot-plant scale at present. 4-6 ton/day wastewater of which ca. 0.2 ton/day organic waste.

Performance

Removal rate

99.995% for PCBs; other components 99.5-100%.

Volume-flux

23 l/hr.

Energy consumption

Heat of reaction is recycled via a heat exchanger so little input energy required.

Emissions

Oxidation products, CO₂, H₂O and other gases, deposited salts.

Bottlenecks

Possible blockages by deposited salts.

Explicit plus-points

Closed system, no catalyst necessary, high oxidation speeds

Costs

Investment

Capacity 10 ton/day, US\$ 5M. Capacity 100 ton/day US\$ 15M.

Operation

Capacity 10 ton/day US\$ 650/m³. Capacity 100 ton/day US\$ 135/m³.

Range of applications

Purification of chemical wastewater. In principle also sludge and clay soils and waste streams that can be brought into suspension in water.

Practical experience

Modar—pilot plant, capacity 4-6 ton/day wastewater. Experiments with waste streams containing chlorinated hydrocarbons, transformer oil contaminated with PCBs. Laboratory experi-

ments with aliphatic compounds, halogenated (aromatic) hydrocarbons, dioxins, nitrotoluene.

3 3 . F L U I D I Z E D B E D I N C I N E R A T O R S

Principle of the process

Waste, pretreated if necessary, is fluidized by passing air through, using fuel if necessary to reach a temperature of 700–900°C. Organic components are burnt to produce CO₂ and H₂O. Volatile components are evaporated, and other components are removed during purification of emission gases. Solid matter can be passed through the process again.

Aim of processing, pollution(s), waste stream(s)

To break down and remove volatile and combustible components, mainly organic, from solid or sludge waste streams.

Technological preconditions

Influent concentration

No limits. If calorific value of waste low, then fuel needed. If calorific value high, inert material e.g. water needed.

Temperature

700–900°C.

Pressure

Atmospheric.

Additives

Fuel if necessary. Calcium (2.5 kg/kg waste) to limit acid gas formation. NaOH for gas scrubber. Coagulation/flocculation agents for water purification.

Capacity

0–30 ton/hr.

Others

High moisture content to be avoided.

Performance

Removal rate

Depends on influent concentration.

Effluent concentration

A-values achieved.

Energy consumption

Fuel amount depends on organic matter content and moisture content. 0–45 liters oil/ton waste.

Bottlenecks

Blockages in input/output pipes, pollution of water coolant.

Costs

Investment

Capacity 5 ton/hr, Dfl. 15M. Capacity 30 ton/hr, Dfl. 45M.

Operation

Capacity 15 ton/hr, Dfl. 300–1350/ton soil. Capacity 30 ton/hr, Dfl. 1150–1200/ton soil.

Range of applications

Treatment of household waste, contaminated soil, mineral sludge organic sludge.

Practical experience

Household waste treatment—used widely in Japan (1900 installations) Sludge from water purification—Thyssen, Lurgi, Seghers, Stork and others. Contaminated soil—Boskalis Esdex, Babcock, Thyssen Engineering: pilot plant with stationary fluid bed installation for treatment of soil contaminated with cyanide, oil or chlorinated hydrocarbons.

3 4 . P L A S M A T E C H N O L O G I E S

Principle of the process

A plasma is generated by causing a voltage difference over an oxidizing, reducing or neutral carrier gas. If the plasma comes into contact with cold material (gas, liquid or solid), energy is released resulting in high temperatures, thus causing organic compounds to break down.

Aim of processing, pollution(s), waste stream(s)

To remove organic compounds, particularly chlorinated compounds, from gaseous, liquid or solid waste. Solid organic waste is pyrolyzed, and heavy metals can be immobilized in a matrix.

Technological preconditions

Influent concentration

No limits.

Temperature

Can reach 45000°C in voltage arc. Free plasma 3000–5000°C. Temperature in reactor area 1200–1650°C.

Additives

Carrier gas, e.g. hydrogen, oxygen, nitrogen. Calcium for cleaning flue gases. Carbon or coke for reduction of metals.

Capacity

0–15 ton/hr.

Performance

Removal rate

> 99.999% for organic components.

Effluent concentration

< A-values.

Energy consumption

Electrical energy required for plasma torch. Energy may be recovered from pyrolysis process.

Emissions

Flue gases. Carbon contaminated with heavy metals, if used in a reducing atmosphere.

Bottlenecks

Heterogeneous materials can cause problems in inputs/outputs.

Residence time

Fluids a few seconds, solids ca. 30 minutes

Costs

Installation for liquid treatment (estimated):

Investment

Dfl. 15-50M.

Range of applications

Processing of industrial and household waste.

Practical experience

Various systems available, experience with treatment of liquid waste containing PCBs, recovery of heavy metals from iron works fly ash. Reports of production of RDF from household waste.

**3 5 . H Y D R O T H E R M A L
D E C O M P O S I T I O N**

Principle of the process

A liquid or solid waste stream is mixed with a hydrogen donor at high temperature and pressure. The hydrogen reacts with organochloride compounds to form hydrochloric acid and simple gases such as methane and ethane which in large quantities can be reclaimed and reused.

Aim of processing, pollution(s), waste stream(s)

To dechlorinate organic compounds occurring in waste. In practice only liquid waste is processed, although theoretically soils and sludge can be treated using fluidized beds.

Technological preconditions

Influent concentration

No limits set. With high content of (chlorinated) organic compounds, the production of usable gas products is an advantage.

Temperature

750-900°C.

Pressure

30-180 bar.

Additives

Hydrogen donor, usually hydrogen gas, can be a mixture of hydrogen and inert gas or syngas ca. 4 mol H₂ per mol Cl₂ Calcium to prevent HCl formation if necessary.

Capacity

0-10 m³/hr.

Performance

Removal rate

Depends on influent concentration—99.95% for C-Cl bonds; 99.999999% for compounds with 4 Cl-bonds

Emissions

Contaminated water and sludge from gas scrubber and water purifier. Small chance of emitted dioxins.

Bottlenecks

Blockages in feed pipes

Explicit plus-points

Usable products produced

Costs (estimated)

Investment

Capacity 2.5 ton/hr (22000 ton/yr). Dfl. 30M

Operation

Dfl. 200-500 ton liquid (higher for soil and sludge treatment).

Range of applications

Treatment of chlorinated compounds in liquid and solid waste.

Practical experience

Only on laboratory scale. Dechlorination of liquids—removal rate 99.9999% for 1,2,3,4-tetrachloro-dibenzo-p-dioxin. Test installation based on fluidized bed under development at TU Delft.

**3 6 . P A R T I C L E
S E P A R A T I O N
T E C H N O L O G I E S**

Principle of the process

Solid particles with a high concentration of impurities are separated from soil and mineral wastes by gravitative separation, based on a difference in density between contaminated and uncontaminated particles. A variety of methods—jig, shaking table, spiral, tilting frame Vanner, and Bartles-Mozley techniques, are available. Particles are brought into suspension with water, and agitated causing heavier particles to sink

Aim of processing, pollution(s), waste stream(s)

To concentrate and remove contaminated particles from soils and other mineral wastes. Impurities include heavy metals, slag, ore or ceramic particles, or organic impurities such as carbon or solid polycyclic aromatic hydrocarbons, where the contaminated particles have higher or lower density than clean soil particles.

Technological preconditions

Influent concentration

No limits set

pH-range

Optimal pH 7

Temperature

0–100°C (limited by boiling and freezing of water)

Additives

Water

Capacity

Jig process 10–100 ton/hr. Others 0.1–10 ton/hr depending on process

Others

Particle size > 0.010 mm, preferably > 0.075 mm. Density difference between clean and contaminated particles minimum 1000 kg/m³

Performance

Removal rate

50–97%

Affluent concentration

Lower A-values possible for soil purification

Energy consumption

A few kWh/ton soil

Emissions

Process water can be recirculated after cleaning. Small amount of residue containing impurities, in some cases can be reprocessed

Costs

Jig, shaking table, spiral techniques, if combined with extraction flotation

Operation

DF: 75–150/ton soil, Dfl: 150–250/ton

Other techniques, combined with extraction flotation

Operation

DF: 100–300/ton

Range of applications

Separation of heavy metals and organic particles from soil
Separation of minerals from ore

Practical experience

Soil treatment: using jig technique with flotation, carbon particles separated with 95% removal rate, particle size 0.075–100 mm. Other methods used for separating minerals from ore

37. EXTRACTION WITH COMPLEXONES

Principle of the process

In a heap leaching or basin leaching process, heavy metals react with a complexone such as EDTA to form a complex which is then removed. The extraction agent is purified by neutralisation and electrolysis and reused.

Aim of processing, pollution(s), waste stream(s)

To remove metals such as lead, cadmium, mercury, zinc, copper and nickel from soil or water beds. Arsenic can be removed under reduction conditions.

Technological preconditions

Influent concentration

No limits set. At high heavy metal concentrations, high EDTA concentration required

pH-range

2–12, usually 6–8 (at pH 2 corrosion of equipment can occur)

Temperature

Environmental

Additives

EDTA-extraction liquid with 5m% EDTA in water is prepared using a solution of 40% (m/m) in water. HCl for pH control, NaOH and CaOH for pH control and sedimentation

Capacity

0–15 ton/hr

Particle size

< 5 mm. If > 0.050 mm pretreatment necessary by coagulation and flocculation

Performance

Removal rate

50–80%. In simple cases > 90%

Volume-flux

4–300 l/m²/hr

Affluent concentration

Typically B-values achieved

Energy consumption

45 kWh/ton wet material. ca. 100 kWh/ton dry material.

Emissions

Following extraction agent purification, residue with high salt concentration. Zn/Fe hydroxide sludge. Other metals separated in metallic form.

Bottlenecks

Possible blockages in feed pipes and soil bed.

Costs (estimated)

Capacity: 12000 ton yr. soil sludge containing heavy metals

Operation

Dfl. 150-170/ton.

If heavy metals and arsenic present

Operation

Dfl. 170-195/ton.

Range of applications

Purification of soil or water beds.

Practical experience

Only at laboratory stage. Research by Project Bureau voor Industrieel Afval. (PBI).

**3 8 . E L E C T R O
R E C L A M A T I O N**

Principle of the process

Electrically charged impurities are separated in an electric field by electro-osmosis, electrophoresis or electrolysis.

Aim of processing, pollution(s), waste stream(s)

To remove electrically charged particles such as ions and ion complexes from clay soil, sand containing peat or sludge, etc., also possibly from groundwater and industrial sludge. Impurities separated include copper, lead, cadmium, nickel, zinc etc. Metals bonded in apolar form cannot be separated. The removal of organic impurities e.g. PCBs and polycyclic aromatic hydrocarbons is under investigation.

Technological preconditions

Influent concentration

In principle no limits. At high concentrations other processes more suitable.

pH-range

In some cases HCl solution with pH 3-4 used to increase separation efficiency.

Temperature

0-70° C, usually rises to ca. 40° C (locally up to 70° C).

Pressure

Environmental.

Additives

Water, chemical conditioners, salts, acids, acidified water, according to type of impurities and soil.

Capacity

In-situ treatment time weeks to months, e.g. 450 ton clay soil over 3 months. On semi-technical scale 1-5 m³/hr.

Performance

Removal rate

50-99%.

Effluent concentration

Depends on type and heterogeneity of soil, moisture content, etc.

Energy consumption

100-500 kWh/ton soil.

Emissions

Filter cake treated before disposal. Possible evaporation of volatile components in soil.

Bottlenecks

Sediment formation in electrode casing.

Costs

Operation

Average Dfl 150-270/ton soil.

Costs increase with shorter treatment time.

Range of applications

In-situ treatment of contaminated land.

Practical experience

Loppersum project: 50 kg As separated from 450 tons clay soil over 3 months.

**3 9 . C H E M I C A L
O X I D A T I O N**

Principle of the process

The waste stream (gas or liquid) is mixed with an oxidation agent such that electron transfer takes place. Oxidation usually takes place in stages, using a catalyst.

Aim of processing, pollution(s), waste stream(s)

To break down dissolved impurities in waste water, or odour components in waste gases. Impurities include cyanides, organic compounds such as phenols, chlorinated hydrocarbons and biocides, metal complexes, and organic microimpurities.

Technological preconditions

Influent concentration

In principle no limits. Due to costs, maximum few hundred ppm. If ozone used minimum few ppm.

pH-range

Usually low. For cyanide pH 9.

Additives

Oxidizing agent, usually chlorine bleach, hydrogen peroxide with iron catalyst, or ozone with UV catalyst

Capacity

Up to several m³/day.

Others

Water required, apart from oxidation of gases using ozone. For UVOX system, transparent reactor wall must be kept clean.

Performance

Removal rate

Cyanide 100%. Gas scrubbing 95% of odour component.

Effluent concentration

Phenols 1-100 ppm.

Energy consumption

Production and oxidation of ozone/UV 2.5 kWh/m³ waste water dosing of oxidation agent 0.01-0.1 kWh/m. Mixing 0.1-0.5 kWh.

Emissions

Oxidation products H₂O, CO₂, sometimes salts. Some undesirable organic compounds may occur in the case of organic impurities. Unused oxidation agent, or its reduced form.

Bottlenecks

Dirtying of reactor wall in UVOX system. Undesirable byproducts e.g. chlorinated hydrocarbons, can affect process.

Explicit plus-points

Simple process.

Costs

Ozone UV process, capacity 25 m³/hr polluted water

Investment

DFI 2-400 000.

Operation

DFI 4.5/m³ water.

Oxidation agents

Chlorine bleach DFI 0.25-0.90/kg. Hydrogen peroxide DFI 1.30/kg solution. Ozone DFI 500/kg.

Range of applications

Disinfection. Purification of industrial waste water. Gas scrubbing.

Practical experience

Purification of industrial waste water—galvanic industry, breakdown of cyanides to CO₂ and N₂ (agent Cl bleach or H₂O₂). Removal of phenols in coke processing, oil refining, tar processing—influent concentration 100 ppm, effluent concentration < 1 ppm (agent H₂O₂). Gas scrubbing—> 95% removal of mercaptans, H₂S and other odour components (agent chlorine bleach, H₂O₂, ozone).

40. FREEZE CONCENTRATION

Principle of the process

Water is removed from a waste stream by cooling until ice crystals are formed, which can be separated by solid-liquid separation techniques such as a wash-column, and melted. The waste stream is thus separated into pure water and a concentrated waste stream.

Aim of processing, pollution(s), waste stream(s)

To concentrate impurities such as metals, metalloids and their compounds, salts, acids, bases and organic substances from waste water, by recovering pure water.

Technological preconditions

Influent concentration

10-30% wt. dissolved matter. Must be lower than that at the eutectic point.

Temperature

-20-0° C.

Additives

Cooling agent if direct cooling used.

Capacity

0.1-25 ton removed water/hr.

Others

Remove insoluble particles to prevent their separation with ice crystals.

Performance

Removal rate

> 99.9%

Effluent concentration

ppm level.

Factor concentration (i.e. concentrate concentration influent)

10-50.

Energy consumption

10–25 kWh/ton removed water.

Emissions

Besides pure water and residue none.

Explicit plus-points

Treatment of relatively concentrated waste possible. Not dependant on type of dissolved matter. Pure water produced.

Costs

Investment

Capacity 25 t/hr. Dfl 12 million.

Operation

Ca. Dfl 50/ton removed water.

Range of applications

Treatment of drinking water and waste water. Concentrated waste streams, e.g. from membrane filtration processes, can be treated.

Practical experience

Pilot plant scale. Impurities concentrated include organic acids e.g. acetic, 1–3% wt. Inorganic salts, organic compounds, heavy metal solutions e.g. from mordant baths.

4 1 . P E R V A P O R A T I O N

Principle of the process

Pervaporation is a membrane separation technique, whereby the concentrate side of the membrane is in a liquid phase, the permeate side in a vapour phase. The driving force is a chemical potential difference (usually partial pressure difference) across the membrane. The waste stream is separated into purified water and a concentrate waste which can be further processed for reuse or combustion.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate soluble, relatively volatile impurities from waste water.

Technological preconditions

Influent concentration

No technical limitations. On economic grounds < 100 mg/l.

pH-range

Depends on membrane type.

Temperature

Depends on membrane type, usually 50–70° C.

Pressure

Concentrate side atmospheric or slight overpressure e.g. 1 bar. Permeate side atmospheric or vacuum (vacuum pervaporation)

Additives

None.

Capacity

5–50 m³/hr estimated for ground water purification.

Others

Remove suspended and colloidal particles. Concentration polarisation may be significant under laminar flow conditions.

Performance

Removal rate

No details given.

Effluent concentration

Depends on influent concentration. May require several modules in series to achieve desired concentration. Maximum concentration in permeate depends on solubility.

Energy consumption

Pump ca. 0.1 kWh/m³ water. Heat if necessary, ca. 6 kWh/m³ water.

Emissions

In vacuum pervaporation some volatile compounds may be emitted via vacuum pump. Otherwise none besides retentate and permeate.

Bottlenecks

Membrane fouling. Sharp variations in influent concentration may affect performance. Freezing of permeate at low condensor temperatures.

Costs

Investment

Capacity 8 m³/hr. Dfl 600000.

Operation

Dfl 1.46–1.85/m³ water.

Range of applications

Dewatering of alcohols; recovery of organic solvents from gaseous effluents; purification of groundwater

Practical experience

Technique is still under development. Dewatering alcohols using composite membranes of polyacrylonitril with thin layer of polyvinyl alcohol. Purification of groundwater—influent concentration 50 g/m volatile hydrocarbons. Flow rate 1 g/m²

hr Retentate conc. 1 g/m³, permeate contains > 10⁶ wt hydrocarbons

Energy consumption

1-5 kWh/m³ waste water, or 1-5 kWh/kg separated metal.

**4 2 . E L E C T R O
D I A L Y S I S**

Principle of the process

A number of membranes, alternately cation- and anion-selective, are placed between two electrodes. Under the influence of an electric field, ions are separated from a wastewater stream so that a high-ion and a low-ion stream are produced. Either or both of these streams may be reused.

Emissions

Besides concentrate and purified water, sometimes small waste stream from membrane cleaning.

Aim of processing, pollution(s), waste stream(s)

To separate ionic substances from waste water, to concentrate and recover ions, or to separate ionic/non-ionic compounds.

Bottlenecks

Membrane fouling, biological fouling. Hard particles may damage membrane.

Technological preconditions

Influent concentration

Wide range possible, but for economic reasons ca. 1-5 g/l.

Explicit plus-points

Modular construction so scaling up quite simple

pH-range

1-13.

Costs

Capacity 4000-100000 m³/day

Operation

\$0.25-0.50/m³ (drinking water preparation).

Temperature

10-45° C, depending on membrane type

Benefits

Less use of chemicals and water, lower discharge taxes and sludge removal costs.

Pressure

Low. Drop of 1-5 bar can occur across membrane stack.

Range of applications

Obtaining salt from seawater, preparation of drinking water from brackish water, food industry, e.g. desalination of cheese whey, recovery of metals from waste water, treatment of power station cooling water.

Additives

In pretreatment—flocculation agents, acids, activated carbon. For membrane cleaning—acids, alkalis

Practical experience

Preparation of salt from seawater, largest application, mainly in Japan. Preparation of drinking water—over 1000 installations, total capacity > 300000 m³/day.

Capacity

For drinking water production > 500 m³/hr. Waste water treatment up to few m³/hr. Modular construction, so almost any capacity possible

Separation of metal from waste water: Ni rinsing bath, capacity 0.55 m³/hr, influent concentration 2.6 g/l Ni, effluent 35 l concentrate, 515 l purified water/hr.

Others

Remove colloids, organic compounds, insoluble salts, iron and manganese oxides to prevent membrane fouling or damage

Investment

\$101000

Operation

\$ 23165/yr

Performance

Removal rate

80-95%

Benefits

\$118 000 savings on chemicals

Effluent concentration

0.1-1 g/l. Concentrate maximum 100-200 g/l. Wider range possible but uneconomic

Aquatech system purification mordant waste water, 6400 m³/yr.

Investment

\$2.2M

Factor concentration (i.e. concentrate concentration influent)

20-100 for Ni

Operation

\$1M/year

Benefits

\$1.5M/year

43. WET AIR OXIDATION

Principle of the process

A waste stream is passed, together with an oxygenated gas, at high pressure through a heat exchanger, then into a reactor where oxidation takes place. Output gases are discharged, after treatment if necessary, and effluent is returned to the heat exchanger.

Aim of processing, pollution(s), waste stream(s)

To break down organic molecules in soil, water, sludge and slurries, by hydrolysis, pyrolysis and (partial) oxidation. Certain inorganic compounds, e.g. cyanides, sulphides and ammonia can also be processed.

Technological preconditions

Influent concentration

Maximum depends on apparatus and oxygen source—underground pipe reactor with heat exchanger 50 g/l; underground pipe reactor without heat exchanger 20 g/l; above ground system at least 100 g/l.

pH-range

Depends on impurity.

Temperature

240–340° C, lower for sludge conditioning.

Pressure

40–250 bar, lower for sludge conditioning.

Additives

(Air) oxygen, nitric acid (deposit separation); NaOH (deposit prevention); Catalyst if necessary.

Capacity

1.3–65 m³/hr, depending on reactor type.

Others

Remove salt deposits regularly. High chlorine content can cause corrosion.

Performance

Removal rate

99.9%.

Affluent concentration

Depends on impurity, temperature, process time. In principle in the order of mg/l, but often not economical.

Energy consumption

For pump and compressors, depending on pressure and performance, 11–25 kWh/m³ waste.

Emissions

Depend on applications. Effluent and output gas usually require treatment. Inorganic ash from sludge/slurry, dissolved metals, suspended matter.

Bottlenecks

Salt deposition on reactor wall and heat exchanger. Sometimes deposits of organic matter.

Costs

Above ground system: capacity 15500 t/yr.

Investment

\$ 2.25M

Operation

\$ 130–530/t waste water

Below ground system: capacity 20000 kg/day

Investment

\$ 16.21 M

Operation

\$ 150–250/1000 kg impurity.

Range of applications

Conditioning of sewage sludge; oxidation of purification sludge and 'night soil'; regeneration of activated carbon; oxidation of paper sludge; waste water purification; chemical waste processing.

Practical experience

Conditioning sewage sludge: Zimpro/Passavant ca. 80 installations, oxidation efficiency 5–10%, 180–220° C. Oxidation sludge and 'night soil': Zimpro/Passavant ca. 40 installations, 50–80% reduction, organic matter 90%, 210–280° C. Waste water purification: Osaka Gas, treatment of water containing cyanide, from gasification of heavy crude oil.

44. HIGH GRADIENT MAGNETIC SEPARATION

Principle of the process

Waste water or slurry is passed through an inhomogenous magnetic field, with or without a filter matrix, to produce a purified effluent stream and a magnetic sludge.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate ferromagnetic, ferrimagnetic or paramagnetic (or magnetizable) particles from polluted water, sludge or slurry. Dissolved or suspended non-magnetic impurities can be separated if pretreated by coagulation, flocculation or (co)-precipitation, e.g. with Fe(OH)₃.

Technological preconditions

Influent concentration

No theoretical limits. Suitable for large streams with relatively few particles to be removed. For separation of magnetic/non-magnetic particles < 25%.

pH-range

Depends on filter material.

Temperature

Not significant.

Pressure

Generally atmospheric. High pressure used for process water purification.

Additives

Magnetite (if used) max. 1 kg/m³, P.E. 1–5 g/m³. For dephosphating sewage effluent lime ca. 200 g/m³.

Capacity

10–2000 m³/hr

Others

Particle size 0.1–1 m. For filter matrix system, particle size ca. 20% of average distance between filter openings.

Performance

Removal rate

> 95%

Effluent concentration

< 10 mg/l. For phosphate separation < 0.2 mg/l.

Factor concentration

(i.e. concentrate/concentration influent) 6000.

Energy consumption

Capacity 225 m³/hr, magnetic induction 1–2T—0.9–1.8 kWh/m³ for dephosphating sewage water, 0.08–0.09 kWh/m³.

Emissions

Magnetic sludge, solid content ca. 30%, chemicals, e.g. lime, if used, cooling agent.

Bottlenecks

Open gradient system—none. Filter matrix system—blockage by large particles.

Costs

Clay processing, capacity 225m³/hr

Investment

\$ 800000

Sewage water, capacity 480m³/hr

Investment

DN 2600000

Operation

DN 0.23/m³ magnetic effluent.

Range of applications

Purification of kaolin (clay); treatment of industrial and household waste; ore purification.

Practical experience

Purification of kaolin: 2 µm particles containing iron, separated from 30% slurry—capacity 60 t dry clay/hr. Industrial waste: used in paper industry, power stations, steel industry, others under research. Dephosphating of household waste: at research stage.

45. CENTRIFUGAL PARTICLE SEPARATION

Principle of the process

Mechanical separation of particles takes place under the influence of centrifugal force, according to the density differential. Pretreatment by coagulation or flocculation may be necessary to increase particle size and separation efficiency.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate suspended particles such as metals and their compounds, salts and organic impurities, from polluted water, sludge or slurry, to produce a purified water stream and a concentrated waste stream.

Technological preconditions

Influent concentration

Few mg/l to several tens kg/m³.

Temperature

Depends on equipment. High temperatures could have advantage of causing lower viscosity.

Pressure

Usually atmospheric. Slight over- or under-pressure possible with decanter centrifuge.

Additives

Only if conditioning required. Additives may be inorganic, e.g. FeCl₃, or organic, e.g. polyelectrolytes. Amounts depend on type of waste.

Capacity

1–90 m³/hr.

Others

Remove abrasive particles, e.g. sand.

Performance

Removal rate

> 96% for sludge concentration

Effluent concentration

Minimum 10 mg/l for sludge concentration < 1 mg/l for clarification applications.

Energy consumption

Sludge concentration 1–2.5 kWh/m³ sludge.

Emissions

Solid residue, treated as chemical waste. Water may contain non-separated particles, salts if chemical conditioning used. Noise: 80–85 dbA at 1400 rev/minimum, 97–102 dbA at 2700 rev/minimum.

Bottlenecks

Fat deposits, coarse particles. More likely with disc centrifuges.

Costs

Investment

Capacity 1 m³/hr, Dfl 90000, Capacity 40–50 m³/hr, Dfl 650000.

Operation

Dfl 150–200/ton dry content sludge.

Range of applications

Concentration of communal and industrial sludge.

Practical experience

No details given.

Additives

Polymers and inorganic flocculation agents For drinking water preparation, pulverised coal, potassium permanganate, filter aids, alkali or lime.

Capacity

25–125 m³/hr depending on process type.

Others

Regular cleaning of filter necessary.

Performance

Removal rate

> 99%

Effluent concentration

For effluent polishing < 1 mg/l

Energy consumption

< 2 kWh/m³. For vacuum filters 6–12 kWh/m³.

Emissions

Non-separated, suspended particles in filtrate. Acid from filter cleaning. Solid residue.

Bottlenecks

Sieve/filter fouling, pump blockage, biological growth in sand filters.

Costs

Sludge processing, capacity 30000 t/yr.

Operation

Dfl 300/t

Sludge dry content, sand filtration, capacity 4000000 m³ yr

Operation

Dfl < 0.10/m³.

Range of applications

Concentration of sewage and industrial waste water purification sludge. Waste water purification (effluent polishing) Groundwater purification.

Practical experience

Industrial waste sludge concentration—used in e.g. galvanic, leather and food industries, slaughterhouses. No details given.

4 6 . F I L T R A T I O N

Principle of the process

Suspended particles are separated from a waste stream by passing through a filter bed or sieve. Pressure is necessary to ensure a continuous flow of waste.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate suspended particles, such as metals and their compounds, salts and organic substances, from polluted water, liquids, sludge or slurry. Dissolved, colloidal and emulsified particles may be also separated if first brought into suspension by pretreatment.

Technological preconditions

Influent concentration

From a few mg suspended solids/l (e.g. effluent polishing) to several 10s kg/m³ (sludge concentration).

Temperature

Up to few 10s° C.

Pressure

0.4–20 bar depending on equipment type

4 7 . E V A P O R A T I O N

Principle of the process

A solution of non-volatile component(s) in a volatile solvent (usually water), is heated to boiling point so that the solvent converts to the vapour phase. The vapour is separated and condensed.

Aim of processing, pollution(s), waste stream(s)

To concentrate impurities present in water, such as salts, and other inorganic or organic compounds if in soluble form and less volatile than water

Technological preconditions

Influent concentration

Depends on impurities

pH-range

Depends on impurity. Can affect volatility.

Temperature

Usually 70–110° C

Pressure

Usually 0–1 bar

Additives

Conditioners to prevent scaling, e.g. in desalination; acid, cooling water 0.8–0.9 m³/m³

Capacity

1–1000 m³/hr.

Performance

Removal rate

Depends on type and volatility of component. Up to 100%

Effluent concentration

Depends on component. For inorganic salts can be 1 mg/l.

Energy consumption

Depends on number of stages—single-stage 1.1–1.25 kg steam/kg evaporated water, 5-stage 0.25 kg/kg evaporated water.

Emissions

Dissolved, volatile components evaporated with water, odourous gases may be produced

Bottlenecks

Fouling of heated surface may hinder heat transfer and evaporation capacity.

Costs

Investment

DN 3500000–11000000

Operation

DN 4–1 M per year

Range of applications

Desalination Treatment of waste water. Concentration of process waste

Practical experience

Used in food industries, e.g. dairy, and chemical process industry. Concentration of metal salts in galvanic industry. Waste-water from textile industry: pilot plant capacity 250 m³/day. Organic waste from yeast and alcohol industry: 70–85% waste concentrated. Ammonium sulphate separation from caprolactum production—capacity 25–1.00 m³/hr.

48. SOLID ION EXCHANGER

Principle of the process

An ion exchanger consists of solid material (mostly synthetic) which is able to combine, more or less strongly, with ions. Solid, charged groups (mostly synthetic), are bonded to the base material, and the strength of the electrochemical bonding causes ions to be exchanged

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate dissolved, ionic particles from waste water.

Technological preconditions

Influent concentration

Maximum ion concentration 10–20 g/l water.

pH-range

Strongly basic or acidic ion exchanger 0–14 Weakly basic ion exchanger < 10, Weakly acidic ion exchanger > 4.

Temperature

Cation exchanger (polysulphonate) 120° C Anion exchanger (polystyrene-based) 0–100° C

Pressure

0.15–0.25 MPa

Additives

Regeneration solution—with high concentration of cations or anions, e.g. HCl, H₂SO₄, NaCl, NaOH, NH₃

Capacity

0.5–2.5 eq/kg ion exchange material

Performance

Removal rate

80–> 99%

Effluent concentration

To (sub) ppm level

Energy consumption

Low, mainly electricity for pump drive.

Emissions

Waste water from regeneration; metallic ions converted to solid residue by electrolysis or chemical precipitation; possibly radioactive components.

Bottlenecks

Blockages by suspended particles, precipitation of calcium sulphate, iron oxide, manganese oxide, bacterial growth, or certain organic material, e.g. aromatic compounds.

Costs

Investment

Cation exchanger Dfl 3000–4000/m³. Anion exchanger Dfl 8000–13 000/m³. Chelating exchanger Dfl 25000/m³

Operation

Dfl 1–10/m³ water

Range of applications

Purification of industrial waste water. Separation/recovery of metal ions in industrial processes.

Practical experience

Purification of industrial waste water used in: food, pharmaceutical, nuclear, galvanic industries. Industrial processes include: separation of metal ions, phenols and ammonium bisulphide, ammonium nitrate, cyanide complexes, and reclamation of valuable metal ions. Treatment of drinking water.

49. SEDIMENTATION
UNDER THE
INFLUENCE OF
GRAVITY

Principle of the process

Particles are separated from a liquid in a gravitational field, the separation taking place according to differences in density or volumic mass between particles and liquid, or mutually between particles. Flocculants may be needed to cause sedimentation of small particles.

Aim of processing, pollution(s), waste stream(s)

To separate solid particles, e.g. metals, metalloids and their compounds, salts, organic impurities, from water (clarifier) or to concentrate solid particles (thickener).

Technological preconditions

Influent concentration

Solid content—clarifier < 5% wt., thickener < 50% wt.

pH-range

Only of significance if polyelectrolyte flocculants used.

Additives

Polymers and inorganic flocculants (e.g. AlCl₃, FeSO₄, Fe₂(SO₄)₃ and polyelectrolytes), in solid, liquid, emulsion or suspension form.

Capacity

In principle no limits.

Others

Particle size and density is significant. Very small particles are not separated unless flocculants used.

Performance

Removal rate

50–99%

Effluent concentration

Clarifier < 0.5% wt solid matter. Thickener < 5% wt solid matter.

Energy consumption

Ca. 12 kW for thickener with diameter 60 m.

Emissions

Unseparated dissolved and suspended particles. Precipitated sludge residue.

Bottlenecks

Blockages in pipes, problems in pump system, corrosion, erosion, leakage, flotation occurrence.

Costs

Investment

Dfl 0.425–11 k/m² (depends on type and amount of waste).

Operation

Dfl 0.05–30/m³ waste water (occasionally > Dfl 100).

Range of applications

Water purification. Metal ore processing. Industrial waste treatment.

Practical experience

Pretreatment in household waste water treatment (separation 60–80%). Industrial uses include: potato processing (removal of starch), iron ore processing and uses in the paper industry.

50. ADSORPTION

Principle of the process

Waste water is brought into contact with a solid adsorbent (usually in granular or powder form). Dissolved impurities are adsorbed and concentrated on the surface of the adsorbent, by means of Van der Waal, dipole or ionic bonding forces. The adsorbent is usually activated carbon, with resin less often used. Regeneration of the adsorbent is possible in some cases.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate dissolved impurities from waste water. Emulsified matter, if present in low concentrations, can also be separated. Impurities are mainly organic, also heavy metals, metalloids and their compounds, Cl compounds and H₂S.

Technological preconditions

Influent concentration

For activated carbon, a few g/m³. For resin, up to 100 g/m³.

pH-range

Acid or alkali pH can increase polarity of organic matter, lowering adsorption.

Temperature

High temperatures decrease adsorption of volatile compounds.

Additives

Besides adsorbent, coagulation/flocculation agents if required. Regeneration agents—steam, acids or bases, solvents.

Capacity

Maximum 100 m³/h.

Performance

Removal rate

Inorganic matter ~90%, higher for organic matter

Effluent concentration

Organic matter, a few ppb. Inorganic matter, a few hundred mg/m³.

Energy consumption

Pumping, ca 0.1 kWh/m³ waste water.

Emissions

Some emissions to air or water may occur during regeneration, depending on materials and equipment.

Bottlenecks

Blockages by suspended or emulsified matter or bacteria. Presence of competitively adsorbent subsidiary impurities. Deactivation by carbon-contaminating subsidiary impurities.

Costs

Capacity 10 m³/h

Investment

DN 3000/m³ (non-regenerable activated carbon) DN 4100/m³ (regenerable activated carbon)

Operation

DN 1.89/m³ water (DN 189/kg separated impurity)

Range of applications

Treatment of waste water, drinking water and groundwater.

Practical experience

Activated carbon adsorption mainly used in water purification. Resin adsorption used in petrochemical and related industries for recovery of valuable materials e.g. phenols from process and waste water. No detailed information given.

**51. ULTRA -
FILTRATION /
MICROFILTRATION**

Principle of the process

Waste water is separated into a small concentrate stream and a large purified stream by passing through a semi-permeable membrane. The driving force is the pressure difference across the membrane.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate colloidal and suspended molecules such as organic components with molecular weight > 500, metal hydroxides, and other particles > 0.01 µm in diameter. Metal ions may be removed after precipitation as hydroxides or sulphides, or complexing.

Technological preconditions

Influent concentration

Up to > 100 g/l. No lower limit.

pH-range

0 - 14 depending on membrane type.

Temperature

Organic membranes up to 90° C. Inorganic membranes 100 - 150° C.

Pressure

Microfiltration 0.1-2 bar. Ultrafiltration 1-10 bar.

Additives

Limited use acids to prevent deposition; NaOH, CaOH to separate heavy metals, detergents, acids, complexing agents to clean membranes.

Capacity

0.5 m³/day - - 100 m³/h

Others

Hard particles, Cl, solvents, oxidising compounds, may damage membrane. Particle size: ultrafiltration 0.005-0.2 µm (molecular wt. 500-100000); microfiltration 0.1-10 µm.

Performance

Removal rate

90-99%

Volume-flux

20–1000 l/m²/h.

Effluent concentration

Few mg/l to several hundred mg/l.

Factor concentration (i.e. concentrate concentration influent)

Up to several hundred.

Energy consumption

0.5–20 kWh/m³ wastewater.

Emissions

Besides concentrate and purified water none.

Bottlenecks

Membrane fouling, leakages.

Costs

Capacity: 1 m³ h

Investment

ДП 1000–10000/m² membrane surface.

Operation

ДП < 1–> 20/m waste water.

Benefits

Savings in chemical and water consumption. Lower discharge taxes.

Range of applications

Electrophoretic deposition. Purification of waste water and recovery of valuable components.

Practical experience

Purification of industrial waste water: oil-contaminated water concentrated to > factor 100, concentrate containing 30–60% oil. Also used in food, textile, paper, electronics, pharmaceutical industries, etc. Separation of heavy metals.

5 2 . R E V E R S E O S M O S I S

Principle of the process

Reverse osmosis is a filtration process whereby separation takes place across a semi-permeable membrane, with high pressure (20 - 100 bar) as the driving force. Waste water is separated into a concentrate and a permeate. In some cases permeate and concentrate can be reused.

Aim of processing, pollution(s), waste stream(s)

To remove/separate small particles (up to ca. 0.1 nm), such as metals, metalloids and their compounds, salts, acids, bases and organic substances from waste water. Larger particles will also be removed

Technological preconditions

Influent concentration

No lower limit. Maximum usually 50–100 g/l

pH-range

2 - 13 depending on membrane type

Temperature

Maximum 80° C.

Pressure

10–100 bar.

Additives

Limited use: acids to prevent salt deposition; sometimes complexing agents and poly phosphates used; detergents, acids, complexing agents in low concentration to clean membranes; sometimes disinfected with chlorine or biocides.

Capacity

0.5–400000 m³/day.

Others

Pretreatment to remove larger (colloidal, suspended) particles by e.g. sedimentation, coagulation, filtration or chemical means. Presence of hard particles, chlorine, softeners, solvents and oxidants must be limited to avoid damage to membrane

Performance

Removal rate

90–99.99%

Volume-flux

5–50 l/m²/hr.

Effluent concentration

A few mg/l to a few hundred mg/l.

Factor concentration (i.e. concentrate concentration influent)

2 - 10.

Energy consumption

1–10 kWh/m.

Emissions

Besides concentrate and permeate none

Bottlenecks

Membrane fouling.

Explicit plus-points

Modular construction so scaling-up simple

Costs

Capacity: 1 m³ hr

Investment

ДП 1000 - 5000/m² membrane surface.

Operation

Dfl 1.50-10/m³ waste water.

Benefits

Savings in use of chemicals and water
Lower discharge taxes.

Range of applications

Desalination of drinking water, purification of industrial and household waste water. Purification of percolation water from rubbish dumps.

Practical experience

Purification of industrial waste water. Used in: food, metal finishing, paper, textile and petrochemical industries. No detailed information given. Purification of percolation water from rubbish dumps-VAM-Wijster, capacity 35 m³/hr, producing 27 m³/hr purified water, 8 m³ concentrate.

Operation

Dfl 8.06/m³ purified water

53. FLOTATION / FOAM SEPARATION

Principle of the process

As air bubbles are passed through waste water, hydrophobic impurities adhere preferentially to the bubbles and are concentrated in a layer of foam on the surface. The foam can then be separated and removed.

Aim of processing, pollution(s), waste stream(s)

To separate/concentrate from waste water, dissolved, suspended, colloidal or floating particles which are surface-active (or thus modified with Additives). Impurities include metals, metalloids and their compounds, salts and organic compounds.

Technological preconditions

Influent concentration

No lower limit. Maximum for particle and flake separation 1% dry matter (m/m), for sludge thickening > 5 kg/m²/hr, for dissolved matter a few hundred mg/l

pH-range

3-11

Temperature

At > 50° C electroflotation or induced air flotation better than dissolved air flotation.

Pressure

DAF bubble generation 400-500 kPa

Additives

Gas (usually air, sometimes N₂, CO₂, O₂/H₂O); pH regulators; collectors; coagulants; flocculants; precipitants; foam formers.

Capacity

< 10- > 100 m³/hr.

Others

Specific density of impurities must be less than water. Dissolved salts can cause corrosion. Limit macro-mixing as this lowers efficiency.

Performance

Removal rate

Depending on impurity 60-99%

Effluent concentration

Usually one or two orders of size less than influent concentration

Energy consumption

0.02-1.8 kWh/m³ fluid depending on process.

Emissions

Stripped impurities and odour components. Some flotation agents may remain in purified effluent. Chlorine released if present in water.

Bottlenecks

Fat, oil, fibres may cause pipe blockages

Costs

Investment

Average size system Dfl 5000-20000/m³. Small units Dfl 20000-60000/m³

Operation

Dfl 0.1-2/m³

Range of applications

Purification of industrial waste water. Activated sludge processing

Practical experience

Purification of industrial waste water. Used in refineries, waste oil processing, slaughterhouses, food, metal, glass, paint, paper, chemical, cosmetics, textile, brewing industries, etc.

54. CARVER - GREENFIELD DRYING PROCESS

Principle of the process

A multi-step evaporation process in which a carrier oil is added to the waste stream before the first evaporation step. This increases the viscosity so that continuous pumping and heat transfer is possible. After drying the oil is separated in a

centrifuge and by steam stripping. The oil can be recirculated. Vapour produced at each step is used to heat the next step, the final step vapour being condensed.

Aim of processing, pollution(s), waste stream(s)

To concentrate dissolved, colloidal, suspended or emulsified particles such as metals, metalloids and their compounds, salts, acids, bases and organic impurities, in sludge, slurries, and waste water.

Technological preconditions

Influent concentration

4–45% dry matter.

pH-range

In principle no limit, but depends on construction material.

Temperature

Evaporation stage ca. 80–100° C. Hydroextractor and steam stripper 120–180° C.

Pressure

0.4–1 bar.

Additives

Carrier oil (naturally present in animal waste). For other waste: 0.5 kg oil/m³ wet sludge for light oil; 5 kg oil/m³ wet sludge for heavy oil. Cooling water.

Capacity

8–265 t dry matter/day.

Others

Limit presence of abrasive materials.

Performance

Removal rate

Almost 100%.

Effluent concentration

98–99% dry matter.

Energy consumption

For 4-step installation 320–675 BTU/lb evaporated water (745–1570 kJ/kg). Electrical energy 400 kW (24 kWh/ton evaporated water). Combustion of extracted oil can produce energy. Combustion value of sludge oil 43.5 MJ/kg

Emissions

Condensate can contain volatile components, volatile components and hydrocarbons emitted as gases, SO₂, NO_x and dust from combustion of extracted oil; dried product contains non-volatile components; dust may need processing for easier handling.

Bottlenecks

At critical dry content emulsion can form (gummy phase), causing pipe blockages. Coarse impurities in too dry suspension may also cause blockages.

Explicit plus-points

Energy efficient—energy consumption lower than conventional drying systems by factor 4.

Costs

Investment

Capacity 265 t dry matter/day \$ 24M.

Operation

Capacity 265 t dry matter/day \$ 39/t.

Range of applications

Processing animal wastes, sewerage, industrial sludge.

Practical experience

Used in meat and fish processing, coffee, chocolate, pharmaceutical, dairy, brewing, paper industries. Treatment of sewage sludge. Problems with HERS (Hyperion Energy Recovery System—sludge drying USA), but Japanese experiences good.

55. PELLET REACTOR

Principle of the process

A cylindrical vessel is partially filled with pellets of sand or other material. Waste water is added at speed so that the pellets are fluidized. Soluble impurities are crystallized as salts on the pellets, with the help of chemicals as necessary. As the pellets increase in size they sink and are periodically removed. Reuse of pellets is sometimes possible. Purified water is removed from the top of the reactor. Filtering often improves removal rate.

Aim of processing, pollution(s), waste stream(s)

To separate/recover impurities such as heavy metals, Ca, Mg, phosphates and fluorides from waste water.

Technological preconditions

Influent concentration

Heavy metals 10–100000 ppm; Phosphates 10–100's ppm.

pH-range

For heavy metals 8–10, for phosphates 10–11

Temperature

Environmental (> 1° C)

Additives

For heavy metals soda, Na₂S or NaHS solution for precipitation as sulphide. For phosphates Ca(OH)₂ or NaOH H₂SO₄ if pH correction necessary. Sand or other pellet material, ca. 3–5g/inhabitant equivalent (i.e.)/day.

Capacity

Heavy metals 0.1–10 m³/hr. phosphates—pilot plants 0.3–15 m³/hr.; operational plant 200 m³/hr. water softening—8500 m³/hr.

Others

Presence of (bi)carbonates (in phosphate removal), suspended matter and ions (metal separation) should be limited.

Performance

Removal rate

Less than 60–> 99.9%.

Volume-flux

40–125 m³/h.

Effluent concentration

Heavy metals 1–10 mg/l (with filtration < 1 mg/l) phosphates few mg/l (with filtration < 0.5 mg/l).

Energy consumption

Phosphate removal—0.1 kWh/m³ effluent; heavy metals—few kWh/kg separated metal.

Emissions

Salt pellets. In some cases pellets recovered and reused. Phosphate removal Ca₃(PO₄)₂ crystallised. CaCO₃ deposition, some organic components. Heavy metals—metal salt pellets (carbonates, sulphides, phosphates).

Bottlenecks

Crystallization on suspended particles. Presence of (bi)carbonates and ions.

Explicit plus-points

Simple to operate.

Costs

Phosphate removal from sewage effluent. Installation 50000 inhabitant equivalent (i.e.)

Investment

Dfl 5.5 million.

Operation

Dfl 17.52/i.e./year.

Heavy metal separation

Operation

Dfl 5–> 50/kg metal.

Benefits

Reuse of metal and water, less chemical waste, lower purification costs.

Range of applications

Softening drinking water. Phosphate removal from sewage effluent. Heavy metal recovery from industrial waste.

Practical experience

Softening drinking water: municipal waterworks Amsterdam, 10 reactors, total capacity 8500 m³/hr. Phosphate removal: Westerbork, capacity 200 m³/hr. Influent concentration 5–12 mg P/l, effluent 0.75–3 mg/l. (after filtration 0.5 mg/l). Heavy metals: Ni recovery from galvanic waste, removal rate 80–99%. Zn, Te, Ni separation from rubber additive waste water, removal rate 60%+.

Activated Carbon

- 6 Activated Carbon Adsorption in Air Purification
- 50 Absorption

Adsorption

- 2 Bioscrubbing
- 6 Activated Carbon Adsorption in Air Purification
- 7 Flue Gas Scrubbing
- 8 Gas Scrubbing
- 50 Absorption

Aerobic Conversion

- 1 Biofiltration

Air Cleaning

- 1 Biofiltration
- 2 Bioscrubbing
- 3 Dry Flue Gas Purification by Means of Chemical Conversion
- 4 Electrofiltration
- 5 Gas Cyclones
- 6 Activated Carbon Adsorption in Air Purification
- 7 Flue Gas Scrubbing
- 8 Gas Scrubbing
- 9 Thermal Afterburning
- 10 Catalytic Afterburning
- 11 Fabric Filtration
- 12 Selective Catalytic Reduction (for NO_x Control in Combustion Processes)

Arsenic

- 37 Extraction with Complexones

Bio-Filtration

- 1 Biofiltration

Biodeterioration

- 2 Bioscrubbing
- 13 Composting

Catalyst

- 10 Catalytic Afterburning
- 12 Selective Catalytic Reduction (for NO_x Control in Combustion Processes)
- Chemical Oxidation

Centrifuge

- 45 Centrifugal Particle Separation
- 54 Carver-Greenfield Drying Process

Chemical Conversion

- 3 Dry Flue Gas Purification by Means of Chemical Conversion

Chemical Reaction

- 39 Chemical Oxidation

Chemicals

- 32 Supercritical Oxidation

Combustion

- 9 Thermal Afterburning
- 12 Selective Catalytic Reduction (for NO_x Control in Combustion Processes)
- Thermal Processing in Rotary Drum Kiln
- 30 Secondary Combustion of Flue Gas in Soil Decontamination

Composting

- 13 Composting

Crystallization

- 55 Pellet Reactor

Cyclone

- 5 Gas Cyclones
- 25 Hydrocyclones
- 27 Process-Moderated Extractive Soil Purification
- 30 Secondary Combustion of Flue Gas in Soil Decontamination

Dechlorination

- 35 Hydro Thermal Decomposition

Distilling

- 23 Distillation

Drying

- 22 Drying
- 54 Carver-Greenfield Drying Process

Electric Charge

- 4 Electrofiltration
- 14 Electrolytic Separation of Metals
- 38 Electroreclamation
- 42 Electrodialysis

Electrolysis

- 38 Electroreclamation

Energy Recovery

- 20 Pyrolysis
- 21 Thermal Processing in Rotary Drum Kiln
- 22 Drying

Evaporation

- 22 Drying
- 23 Distillation
- 33 Fluidized Bed Incinerators
- 47 Evaporation
- 54 Carver-Greenfield Drying Process

Filtering

- 1 Biofiltration
- 4 Electrofiltration

- 11 Fabric Filtration
- 30 Secondary Combustion of Flue Gas in Soil Decontamination
- 46 Filtration
- 51 Ultrafiltration/Microfiltration
- 52 Reverse Osmosis

Flotation

- 28 Flotation of Contaminated Soil
- 53 Flotation/Foam Separation

Flue Gas

- 3 Dry Flue Gas Purification by Means of Chemical Conversion
- 7 Flue Gas Scrubbing
- 12 Selective Catalytic Reduction (for NO_x Control in Combustion Processes
- Secondary Combustion of Flue Gas in Soil Decontamination

Fluidized Bed

- 33 Fluidized Bed Incinerators

Freezing

- 40 Freeze Concentration

Gravitation

- 25 Hydrocyclones
- 26 Sieving of Soil
- 36 Particle Separation Technologies
- 49 Sedimentation Under the Influence of Gravity

Grinding

- 19 Grinding/Size Reduction

Heat Exchanger

- 9 Thermal Afterburning
- 43 Wet Air Oxidation

Heat Treatment

- 34 Plasma Technologies

Heavy Metals

- 37 Extraction with Complexones

Household Waste

- 22 Drying

Hydrogen

- 35 Hydro Thermal Decomposition

Hydrolysis

- 43 Wet Air Oxidation

Incineration

- 29 Thermal Treatment of Soil in Incinerators
- 33 Fluidized Bed Incinerators

Inorganic Contaminants

- 15 Leaching with Acid/Alkali/Complexing Agents (Dissolving)
- 18 Immobilisation

Ion Exchange

- 48 Solid Ion Exchanger

Ionogenic Contaminants

- 18 Immobilisation

Kiln

- 21 Thermal Processing in Rotary Drum Kiln

Leaching

- 15 Leaching with Acid/Alkali/Complexing Agents (Dissolving)
- 37 Extraction with Complexones

Liquid Waste

- 16 Solvent Extraction
- 18 Immobilisation
- 20 Pyrolysis
- 21 Thermal Processing in Rotary Drum Kiln
- 23 Distillation
- 33 Fluidized Bed Incinerators
- 34 Plasma Technologies
- 35 Hydro Thermal Decomposition
- 38 Electroreclamation
- 39 Chemical Oxidation
- 40 Freeze Concentration
- 41 Pervaporation
- 43 Wet Air Oxidation
- 44 High Gradient Magnetic Separation
- 45 Centrifugal Particle Separation
- 46 Filtration
- 49 Sedimentation Under the Influence of Gravity
- 54 Carver-Greenfield Drying Process

Magnetic Treatment

- 44 High Gradient Magnetic Separation

Membrane Technology

- 41 Pervaporation
- 42 Electrolysis
- 51 Ultrafiltration/Microfiltration
- 52 Reverse Osmosis

Metals

- 14 Electrolytic Separation of Metals
- 16 Solvent Extraction
- 17 Precipitation
- 38 Electroreclamation
- 44 High Gradient Magnetic Separation

Microorganisms

2 Bioscrubbing

Odour Pollution

1 Biofiltration

39 Chemical Oxidation

Organic Contaminants

8 Gas Scrubbing

9 Thermal Afterburning

10 Catalytic Afterburning

15 Leaching with Acid/Alkali/Complexing Agents (Dissolving)

23 Distillation

35 Hydro Thermal Decomposition

Organic Waste

13 Composting

20 Pyrolysis

Oxidation

10 Catalytic Afterburning

32 Supercritical Oxidation

39 Chemical Oxidation

43 Wet Air Oxidation

Particle Reduction

19 Grinding/Size Reduction

Particle Separation

5 Gas Cyclones

11 Fabric Filtration

24 Sieving of Waste Matter (Dry)

26 Sieving of Soil

36 Particle Separation Technologies

45 Centrifugal Particle Separation

49 Sedimentation Under the Influence of Gravity

52 Reverse Osmosis

53 Flotation/Foam Separation

Precipitation

4 Electrofiltration

17 Precipitation

Purification

2 Bioscrubbing

3 Dry Flue Gas Purification by Means of Chemical Conversion

28 Flotation of Contaminated Soil

33 Fluidized Bed Incinerators

40 Freeze Concentration

44 High Gradient Magnetic Separation

Pyrolysis

20 Pyrolysis

34 Plasma Technologies

43 Wet Air Oxidation

Scrubbing

2 Bioscrubbing

7 Flue Gas Scrubbing

8 Gas Scrubbing

30 Secondary Combustion of Flue Gas in Soil Decontamination

Sedimentation

27 Process-Moderated Extractive Soil Purification

36 Particle Separation Technologies

49 Sedimentation Under the Influence of Gravity

55 Pellet Reactor

Separation

14 Electrolytic Separation of Metals

41 Pervaporation

42 Electrodialysis

Sieving

24 Sieving of Waste Matter (Dry)

26 Sieving of Soil

Site Remediation

27 Process-Moderated Extractive Soil Purification

28 Flotation of Contaminated Soil

29 Thermal Treatment of Soil in Incinerators

30 Secondary Combustion of Flue Gas in Soil Decontamination

31 Steam Stripping

Slurry

14 Electrolytic Separation of Metals

20 Pyrolysis

21 Thermal Processing in Rotary Drum Kiln

25 Hydrocyclones

28 Flotation of Contaminated Soil

43 Wet Air Oxidation

44 High Gradient Magnetic Separation

45 Centrifugal Particle Separation

46 Filtration

54 Carver-Greenfield Drying Process

Soil Pollution

25 Hydrocyclones

26 Sieving of Soil

27 Process-Moderated Extractive Soil Purification

28 Flotation of Contaminated Soil

29 Thermal Treatment of Soil in Incinerators

30 Secondary Combustion of Flue Gas in Soil Decontamination

31 Steam Stripping

36 Particle Separation Technologies

37 Extraction with Complexones

38 Electroreclamation

43 Wet Air Oxidation

Solid Waste

15 Leaching with Acid/Alkali/Complexing Agents (Dissolving)

S u b j e c t I n d e x

- 19 Grinding/Size Reduction
- 20 Pyrolysis
- 21 Thermal Processing in Rotary Drum Kiln
- 22 Drying
- 24 Sieving of Waste Matter (Dry)
- 33 Fluidized Bed Incinerators
- 34 Plasma Technologies
- 35 Hydro Thermal Decomposition
- 36 Particle Separation Technologies

Solidification

- 18 Immobilisation

Solvent

- 15 Leaching with Acid/Alkali/Complexing Agents (Dissolving)
- 16 Solvent Extraction

Steam Stripping

- 31 Steam Stripping
- 54 Carver-Greenfield Drying Process

Thermal Splitting

- 20 Pyrolysis

VOCs

- 6 Activated Carbon Adsorption in Air Purification
- 31 Steam Stripping
- 33 Fluidized Bed Incinerators
- 34 Plasma Technologies
- 41 Pervaporation

Waste Gas

- 1 Biofiltration
- 2 Bioscrubbing
- 4 Electrofiltration
- 5 Gas Cyclones
- 6 Activated Carbon Adsorption in Air Purification
- 8 Gas Scrubbing
- 9 Thermal Afterburning
- 10 Catalytic Afterburning
- 11 Fabric Filtration
- 34 Plasma Technologies
- 39 Chemical Oxidation

Waste Water

- 14 Electrolytic Separation of Metals
- 16 Solvent Extraction
- 17 Precipitation
- 23 Distillation
- 32 Supercritical Oxidation
- 42 Electrodialysis
- 44 High Gradient Magnetic Separation
- 45 Centrifugal Particle Separation
- 47 Evaporation
- 48 Solid Ion Exchanger
- 50 Absorption
- 51 Ultrafiltration/Microfiltration
- 52 Reverse Osmosis
- 53 Flotation/Foam Separation
- 55 Pellet Reactor

Water Pollution

- 25 Hydrocyclones
- 37 Extraction with Complexones

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