Background on Air Quality Control

(Obtained from UNIDO , Sustainable Industrial Development)

A preview is made of types of pollutant, solid, liquid or gas which contaminate the air, which fall into the following categories; inert particulates (e.g. ash, dust), active particulates (e.g. metals, organic matter), aerosols and fumes (e.g. oil and metal oxides respectively), hydrocarbons (e.g. petrol), and gaseous oxides (e.g. CO_2 and NO_x)

The equipment to control air quality fall into four main classes of collector; dry collectors, filters, electrostatic precipitators and wet scrubbers.

Waste Management Technologies	AIR (GASES)	LIQUID	SOLIDS
Biological Processes	Bio filtration	Activated Sludge Process	
	Bio Scrubbing	Anaerobic Waste Water Treatment	
	Air treatment	Fixed Bed Cascade Bioreactor for sewage pre-purification	
	Activated Carbon Adsorption in Air Purification	Trickling Filter	
Chemical Processes	Adsorption	Adsorption	
	Catalytic Oxidation	Chemical Oxidation	
	Chemical Oxidation	Coagulation/Flocculation	
	Dentrification of flue gases	Ion Exchanger Process	
	Dry Flue Gas Purification by Means of Chemical Conversion	Oxidation / Reduction Neutralising Precipitation . Waste water treatment in the metal-processing industry	
	Flue gas scrubbing	Pervaporation	
	Gas scrubbing	Precipitation	
	Gypsium prod	Recovery of metals from metal sludges	
	Selective Catalytic Reduction (for NOx control in combustion processes)	Solvent Extraction	
Electrical Processes	Electrical Precipitator	Electrodialysis	
	Electro Filtration	Electrolytic Separation of Metals	
	Plasma Technologies	Electroreclamation	
		Plasma Technologies	
		Solid Ion Exchanger	
Thermal Processes	Catalytic afterburning	Carver-Greenfield Drying Process	Fluidized Bed Incinerators
	Hazardous Waste Incinertion	Distillation	Hazardous Waste Incineration

	Thermal after burning	Evaporation	Incineration plant for domestic waste
	Secondary Combustion of Flue Gas in Soil Decontamination	Fluidized Bed Incinerators	Plasma Technologies
	Thermal oxidation	Hazardous Waste Incineration	Pyrolysis
		Hydro Thermal Decomposition	Secondary Combustion of Flue Gas in Soil Decontamination
		Pyrolysis	Sewage Sludge Incineration
		Sewage Sludge Incineration	Solid Waste Treatment Process(overview)
		Supercritical Oxidation	Solid Waste Treatment Process(Technology transfer case study) http://www.unido.org/s sites/env/sectors/SWT_ case1.html
		Thermal Processing in Rotary Drum Kiln	Steam Stripping
		Treatment of mixed paint sludges	Thermal Processing in Rotary Drum Kiln
		Wet Air Oxidation	Thermal Treatment of Soil in Incinerators
Mechanical Processes	Droplet seperators	Belt Filter Press for Draining Domestic and Industrial Sludge From Sewage Treatment Plants	
	Fabric Filtration	Centrifugal Particle Separation	
	Gas cyclones	Coarse Sieves	
		Conical Multiway Gate Valves	
		Conventional type Seperator for light liquids.	

Separation Processes			Electroreclamation
			Extraction with Complexones
			Flotation of Contaminated Soil
			Hydro Thermal Decomposition
			Leaching with Acid/Alkali/Complexing Agents (dissolving)
			Particle Separation Technologies
			Process-moderated Extractive Soil Purification
			Recovery of Metals from Metal Sludges
			Refuse Sorting Plant
			Sieving of Soil
			Sieving of Waste Matter
			Treatment of Mixed Paint Sludges
			Wet Air Oxidation
Other	Processing of Filter & Flue Dust *SEARCH*: air quality control, air purification	Freeze Concentration	Composting
		High Gradient Magnetic Separation	Composting Plant
		Immobilisation	Drying
		Measurement of flow volume of waste water	Grinding/Size Reduction
		Rubber Sealing Rings for water and waste water pipes	Immobilisation
			Processing of used plastic material from refuse
			Vitrification process for the inertia of residue products from refuse incineration plants

Biofiltration

Technology Principle

Biofiltration is the aerobic conversion of air-borne impurities into non-polluting components (primarily CO_2, H_2O 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

To remove impurities and odours from waste gases. Impurities are mainly organic, with some inorganic components (H_2S, NH_3, CS_2) being suitable.

Technological Preconditions

- **Influent concentration**: 0.001 -- 4 g/m^3 (usually less than 1 g/m^3) depending on impurity.
- **Temperature**: 10-40 degC
- **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/m^3/h
- **Others**: Dry matter content less than 20-50 mg/m^3. Moisture content greater than 95%, in some cases 99%. Filter must be leakproof for gas and fluid. Air load on filter less than 600 m^3/m^2/h to keep energy costs low.

Performance Evaluation

- **Removal rate**: Depends on filter design.
- **Effluent concentration**: Usually 1-10% of influent concentration
- **Volume flux**: 1-200 g/m^3/h.
- **Electricity consumption**: Electrical energy required for ventilator. Only substantial if air load greater than 600 m^3/m^2/h
- **Emissions**: Microorganisms in exhaust gas (max 104 CFU/m^3). 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 cost**: Installation Dfl 500-7500/m^3 filter surface. Filter material Dfl 75-400/m3
- **Operation/maintenance**: Dfl 0.50-5/1000 m^3 gas.

Experience

- **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.

Bioscrubbing

Technology Principle

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 H_2O and CO_2. 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

To separate and destroy biodegradable pollutants such as organic matter, NH_3, odour components from waste gases.

Technological Preconditions

- **Ph range**: 6-8
- **Influent concentration**: 0.001-20 g/m^3
- **Temperature**: 10-40 deg 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/m^3/h
- **Others**: Particle content 20-50 mg/m^3. Air load 600 m^3/m^2/h.

Performance Evaluation

- **Removal rate**: 50-90%.
- **Effluent concentration**: 1-40% of influent concentration.
- **Electricity consumption**: 1.6-3 kWh/1000 m^3 treated gas.
- **Emissions**: Residual emission of contaminants determined by process. Sludge emitted via waste water contains PO_4, decomposition products etc.
- **Bottlenecks**: Sensitive to excessive temperatures and impurity concentrations, and fluctuations in impurity concentrations. Dry particles can cause blockages.

Costs

- **Investment cost**: Capacity 30-130 m^3/h, Dfl 0.55-2.5 x 10^6
- **Operation/maintenance**: Capacity 30-130 m^3/h, Dfl 11-66/h

Experience

- **Range of applications**: Odour removal, treatment of hydrocarbons.
- **Practical experience** : At laboratory and pilot-plant stage. Examples include removal of: dichloromethane--capacity 200 g/m^3/h (70%); dichloroethane--capacity 80 g/m^3/h (70%); odour components in cocoa industry (65%), pigsties (50-90%), fat processing (75%), foundries (60%); solvents (90%), NH_3, amines, phenols, etc. in various industries.

Activated Carbon Adsorption in Air Purification

A polluted gas stream is passed through adsorbers with actived carbon grains in a fixed or moving bed, or fibres. The impurities are adsorbed by the activated carbon until a saturation point is reached, whereupon the carbon is either replaced, or regenerated. If regeneration is required, particularly if used for the recovery of volatile organic substances, desorption using steam, hot inert gas, or vacuum, is followed by condensation, drying and cooling. The main areas of use are in the removal of odorous components from chemicals, foodstuff and other industries, and the recovery of volatile organic substances from a variety of chemical processes.

Catalytic Afterburning

Technology Principle

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

To destroy harmful components found in waste gases. Contaminants include organic substances, CO_2, H_2S, CS_2, COS, SO_2, H_2, O_3, HCN, NH_3 and NO_x.

Technological Preconditions

- **Influent concentration:** Maximum generally 10-20 gC/m^3 gas.
- **Temperature:** Maximum 900 degC for alumino-silicate catalysts. Maximum 600 deg 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 m^3/m^3 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 NH_3/kg NO_x.
- **Capacity:** Less than 2000- greater than 20000 m^3/h.
- **Others:** Calorific value of waste less than 750 kJ/m^3 (ca. 35% of LEL). Remove particles by pretreatment (filtration) if more than 2g/m^3 gas.

Performance Evaluation

- **Removal rate:** 90-99.9%.
- **Effluent concentration:** Hydrocarbons less than 200 mgC/m^3. CO negligible.
- **Electricity consumption:** Electricity 0.001-0.002 kWh/m^3 gas. Fuel 0-1000 kJ/m^3 gas (depends on degree of heat recovery and calorific value of contaminants).
- **Emissions:** NO_x less than 15 ppm, CO_2, 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 cost:** Catalytic afterburner Dfl 30-60/m^3/h. Catalyst material Dfl 3-35/m^3/h.
- **Operation/maintenance:** Dfl 2.50-20/1000 m^3 gas.

Experience

- **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.

Hazardous Waste Incineration

The increase in industrialisation has caused a sharp rise in the volume and diversity of hazardous waste generation. This is mostly organic material which cannot be destroyed or eliminated directly. The general definition of hazardous waste is explained and classified physically into; solid, pasty, liquid and gaseous. Before handling, hazardous waste must be carefully analysed, classified and stored before deciding the best method of disposal. The chosen method of disposal is thermal conversion (incineration) and this chapter concentrates on the most common incinerator (rotary kiln). The hazardous waste disposal plant, which is illustrated by a diagram consists of the following parts; feeding and batching facilities, incinerator (kiln), post- combustion chamber, waste heat boilers, flue gas cleaning system, and supply and disposal equipment. The key to the process is the rotary kiln in which temperatures of 1200-1400 degC are reached, its operation and special design features are reviewed. The gaseous products from the kiln need to undergo after-burning to destroy heat stable molecules (e.g. dioxin), then pass on their heat to a waste heat boiler before being finally purified by e.g. some absorption technique and discharged to atmosphere. The solid arisings is merely slag for disposal. A facility for making incinerators is projected. A flow chart indicates the process and tabulated data outline the costs and requirements. It must be emphasised that such a product is very large, the delivery time for an incinerator plant is 18 months and the kiln alone takes 12 months. (**Reference:** How to Start Manufacturing Industries: Technological and Investment Perspectives--Environmental Technologies. Volume V, File Z 28, 6 pages). The description of the technology is available in full in Adobe Acrobat format , select the reference above.

Thermal Afterburning

Technology Principle

Combustible components in waste gases react with oxygen at high temperatures to produce CO_2, H_2O and other products. The output gas is passed through a heat exchanger to partially preheat incoming gas.

Aim of Processing

To destroy components such as organic substances, H_2S, CO, NH_3, COS, CS_2, H_2 and HCN in waste gases. In principle all gaseous compounds containing C, H, N or S which react with oxygen at 600-2000 degC can be treated.

Technological Preconditions

- **Influent concentration:** Max. concentration of combustible components 25% of lower explosion limit, i.e. for hydrocarbons 10--2-gC/m^3 gas.
- **Temperature:** Input gas usually less than 300 degC, raised to 500 degC in heat exchanger, 600-1200 degC in combustion chamber.
- **Pressure:** Atmospheric.
- **Additives:** Fuel to produce 0-2000 kJ/m^3 gas. Combustion air l0 m^3/m^3 natural gas or kg oil.
- **Capacity:** Less than 5000- greater than 20000 m^3/h.
- **Others:** Oxygen content 10-100% higher than necessary for combustion of the contaminant.

Performance Evaluation

- **Removal rate:** Greater than 99%.
- **Effluent concentration:** CO less than 100-1000 mg/m^3. Hydrocarbons less than 20-50 mg C/m^3. NO_x less than 40-200 mg/m^3.
- **Electricity consumption:** Electricity 0.001-0.003 kWh/m^3 gas. Fuel 0-2000 kJ/m^3 gas depending on degree of heat exchanger use.
- **Emissions:** Exhaust gas treatment necessary to prevent excessive amounts of organic compounds, Co, NO_x, SO_2, HC1, HF, CO_2 etc.
- **Bottlenecks:** Inert and combustible solid particles (dust, soot and coke).

Costs

- **Investment cost:** Capacty 5000 m^3/h, Dfl 60-150/m^3/h. Capacity 20000 m^3/h, Dfl 25-70/m^3/h. ump capacity 1,000 m^3 fluid/h.: Dfl 6 900 000 (1986)
- **Operation/maintenance:** Dfl 2.5-25/1000 m^3 gas. Dfl 1-5/m^3 fluid.

Experience

- **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).

Chemical Oxidation

Technology Principle

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

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

- **Ph range:** Usually low. For cyanide pH 9.
- **Influent concentration:** In principle no limits. Due to costs, maximum few hundred ppm. If ozone used minimum few ppm.
- **Additives:** Oxidizing agent, usually chlorine bleach, hydrogen peroxide with iron catalyst, or ozone with UV catalyst.
- **Capacity:** Up to several m^3/day.
- **Others:** Water required, apart from oxidation of gases using ozone. For UVOX system, transparent reactor wall must be kept clean.

Performance Evaluation

- **Removal rate:** Cyanide 100%. Gas scrubbing 95% of odour component.
- **Effluent concentration:** Phenols 1-100 ppm.
- **Electricity consumption:** Production and oxidation of ozone/UV 2.5 kWh/m^3 waste water dosing of oxidation agent 0.01-0.1 kWh/m. Mixing 0.1-0.5 kWh.
- **Emissions:** Oxidation products H_2O, CO_2, 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

- **Investment cost:** Ozone/UV process, capacity 25 m^3/hr polluted water: Dfl 2 400 000.
- **Operation/maintenance:** Dfl 4.5/m^3 water. Oxidation agents: Chlorine bleach Dfl 0.25-0.90/kg. Hydrogen peroxide Dfl 1.30/kg solution. Ozone Dfl 500/kg.

Experience

- **Range of applications:** Disinfection. Purification of industrial waste water. Gas scrubbing.
- **Practical experience:** Purification of industrial waste water--galvanic industry, breakdown of cyanides to CO_2 and N_2 (agent Cl bleach or H_2O_2). Removal of phenols in coke processing, oil refining, tar processing--influent concentration 100 ppm, effluent concentration less than l ppm (agent H_2O_2). Gas scrubbing--greater than 95% removal of mercaptans, H_2S and other odour components (agent chlorine bleach, H_2O_2, ozone).

Flue Gas Scrubbing

Technology Principle

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

To separate and destroy or concentrate acid components, SO_2, HC1, HF and NO_x from flue gases.

Technological Preconditions

- **Influent concentration**: 1000-10 000 mg/m^3
- **Temperature**: less than 100 degC, usually 40-80 degC
- **Pressure**: Atmospheric
- **Additives**: $CaCO_3$, CaO ($Ca(OH)_2$) for neutralisation
- **Capacity**: less than 50000-2000000 m^3/h

Performance Evaluation

- **Removal rate**: 85-90%. In waste incineration (HC1, HF) greater than 90%.
- **Volume flux**: 104-2106 m^3/h
- Electricity consumption: 20 kWh/ton waste (3kWh/1000 Nm^3 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

- **Operation/maintenance**: For flue gas desulphurisation: 0.5-1 ct/kWh (Dfl l/kg SO_2) For HC1 removal from waste incineration: Dfl 30-45/ton waste (5-1/1000 m^3 flue gas).

Experience

- **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

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Gas Scrubbing

Technology Principle

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

To separate/concentrate contaminants including organic substances, SO_2, NO_x, HC1, HF, NH_3, $C1_2$, H_2S, SiF_4, Br_2, CO and CO_2 from waste gas.

Technological Preconditions

- **Ph range:** Acid, neutral or alkaline liquids used according to the impurity to be removed.

- **Influent concentration:** less than 1 mg/m^3-100 g/m^3
- **Temperature:** Up to greater than 100 degC, usually 20-40 degC.
- **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:** Less than 10 000- less than 100000 m^3/h.
- **Others:** Impurity must be highly soluble in scrubbing liquid, e.g. Henry coefficient less than 0.l x $l0^5$.

Performance Evaluation

- **Removal rate:** 75-99%
- **Effluent concentration:** Less than 10 mg/m^3.
- **Volume flux:** 0.3-2.5 m/s.
- **Electricity consumption:** Electricity--0.1-10 kWh/1000 m^3 gas. Heat--up to 5 m^3 natural gas/1000 m^3 gas.
- **Emissions:** Polluted scrubbing liquid and vapours.
- **Bottlenecks:** Blockages in scrubbing liquid recirculation process. Gas containing sticky particles.

Costs

- **Investment cost:** System without recovery Dfl 10-30 m^3 gas. System with recovery Dfl 30-200/m^3 gas.
- **Operation/maintenance:** Dfl 0.5- greater than 5/1000 m^3 gas.

Experience

- **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.

Electrofiltration

Technology Principle

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

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**: less than 50 g/m^3. For higher concentrations pre-separation is necessary--e.g. gas cyclone.
- **Temperature**: Up to 400 degC at atmospheric pressure. Up to 900 degC at high pressure.
- **Pressure**: Usually atmospheric.
- **Additives**: For wet electrofilters with water-misting, ca. 0.6 1 water/m^3 gas occasionally SO_3 (15-20 ppm) added to improve efficiency if particles have high resistivity.
- **Capacity**: 200- greater than 100000 m^3/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 Evaluation

- **Removal rate**: 95-99.99%
- **Effluent concentration**: Less than 5 mg/m^3
- **Volume flux**: 0.5-2 m/s
- **Electricity 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 cost**: Dfl less than 5-150/m^3/h
- **Operation/maintenance**: Dfl 0.5-3/1000m^3

Experience

- **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.

Plasma Technologies

Technology Principle

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

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

Technological Preconditions

- **Influent concentration:** No limits.
- **Temperature:** Can reach 45000 degC in voltage arc. Free plasma 3000- 5000 deg C. Temperature in reactor area 1200-1650 degC.
- **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 Evaluation

- **Removal rate:** Greater than 99.999% for organic components.
- **Effluent concentration:** Greater than A-values.
- **Residence time:** Fluids a few seconds, solids ca. 30 minutes
- **Electricity 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.

Costs

- **Investment cost:** Installation for liquid treatment (estimated): Dfl. 15-50M.

Experience

- **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

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Droplet Separators

Droplet separators are widely used in exhaust air, off-gas and flue gas cleaning. This ensures that no droplets laden with air dusts and toxic materials escape into the atmosphere via stacks and chimneys etc. These are often installed at the back of scrubbers and can remove droplets of sized less than 10 microns in diameter. Droplet separators are mainly used in the following industrial fields; flue gas desulphurisation, offshore installations, nuclear power plants etc. The droplets are collected in lamellar separators, which consist of lamellae, which are parallel, bent and profiled so that they form retaining grooves. These grooves allow the droplets to hit the walls, coalesce and flow back downwards. The principles involved are explained and illustrated by photographs and diagrams. The choice of situating the separator in the vertical, horizontal or inclined afflux is discussed. The separators tend to become more efficient as the flow rate increases. Separators can be fabricated in many plastics including glass-reinforced stainless steel or Al, the choice being influenced by the gas stream and temperatures to be withstood. Dimensioning a droplet separator is considered. A production facility for making droplet separators is projected, which is capable of turning out 100 standard droplet separators in polypropylene on a standard 2 x 3-m frame per month. A flow chart illustrates the process and tabulated data are produced indicating the requirements and costs. (**Reference:** How to Start Manufacturing Industries: Technological and Investment Perspectives--Environmental Technologies. Volume V, Section B. Water Purification, File K 22, 5 pages.)

Gas Cyclones

Technology Principle

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

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/m^3 gas. 0.02-0.5 g/m^3 for droplet separation.
- **Temperature**: Up to 1000 deg C
- **Pressure**: No effect on process.
- **Additives**: Water sometimes sprinkled in the cyclone to increase efficiency by causing agglomeration.
- **Capacity**: Average 10000 m^3 gas/hour
- **Others**: Particle size greater than 200 mm require pre-separation. Constant input gas speed and particle concentration for maximum efficiency. Volatile impurities unsuitable.

Performance Evaluation

- **Removal rate**: 80-99%, less if particle size less than 2 mm
- **Volume flux**: Input air 6-15 m/s

- **Electricity consumption**: 0.25-1.5 kWh/1000 m^3
- **Emissions**: Can occur depending on cyclone efficiency.
- **Bottlenecks**: Blockages can occur, often due to too high moisture content or partially smolten particles.

Costs

- **Investment cost**: Capacity- 9000 m^3/h--Dfl 9000
- **Operation/maintenance**: Dfl 0.10-0.30/1000 m^3 air

Experience

- **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.

Fabric Filtration

Technology Principle

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 fibers and other particles. The particles are then removed from the filter fabric and can often be reused.

Aim of Processing

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/m^3. At concentrations greater than 50 g/m^3 mechanical separation, techniques are used first.
- **Temperature:** Up to 450 deg 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:** Less than 1000- greater than 100000 m^3/h.
- **Others:** Particle diameter greater than 0.01 mm.

Performance Evaluation

- **Removal rate:** 95-99%.
- **Effluent concentration:** 1-75 mg/m^3.
- **Electricity consumption:** 0.5-2.0 kWh/1000 m^3 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 cost:** Dfl 3-25/m^3 gas/h. Higher if system is thermally insulated in stainless steel, or if special fabric filter required.
- **Operation/maintenance:** Dfl 0.50-3/1000 m^3 gas.

Experience

- **Range of applications:** Treatment of gases from industrial processes and incineration.

- **Practical experience:** Widely used.

Dry Flue Gas Purification by Means of Chemical Conversion

Technology Principle

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

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/Nm^3 (1-100 mg/Nm^3 for HF)
- **Temperature**: 300-1100 depending on impurity
- **Pressure**: Usually atmospheric. For pressurized fluidised bed combustion 10 bar.
- **Additives**: Neutralizing agent--usually $CaCO_3$, Ca $(OH)_2$, and CaCO3.MgCO3. Catalyst material--usually oxides of vanadium or tungsten, on titanium carrier. NH_3 for reduction of NO_x-0.5 kg per kg NO_x.
- **Capacity**: 1000-2000000 Nm^3/h.

Performance Evaluation

- **Removal rate**: 50-90%
- **Effluent concentration**: SO_2, HCl, NO_x: 50-1000 mg/Nm ^{3}. HF less than 1 mg/Nm^3
- **Electricity consumption**: 10-20 kWh/ton waste (2-3 kWh/1000 Nm^3 flue gas) for neutralisation of acid components in waste incineration. 1 kWh/kg NO_x (0.6 kWh/1000 Nm^3 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 mg/Nm^3 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

- **Other**: Integrated system: Total costs ca. Dfl l/kg SO_2 or HCl, of which investment less than half. Secondary processes: ca. Dfl 1-l0/kg acid component.

Experience

- **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 $Ca(OH)_2$ 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.

Selective Catalytic Reduction (for NO_x control in combustion processes)

Technology Principle

Ammonia, usually in solution, reacts with nitrogen oxides to produce molecular nitrogen and water vapour, as follows: $4NO + 4NH_3 + O_2$ implies $4N_2 + 6H_2O$ $6NO_2 + 8NH_3$ implies $7N_2 + 12H_2O$. 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 degC).

Aim of Processing

To convert NO and NO_2 in flue gases into N_2 and H_2O.

Technological Preconditions

- **Influent concentration:** No strict limits, but in practice: NO_x 600-2000 mg/m^3 (at 2.5% O_2); SO_2 700-2600 mg/m^3 (at 2.5% O_2); high dust 5-25 g/m^3; low dust 0.01 g/m^3.
- **Temperature:** 250-400 degC. Low temperature units (180 degC) 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 m^3/h. Waste incineration 100-130 m^3/h.

Performance Evaluation

- **Removal rate:** 75-90%.
- **Effluent concentration:** Existing installations 100-200 mg/m^3 NO_x. New installations 70 mg/m^3. Pilot plants 20-70 mg/m^3.
- **Electricity 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, H_2O plus N_2O if reaction temperature too high. Ammonia max. 5 mg/m^3. 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

- **Investment cost:** Power stations: DM 66.3/kW
  Waste incineration: (estimated) Dfl 8000 - 13000/ton NO_x removed (Dfl 6000 for activated carbon catalytic reduction).
- **Operation/maintenance:** DM 100-170/kW.

Experience

- **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 nm/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

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Secondary Combustion of Flue Gas in Soil Decontamination

Technology Principle

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

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 degC or higher. For compounds difficult to decompose or toxic compounds greater than 1200 degC.
- **Pressure:** Atmospheric.
- **Additives:** Fuel (oil or gas); air for combustion; caustic soda or calcium for gas scrubber.
- **Capacity:** Less than 5000- greaster than 20,000 m^3/hr.
- **Others:** Oxygen content 1-10%.

Performance Evaluation

- **Removal rate:** 99-99.9999%.
- **Effluent concentration:** Very low concentrations possible.
- **Residence time:** (in burner) 0.2-2 seconds
- **Electricity consumption:** Fuel 0-2000 kJ/m^3 gas depending on concentration of combustible components. Electricity 0.001-0.003 kWh/m^3 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 cost:** Dfl 45-70/m^3 gas.
- **Operation/maintenance:** Dfl. 10-25/1000 m^3 gas.

Experience

- **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.

Liquid Waste Treatment Processes

Technological profiles are presented on water purification targetted mainly on the small and medium sized industries in developing countries. Waste water composition is reviewed, and classified according to its five most important indicators; biological oxygen demand (BOD), chemical oxygen demand (COD), total oxygen demand, total organic carbon, and ammonia nitrogen content, all of which are defined. The difference is drawn between inorganic waste water and organic waste water, and how and from where these impurities came from in the first place. Sewage treatment/purification technology is discussed, highlighting the methods employed and the types of equipment used in these methods. Finally, water purification in developing countries is considered in the light of the UN Water

Conference of 1977 (Mar de Plata), and developments which have taken place more recently. (**Reference:** How to Start Manufacturing Industries: Technological and Investment Perspectives--Environmental Technologies.

Additional sources of information

Database of Water Pollution Control Technology in JAPAN
Database of Japanese Advanced Environmental Equipment

Biotechnology for Waste and Wastewater Treatment (by: National Association of Safety & Health Professionals)--This book examines the practices used or considered for biological treatment of water/wastewater and hazardous wastes. The technologies described involve conventional treatment processes, their variations, as well as future technologies found in current research. Contents: biotechnology for industrial and municipal wastes; biological degradation of hazardous wastes; biological treatment of industrial wastes/mutant bacteria; nitrification and denitrification in the activated sludge process; and in-situ bioreclamation of contaminated groundwater.

Wastewater Management Primer--This is a recently released report which outlines the role of EPA's Wastewater-Management Office in the control of wastewater and water pollution across the US. The PRIMER features information about: EPA's National Pollutant Discharge Elimination System (NPDES) Program, Pretreatment, Biosolids/sludge management, State Revolving Funds and other alternative funding mechanisms for wastewater construction, NAFTA-related developments along the US-Mexico border. Also included is a brief overview of the wastewater-treatment process.

Adsorption

Technology Principle

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 adsorbant is usually activated carbon, with resin less often used. Regeneration of the adsorbent is possible in some cases.

Aim of Processing

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 H_2S.

Technological Preconditions

- **Ph range:** Acid or alkali pH can increase polarity of organic matter, lowering adsorption.
- **Influent concentration:** For activated carbon, a few g/m^3. For resin, up to 100 g/m^3.
- **Temperature:** High temperatures decrease adsorption of volatile compounds.
- **Additives:** Besides adsorbent, coagulation/flocculation agents if required. Regeneration agents--steams, acids or bases, solvents.
- **Capacity:** Maximum 100 m^3/h. Capacity l0 m^3/h

Performance Evaluation

- **Removal rate:** Inorganic matter greater than 90%, higher for organic matter.
- **Effluent concentration:** Organic matter, a few ppb. Inorganic matter, a few hundred mg/m^3.
- **Electricity consumption:** Pumping, ca. 0.1 kWh/m^3 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

- **Investment cost:** Dfl 3000/m^3 (non-regenerable activated carbon). Dfl 4100/m^3 (regenerable activated carbon).
- **Operation/maintenance:** Dfl 1.89/m^3 water (Dfl 189/kg separated impurity).

Experience

- **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.

Chemical Oxidation

Technology Principle

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

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

- **Ph range:** Usually low. For cyanide pH 9.
- **Influent concentration:** In principle no limits. Due to costs, maximum few hundred ppm. If ozone used minimum few ppm.
- **Additives:** Oxidizing agent, usually chlorine bleach, hydrogen peroxide with iron catalyst, or ozone with UV catalyst.
- **Capacity:** Up to several m^3/day.
- **Others:** Water required, apart from oxidation of gases using ozone. For UVOX system, transparent reactor wall must be kept clean.

Performance Evaluation

- **Removal rate:** Cyanide 100%. Gas scrubbing 95% of odour component.
- **Effluent concentration:** Phenols 1-100 ppm.
- **Electricity consumption:** Production and oxidation of ozone/UV 2.5 kWh/m^3 waste water dosing of oxidation agent 0.01-0.1 kWh/m. Mixing 0.1-0.5 kWh.
- **Emissions:** Oxidation products H_2O, CO_2, 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

- **Investment cost:** Ozone/UV process, capacity 25 m^3/hr polluted water: Dfl 2 400 000.

- **Operation/maintenance:** Dfl 4.5/m^3 water. Oxidation agents: Chlorine bleach Dfl 0.25-0.90/kg. Hydrogen peroxide Dfl 1.30/kg solution. Ozone Dfl 500/kg.

Experience

- **Range of applications:** Disinfection. Purification of industrial waste water. Gas scrubbing.
- **Practical experience:** Purification of industrial waste water--galvanic industry, breakdown of cyanides to CO_2 and N_2 (agent Cl bleach or H_2O_2). Removal of phenols in coke processing, oil refining, tar processing--influent concentration 100 ppm, effluent concentration less than 1 ppm (agent H_2O_2). Gas scrubbing--greater than 95% removal of mercaptans, H_2S and other odour components (agent chlorine bleach, H_2O_2, ozone).

Pervaporation

Technology Principle

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

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

Technological Preconditions

- **Ph range:** Depends on membrane type.
- **Influent concentration:** No technical limitations. On economic grounds less than 100 mg/l.
- **Temperature:** Depends on membrane type, usually 50-70 degC.
- **Pressure:** Concentrate side atmospheric or slight overpressure e.g. 1 bar. Permeate side atmospheric or vacuum (vacuum pervaporation).
- **Additives:** None.
- **Capacity:** 5-50 m^3/hr estimated for ground water purification.
- **Others:** Remove suspended and colloidal particles. Concentration polarisation may be significant under laminar flow conditions.

Performance Evaluation

- **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.
- **Electricity consumption:** Pump ca. 0.1 kWh/m^3 water. Heat if necessary, ca. 6 kWh/m^3 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 influnent concentration may affect performance. Freezing of permeate at low condensor temperatures.

Costs

- **Investment cost:** Capacity 8 m^3/hr; Dfl 600000.
- **Operation/maintenance:** Dfl 1.46-1.85/m^3 water.

Experience

- **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/m^2 hr. Retentate conc. 1 g/m^3, permeate contains greater than 10% wt hydrocarbons.

Precipitation

Technology Principle

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

Aim of Processing

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

- **Ph range:** Depends on the effect of pH on compound solubility. Generally not acid.
- **Influent concentration:** No limits specified.
- **Temperature:** Usually 0-25 degC.
- **Pressure:** Not applicable.
- **Additives:** Substance required to form insoluble compound with desired impurity.
- **Capacity:** Can be carried out on any scale.
- **Others:** May be required to alter pH or break down sequestering agents.

Performance Evaluation

- **Removal rate:** Over 99.5%.
- **Effluent concentration:** A few mg/l (depending on treatment process).
- **Process time:** Less than 1 min. to several hours depending on distribution of solids.
- **Electricity 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

- **Investment cost:** Depend on technique, chemicals used and waste concentration. Examples: For waste water containing 113 mg/l Zn Dfl 200k (1978). For concentrated chemical waste: Dfl 100-3000/ton waste (1989). Dfl 300-400/ton on the average
- **Operation/maintenance:** Dfl 0.29/m^3

Experience

- **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.

Solvent Extraction

Technology Principle

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

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

Technological Preconditions

- **Ph range:** Less than 0- greater than 10 depending on extractant used.
- **Influent concentration:** No limits in principle.
- **Temperature:** Generally 20-60 degC.
- **Pressure:** Atmospheric.
- **Additives:** Extractant, solvent and additives comprising the organic phase acids, bases or salts for regenrating extraction medium. Oxidising or reducing agents or complexing agents to extract the separated impurities.
- **Capacity:** Mixer-settler combination 0.2-2000 m^3/hour. Separators and centrifugal extractors 1-180m^3/hour. Column extractors 0.1-6000 m^3/hour.

Performance Evaluation

- **Removal rate:** 60-99%.
- **Effluent concentration:** ppm level.
- **Electricity consumption:** Centrifugal extractor 0.25-9 kW/m^3. Column extractor 0.1-0.3 kW/m^3. Mixer-settler combination 0.2-0.8 kW/m^3.
- **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

- **Investment cost:** Depend greatly on apparatus type, extractant and process conditions. US$ 60-200k (1974).
- **Operation/maintenance:** US$ 1000-2000/1000 m^3 water (1974).

Experience

- **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 m^3/hour, Zn concentration influent 800 mg/l, effluent 15-20 mg/l. Solvent Solvesso 15 and extractant DEHPA.

Electrodialysis

Technology Principle

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.

Aim of Processing

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

Technological Preconditions

- **Ph range:** 1-13
- **Influent concentration:** Wide range possible, but for economic reasons ca. 1-5 g/l.
- **Temperature:** 10-45 degC, depending on membrane type.
- **Pressure:** Low. Drop of 1-5 bar can occur across membrane stack.
- **Additives:** In pretreatment--flocculation agents, acids, activated carbon. For membrane cleaning--acids, alkalis.
- **Capacity:** For drinking water production greater than 500 m^3/hr. Waste water treatment up to few m^3/hr. Modular construction, so almost any capacity possible.
- **Others:** Remove colloids, organic compounds, insoluble salts, iron and manganese oxides to prevent membrane fouling or damage.

Performance Evaluation

- **Removal rate:** 80-95%.
- **Effluent concentration:** 0.1-1 g/l. Concentrate maximum 100-200 g/l. Wider range possible but uneconomic.
- **Factor concentration:** 20-100 for Ni.
- **Electricity consumption:** 1-5 kWh/m^3 waste water, or 1-5 kWh/kg separated metal.
- **Emissions:** Besides concentrate and purified water, sometimes small waste stream from membrane cleaning.
- **Bottlenecks:** Membrane fouling, biological fouling. Hard particles may damage membrane. 553-Modular construction so scaling up quite simple.

Costs

- **Investment cost:** $101000, $2.2M
- **Operation/maintenance:** Capacity 4000-100000 m^3/day; $0.25-0.50/$m^3$ (drinking water preparation). $ 23165/yr; $1M/year

Experience

- **Benefits:** Less use of chemicals and water, lower discharge taxes and sludge removal costs. $118 000 savings on chemicals. Aquatech system purification mordant waste water, 6400 m^3/yr $1.5M/year
- **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.
- **Practical experience:** Preparation of salt from seawater: largest application, mainly in Japan. Preparation of drinking water--over 1000 installations, total capacity greater than 300000 m^3/day. Separation of metal from waste water: Ni rinsing bath, capacity 0.55 m^3/hr, influent concentration 2.6 g/l Ni, effluent 35 l concentrate, 515 l purified water/hr.

Electrolytic Separation of Metals

Technology Principle

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

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

Technological Preconditions

- **Ph range:** Greater than 5.
- **Influent concentration:** Greater than/equal to 0.1 mg/l. Upper limit depends on solubility of metal.
- **Additives:** Sometimes necessary to alter pH
- **Capacity:** 1-10 m^3/h.
- **Others:** Presence of salts for good conductivity.

Performance Evaluation

- **Removal rate:** Greater than 99.9%.
- **Effluent concentration:** Less than 0.1ppm-100ppm.
- **Factor concentration:** 1-10.
- **Volume flux:** 1-3 m^3/h
- **Electricity consumption:** 10.1-10 kWh/m^3.
- **Emissions:** Salts, acids present in waste water. Hydrogen, oxygen and chlorine depending on waste content.

Costs

- **Investment cost:** Capacity 1 m^3/h Dfl 100000
- **Operation/maintenance:** 10 m^3/day wastewater containing 100ppm Cu(II) purified to l ppm Dfl 3.00-Dfl 5.50.

Experience

- **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.

Plasma Technologies

Technology Principle

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

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

Technological Preconditions

- **Influent concentration:** No limits.
- **Temperature:** Can reach 45000 degC in voltage arc. Free plasma 3000- 5000 deg C. Temperature in reactor area 1200-1650 degC.
- **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 Evaluation

- **Removal rate:** Greater than 99.999% for organic components.
- **Effluent concentration:** Greater than A-values.
- **Residence time:** Fluids a few seconds, solids ca. 30 minutes
- **Electricity 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.

Costs

- **Investment cost:** Installation for liquid treatment (estimated): Dfl. 15-50M.

Experience

- **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.

Solid Ion Exchanger

Technology Principle

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

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

Technological Preconditions

- **Ph range:** Strongly basic or acidic ion exchanger 0-14. Weakly basic ion exchanger less than 10. Weakly acidic ion exchanger greater than 4.
- **Influent concentration:** Maximum ion concentration 10-20 g/l water.
- **Temperature:** Cation exchanger (polysulphonate) 120 degC. Anion exchanger (polystyrene-based) 0-100 degC.
- **Pressure:** 0.15-0.25 MPa.
- **Additives:** Regeneration solution-with high concentration of cations or anions, e.g. HCl, H_2SO_4, NaCl, NaOH, NH_3.
- **Capacity:** 0.5-2.5 eq/kg ion exchange material.

Performance Evaluation

- **Removal rate:** 80- greater than 99%.
- **Effluent concentration:** To (sub) ppm level.
- **Electricity 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 cost:** Cation exchanger Dfl 3000-4000/m^3. Anion exchanger Dfl 8000-13 000/m^3. Chelating exchanger Dfl 25000/m^3
- **Operation/maintenance:** Dfl 1-l0/m^3 water

Experience

- **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.

Solid Waste Treatment Processes

Four main branches exist for the long term management of solid waste, namely; material recovery, organic stabilisation, energy recovery and landfilling of residuals. These are indicated and explained by flow charts. The composition of solid waste is reviewed and illustrated by tabulated data for waste generation in USA and Germany in 1991. Recycling of waste in various industries is examined. The mining industry is well suited to recycling as most of its residues are non toxic; metallurgy recycles most of its slags and metal scraps, but little of its sludges; food processing is good on recycling vegetable and meat residues in industrialised countries but is less good on recycling slaughter waste products and has thus good potential for recycle. The construction industry is another which has scope for more recycling whilst the chemical industry and pharmaceutical industry create wastes which are seldom recyclable. Mechanical methods of sorting waste are reviewed. An important product of this is refuse derived fuel (RDF) which can be pelleted or briquetted then thermally treated to give a fuel. Biochemical treatment is mainly concerned with the anaerobic digesting of solids (preferably RDF and sewage sludge) to give a biogas of CH4 and CO2. Another possible biochemical conversion of leaves, wood, foodstuffs etc. can produce ethanol, a valuable fuel as a by-product. (Reference: How to Start Manufacturing Industries: Technological and Investment Perspectives--Environmental Technologies. Volume V, Solid Waste Treatment, File Z 24, 4 pages).

Composting

Technology Principle

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

Aim of Processing

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 degC 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 less than 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 Evaluation

- **Compost yield:** 40-50% of starting material.
- **Emissions:** CO_2 and H_2O 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 H_2S and mercaptans if anaerobic zones are formed.
- **Bottlenecks:** Porosity too low. Insufficient aeration.

Costs

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

Experience

- **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

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Composting Plant

Composting is an ancient agricultural process for reutilising organic waste as a carrier of nutrients for plants. It consists of decomposing organic waste in damp and aerobic conditions by means of microorganisms. Among the many waste materials presently composted are; organic household waste, sludge, leaves, waste from abattoirs, and residues from the food industry/wine-making etc. Composting takes place in three stages; pre-rotting or intensive rotting (characterised by high oxygen uptake and exotherms), conversion or main rotting (slower, less oxygen absorption and done by fungi rather than bacteria), and post rotting. These processes and the parameters influencing them are reviewed. The design of an automatic composting plant is considered as a case example and illustrated by a flow chart and diagram. A factory for producing composting plants is projected, illustrated by a flow chart which indicates all stages. Tabulated data are given, showing costs and requirements for a factory making 3 units per day. Certain assumptions had to be made since the factory envisaged handled largely cement, and such a factory is never dedicated to making concrete rotting channels exclusively. (**Reference:** How to Start Manufacturing Industries: Technological and Investment Perspectives--Environmental Technologies. Volume V, File Z 26, 7 pages).

Drying

Technology Principle

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

Aim of Processing

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

- **Temperature:** Air input 350-400 degC for paper in drum dryer. 100 degC 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.
- **Moisture Contents:** Paper 50-55%. Plastic 20-25%.

Performance Evaluation

- **Removal rate:** 100%.
- **Final moisture contents:** Plastic 0%. Paper usually dried to normal 10% moisture content.
- **Drying time:** 5-10 minutes.
- **Electricity consumption:** Per ton dried paper--115 m^3 natural gas, 30 kWh electricity (125 m^3 natural gas equivalent). No data available for plastics.
- **Emissions:** Water vapour and dust.
- **Bottlenecks:** Accidental combustion caused by sparks.

Costs

- **Investment cost:** Capacity 4 ton/h drum dryer Dfl 460000.
- **Operation/maintenance:** Dfl 56 per ton.

Experience

- **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.

Immobilisation

Technology Principle

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

Aim of Processing

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

- **Ph range:** 6-11
- **Influent concentration:** Too low to be otherwise recovered but too high to be safely dumped.
- **Temperature:** Physical confinement 10-20 degC. Chemical stabilisation up to 50 degC.
- **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:** 10-400m^3/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 less than 20-30%.

Performance Evaluation

- **Effluent concentration:** Similar to influent concentration.
- **Process time:** Mixing time 2-5 minutes, hardening time several days to several weeks.
- **Electricity 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.

Costs

- **Investment cost:** For capacity of 20000 ton waste/year: Dfl 10 M
- **Operation/maintenance:** Dfl 205/ton waste (Dfl 4,100 k/year). Dumping costs: Dfl 100-350/ton immobilisate

Experience

- **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

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An overview

A closed-loop solid waste material recovery process which surpasses the strictest emission standards for air and water, capable of efficiently treating, in an environmentally safe manner, a broad cross-section of waste streams.

The alternative process is a commercial process which recovers from municipal, commercial and industrial wastes, sludges, medical wastes or shredded tire waste >99% of the input as raw materials.

Products of the process include:

Energy-Gas

- A clean synthesis gas containing recovered energy (250 Btu/cu.ft.) from the waste is produced from the organic portion of the waste. This clean gas has uses that include: boiler fuel, gas engine to electricity production, use as a chemical feedstock or steam production.
- Air emissions produced from the combustion of the synthesis gas are far below allowed USEPA, Republic of Germany and European Union air emission regulations.

Recovered water

- Water is naturally contained in the waste input (>25%) and is recovered, cleaned and available for reuse by the process, reducing process make-up water requirements, facilities are able to achieve zero discharge.

Vitrified mineral product

- Inorganic components in the waste form a mineral product that is non-toxic, inert, passes TCLP elution testing and does not require landfilling. Reuse as an abrasive, filler, road aggregate, formed decorative bricks or cement additive represent uses for this product.

Metal alloy

- Metal materials which are contained in solid wastes are melted by the process and recovered, ready for reuse by a smelter. Appliances can be shredded into the input feed; the metal is recovered, paint, grease and plastic parts produce energy containing synthesis gas.

Elemental Sulfur

- Sulfur contained in the waste input is recovered as elemental sulfur. Although the total quantity is minimal, the product is reusable as industrial grade sulfur.

Lead/Zinc concentrate

- The process is able to contain, capture and concentrate the heavy metal substances common to solid wastes safely. Economic recovery of lead and zinc from the concentrate is possible using local smelters.

Mixed Salts

- Cleaning and recovery of the process water yields a high quality mixture of salt (sodium/potassium chloride).

Benefits of this process include

- The process is compatible with totally integrated solid waste management planning, including front-end curbside separation. No front-end presorting of the waste input is necessary.
- Dioxin and furan components are destroyed by the process at high temperatures (> 2100°F, >2.5s) and not allowed to reform (de Novo synthesis).
- There is no ash residue requiring a permitted landfill.
- Facilities are only 60 feet tall, require no tall stacks; a 660t/d facility requires approximately 5 acres of real estate.
- Desired throughput is achieved by combining multiples of modular process lines, each capable of processing 13.75 t/h, 8000 h/y. A two line facility (TS 100-2) will process 220,000 t/a.; using the synthesis gas to produce electricity will yield ~ 12-15 mega watts gross, 6-9 megawatts net electricity

For further details on this technology, please contact:

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Vision 21

Environmental protection has come to the forefront nationwide, and more recently has become especially important in South Korea. In a country where 45 million people share a land mass the size of Switzerland (which has 8 million citizens), concern for the environment becomes of paramount importance.

In 1996 the South Korean Government announced a project called "Vision 21". The project is budgeted to spend 7.7 billion Won ($5 billion US) on environmental protection projects over the next ten years. Simultaneously, new stricter environmental regulations for industries, transport and households were being generated. A large portion of the budgeted funds will be used for better water quality and treatment of waste.

As an example, the city of Seoul has attracted its districts and offered them subsidies of 100 billion Won each, if they construct a thermal process for the treatment of their waste until year 2001. Currently, the city of Seoul daily produces 9,000 tons of waste and thermally processes only 0.7%. In the year 2001, with the offered incentives, the city expects the thermal treatment of waste to be greater than 30%.