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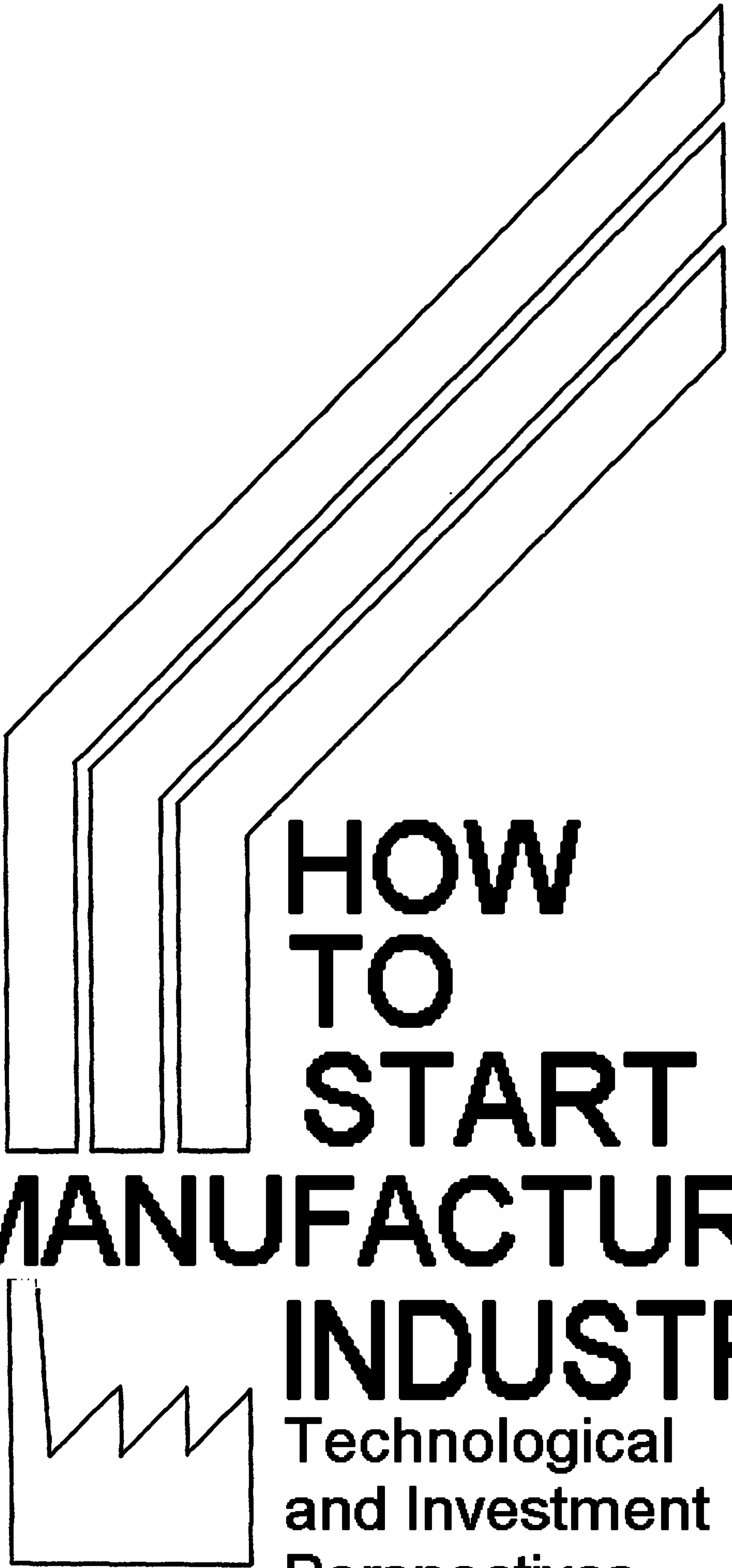

HOW TO START MANUFACTURING INDUSTRIES

Technological and Investment Perspectives

Volume V

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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U2	1110	Egg Production
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File V: Water Works and Supply ISIC 420 (Rev.2), 410 (Rev.3)*

In Volume II

V1	4200	Solar Desalination Unit

In Volume V

V2	4100	Filter Nozzle for Fast-run Filters in Water Purification (Oct. 1990)
V3	4100	Filter Cartridge for Domestic Water Filters (Oct. 1990)

File W: Other Mining ISIC 290*

In Volume IV

W1	2903	Salt Production Plant
W2	2901	Processing of Gravel and Sandworks
W3	2901	Quarries for Building Materials
W4	2903	Salt Refining Plant

File Z: Activities Not Adequately Defined ISIC 000, 900*

In Volume IV

Z1	0000	Recycling Plant for Oil Filters and Other Oily Waste Materials

In Volume V

Z2	9000	Industry Briefing Paper: Water Purification (Oct. 1992)
Z3	9000	Fixed Bed Cascade Bioreactor for Sewage Prepurification (Oct. 1990)
Z4	9000	Conventional Type Separator for Light Liquids (Oct.1990)
Z5	9000	High Performance Separator for Light Liquids (Oct. 1990)
Z6	9000	Separator for Organic Grease and Oil (Oct. 1990)
Z7	9000	Separator for Waste Water with a Starch Content (Oct. 1990)
Z8	9000	Sedimentation/Flotation Unit (Oct. 1990)
Z9	9000	Filter Plates for Filter Presses Used in Sludge Drainage (Oct. 1990)
Z10	9000	Fine-mesh Filter for Filter Cartridge Used in Micropurification of Waste Water (Oct. 1990)
Z11	9000	Filter Sand (Oct. 1990)
Z12	9000	Screens (Oct. 1992)
Z13	9000	Coarse Sieves (Oct. 1992)
Z14	9000	Filter Cloth for Diffuser Plates (Oct. 1992)
Z15	9000	Hydrocyclone (Oct. 1992)
Z16	9000	Trickling Filter (Oct. 1992)
Z17	9000	Activated Sludge Process (Oct. 1992)
Z18	9000	Anaerobic Waste Water Treatment (Oct. 1992)
Z19	9000	Oxidation/Reduction (Oct. 1992)
Z20	9000	Coagulation/Flocculation (Oct. 1992)
Z21	9000	Ion Exchanger Process (Oct. 1992)
Z22	9000	Belt Filter Press for Draining Domestic and Industrial Sludge from Sewage Treatment Plants (Oct. 1992)
Z23	9000	Measurement of Flow Volume of Waste Water (Oct. 1992)
Z24	9000	Industry Briefing Paper: Solid Waste Treatment (Dec.1993)
Z25	9000	Incineration Plant for Domestic Waste (Dec. 1993)
Z26	9000	Composting Plant (Dec. 1993)
Z27	9000	Refuse Sorting Plant (Dec. 1993)
Z28	9000	Hazardous Waste Incineration (Dec. 1993)
Z29	9000	Sewage Sludge Incineration (Dec. 1993)
Z30	9000	Recovery of Metals from Metal Sludges (Dec. 1993)
Z31	9000	Vitrification Process for the Inertia of Residue Products from Refuse Incineration Plants (Dec. 1993)
Z32	9000	Treatment of Mixed Paint Sludges (Dec. 1993)

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*ISIC (International Standard Industrial Classification) Codes Rev.2 for Volumes I to IV, or Rev.3 for Volume V

AIR PURIFICATION

File: O 32
ISIC CODE 2811
May 1993

Industry briefing paper:
Air quality control

Introduction

Air quality control is one of the important aspects of the environmental protection problem. There are many emission sources of air pollutants like mining, manufacturing, power generation, vehicles or households. The types of air pollutants and their physical and chemical properties affect the selection of the control system. In principle, there are two basic approaches of air pollution control from existing sources: either to change the process which emits the pollutants or to install final control (purification) equipment.

The designer of an air pollution control unit must be familiar with many operation designs such as sedimentation, filtration, distillation, crystallization, absorption, adsorption, combustion and catalytic reaction. In addition, commercial applications have many problems to solve, like corrosion, side reactions, foaming or catalyst deactivation.

This paper is restricted to air quality control in industry. The information on emission sources, types of air pollutants, and purification equipment on processes focuses on industrial applications.

Types of pollutants

Pollutants are solid, liquid and gaseous matter which when emitted in the air change its natural composition. There are five major categories of air pollutants:

- *Inert particulates:* very fine-grained solid airborne material which do not react with the environment, for example, ash, dust from quarries, etc.
- *Active particulates:* very fine-grained airborne material that can be oxidized or which will otherwise react with the environment, for example, metals, polycyclic organic matter, etc.
- *Aerosols and fumes:* aerosols are liquids below 5 micrometres (oil, acids, etc.) and fumes are condensed metals, metal oxides or metal halides (exhalations of pyrometallurgical processes of lead, zinc, mercury, etc.).
- *Hydrocarbons:* all organic compounds composed primarily of hydrogen and carbon. There are saturated and unsaturated hydrocarbons, with chain or ring structure. Oxygenated hydrocarbons include aldehydes, esters, ketones, ethers, acids and oxides. Halogenated hydrocarbons include many solvents and refrigerants.
- *Gaseous oxides:* acid gases of carbon (CO, CO_2), sulphur (SO_2, SO_3), nitrogen (NO, NO_2) and halogen oxides. CO is produced mainly by combustion engines in cars or by household fire places; SO_2 is emitted by power plants, oil refineries and metal smelters; NO_x originates from all kinds of combustion processes in engines or furnaces.

As far as quantity is concerned, gaseous oxides and hydrocarbons contribute major emissions. The most dangerous emissions however are active particulates and some halogen compounds.

Major industrial sources of air pollution

Industrial dust and fumes originate from mechanical, physical or physico-chemical processes. Some industrial operations producing dust and fumes are: crushing, grinding, drying, mixing, screening, transporting, storing, burning or cooking. Industries that produce major dust and fume emissions are: *(a)* mining, and dressing, of coal, ore and industrial minerals; *(b)* smelting of ores and ore concentrates; *(c)* construction material quarries and cement factories; *(d)* chemical and petrochemical plants; *(e)* fuel-fired power generating plants; and *(f)* textile plants.

Mining

Mining of coal and ore minerals generates significant air pollution in open pit operations and in benefication plants. Processes like crushing of crude ores or raw coal, grinding and dry screening of ores, sorting of minerals, transportation of material, and disposal of tailings emit considerable quantities of coal dust, metal contaminated rock dust and gases like SO_2 into the air. The quantity of dust emissions depends to a large extent on the moisture content of the material processed. The dust effects mainly the quality of the air of the working places in the mine, the mineral dressing plant or the coal washing plant but can contaminate the soil and the groundwater of the mining region when the dust is emitted to the surface by rain.

Briquetting and coking of coal

Briquetting of coal and lignite generates large amounts of dust containing coal particles as well as gases and impurities of coal (FeS_2, CH_4, etc.) and of bitumen. Major dust sources are: dryers, crushers, screens and all kinds of transport on conveyor belts, hoppers, etc. The total dust generated in briquetting factories amounts to up to 20% of the production and has to be separated from the workplace air.

Also in coking plants and gasworks, dust and gases are emitted from industrial operations: *(a)* the filling of the furnace chamber disperses coal dust and releases gases such as CO, CO_2, N_2, H_2, CH_4 and SO_2; *(b)* the slaking of coke with water disperses fine coke particles and coking gases into the air, *(c)* the exhaust fumes from coking plants and gasworks contain sulphur amounting to 1-3 kg S per tonne of coke.

Production of construction material

Many working processes in quarries produce dust. The drilling, blasting and loading of rock material or the crushing, screening, jigging, sawing, drying and packing of stones generate dust of various compositions. Dust and fumes in large quantities are also emitted in the following construction material industries :

Lime kiln, in which limestone is burned to quicklime;

Dolomite kiln and gypsum kiln;

Glass factories, in which fumes containing dust (silicon and carbon compounds) and gases containing CO_2 and CO are generated;

Cement plants, in which raw materials of limestone, clay, and marl are crushed and ground, cement clinker is dried and ground and cement is filled in bags;

Ceramic plants, in which various non-malleable raw materials of quartz, silica, feldspar, limestone, dolomite, magnesite and bauxite is ground. Dust is also dispersed in ceramic plants when products like porcelain or stoneware are cleaned with brushes or cutters;

Bitumen-mixing for road construction, in which filling material like sand, gravel, stone chippings or crashed slags are first dried and then mixed with hot bitumen. Dust contains particulates of the stony material and gases with various hydrocarbons.

Iron processing industry

Emissions of dust, fumes, gases and vapours are very common in iron smelting, iron foundry and steel making. Major sources of emissions are from the sinter processes (in rotary kiln or on sinter belts), the reduction of iron ore in blast furnaces and the foundry works.

Blast furnaces generate high amounts of dust and gas (20-200 kg/t pig iron). The gases contain CO_2, Co, H_2, CH_4, N_2 and H_2O; the dust contains particulates of coke, slag and metals (Fe, Zn, Pb, Mn, Al), sulphur and phosphorus.

Foundry furnaces produce also throat gases which contain similar chemical compounds, e.g. CO_2, CO, SO_2, N_2 and F. The fluorine and its compounds are exhausted when fluorite is used in basic cupol furnaces. Fluorine is one of the most hazardous substances to vegetation. The throat gas from foundry furnaces, contains also a substantial amount of dust with SiO_2, CaO, Al_2O_3, MgO, Fe_2O_3, MnO, ZnO and coke particles. A special source of fine quartz dust is the mould sand. Fine-grained quartz in the air we breathe can cause silicosis.

The steel industry has similar emission problems with dust and gases but special considerations are required for the emission of iron oxides and fluorine compounds. The high temperature processes in modern steel works produce iron oxide which can be realized in the brown smoke exhalations. Fluorides are generated from fluorite which is used to melt the pig iron and steel.

Base metal smelting

The ore concentrates for producing base metals like copper, zinc, lead, antimony, etc. are dominantly metal sulphides. Before smelting, the sulphides need to be calcined to oxides. The fumes of roasting furnaces contain SO_2 and various volatile (hazardous) metals like Hg, As, Pb, Cd etc. The smelting of base metals generates fumes again and the electrolytic refinery of raw metals produces gases from the electrolytes. Special problems arise from smelting operations of scrap metals (especially copper and aluminium). These smelting processes can generate fumes and gases containing metal oxides and many impurities such as oil, grease, alloy material.

Most dangerous for human health are emissions of cadmium, mercury and beryllium. Also hazardous are the increasingly common hard metal alloys containing Co, Cr, W, Mn, Ni, Mo, V, Ti, Ta, when used as tools in metalworking, because of the very fine-grained metal dust produced by processing operations.

Chemical industry

There are hundreds and thousands of chemical products and every single operation causes emissions to the air. Major emissions are HCl, HF, H_2S, NO_x, NH_3, hydrocarbons, organic solvent vapours, metal oxide dust, carbonizing gases. Examples of gaseous and/or dust emissions in the chemical industry are found when producing the following products:

Fertilizer: fluorides, ammonia;

Caustic soda: chlorides, chlorine gas;

Carbides (Ca-, Si-carbide): SiO_2, MgO_2, CO, sulphides;

Paints: metal compounds, HCl, HBr, H_2S, synthetic pigments;

Linoleum: linseed oil vapour;

Film: solvent vapour;

Crude oil refinery: hydrocarbons, SO_2, H_2S, H_2;

Cellulose: SO_2, leaching vapour;

Synthetic rubber: soot, talcum.

Textile industry

Some basic operations in the textile industry, such as weaving or spinning, generate dust containing fine fibres. Dust from cotton factories is known for many lung diseases like asthma, bronchitis or lung cancer. A special problem of hazardous dust generation are asbestos operations. The production of fireproof fabrics, acid-resistant filters, isolation material or brake linings using asbestos as a raw material requires sophisticated air quality control because asbestosis can cause lung cancer.

Air quality control equipment

Particulate pollutants collection

The collection of particles from dust, fumes, smoke or mist requires an applied force. There are four major classes of collectors in use:

Dry collectors such as *gravity settling chambers* involving gravitational force or *cyclones* involving centrifugal force;

Filters involving impaction, interception and diffusion;

Electrostatic precipitators involving electrostatic force (high voltage);

Wet scrubbers involving the same mechanisms as filters: impaction, interception and diffusion.

Gases and vapours removal

For the removal of air contaminants in the form of gases or vapour, a variety of methods are in operation. The major types are based on three mechanisms: absorption; adsorption; and oxidation (chemical conversion, combustion).

Absorption is the most common gas purification technique and is applied in various processes. It involves the transfer of substances from the gaseous phase to the liquid phase and the absorbed substance dissolved or reacted with the liquid. The majority of gas absorbers are *spray towers, packed towers and plate or fibre cell towers.*

Adsorption is the concentration of gas impurities on the surface of a solid substance. Commercial adsorbents are granular material with a large surface area per unit weight (e.g. activated charcoal). The common installation for gas adsorption operations is a fixed-bed (deep-bed) *packed adsorption column.* Adsorption rates can be controlled by external diffusion in the gas-phase, by pore diffusion and by surface reaction rate.

Oxidation of gas impurities is simply a combustion process (burning of contaminants with air or oxygen) or a more complex catalytic chemical conversion. The three major types of combustion devices are *flares, afterburners* and catalytic oxidizers.

Pollutant collection and removal equipment

In industry, many specific types of the above mentioned general equipment are in commercial use. They have specific characteristics such as optimum size of particles, optimum concentration of pollutants, temperature limitations, face velocity, air resistance and efficiency (see table 1). Taking a more practical approach into account, the major types of commonly used particle collectors can be characterized from the following.

Gravity settling chambers are simple and inexpensive. Such units have no moving parts except for the periodic removal of the separated material. Gravity settling chambers are a good choice for an initial separation of large masses of coarser grains. To be effective, a longer period of settling should be involved. For higher efficiency, a baffled chamber can be used because coarse-grained particles will impinge on the baffles and lose kinetic energy for dropping out of the gas stream.

Cyclones are low-efficiency collectors for small particles but quite efficient for the collection of larger particles. Cyclones accelerate the gas stream into rapid rotational motion which throws the larger material to the wall of the cyclone. The cut diameter (50% of that size is collected) of cyclones is about 10 micrometres. Cyclones can be operated, however, either wet or dry. In a wet operation, water is injected into the cyclone inlet.

Filters are woven or felted fabrics in which particulates are collected from an air or fluid stream by rotation on the porous structure of the fabrics. A brand new filter cloth is not optimally effective because the true filtering surface is formed when some particles bridge the openings between the fibres. Filter bags have to be cleaned after some time.

Electrostatic precipitators are pollutant collectors in which a high voltage electric field is created. Particles in the air stream acquire an electric charge and move to neutralizing collection plates. The collection potential decreases as the thickness of the dust layer on the plates increases. This results in power losses and in inefficient collection of fine particles. To prevent this problem, the collection plates have to be struck by hammers (rappers).

Wet scrubbers collect all kinds of soluble contaminants in liquids. The spraying of the scrubber liquid provides a large surface area for the collection of pollutants present in the gas. Various scrubber designs are in operation and provide high removal efficiency in different particle size regions: spray chambers for the removal of particles larger than 25 micrometres, wet cyclones for 10-20 micrometre particles, self-induced scrubbers for 1-5 micrometre particles or venturi scrubbers for particles below 1 micrometre.

For the control of polluted gases or vapours (see table 2) two principle types of equipment are in use: absorbers which depend on the solubility of the contaminants and reactive scrubbers which depend on absorption and chemical reaction for the removal of the gaseous pollutants.

Gas absorbers are used in the form of vertical up-flow chambers with downward sprays (spray towers), in the form of towers with packing (packed towers), or in the form of several stages of fibre cells. Absorption is enhanced by high diffusion rates, large interfaced areas and turbulence.

Afterburners or thermal oxidizers are operating in rather high temperature areas (800°-1000 °C). Most of the fuel should come from waste gas and even heat recovery might be possible. Catalytic oxidation systems operate cooler (150°-300 °C). Afterburners have high removal efficiency of submicron odour-causing particulate matter. After combustion, all non-toxic gases can be released directly to the atmosphere.

Table 1. Characteristics of selected particulate collectors

Type	*Size of particles (micrometres)*	*Grain limitations (per cu ft)*	*Temperature limitations (°C)*	*Efficiency (weight %)*
I. *Industrial Filters:*				
Cloth Bag	> 0.3	> 0.1	–20-250	99
Cloth Envelope	> 0.3	> 0.1	–20-250	99
II. *Electronic Precipitators:*				
Plates	> 0.3	>0.1	–20-450	99
Pipes	> 0.3	> 0.1	–20-650	99
III. *Dry Collectors:*				
Setting Chamber	> 50	> 5	–20-350	< 50
Baffle Chamber	> 30	> 5	–20-350	< 50
Skimming Chamber	> 20	> 1	–20-350	< 70
Cyclone	> 10	> 1	–20-350	< 80
Multiple Cyclone	> 5	> 1	–20-350	< 90
IV. *Wet Scrubbers:*				
Cyclone	> 10	> 1	0-350	< 90
Impingement	2-10	> 1	0-350	< 95
Submerged	> 1	> 1	0-350	< 95
Pebble Bed	> 5	> 0.1	0-350	< 90
Multidynamic	< 0.5	> 0.1	0-350	< 99
Venturi	< 2	> 0.1	0-350	< 99
Crossflow	> 3	> 0.1	0-130	< 95
Jet	> 2	> 0.1	0-350	< 90

Table 2. Gas quality control techniques in industry

Process	*Industrial application*	*Pollutant collected*
Absorption	power plants aluminium smelters foundries	SO_2, HCl, HF, F, phenol, NH_3, CH_2Cl, metals
Adsorption	incinerating plants paint shops fish meal factories	SO_2, halogens, solvents, amines
Afterburners (Thermal Oxidizers)	paper mills synthetics industry	solvents, softeners
Catalytic Oxidizers	chemical industry pharmaceutical industry paint shops	H_2S, amines, organic sulphur compounds CH_3OH, tetrahydrofurane

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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ISIC CODE 2811
May 1993

How to Start Manufacturing Industries

Electrical precipitator

Introduction

Electrical precipitators are mainly used, where a dust separation from large gas streams (up to more than a million m³/h) is necessary. They are used today in many branches of industry for flue gas cleaning. The main applications are for flue gases from:

Power plants (coal-fired furnaces);
Iron and steel industry (blast furnaces and converters);
Foundries (furnaces);
Non-ferrous metal refineries (furnaces);
Refuse incinerators (furnaces);
Cement plants (rotary kilns and mill drying);
Expanded-clay aggregate plants;
Chemical plants;
Glass industry;
Pulp and paper industry.

Electrical precipitators are more effective in dust separation than the old mechanical filters (as, for example, cyclones and fibrous filters). An important area for the use of electrical precipitators is in dust separation in power plants. For this, also, fibrous microfilters, the so-called bag filters, are used (see separate profile). Bag filters have similar separation qualities but need less space and have lower investment costs. However, these advantages have to be paid for by a higher pressure loss, i.e. by a higher need for energy by the blowers. The pressure loss of an electrical precipitator is generally in the category of 1-4 mbar (< 500 Pa).

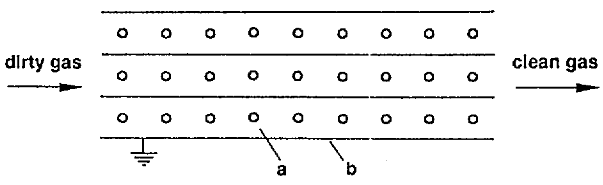
The aim of dust separation is the removal of fly ash and sooty particles from the flue gases as they not only pollute the air, especially in the immediate surroundings, but they also contribute to the greenhouse effect. Many developed countries, and some developing countries, have introduced limits for the dust emission in flue gases. Germany and Indonesia, for example, have laid down a limit of 50 mg/nm³ flue gas (under normal conditions).

Besides their use in the dust separation of industrial flue gases, electrical precipitators are also used in air-conditioning devices where the two-phase parallel-plate precipitator, with a positive corona electrode is preferred because no ozone is created. However, for flue gas cleaning the one-phase parallel-plate precipitator with a negative corona electrode is used—as described in the following.

Description of the process

In electrical precipitators the dust particles having been electrostatically charged are deposited at the collecting plates. Separation results from electrical fields, which have been built up between the negatively charged emission electrodes and the earthed collecting electrodes. The schematic structure of such a precipitator is shown in figure 1.

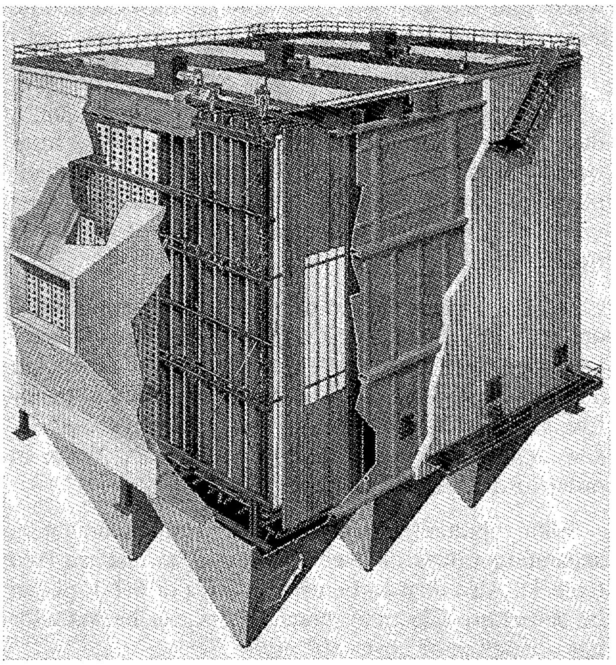
Figure 1. Single-stage parallel-plate precipitator with negative emission electrodes



a = negative emission (corona) electrode
b = collecting electrode

Industrial filters work with typical voltages of 20-80 kV and with channel widths of 200-600 mm. The flue gases loaded with dust pass through the electrical fields, whereby the gas ionizes in the vicinity of the corona electrodes. This is achieved by an adequate choice of voltage, which means that a minimum voltage is required (corona inception voltage; typical value: 10-30 kV).

If this voltage is raised, the current increases until electrical breakdown (sparking) occurs (breakdown voltage). Both of these voltage values depend on the electrode geometry as well as on the type of gas and its properties. For optimal collection efficiency, high field strength and high corona currents are required; but they must stay just below the electrical breakdown. If pulsed voltage is used, the voltage peaks can exceed the breakdown voltage.



To allow precipitator operation, the difference between the corona inception voltage and the breakdown voltage must not be too small. This difference is influenced by two factors:

Gas temperature: increasing temperatures decrease the difference;

Gas pressure: increasing pressure enlarges the difference.

At atmospheric pressure, operation is difficult above 400 °C. With high pressures > 1 MPa operation is possible even at 800 °C.

After ionization the negative ions are accelerated towards the positive collecting electrodes and thus meet up with fly ash particles of the gas stream through which they have to pass. The ions stay attached to these particles, where they are electrically charged and also accelerated towards the collecting electrodes; here they settle temporarily.

The acceleration of the charged particles as well as the forming of the dust layer depend on the electrical properties of the particles, particularly on their electrical resistance. The favourable range of resistivity to collection is 10^4-10^{11} Ωcm. Particles with a lower resistance ($< 10^4$ Ωcm) give up their charge when they collide with the collecting electrode, change their polarity and are repelled back into the gas stream. Particles with a higher resistance ($> 10^{11}$ Ωcm) form a growing layer that accumulates more charge, thus leading to a weakening of the electrical field and "re-emission".

For a successful operation of electrical precipitators dust resistivity should be measured under conditions as close as possible to those in practice. Unfavourable resistivity can lead to the abandonment of electrical precipitators and to the use of bag filters instead. This can be the case in power plants, for example, using coal of a very low sulphur content, thus of high resistance. Problems caused by high dust resistivity can be overcome through gas conditioning (e.g. spraying water into the gas or adding sulphur trioxide in low concentrations) or through the pulsed-voltage technique.

In an optimally designed electrical precipitator a dust cake forms on the collecting electrodes, from where it is removed by periodic rapping of the precipitator elements. This dust cake falls into a hopper underneath the precipitator, from where it is further transported.

Dust removal is carried out at regular intervals without the gas stream being cut off. Consequently, previously collected dust is re-introduced into the stream and transported further. The collector length is therefore subdivided into several (three to five) successive zones, which are cleaned at different times in order to minimize dust penetration.

With optimally designed electrical precipitators separation values of over 99.9% can be reached (see table 1). Also dust particles with sizes of 0.1-1 m can be separated. Electrical precipitators can be built for gas quantities of up to 10^6 m^3/h.

Table 1. Advantages and disadvantages of electrical precipitation

Advantages	*Disadvantages*
High separation degree (also with big units);	High investment costs;
Equally high degree of separation independent of corn size;	A lot of space reqired;
More or less no influence on separation degree through load alterations;	Frequently necessary to condition the dust before electrical separation in order to bring the dust resistance into optimal dimensions;
Slight mechanical wear (low maintenance need);	Very high voltages (several kV) necessary
Low electricity consumpting.	

Product description

Electrical precipitators are made up of a steel casing in which the negative emission electrodes and the positive collecting electrodes are situated in rows.

There are different types of emission electrodes, though spiral electrodes have proven to be ideal for electrical precipitators, as they offer the following advantages:

- Excellent eelctrical capabilities because of their round cross-section and their smooth surface;
- An even distribution of electricity over the whole electrode as a precondition for an effective separation;
- Simple installation, thus low costs and good maintenance.

The spiral electrodes are vertically hooked into the stable corona-frame construction in such a way that they are positioned in the middle between the collecting electrodes. The collecting electrodes are situated at equal distances, this distance being between 20 and 60 mm.

The collecting electrodes mostly consist of cold-rolled steel profiles that are shaped in such a way that an optimal distribution of the current and a high stability is achieved.

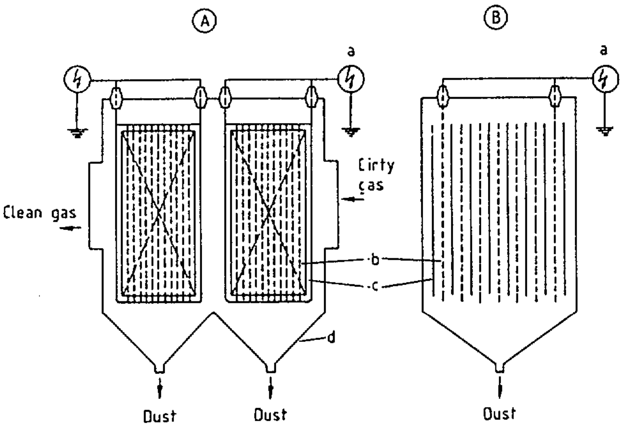
A fixed number of steel profiles are built into one frame. These frames are then put into the corona-frame construction in a vertical position and electrically insulated. Both electrode systems are connected with the relevant rapping devices.

According to the volume of the gas stream and of the dust several single precipitator elements are used, situated in rows (3-5 elements) one behind the other or parallel to each other. The total frame construction is surrounded by gas-tight welded steel-plate elements. Beneath each precipitator element a hopper is welded to collect the dust after rapping.

Today many precipitators no longer work with a constant high voltage but use energy pulses instead, so that the efficiency of the precipitator is so much increased, that a considerable reduction in the size of the precipitator is possible. Also electricity consumption is considerably reduced by the pulse system.

Dry electrical precipitators with horizontal gas streams are mostly used today. Figure 2 shows a two-zone parallel-plate electrical precipitator with a horizontal gas stream.

Figure 2. A two-zone parallel-plate electrical precipitator showing vertical sections A and B at right-angles to each other



Key:

a High-voltage power supply

b Emission electrode

c Collecting electrode

d Hopper

The velocity of the gas stream in the precipitator is considerably lower than that in the inflow channel. In order to get an even gas distribution over the whole cross-section of the precipitator, necessary for a successful dust separation, a gas distribution system is fitted at the entry of the precipitator; this consists mostly of two to three rows of perforated iron plates.

The electrical precipitator needs a precision control. This is mostly done today by independent control devices combined with an integrated control system. Independent control units are used for the following:

Control of the high-voltage aggregates;

Control of the rapping device;

Automatic control of the fly ash transport.

Dimensioning

The size of an electrical precipitator is dependent on the following:

Gas volume;

Temperature;

Entry concentration;

Dust properties;

Emission regulations.

Important properties are the specific dust resistance, which in the case of the usual dust types ranges from 10^9-$10^{13}\Omega$, and the effective velocity of the charged dust particles, which is usually at 2-25 cm/s. The common gas velocities in the precipitator are at the most 1-3 m/s.

Besides this, the composition of the coal used plays an important role in power stations because it influences the resistivity (specific dust resistance) of the fly ash. The resistivity is further dependent on the sulphur or alkali content of the fly ash. With a low sulphur or alkali content it is more difficult to separate fly ash because of its higher resistivity. On the other hand, a high sulphur content (> 1%) facilitates dust separation because the flue gases and dust have better electrical characteristics.

In addition, the technical construction also influences the size of the precipitator. The degree of separation is not only dependent on the area of the precipitator, but also on voltage and strength of current. The intensity of separation increases with increasing voltage and thereby with increasing strength of current. However, there is an upper limitation to this, because at some point the dust cake on the collecting electrodes will be discharged, thus diminishing the degree of separation.

To avoid these negative effects, but at the same time to achieve the necessary high production of ions through high voltages, pulsed separators are used today. The necessary high voltage is realized in the pulse maximum, while the pulse pause determines the average current flow.

The use of pulse technology is not necessary in every case, however its advantages increase with the resistivity of the fly ash. Further advantages of pulse technology are:

Lower electricity consumption (a saving of up to 70% compared to conventional high-voltage aggregates);

Smaller sizes of the precipitator (a saving of up to 50% with slightly higher efficiency);

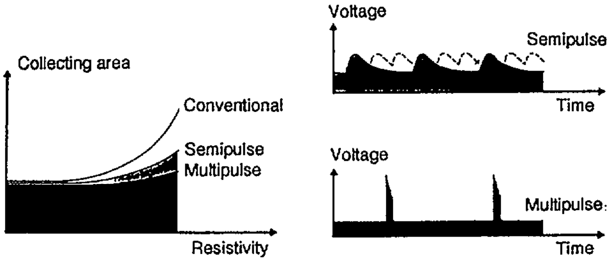
Greater variety in the sorts of coal used without exceeding emission limits.

Pulsing itself can be done by two different methods, both to be found in practice: the semipulse method or the multipulse method.

The *semipulse* method is technically simpler and less expensive. It can even be built into existing electrical precipitators without the exchange of rectifiers.

The *multipulse* method is technically more difficult and needs a precise energy control. Here special rectifiers are necessary. This method is more expensive and will primarily be used in the burning of extremely resistive sorts of coal.

Figure 3. Chart showing differences of semi- and multipulse waves



Description of the production process

The production of electrical precipitators is quite often shared by a number of firms from the following fields:

Design and engineering;

Steel construction;

Steel plate processing;

Assembly;
Electrical;
Insulation;
Painting.

In the following example of a production plant only steel plate processing is taken into consideration. Co-ordination of all activities is done by the design and engineering firm on a contract basis with all participating firms.

The task of the steel plate processing firm is the production of the actual precipitator units according to given drawings. This work consists of the following:

Production of steel frames to hold the corona electrodes as well as the collecting electrodes;

Production of the collecting electrodes consisting of standardized and profiled steel plates;

Production of perforated plates for the gas stream inlet;

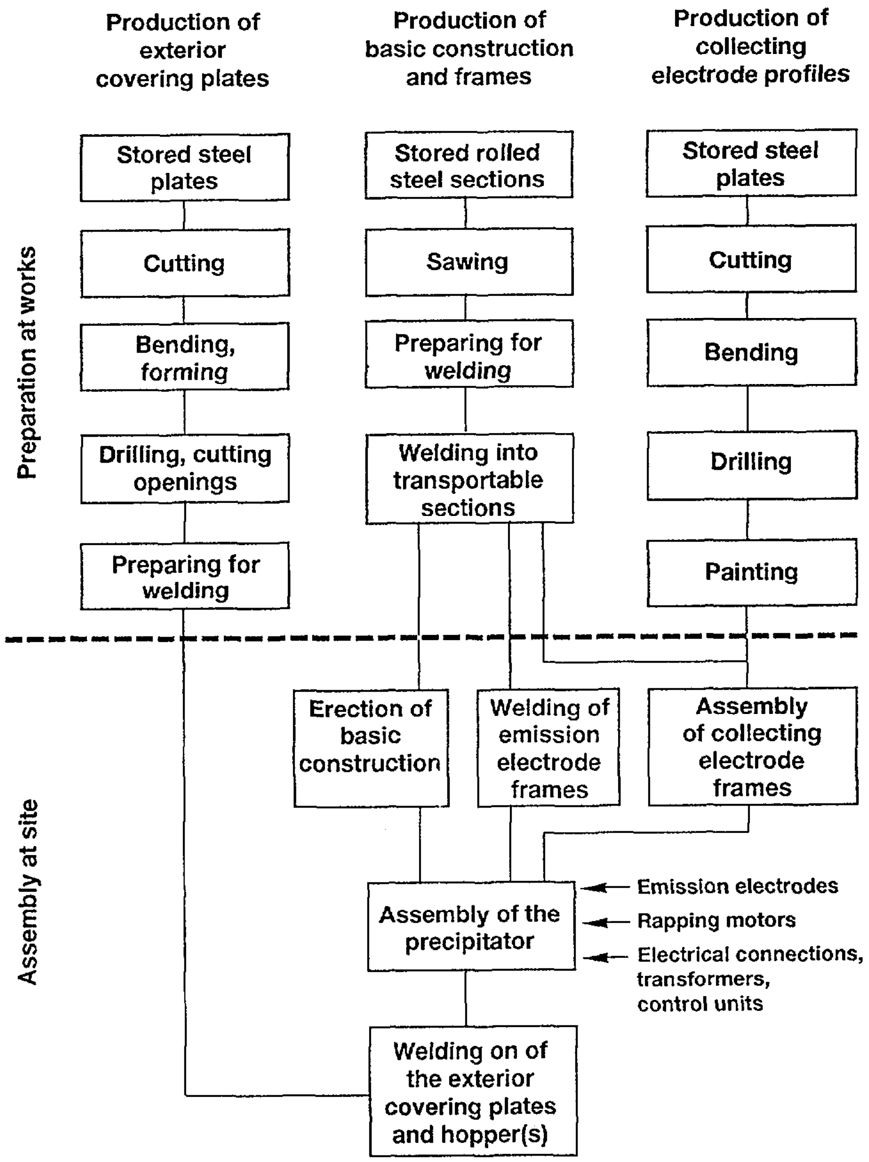
Production of formed steel plates for use as wall, roof and gable elements.

Some of the units are pre-assembled or welded together at the works to form transportable elements. The production of elements has the advantage that the main part of production can be done at the works in order to keep to small tolerances and to guarantee a better surveillance. Another advantage is the reduction in assembly time at the site.

The elements are brought to the site after the foundations and the supporting steel structure have been finished. They are then further assembled and welded together to form the casing of the precipitator. The hopper is welded to the casing floor. The casing has to be gas-tight.

When this basic construction has been completed the actual precipitator elements i.e. the corona and collecting electrode elements, and the rapping devices are installed.

Figure 4. Flow chart



Example of a production plant

Electrical precipitators can be built in a wide range of sizes, starting from 30 to 5000 tonnes. To enable the production of every size of precipitator, the production plant has to be equipped with different, and also heavy machinery.

The following example is based on the assumption, that precipitators of all sizes will be produced and that the output per year will be around six units of different sizes.

Required machinery and equipment

Description	*Pieces*
Cutting bench	1
Folding bench	1
Saw	1
Form bending machine	1
Column-type drilling machine	2
Lathe	1
Punch press	1
Planing machine	1
Welding unit	2
Bridge crane (5 tonnes)	1
Fork lift truck (3 tonnes)	2
Workplace (incl. standard tools)	5
FOB-price for machinery and equipment (1992) Approx. US$	250,000

Required manpower

Manager	1
Engineers	5
Managerial and administrative staff	9
Metalworkers	25
Welders	5
Semi-skilled workers	2

Required area

	Square metres
Production hall	1000
Outside storage	300
Intermediate and final storage	1000
Facilities	150
Administration	150

Required energy

Electric power	300 kW

Required inputs

Steel plates 4-6 mm
Rolled steel sections
Welding electrodes
Steel pipes
Fitting material

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May 1993

How to Start Manufacturing Industries

Flue gas desulphurization of power and heating stations

Wet and wet-dry absorption process

Introduction

The desulphurization of flue gases was started at the beginning of the 1970s; quite a number of different technologies have since been developed.

Desulphurization is important, because the sulphur dioxide, contained in the flue gases, falls back to earth as sulphuric acid and sulphate ions, i.e. acid rain, and acts there in a toxic manner.

Acid rainfall, to which the harmful acid substances HCl and HF in the flue gases also contribute, leaches the ground, leads to a decrease in the pH-value of lakes, and through this to the destruction of fish and plants, and it considerably increases damage to vehicles, buildings, bridges and other structures by corrosion.

There are fixed limits for SO_x emissions in most countries; in Germany, for example, the limit is laid down at 400 mg/nm^3 flue gas (dry, 6% O_2).

Harmful gases can be removed from flue gases by adsorption as well as absorption. For the desulphurization of flue gases, absorption processes are mainly used. The harmful substances are thereby made physically solvent or are bound chemically.

For large flue gas volumes, as they occur in coal-fired as well as in oil-fired power and heating stations, two main processes have been developed.

Wet absorption process

The wet process is suitable for large installations with strict deposit regulations. The washing is done with a lime or limestone suspension, which yields calcium sulphite or after oxidation gypsum as end products.

Wet-dry absorption process

This process is mainly used in medium-sized installations, especially in the case of less stringent deposit regulations. In this process lime milk is injected into the flue gas stream, whereby a mixture of fly ash, calcium sulphite and calcium sulphate arises. This end product can be used in the building industry or it can be deposited in a dump.

Both processes have to be designed in such a way that they can cope with the extremely large gas volumes (e.g. 2 mill. nm^3/h for a 700 MW power station) and the small SO_2 concentrations (0.05-0.5 vol.%) to be removed from them. Another complication to be found in many installations is the fact that they have to adapt to the continually changing operating conditions of thermal coal-fired power stations, often working as peak-load stations. Nevertheless, the flue gas desulphurization plant must have a high availability.

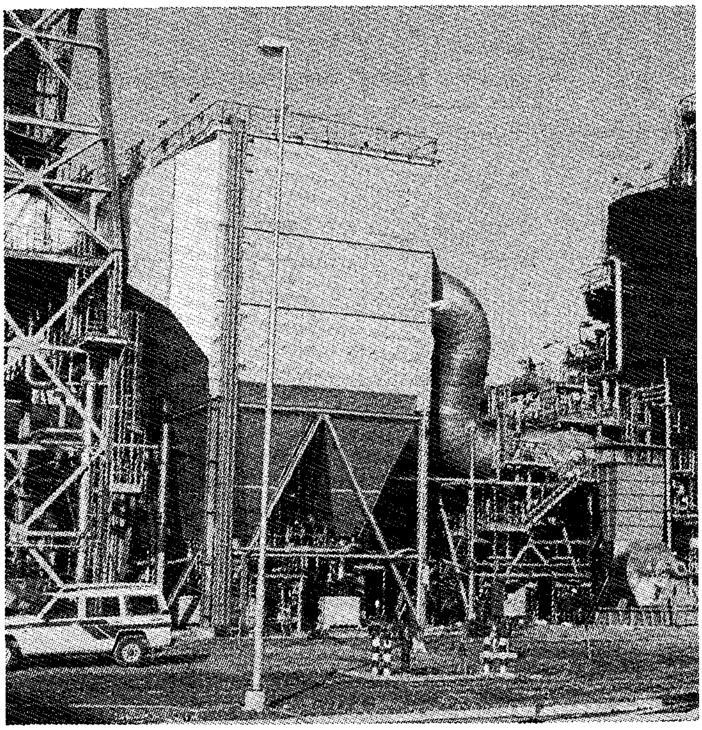
An important aspect for the decision on the most appropriate desulphurization process is the end product and its utilization possibilities.

The wet absorption process produces an extremely large number of end products. In the case of a 2 × 700 MW power station, using coal with a 1% sulphur content, and with a 50% flue gas desulphurization and 4000 operation hours per year, approx. 900,000 m^3 of gypsum or more than 2 mill. m^3 of sulphite sludge are produced.

Description of the wet absorption process

Description of the general process

Coal-fired power and heating stations produce a large amount of flue gases, containing besides soot and fly ash also particles of sulphur dioxide.



In the wet process flue gas desulphurization takes place by washing. After passing a dust collector, mostly an electrical precipitator, the flue gases enter the washer, which can be designed as a single-stage or a double-stage washer. Here the SO_2 is separated in a washing liquid cycle, whilst at the same time the flue gases are cooled down to 50 °-80 °C; watery solutions are used as washing liquids.

The harmful substances to be separated are absorbed by the washing liquid. The absorption is thus determined by the following factors:

Exchange areas available for particle absorption;

Duration in the absorption chamber;

Type of washing liquid and level of concentration;

Absorption coefficient.

The washing liquid represents the absorbent. Basically different absorbents can be used as, for example, NH_3, NaOH, KOH, Na_2SO_3, $Ca(OH)_2$, $CaCO_3$, $CaCl_2$, $MgCO_3$ or H_2SO_4. Widespread today are absorbents on a lime basis, as lime is cheap and available nearly everywhere. Besides this the end product can be easily handled.

There are also different types of washers based on the counterflow principle (e.g. spray washers with or without attached aggregates) or on the principle of unidirected flows (e.g. Venturi washer, ring slot washer).

After leaving the washer the flue gases often pass through a mist collector into a heater before reaching the stack. These measures are necessary to compensate for some negative consequences: through the cooling-down process the off-gases loose their natural thermal lift. This can lead to corrosion in the stack, clouds of steam at the stack top and reduced diffusion of the still emitted harmful substances. These disadvantages are avoided by the collector and heater.

Figure 1 shows a flue gas desulphurization plant on a lime basis with three alternative possibilities of further processing the products.

Two examples of desulphurization plants using the wet process

In the following examples two process alternatives of the lime-based wet process are presented.

Double-phase desulphurization process

In this process (see figure 2) the flue gases are first cooled down to saturation temperature by water in a *gas cooler* and freed from any remaining dust and gaseous components like chlorine and fluorine. This measure guarantees a relatively pure gypsum as the end product of the process.

As the washing water is conveyed in a closed circuit, the solid content in the cooling circuit increases with the separation of dust. At the same time the pH-value declines because of the separation of chlorine and fluorine. To limit the thickening in the cooling circuit part of the circulation stream is elutriated. This elutriated amount and the water needed for the cooling of the flue gases are added to the cooling circuit from the process water container.

The gas cooler can be designed as a spray cooling tower or a low pressure Venturi unit.

Figure 1. Flow chart of gas desulphurization plant

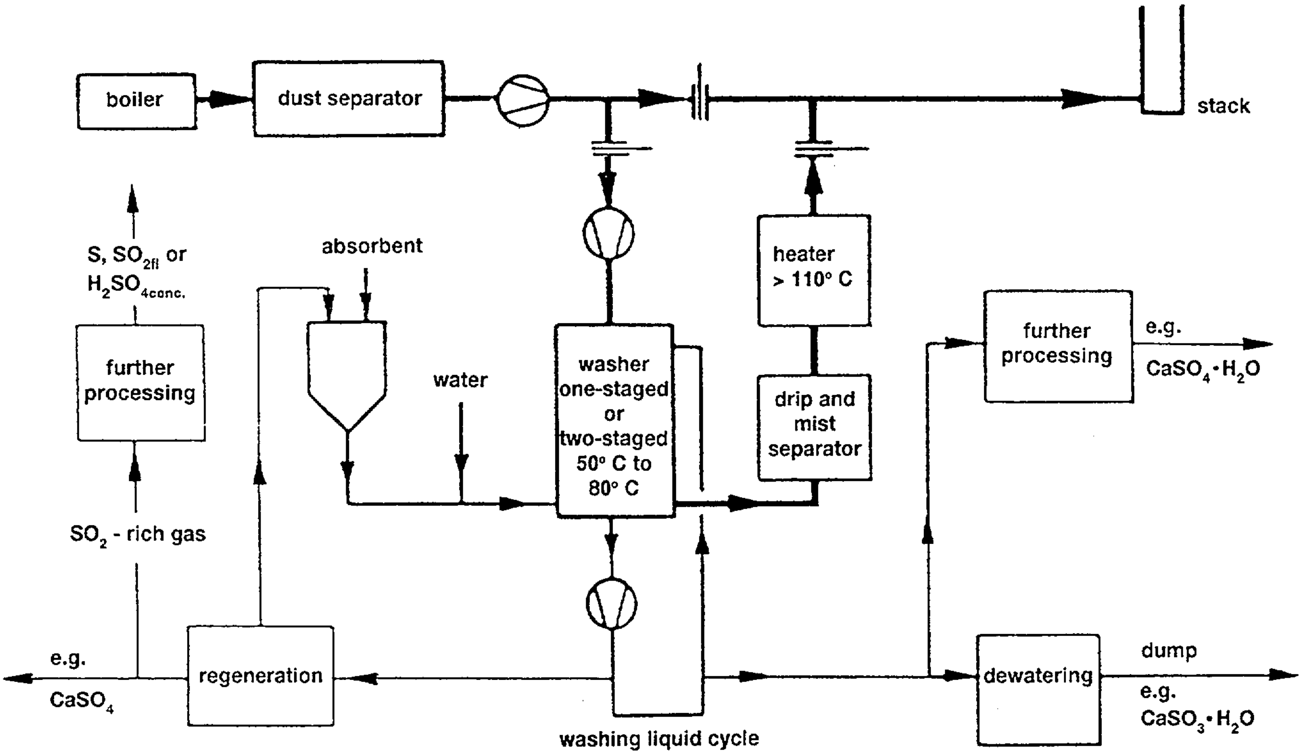
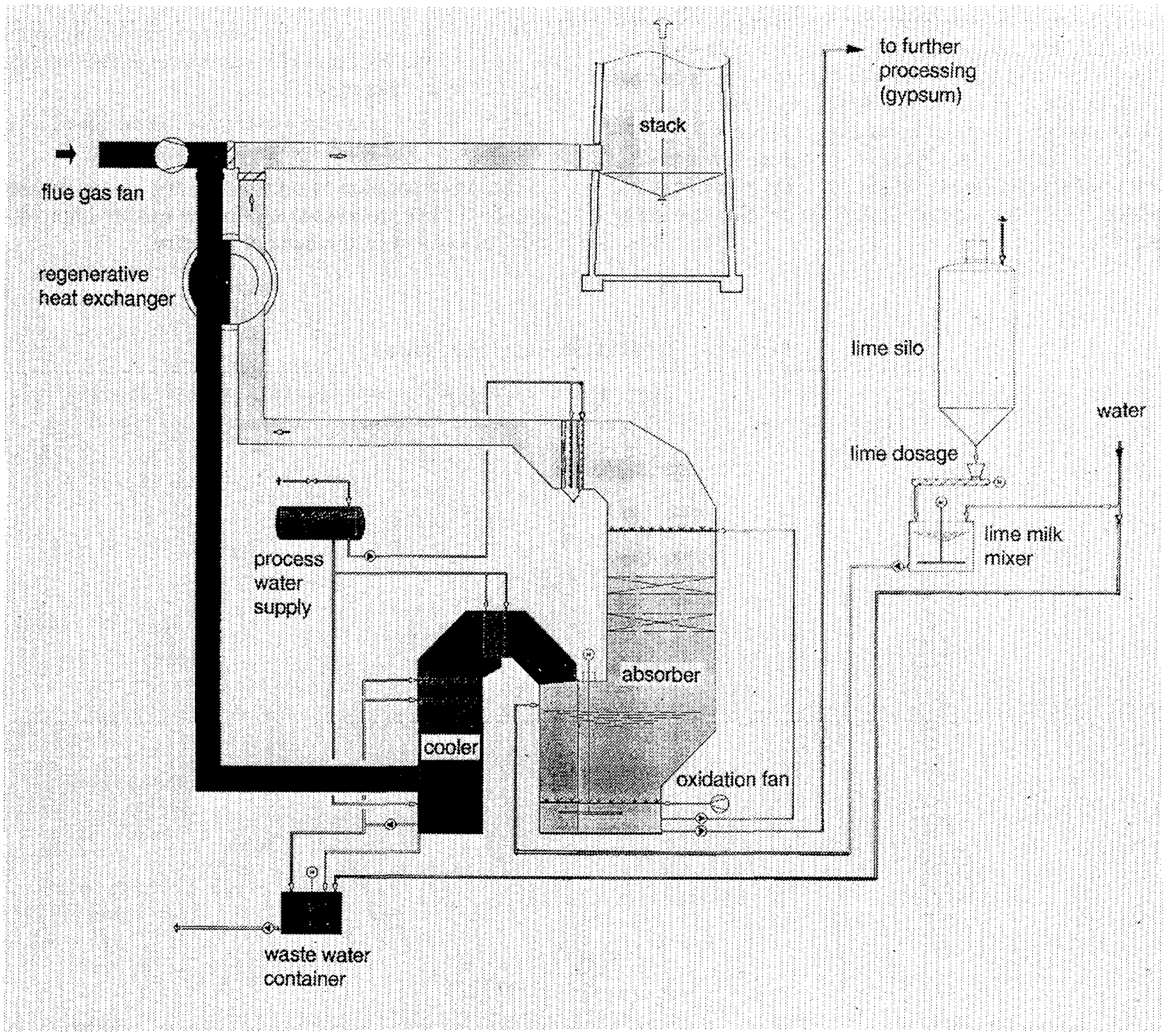


Figure 2. Double-phase desulphurization



In the *absorber* the sulphur dioxide is washed out by water:

$$(1)\quad SO_2 + H_2O \rightarrow H_2SO_3.$$

The sulphuric acid reacts with the calcium sulphite contained in the washing liquid:

$$(2)\quad H_2SO_3 + CaSO_3 \rightarrow Ca(HSO_3)_2.$$

In the bottom section of the absorber the created calcium hydrogen sulphite is neutralized with the lime milk, coming from the lime milk processing unit:

$$(3)\quad Ca(HSO_3)_2 + CaCO_3 \rightarrow 2CaSO_3 \cdot H_2O + CO_2.$$

Depending on the O_2 content of the flue gases and the pH-value of the absorber circulation fluid, the calcium sulphite is oxidized:

$$(4)\quad CaSO_3 \cdot \tfrac{1}{2}\, H_2O + \tfrac{1}{2}\, O_2 + 1\tfrac{1}{2}\, H_2O \rightarrow CaSO_4 \cdot 2H_20.$$

In the bottom section of the absorber the remaining calcium sulphite content is oxidized to calcium sulphate by the oxygen of the blown-in air.

The absorber is built as a scrubbing tower with contact surfaces. It can be built either as a unidirected flow or as a counterflow type. The washing liquid is conveyed in a closed circuit, whereby the amount of absorbent limestone or calcium hydroxide fed into the absorber depends on the pH-value in the absorber circuit. The washing liquid is sprayed into the reactor by a set of jets.

As basic materials for the absorption the following can be used:

Limestone ($CaCO_3$);

Calcium hydroxide ($Ca(OH)_2$);

Unslaked lime (CaO).

The absorbent is produced in the *lime milk mixer.*

The last step before the off-gases reach the stack is their *re-heating.* For this several systems can be used according to specific needs and local conditions:

Hot gas producer: off-gas from a gas or oil-fired combustion chamber is mixed with the desulphurized flue gases;

Steam-powered heat exchanger;

Regenerative heat exchanger: the heat of the flue gases before desulphurization is used to heat the desulphurized flue gases via heat exchange surfaces.

One-phase desulphurization process

In this process (see figure 3) the cooling of the gases takes place in the reactor itself. A washer cools down the flue gases to saturation temperature and desulphurizes them in one step. All further steps are identical to those in the double-phase desulphurization process.

The absorber is designed as a counterflow absorber with several jet levels, whereby contact surfaces are added for the desulphurization of the remaining sulphur.

Description of the wet-dry absorption process

In the wet-dry process fly ash and sulphur dioxide, as well as SO_3, HCl and HF, can be separated in only one flue gas cleaning system.

This flue gas cleaning system can be designed as a two-stage or a three-stage process (see figure 4).

The pre-separation is only necessary, if the fly ash is to be further processed (e.g. for the quality improvement of cement in the cement industry).

Figure 3. One-phase desulphurization

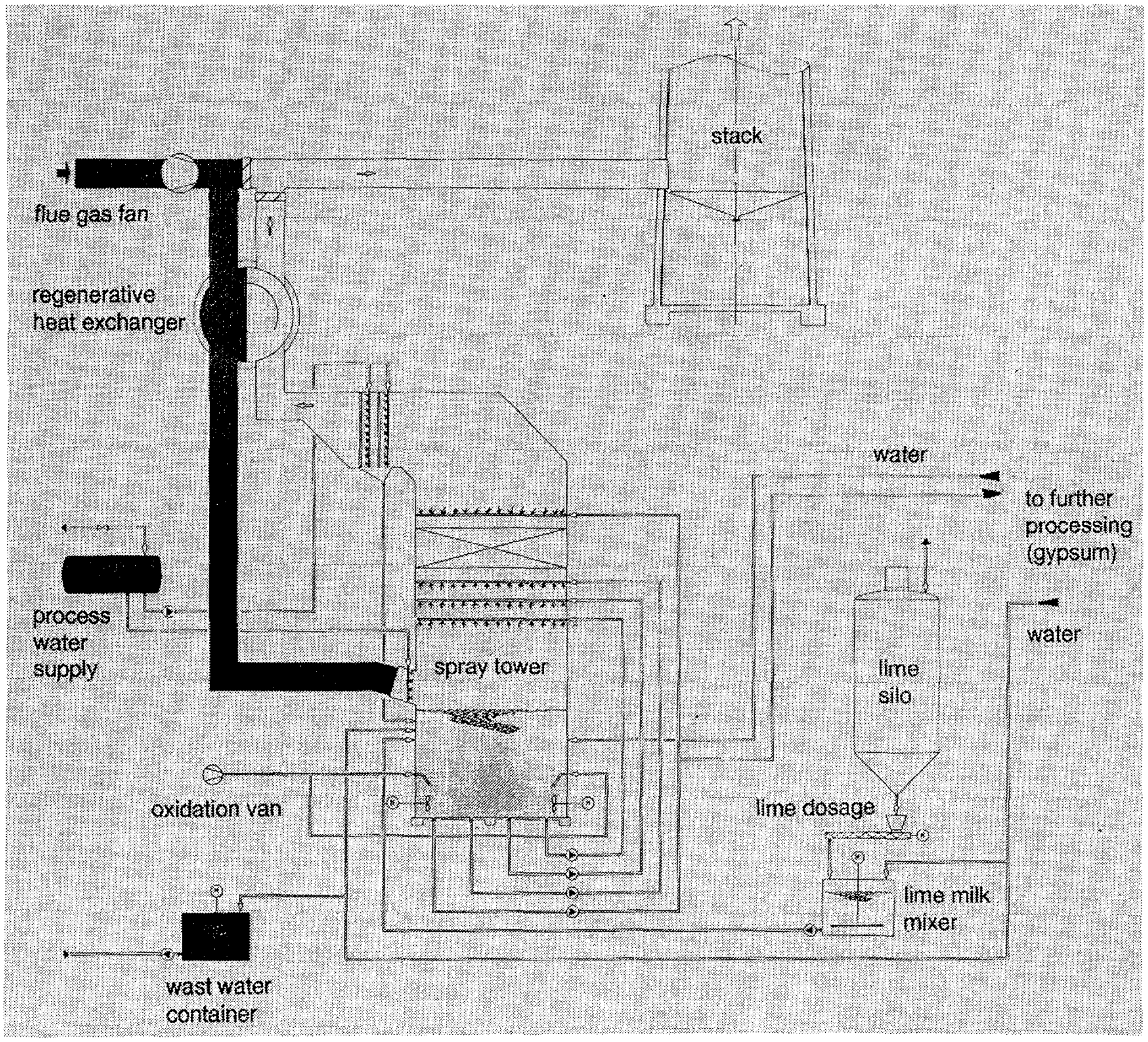
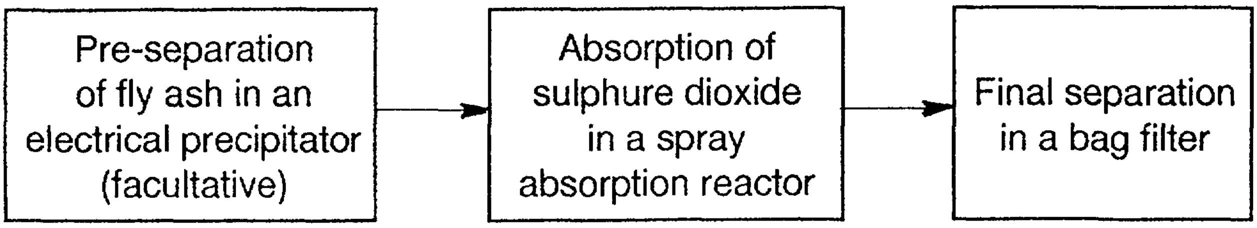


Figure 4. Flue gas cleaning in stages



In the wet-dry process a certain amount of absorbent (e.g. lime milk) is sprayed into the upper part of the reactor.

Depending on the flue gas volume, the flue gas temperature and the SO_2 content in the flue gas, the amount is controlled by a valve.

The spray head in the absorber is either a centrifugal sprayer or pressure nozzles of compressed air or binary jets are used. In the latter case quite a number of nozzles or jets are necessary in order to guarantee a satisfactory spraying capacity. The centrifugal sprayer's main advantage is its simplicity and in the fact that it is less likely to become clogged.

The absorbent reacts with the sulphur dioxide mainly in the wet phase and binds it in the form of calcium sulphite. At the same time the water evaporates. The amount of water and the temperature are chosen in such a way that the water evaporates completely. By this method a dry end product occurs that can be easily handled.

The following main reactions take place in the reactor:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$
$$CaSO_3 + 1/2\ O_2 \rightarrow CaSO_4$$
$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

Part of the dry end product is collected at the bottom of the reactor from where it is discharged. The biggest part, however, is transported further with the flue gases.

The reaction products as well as the fly ash remaining in the flue gases are finally separated in a bag filter where a secondary SO_2 absorption takes place. This is dependent on a permanent dust layer on the filter bags, therefore the cleaning frequency for the filter bags has to be minimized, which also lengthens the life of the bags.

Figure 5 shows the flow process of such a plant where fresh lime slurry is prepared in the storage tank by using unslaked lime (CaO) from the lime storage silo and slaking it into calcium hydroxide ($Ca(OH)_2$).

Practically all wet-dry flue gas desulphurization plants are based on unslaked lime (CaO). $Na(OH)_2$ and $NaHCO_3$ solutions have also been used successfully; but the resulting reaction product, sodium sulphate, is not quite as easy to handle. Limestone ($CaCO_3$) is not very suitable due to its low reactivity, which increases operating costs.

The greater part of the dust, separated in the bag filter and containing some unreacted lime, is recycled to the SO_2 reactor via the absorbent processing unit, in order to improve the economy of the absorption. The rest of the dust is fed into the final product silo ready for the dump. The cleaned flue gases are transported on to the stack by a large flue gas fan.

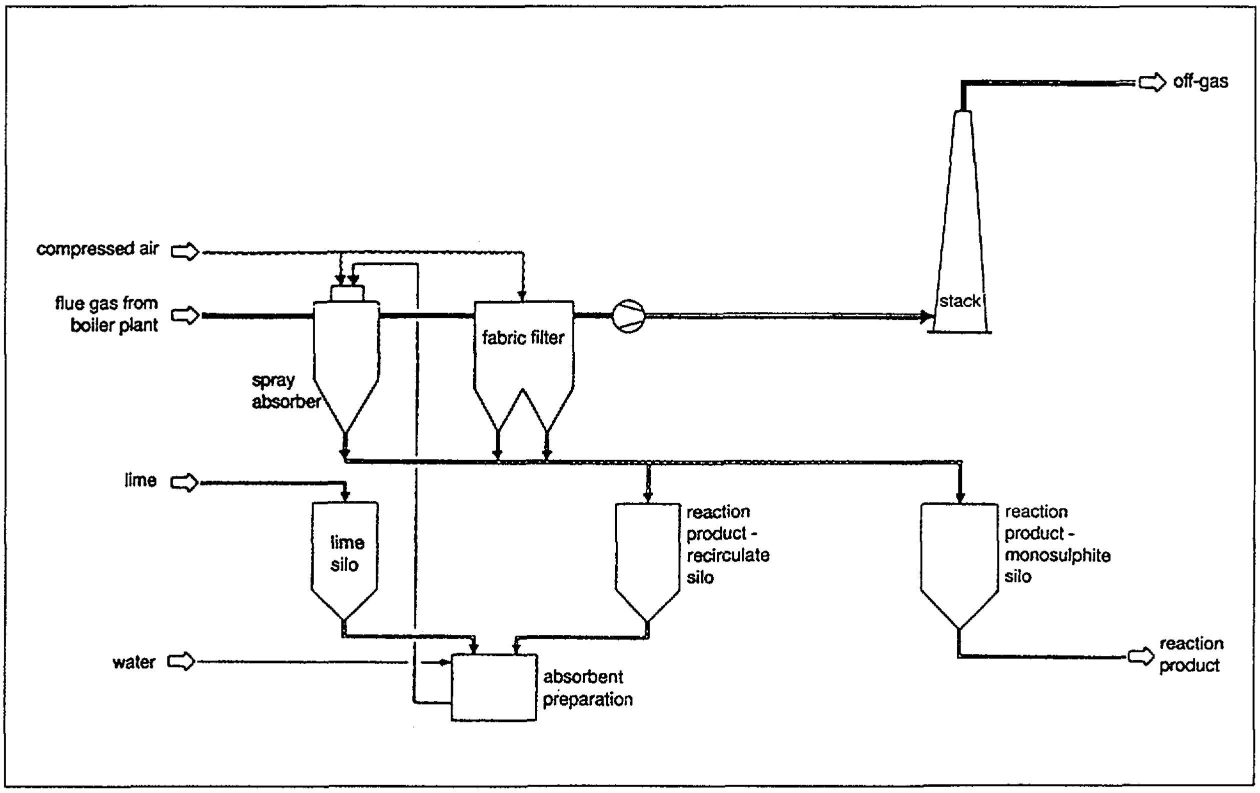
The end product of the wet-dry desulphurization plant can be used to manufacture many different building materials. It has therefore to be stabilized by mixing it with fly ash from the boiler plant. It can then be used for landfilling, landscaping and road beds.

The wet-dry desulphurization process has a number of advantages over the wet process:

Uncomplicated construction of the plant;

Less corrosion problems (stainless steel or acid proof construction materials are not needed);

Figure 5. Flow chart of a wet-dry desulphurization plant



Higher operation safety;
Simpler maintenance;
Better process control;
Lower operating costs;
No heating-up of the flue gases after washing;
Completely dry end product;
No waste water.

Dimensioning

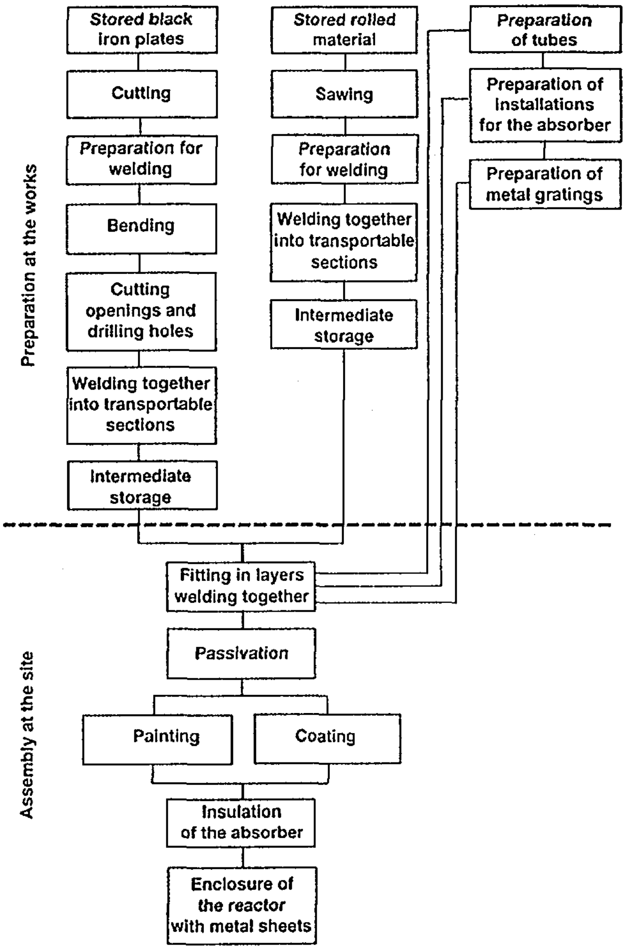
The desulphurization plants have to be designed according to local conditions. Adaptation processes are necessary according to:

Amount of flue gas;
Type of coal;
Choice of absorbent;
Separation degree to be reached.

In the wet-dry process the design and the construction of the spray absorber are most critical. Spray absorbers have to be constructed and dimensioned in such a way, that the limemilk droplets, suspended in the off-gas stream, do not lead to deposits in the absorber casing. Lime injection has to be done in such a way, that only slight erosion takes place on the spray heads.

Today mostly parallel modules are used for power stations with great capacities. At full load all modules are in operation at the same time, at partial load single modules can easily be taken out of operation.

Figure 6. Flow chart



Description of the production process

The black iron plates, ordered from outside, are shaped and cut to size by a flame-cutting machine. The edges to be welded are prepared by a longitudinal planing machine. The single plate pieces are then, where necessary, bent into a curved shape according to a given radius to serve as the casing for the absorber or as pieces for the tubes. These pieces are stiffened by rolled sections, welded on from outside. Openings are cut out by a cutting torch, holes are drilled and flanges are welded on.

Parallel to this, pieces for the supporting framework are sawn to length, prepared for joining and welded together to transportable units where appropriate. Finally the installations for within the absorber are prepared.

All pieces and prepared sections are then transported to the site, where they are assembled step by step according to the construction plan, either by using own cranes and lifting devices or by hiring them from an outside firm. The electricity required for the assembly is mostly available on the site. When not available, a diesel-powered generator has to be used.

The finished components are painted to protect them from corrosion. The inside of the absorber is coated in accordance with the particular needs. As a coating material either special protective paint or rubber is used. In most cases the first is rolled on whereas the latter is fixed with the help of an adhesive.

On the outside the absorber is insulated against heat loss by stonewool mats and nowadays it is also mostly enclosed by metal sheets to give it a better appearance and to serve as sound-proofing.

Example of a production plant

Desulphurization installations have to be adapted to the size of the power or heating station, i.e. the flue gas volume. Therefore a wide range of different installation sizes have to be produced. The following example is based on the assumption that the whole range up to very large installations will be produced, but under contract to an engineering firm, which supervises both production and assembly.

Production includes the following major components: absorber with installations; absorbent silo; absorbent preparation; end-product silo; water tank and piping. With the machinery and workforce given below the plant should be able to produce approximately 3 very big desulphurization plants, or alternatively, 5-6 medium-sized plants per year.

It should be stated, however, that there is at present a trend away from the very large absorbers towards more medium-sized ones and then those in parallel operation.

Required machinery and equipment

Description	*Pieces*
Flame-cutting machine	1
Longitudinal planing machine	1
Bending machine (3 m butt length, for up to 25 mm plates)	1
Column-type drilling machine	3
Circular metal saw	1
Plate shearing machine	1
Welding apparatus	12
Acetylene cutter	5
Hand grinding machine	8
Hand drilling machine	4
Workbench with hand tools, measuring tools, templates etc.	12
Bridge crane (15 tonnes)	2
Fork lift truck (2 tonnes)	2
Sandblast machine	1
Air compressor (10 m^3/h)	1

FOB-price for machinery and equipment (1992) Approx. US$ 1,200,000

Required manpower

Manager	1
Works engineer	1
Managerial and administrative staff	5
Engineers (work preparation and control)	6
Foremen	3
Welders	10
Metalworkers	10
Semi-skilled workers	13
Crane operators	2
Painters	2

Required area

	Square metres
Production hall	6000
of this: inside storage	1700
Outside storage	2000
Facilities	200
Administration	400
Free outside area	1000

Required energy

Electric power	350 kW
Acetylene cylinders	
Oxygen cylinders	
Propane cylinders	

Required inputs

- Steel plates (6-25 mm)
- Rolled steel sections (up to 300 mm)
- Tubes (up to 750 mm)
- Tube bends
- Flanges and lids
- Plastic pipes (different diameters)
- Bar grates
- Jets and spray tubes
- Welding and cutting gases
- Welding material
- Blast material
- Working and auxiliary material
- Paints
- Coating material
- Rubber coating material and adhesive
- Lamellar separators

Depending on the given circumstances in a country or an area within the country, the assembly can either be done by a specialized assembly firm on a subcontractual basis or it has to be done by the production firm itself. In the latter case not only additional manpower is needed, but also additional machinery and equipment. The following lists should give the necessary information.

Required machinery and equipment for assembly

Lorry for container transport	1
Van	1
Living container (20 feet)	6
Magazine container (20 feet)	4
Welding apparatus	20
Grinding machine	20
Drilling machine	4
Hand tools and measuring tools	
Scaffolding	
Construction lift	1
Tent equipment	
Rotary-tower crane (20 tonne, 60 m hook height)	1
Mobile crane (140 tonne, 60 m hook height)	1

Required manpower for assembly

Foremen	3
Welders	20
Metalworkers	10

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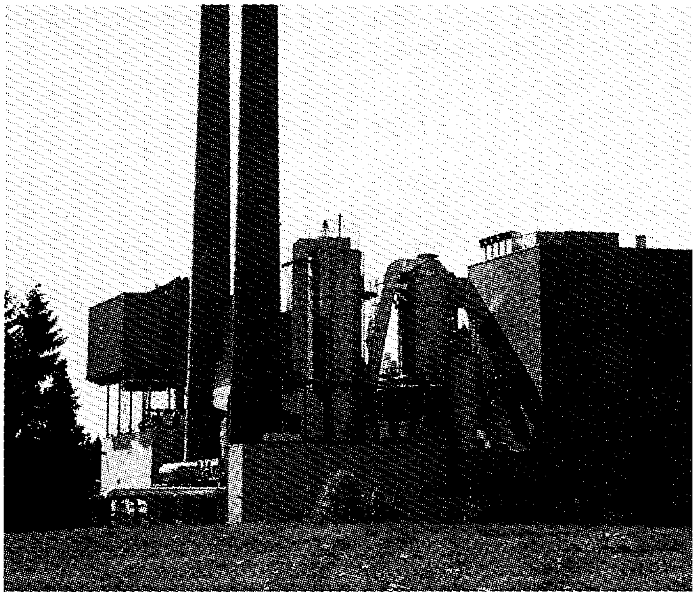
May 1993

How to Start Manufacturing Industries

Flue gas desulphuization in industry and refuse incineration

Conditioned dry and dry process

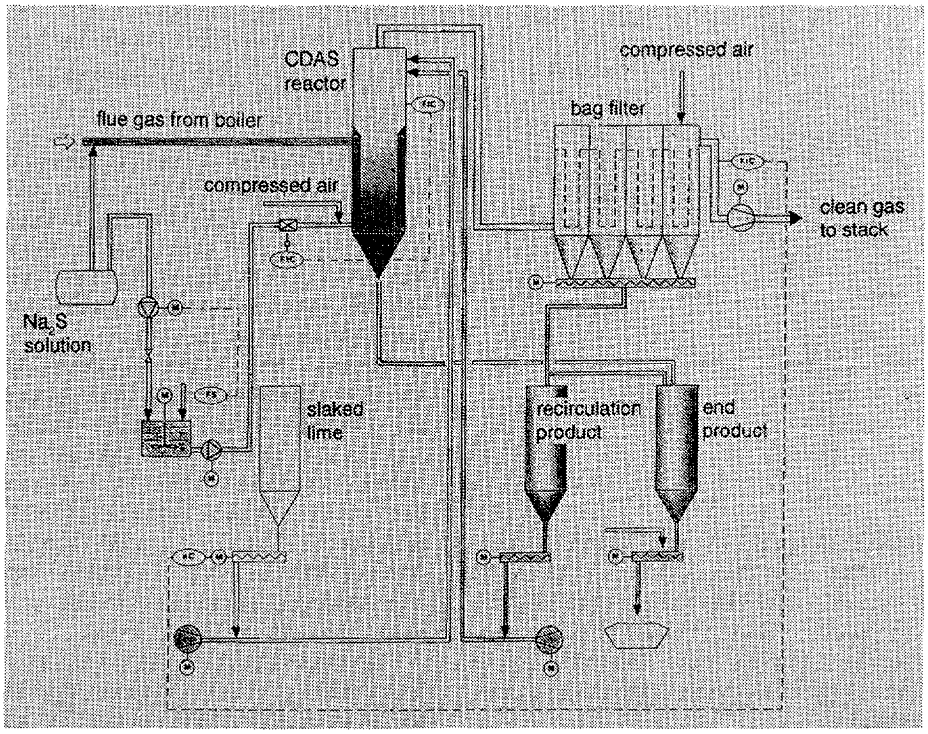
Introduction



Processes for the desulphurization of flue gases have been developing especially during the past 20 years; today numerous process possibilities are known. The vast number of different processes originate according to: their field of employment; the question of their economy; the availability of reagents; and the possibilities of using the waste products, or alternatively the possibilities of dumping.

Desulphurization has become important with the knowledge that sulphur dioxide contained in the flue gases is causing acid rain, leading to damage to vegetation, water, buildings and vehicles. Many countries today have fixed limits for SO_x emissions; in Germany the relevant value is 400 mg/nm^3 flue gas (dry, 6% O_2). For smaller amounts of flue gas, as they occur in industrial furnaces or in refuse incineration, two processes are mainly used: either the conditioned dry absorption process or the dry absorption process.

Figure 1. Conditioned dry absorption process



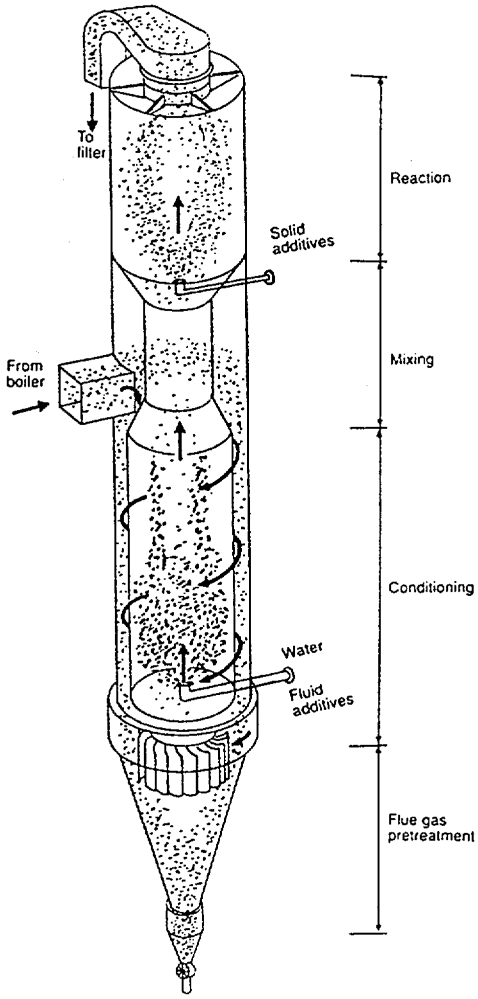
Description of the conditioned dry absorption process

This process is used in the capacity range of 5-50 MW_{th}, mainly in smaller power stations and refuse incineration installations. In both cases the process is broadly identical, however different temperatures are used and there are certain differences in the construction of the reactors.

In the conditioned dry absorption process (see figure 1) the first step is the conditioning of the flue gases. The process, which uses slaked lime as an additive, consists primarily of the following components: reactor, fabric filter and exhaust fan.

The flue gases containing fly ash and toxic substances enter tangentially into the central area of the reactor (see figure 2) and travel in spirals downwards along the jacket of the cooler. Larger dust particles are collected in the hopper.

Figure 2. CDAS reactor



The gas proceeds through a flow straightener at the bottom of the reactor into the evaporation cooler, where it moves upwards. Here the temperature of the gas is reduced to approx. 130 °C and its relative humidity is increased by a few per cent. This conditioning effect is achieved by water being sprayed into the evaporation chamber.

In the following phase the toxic gases are brought into contact with recirculated and fresh lime, blown into the upper chamber of the reactor in the quantities required for reducing the SO_2 and HCl emissions. A gas rotator at the outlet of the reactor ensures a good mix of the absorbent in the flue gases contributing to increased absorption.

The final collection of dust and a secondary absorption of the remaining toxic gases takes place in a fabric filter.

In special cases it may be necessary to add a washer. The elimination of harmful substances is then done in two stages:

Dust, heavy metals and the greater part of the acid gases are separated in the reactor and the fabric filter;

The final separation of the remaining acid gases takes place in the added washer.

The conditioned dry absorption process produces dry final products. They can either be recycled after appropriate processing or can be dumped.

The fly ash can be processed in three different ways:

(a) The fly ash is vitrified at temperatures of more than 1200 °C and later used as building material.

(b The fly ash is solidified by adding cement, is poured into blocks and then dumped.

(c) The fly ash is washed out of the reactor by means of acid and deposited on a mono dump.

From the reaction product the soluble salt is washed out, cleaned and recycled.

Description of the dry absorption process

This process is an alternative to the conditioned dry absorption process and is especially suitable for the capacity range from 3-30 MW_{th}. The main fields of application are:

Furnaces exclusively supplying heat;

Furnaces providing process heat;

Boiler furnaces.

The main areas for the application of this process are in the chemical industry, paper and wood industry, or in breweries. This process is used for the desulphurization of flue gases, and for the separation of fly ash. It works without flue gas conditioning and achieves, despite its technical simplicity, desulphurization degrees of up to 95%.

The most important components of the installation are a simple reactor and a fabric filter, used as secondary reactor and final separator. In the dry absorption process the absorbent is injected into the flue gas stream in a dry condition by compressed air. As sorbent either calcium hydroxide ($Ca(OH)_2$) or sodium bicarbonate ($NaCO_2$) are used. The latter is especially advantageous because of its high reactivity; in practice, however, calcium hydroxide is used more often because of the cost advantages.

The uncleaned off-gases, coming from a furnace, boiler plant or industrial production plant are fed into the lower section of the reactor. By means of a special flue gas guidance a pre-separation of coarse and inert solid material takes place in order to relieve the absorption cycle. These materials are directly fed into the end product silo.

Afterwards the flue gases pass a fluidized bed consisting of a basic material and the recirculated mixture of additive and reaction product. Here a processing takes place of the particles partly agglomerated in the filter and intermediate transport aggregates; at the same time the harmful gases SO_2, HCl and HF are adsorbed and absorbed.

The chemical reactions can be given as follows:

$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$

$Ca(OH)_2 + SO_2 + \frac{1}{2} O_2 \rightarrow CaSO_4 + H_2O$

$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

$Ca(OH)_2 + 2HF \rightarrow CaF_2 + 2H_2O$

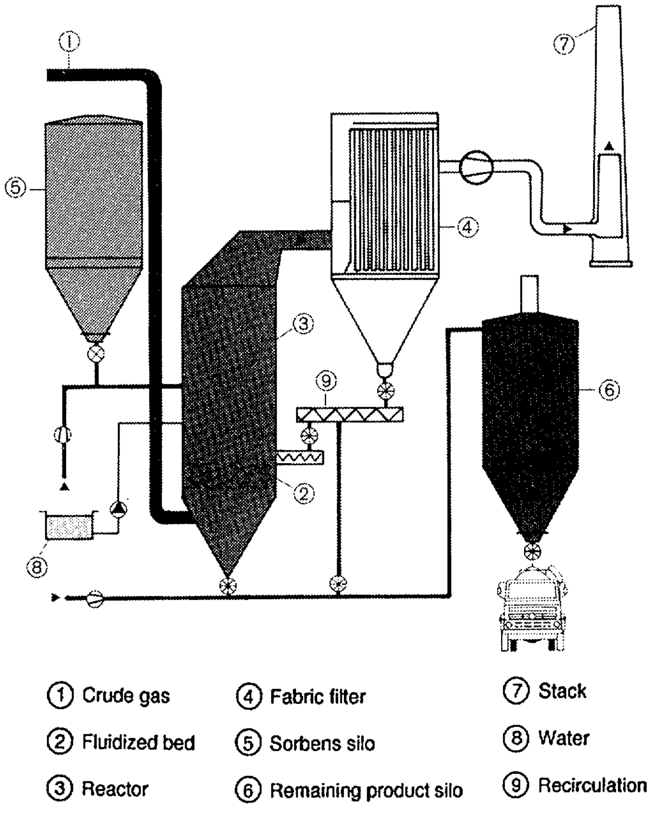
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Above the fluidized bed the fresh absorbent is injected into the reactor. The amount injected depends on the SO_2 content in the flue gases and on the SO_2 content required in the clean gas.

The flue gases with the mixture of reaction products are transported further and the excess absorbent is led into a fabric filter. Solid particles accumulate on the filter material. The gases pass this dust layer where a secondary separation and a binding of the harmful gases takes place.

The filter material is cleaned at regular intervals. For optimum separation the filter material, the rate of flow and the type of cleaning, are adjusted to operation conditions.

Figure 3. Outline of a conditioned dry absorption plant



The product separated in the filter is fed back into the reactor by mechanical means. In order to avoid a too high concentration of the circulating product, a partial amount is drawn off by a control unit and fed into the end product silo.

Before entering the reactor the recirculated reaction product passes through a special mixer, where small amounts of water are added in order to activate the sorbent for the absorption in the fluidized bed and to reach a certain agglomeration, ensuring a desired duration in the fluidized bed.

In cases where the temperature rises too high in the reactor, water is directly injected.

In order to reach the desired concentration of harmful gases in the clean gas, the desulphurization process can be controlled by the following parameters:

Amount of added sorbent $Ca(OH)_2$;

Amount of recirculated product;

Temperature and moisture of the flue gases;

Thickness of the dust layer on the filter material of the fabric filter.

The dry desulphurization process has the following advantages:

Low investment costs;

Low maintenance costs;

Simple operation;

Fully automatic operation;

No waste water problem;

Dry end product.

Description of the production process

The steel plates, ordered from outside, are cut to shape and size by a plate shearing machine or flame-cutting machine. The edges to be welded are planed off by a planing machine. The plate pieces are, when necessary, bent into curved shapes according to given radii to serve as parts for the reactor, for the silos or pipes.

These pieces are strengthened by welding on rolled sections on the outside. Openings are cut out by an acetylene cutter, holes are drilled and flanges welded on.

Parallel to this, rolled sections for the supporting framework are sawn to length, prepared for joining and welded together into transportable units.

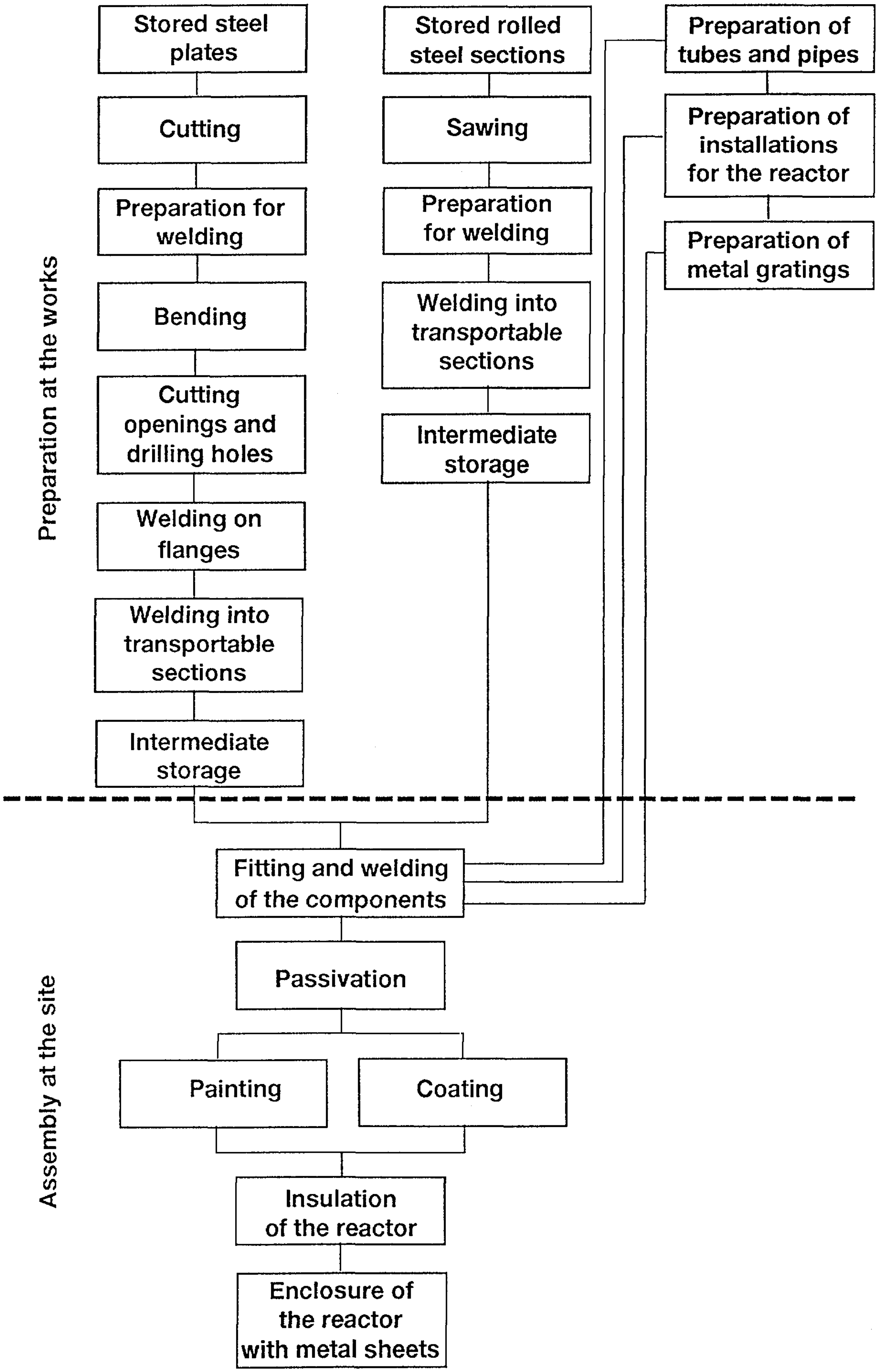
Finally the installations for the inside of the reactor are prepared.

All pieces and prepared sections are then transported to the site where they are assembled according to the construction plan. For their assembly, cranes and lifting devices are necessary; these can best be hired from outside. The electricity required for the assembly is mostly available on the site. When not available, a diesel-powered generator has to be used.

The finished components are painted to protect them from corrosion. The inside of the reactor is coated in accordance with the particular need.

On the outside the absorber is insulated against heat loss and then enclosed by metal sheets to serve as sound-proofing and to give a better appearance.

Figure 4. Flow chart



Example of a production plant

The example is based on the assumption that the firm produces the main steel components itself, i.e. the reactor, the sorbent silo, the end product silo, the water container, the pipes and the necessary supporting construction. Outside firms make the design for the desulphurization plant, produce the fabric filter, the pumps, dosing units, fan etc. Also the assembly is carried out by an external firm.

The following lists have been made on the basis, that components and parts for 7-8 desulphurization plants are produced each year.

Required machinery and equipment

Description	*Pieces*
Plate shearing machine	1
Flame-cutting machine	1
Bending machine	1
Planing machine	1
Saw	1
Column-type drilling machine	2
Welding apparatus	8
Acetylene cutter	2
Hand grinding machine	5
Hand drilling machine	3
Workplace (including standard tools)	8
Bridge crane (5 tonne)	1
Fork lift truck (2 tonne)	2
FOB-price for machinery and equipment (1992) Approx. US$	750,000

Required manpower

Manager	1
Engineers	5
Managerial and administrative staff	5
Foremen	2
Welders	8
Metalworkers	20
Semi-skilled workers	10

Required area

	Square metres
Production hall	3500
inside storage	1200
Outside storage	1000
Facilities	150
Administration	250

Required energy

Electric power	300 kW
Acetylene cylinders	
Oxygen cylinders	

Required inputs

Steel plates
Rolled steel sections
Pipes and pipe bends
Metal gratings
Jets and spray tubes
Welding and cutting gases
Welding material
Paints
Coating material

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Denitrification of flue gases by the selective catalytic reduction process (SCR)

Introduction

Denitrification of flue gases started in the early 1980s. Of the great number of processes developed only a few are used today. The aim of denitrification is to reduce nitric oxide (NO_x) emissions that destroy the ozone layer in the stratosphere and cause acid rain in the troposphere.

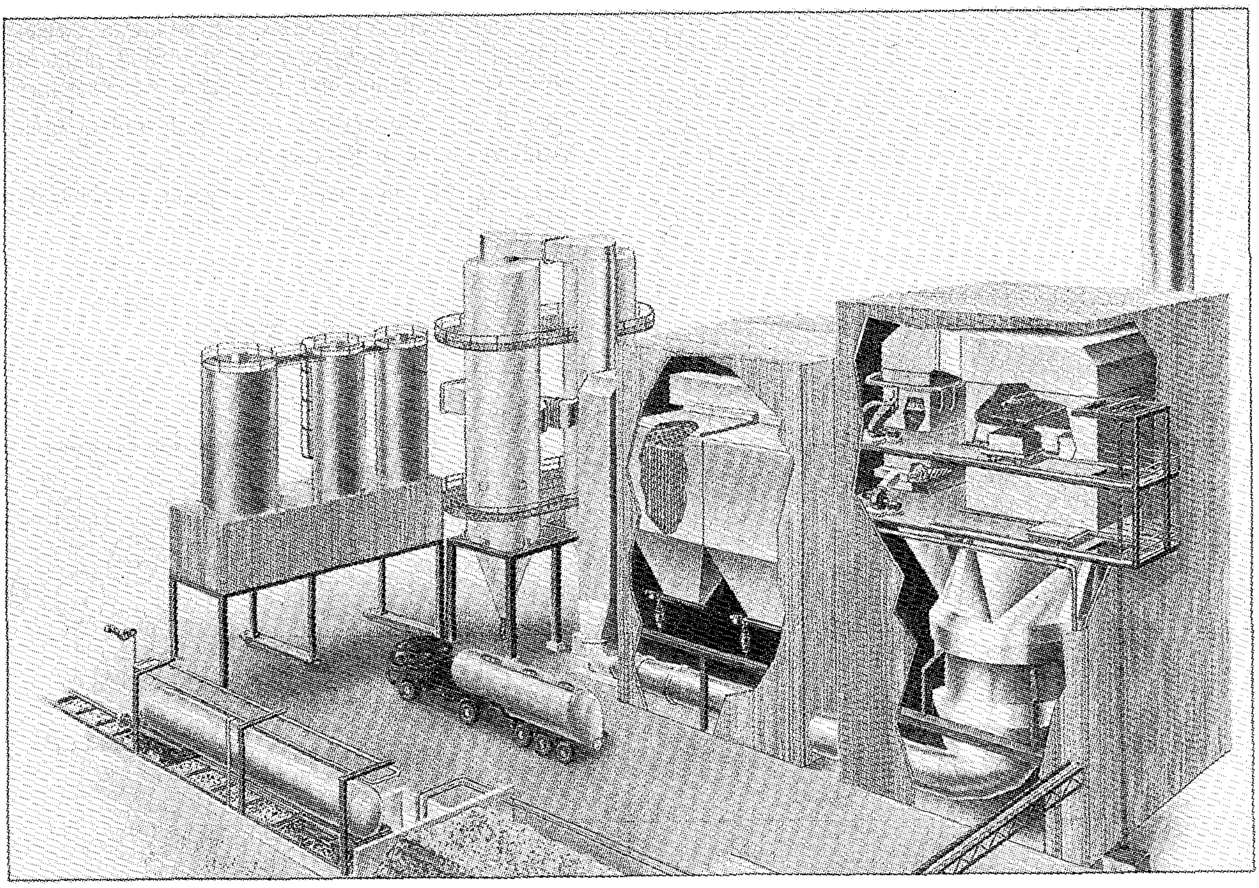
There are limits laid down in various countries regarding the emission of NO_x; in Germany for example, the limit is 200 mg/nm^3 flue gas (dry, 6% O_2).

Denitrification plants are mainly used in the following heat-intensive industries:

Power stations;
Heating stations;
Refuse incineration plants;
Glass industry;
Chemical industry (e.g. production of nitric acid);
Metalworking industry.

Description of the process

The formation of nitric oxide is strongly influenced by the firing control of furnaces. That is why today appropriate firing control should be the first step in order to reduce nitric oxides. By using modern apparatus in firing control, NO_x emissions can be limited, in the case of coal-fired furnaces, to 350 mg/nm^3, though this is still above the allowed emission values of Germany. Therefore, a second stage of flue gas cleaning has to be added in order to reduce NO_x



emissions even further. This reduction, where the remaining nitric oxide is converted back to its components of pure nitrogen and water vapour, can be achieved by two different ways:

Catalytic reaction at a temperature between 350 °C and 450 °C and by the adding of ammonia;

Non-catalytic reaction at a temperature between 900° and 1100 °C and adding other reagents.

With the catalytic reduction, values of 50-100 mg/nm^3 can be achieved without difficulty. In the case of even lower values there is the danger of ammonia slippage, which puts other undesired burdens on the environment.

In the SCR process, (see figure 1) a dry denitrification process, ammonia (NH_3) is used as the reducing agent. The nitric oxides entering the system are transformed into nitrogen (N_2) and water (H_2O) as a result of the oxygen and ammonia within the catalyzer:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$$

The effect of the transformation depends on the reaction temperature as well as on the type and volume of the catalyzer. In the case of temperatures between 250 °C and 300 °C and with the corresponding volume of the catalyzer denitrification, results of up to 90% can be reached.

The type and volume of the catalyzer, as well as its lifetime, are strongly influenced by the contents of the flue gases, namely ash, SO_2, SO_3, HCl, HF. The higher the concentration of the contents of the flue gases, the higher the volumes of the catalyzer have to be. Besides this the catalyzer has to have wider passages to prevent clogging and has to be resistent against erosion. This leads to larger catalyzers, because for every cubic metre of catalyzer, less active catalyzer surface can be accommodated.

Flue gases, rich in SO_x, need a process temperature range of between 320 °-380 °C. In the case of flue gases with a low SO_x concentration (e.g. gas-fired furnaces, refuse incinerators) the process temperature can be lower; this requires, however, a greater catalyzer volume in order to reach the same separation efficiency.

The transformation itself takes place in the SCR reactor. This can be installed in front of, or behind, a desulphurization plant. Installation in front of the desulphurization plant, i.e. between boiler and air preheater, has the advantage that the temperature needed for denitrification is given, but it has the disadvantage that the flue gases still contain all the particles released during burning, such as dust, SO_x and HCl, with the already mentioned negative consequences for the catalyzer. This arrangement is used today in modern coal-fired power stations with dry ash removal (high dust arrangement).

The quicker ageing catalyzers, and their earlier exchange, is considerably cheaper than the higher-energy investment requirements for reheating and pressure losses. This situation can be modified by adding a hot gas electrical precipitator in front of the denitrification plant; this eliminates some of the disadvantages of the first variant, but the hot gas electrical precipitator requires high investment costs and more space.

Installation behind the desulphurization plant is to be found in nearly all other cases especially with refuse incineration plants, and has the following technical and economic advantages:

The SCR plant can be installed on the clean gas side completely independent of the boiler plant, thereby enabling an optimal operation and a good accessibility to furnace and denitrification plant;

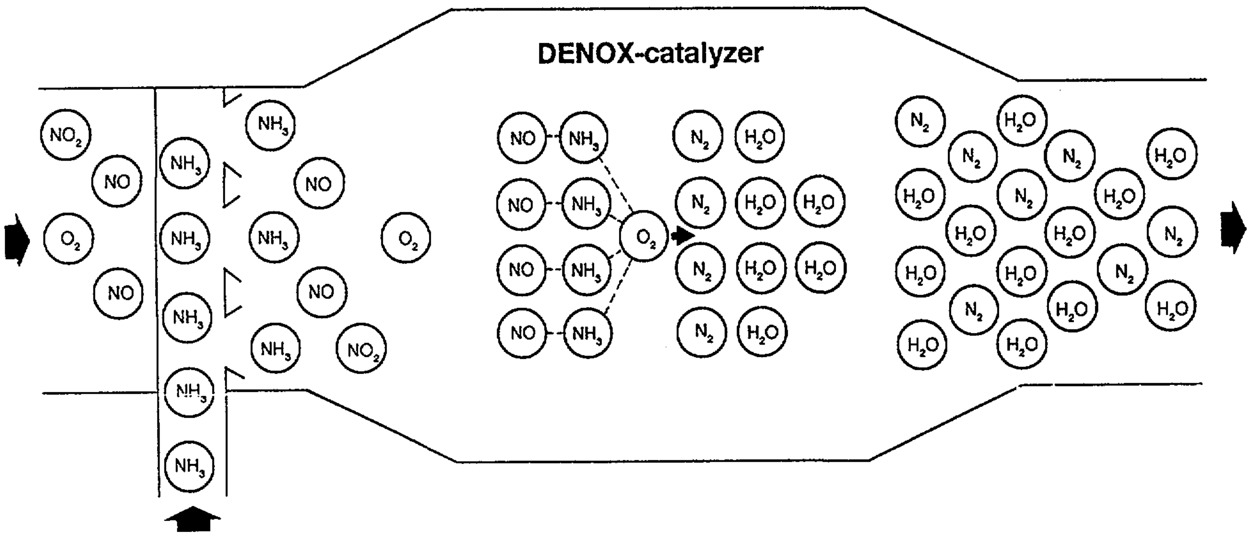
The SCR plant can be retrofitted at the clean gas side at any time. It can be connected for example during the yearly inspection and therefore only work on the flue gas pipes is necessary;

Site and location problems can be more suitably solved, as, for example, a common SCR plant can serve several individual furnaces at the same time;

The degree of efficiency of the boiler plant is not reduced by the SCR process;

Because of the pre-cleaned flue gases the catalyzers have a considerably longer lifetime;

Figure 1. The reaction principle of selective catalytic reduction (SCR)



The reaction temperature can be optimally adjusted independent of the boiler load;

More compact catalyzers with a considerably higher activity level can be used.

But there are also some disadvantages as can be seen from the following:

Reheating of the flue gases causes additional operating costs;

Considerably higher installation need causes higher investment costs.

Figure 2 shows denitrification in the clean gas stream, i.e. behind the electrical precipitator and the desulphurization plant.

In the case of refuse incineration plants or refuse-fired heating plants it is recommendable to add an appropriate aerosol filter behind the desulphurization to avoid damage to the catalyzers by vaporous heavy metals (especially mercury), sodium organic compositions, remaining droplets and aerosols. Appropriate aerosol filters could be, for example, condensation-wet electrical precipitators or coke filters.

After the extensive removal of harmful substances the flue gases with a temperature of around 70 °C are directed to the SCR plant. In a regenerative heat exchanger the off-gas is heated up to between 290 °C and 310 °C through a heat exchange with the hot gases from the SCR reactor. An additional firing brings the flue gases to the reaction temperature of 320 °C to 330 °C, optimal for denitrification.

After heating the flue gases, a certain amount of ammonia, corresponding to the amount of NO_x to be reduced, is added to the flue gases in a mixing chamber. The mixture is then fed into the reactor. The off-gases coming out of the reactor are cooled down to around 100 °C in a heat exchanger and then taken to the stack.

Description of the denitrification plant

The denitrification plant consists of the following essential components: catalyzer; reactor; reheating unit; ammonia supply; and control units. For the catalyzer two forms and types of materials are mainly used today, either ceramic plates or plates with metal carriers covered with ceramic material. Most catalyzers are TiO_2-based, covered with active components such as V_2O_2 (vanadium pentoxide).

The ceramic catalyzers consist of single elements with an edge length of 150 × 150 mm, and according to demand, can go up to 1000 mm. Depending on the dust content of the flue gases, catalyzers with bigger or smaller square passages are used with walls approximately 1 mm thick.

To make handling easier the single elements are combined into greater units or modular baskets (see figure 3) of 1 × 1 m or 1 × 2 m with heights of 1-1.5 m comprising 36 or 72 elements. The plate catalyzers are also placed in modular baskets. The distance between the plates is automatically given by the profile. Depending on the degree of denitrification one or several layers are necessary. Each layer consists of a certain number of modular baskets placed next to each other.

The SCR reactor (see figure 4) consists of a rectangular steel casing with inner installations to take up the

Figure 2. Denitrification in the clean gas stream

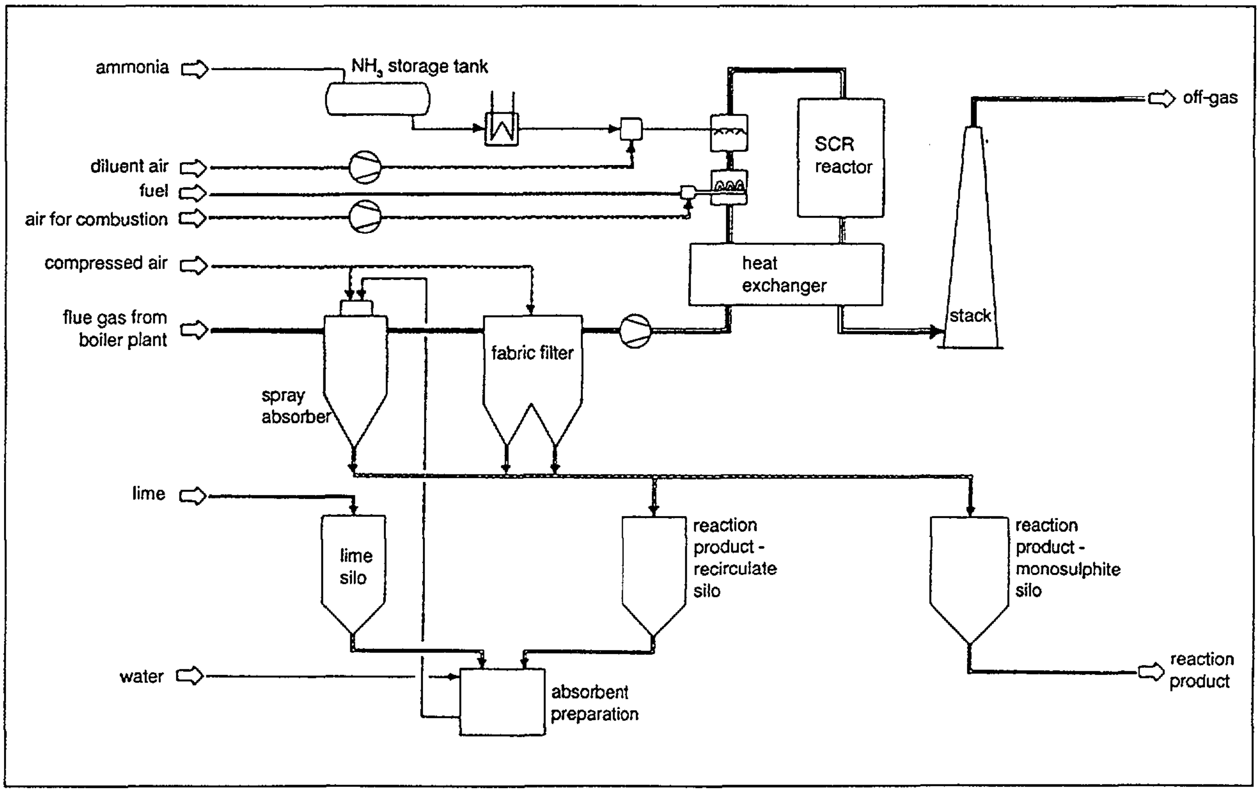


Figure 3. Modular baskets with honeycomb or plate elements

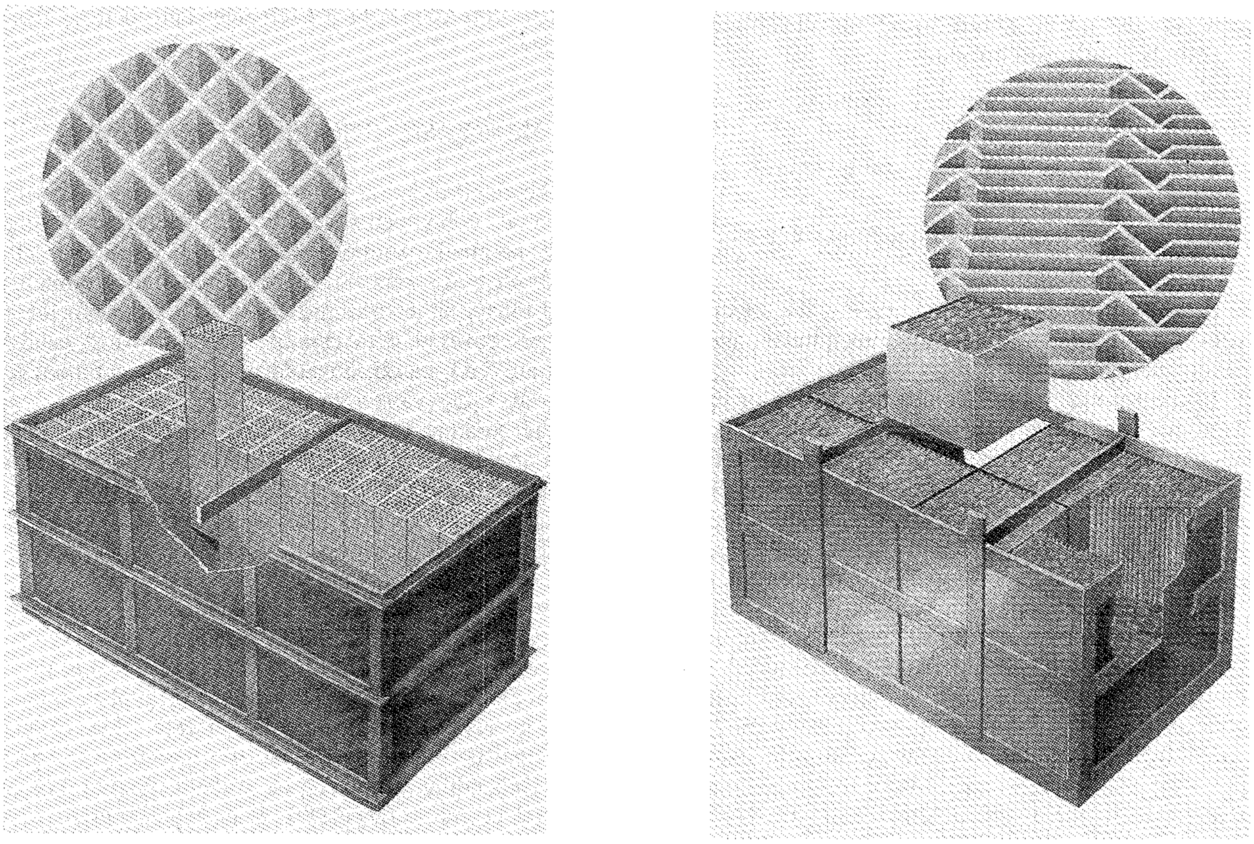
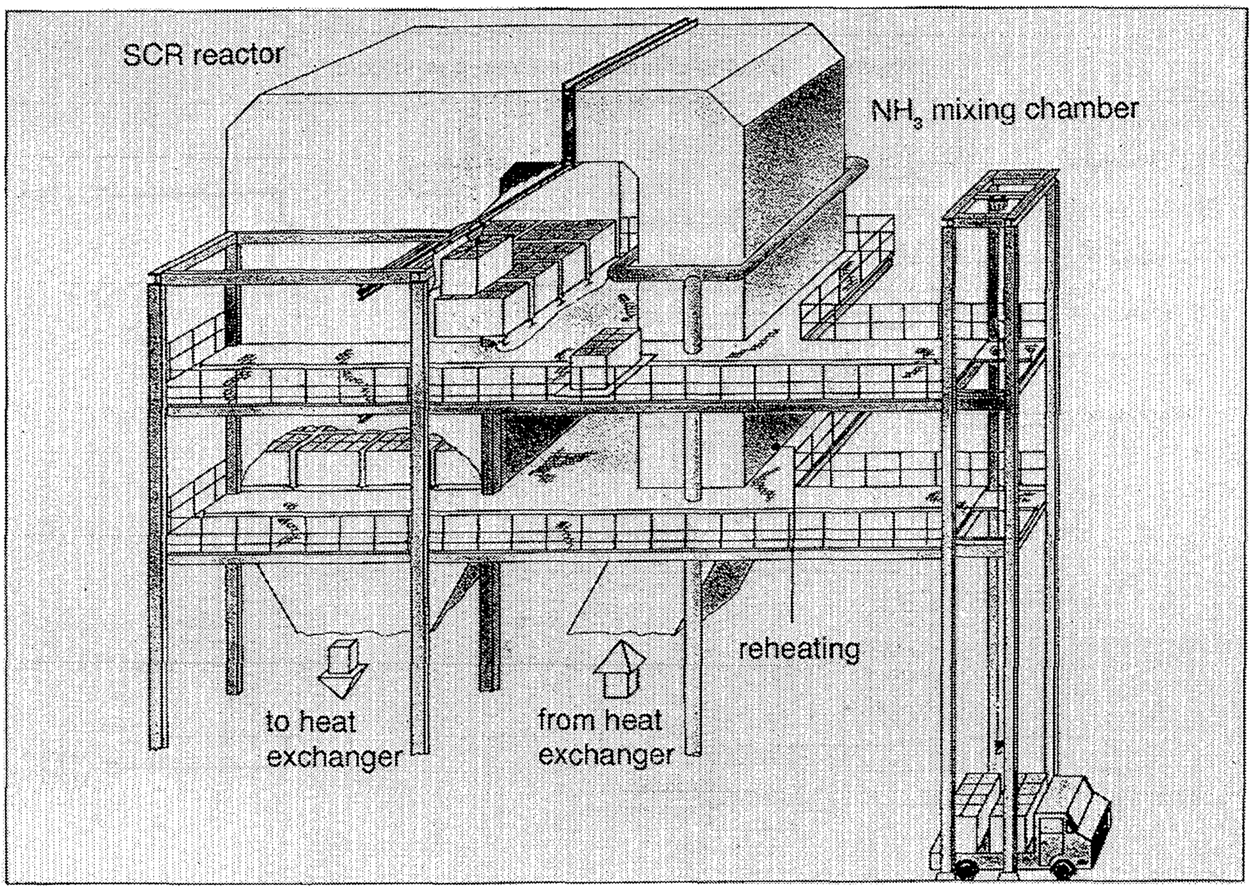


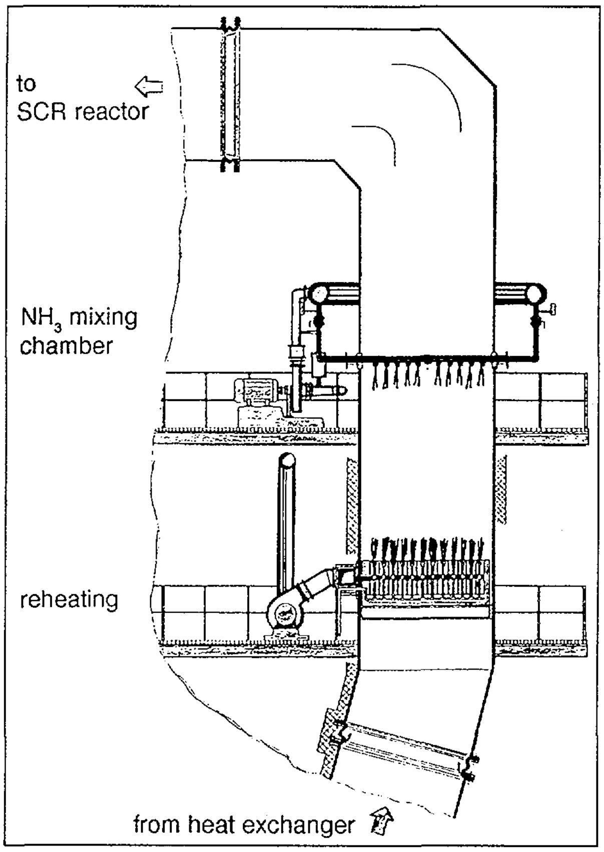
Figure 4. SCR reactor with reheating unit, NH_3 mixing chamber and catalyzer



modular baskets of the catalyzer. The flue gases flow through the reactor from top to bottom. In order to reach an optimal distribution and throughflow of the gases as a main pre-condition for every catalytic reaction, baffle plates and flow straighteners are placed at the entry of the reactor. For an easy change of the catalyzers a certain number of platforms are installed.

The reheating unit (see figure 5) consists of an area burner fired by gas or light petrol which is built in the flue gas channel behind the heat exchanger and in front of the reactor. In the same flue gas channel the NH_3 mixing chamber is fitted, situated behind the reheater.

Figure 5. Reheater and NH_3 mixing chamber

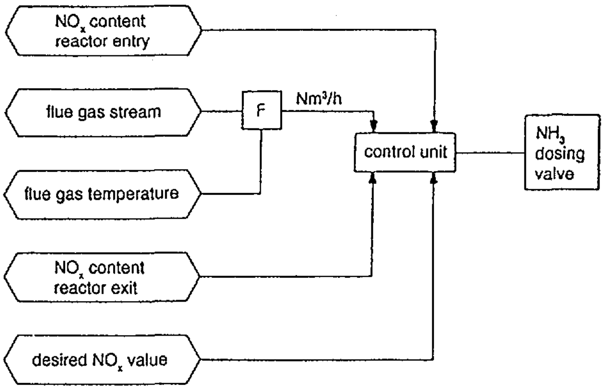


Ammonia is used in fluid form and stored in pressure tanks. Because ammonia changes its pressure according to temperature, extensive safety measures have to be taken into consideration. The ammonia water is sprayed into the hot flue gases before they enter the SCR reactor through nozzle lances, where it immediately evaporates.

The amount of NH_3 needed for this is taken in liquid form from the storage tank and then converted into gas by means of evaporation, where warm water, steam or electricity can be used. After evaporation NH_3 is rarefied by air or flue gases to concentrations that fall below NH_3 explosion limits. The ammonia gas is then blown into the flue gases at a high velocity to reach an intensive mixture with the flue gas stream.

An important part in the denitrification process is played by the control units. Their most important task is the NH_3 dosage, depending on the parameters (see figure 6).

Figure 6. Controlling NH_3 dosage



Dimensioning

The dimensioning of a denitrification plant needs experience and data gained from already installed units and from extended experimental series pilot plants. It is recommended to store all necessary information in a computer data bank to enable dimensioning of the reactors; catalyzer volumes; structure; and in order to optimize the reactor's efficiency with regard to flue gas volume streams, temperatures, and stochiometrics.

Critical aspects in designing a denitrification plant are: the reactor's construction; the flue gas guidance; and the ammonia injection system especially for injecting places and distribution arrangements.

To reach optimization a number of firms use, in the project phase, models to scale and for simulation.

Description of the production process

The heat-proof steel plates are cut to shape and size by a plate shearing/flame-cutting machine. A planing machine prepares the edges for welding. These plate pieces are strengthened by welding on rolled steel sections on the outside (see figure 7).

Different rolled steel sections, for the supporting framework, for the strengthening of the supporting plates and the service and exchange platforms (exchange of catalyzer baskets) are sawn to length, prepared for joining and welded together into transportable units.

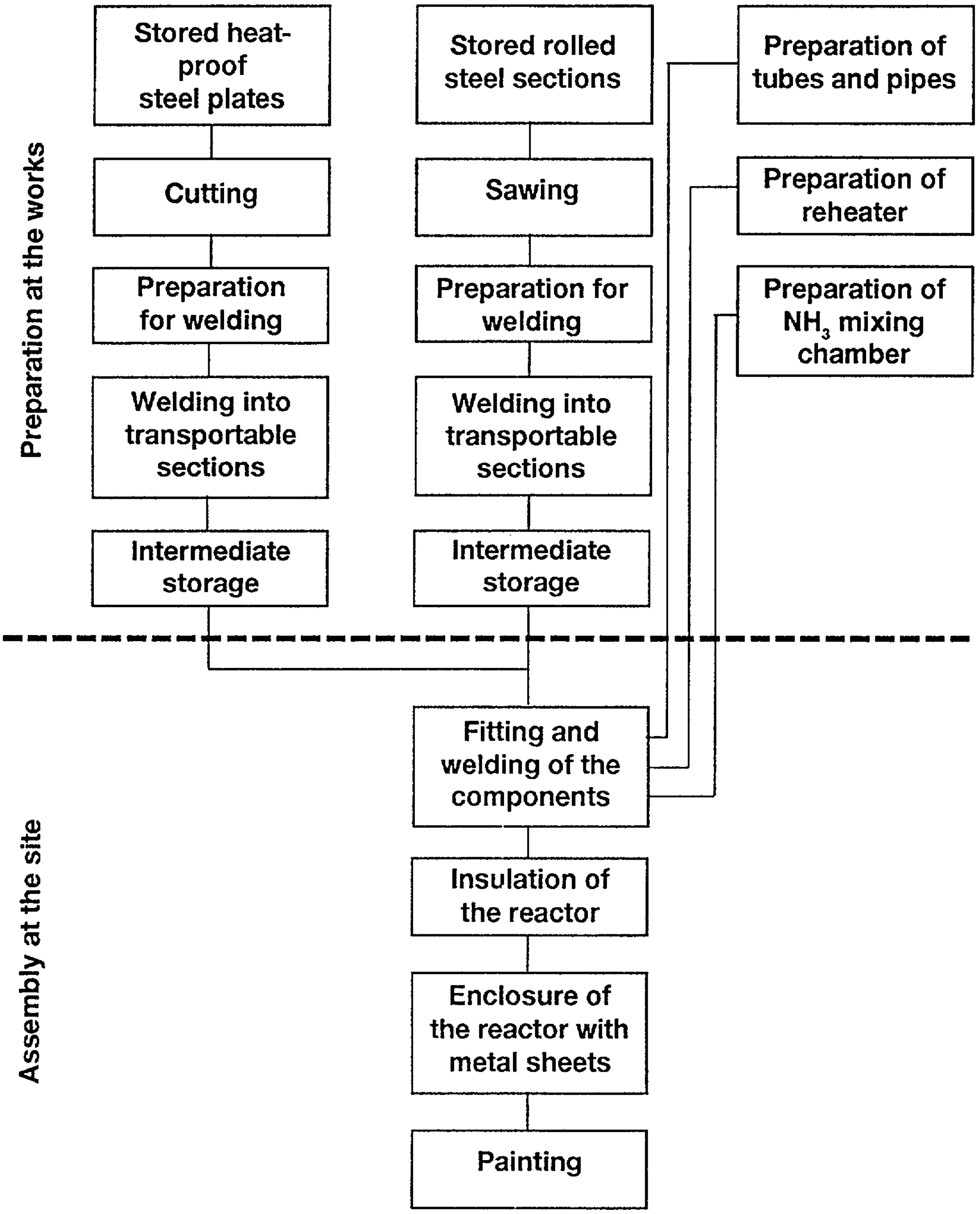
In a third production line the internal installations for the reactor are prepared, i.e. the reheating installation, the NH_3 mixing chamber and the baffle plates and flow straighteners.

The prepared units and sections are transported to the site for assembly. Cranes and lifting gear to bring the pieces into position are best hired from outside.

When finished, the reactor is insulated on the outside against heat loss and enclosed by metal sheets. The latter is done for sound-proofing reasons and to give a better appearance.

Finally the construction and the outside sheets are painted to protect them from corrosion.

Figure 7. Flow chart



Example of a production plant

The firm, considered here, produces the main steel components itself, based on the design coming from an engineering firm. Special parts and installations are ordered from outside, as for example the ammonia storage tank, the evaporator, pumps, blowers, jets, pipes and tubes, catalyzer elements and modular baskets.

The following example is based on the assumption, that denitrification plants of different sizes will be produced and that the output per year will be around 8 units. Assembly is done by a separate firm.

Required machinery and equipment

Description	*Pieces*
Plate shearing machine	1
Flame-cutting machine	1
Planing machine	1
Saw	1
Column-type drilling machine	2
Welding apparatus	6
Workplace (including hand tools)	6
Bridge crane (5 tonne)	1
Fork lift truck (2 tonne)	2
FOB-price for machinery and equipment (1992)	Approx. US$ 350,000

Required manpower

Manager	1
Engineers	3
Managerial and administrative staff	5
Foremen	2
Welders	6
Metalworkers	15
Semi-skilled workers	8

Required area

	Square metres
Production hall	2000
inside storage	600
Outside storage	400
Facilities	150
Administration	200

Required energy

Electric power	250 kW

Required inputs

Heat-proof steel plates 6-8 mm
Rolled steel sections
Steel pipes
Ammonia storage tank
Evaporator
Pumps
Blowers
Jets
Fitting material
Catalyzer elements
Modular baskets
Welding material
Paint

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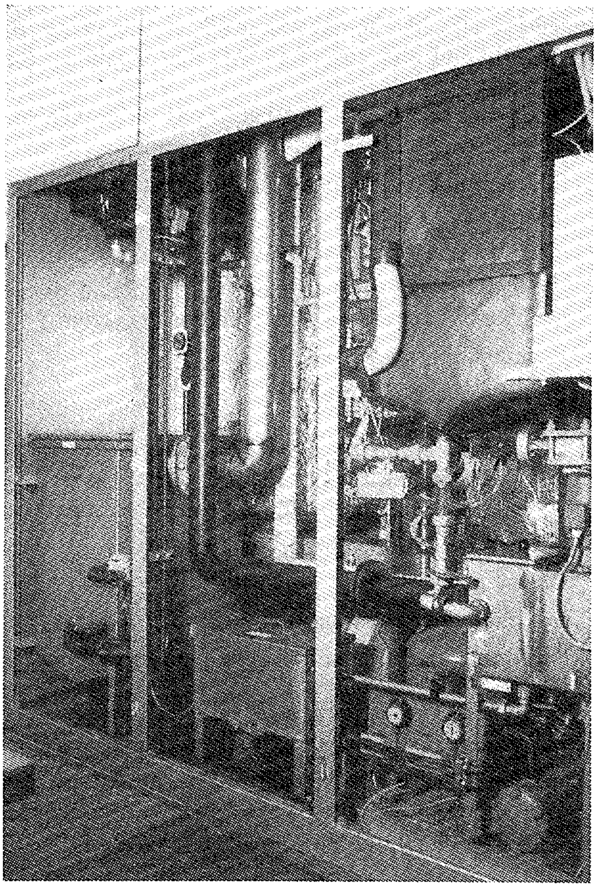
Adsorption



Introduction

Adsorption is an old process first used in 1917 to regain solvents on the basis of activated carbon. Improvements and new developments in adsorbents as well as in equipment components made this technology well known in exhaust air and off-gas cleaning.

Adsorption technology is mainly used for the removal of organic components with or without regaining the adsorptive, the material accumulated on the adsorbent. Adsorption processes are not suitable for the removal of dust, suspended substances, mist, or aerosols. Their use is also not to be recommended in cases:

Where the exhaust air or the off-gases are loaded with components which plug or resinify the pores;

Where the cleaning fluids can only be reconditioned at a disproportionately high cost; or,

Where the exhaust air has to be treated with substances, which are not condensable in connection with desorption.

Adsorption processes are mainly used when the substances to be separated from the exhaust air, or off-gases, are either highly diluted or are to be re-used. Examples are:

The elimination of smelling substances;

The regaining of solvents;

The desulphurization and denitrification of flue gases.

The main areas of employment of the adsorption technology with activated carbon are in the following, see table 1, industrial branches with the use of specific solvents.

Table 1. Industries where adsorption technology is applied

Industry	*Solvent*
Chemical industry	Different solvents, not soluble or only slightly soluble in water, e.g. Methyl chloride Methanol Ethyl chloride
Automobile industry	Methyl chloride Perchloroethylene Lacquer solvents
Printing works	Trichloroethylene Trichloroethane Ethyl acetate Ethanol Toluol
Electrical industry	Toluol
Electronic industry	Benzene
Film industry	Xylol
Food industry	Styrol
Metal cleaning	Butyl acetate Perchloroethylene
Textile industry	Trichloroethylene.

Description of the process

Adsorption is the accumulation of material on the surface of solid adsorbents. The main characteristic of the adsorbent is its multiplicity of different sized pores from macropores (> 50 nm) down to micropores of < 2 nm.

The most important adsorbents are activated carbon, zeolites, silica gel, and aluminium oxide. Activated carbon has a hydrophobic character and is especially suitable for the removal of nonpolar, in water undilutable organic substances contained in gases, such as carbon disulphide, benzol or carbon hydrochlorides. Zeolites preferentially adsorb polar or polarizable materials.

In table 2 different adsorbents are given, stating in which form they are mostly used and giving some examples of their application.

Table 2. Adsorbents and their application

Adsorbent	*Form*	*Application examples*
Activated carbon	Grain, powder, ball, fibre	Exhaust air/off-gas cleaning, gas cleaning
Activated coke	Grain	Off-gas cleaning, desulphurization/denitrification of flue gases, off-gas filter
Carbon molecular sieves	Grain	Separation of gases and hydrocarbons
Adsorber resins	Grain	Gas cleaning
Silica gel	Grain	Drying, catalyzer
Activated alumina (aluminium oxide)	Grain	Drying, catalyzer, adsorption of polar substances
Zeolitic, molecular sieves	Grain, powder	Drying, gas separation, off-gas cleaning (polar substances)

In adsorption, organic substances accumulate on solid adsorbents with a high specific internal surface (specific surfaces are between 200 and 1500 m^2/g) by different bonding forces, especially capillary condensation. Adsorption is an interfacial process between two different phases. For the adsorption of organic substances from gases, fixed bed adsorbers are almost exclusively used. In only a few cases are moving or fluidized bed adsorbers employed, which are technically more demanding (see figure 1).

An extremely important criterion for the technical use of adsorbents is the possibility of regeneration, i.e. the unloading of the adsorbent by desorption. Both adsorption and desorption have to be considered when looking at the process from an economical point of view.

There are some cases, where small amounts of adsorbents are used, where the adsorbate is not regained, or where the loaded adsorbent is dumped or incinerated; however these forms will not be further considered.

Regeneration is carried out either because the adsorbate is to be regained and/or because the adsorbent itself has a high value and should for this reason be reused. Two processes can therefore be distinguished: regeneration with the regaining of the adsorbate; or reactivation of the adsorbent without regaining the adsorbate.

When the adsorbent is loaded, it has to be regenerated by desorption. For this several methods are in use:

Regeneration by temperature swing (steam, hot air, hot gas);

Regeneration by pressure swing;

Regeneration by displacement (e.g. removal of organic substances from active carbon by steam);

Regeneration by extraction;

Reactivation of adsorbents.

Every desorption process leaves gaseous or liquid products depending on the method used. These products can be re-treated by the following variants:

Physical separation (phase separation);

Dewatering;

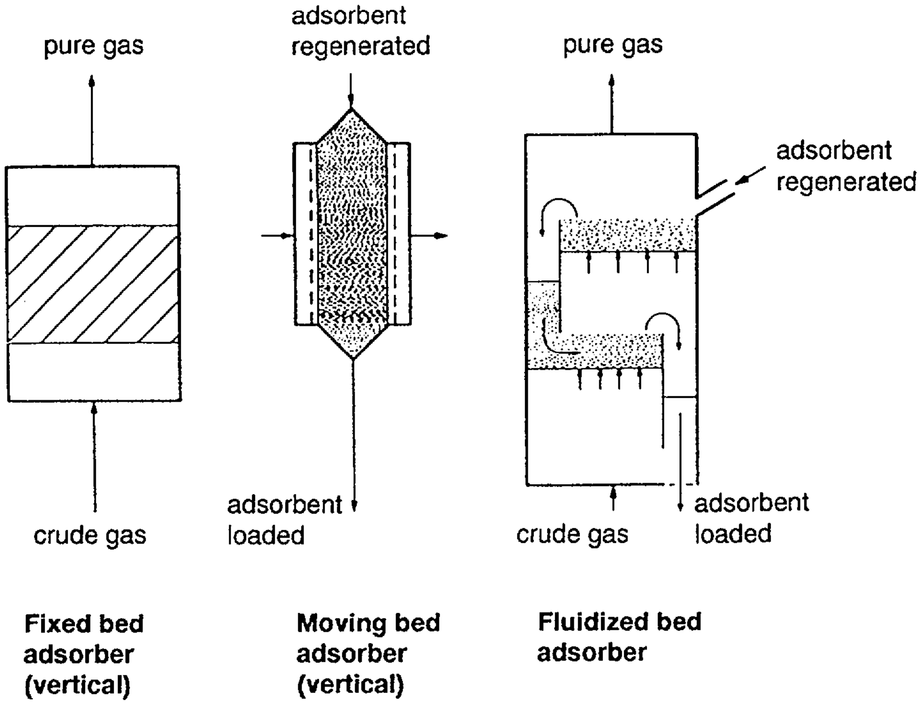
Distillation/rectification;

Regaining of different valuable substances;

Regaining of mixtures.

Regaining is worthwhile when there is a certain concentration of, for example, solvents in the off-gas stream, or when the cost of desorption (time required and the use of steam) stays under a certain limit.

Figure 1. Adsorbers and their application



When regenerating with steam, a four-phase cycle is passed consisting of loading, steaming, drying, cooling. Drying is necessary to remove the condensation water and to expose the capillaries. In a few cases a two-phase cycle is possible using the loading phase for drying and cooling.

Reactivation of the adsorbent may be necessary when the adsorbate is not volatile or soluble enough to be desorbed by increasing the temperature. This can happen when adsorbed organic impurities coke during heating and permanently damage the adsorption agent. New pores for adsorption can be created by gas activation and the burning of the activated carbon in a reactivation furnace.

Functioning of an adsorption installation

In its simplest form an adsorption installation consists of one tank containing the adsorbent, through which the air or gas stream passes, travelling from the bottom upwards. The gas diffuses into the pores of the adsorbent. In a certain layer of the fixed bed the gas load settles in the pores. Once this layer has been saturated, the succeeding mixture entering the bed flows past it into the upstream layers which then also become saturated. This process continues till the whole fixed bed is saturated.

If the exhaust air or off-gas stream can be interrupted for a time to allow the adsorbent to be changed or regenerated, no additional equipment is necessary (batchwise treatment). In the case of continuous treatment, at least two different adsorbers for alternative operation are necessary. While the one works as adsorber, the other functions as desorber, regenerating the adsorbent. However, it should be taken into consideration that the time for regeneration must be considerably shorter than the adsorption time in order to avoid interruptions, or a third adsorber should be used.

Figure 2 shows an installation for purifying exhaust air, whereby organic components are adsorbed on activated carbon in two fixed bed assorbers; the loaded adsorbent is regenerated by steam.

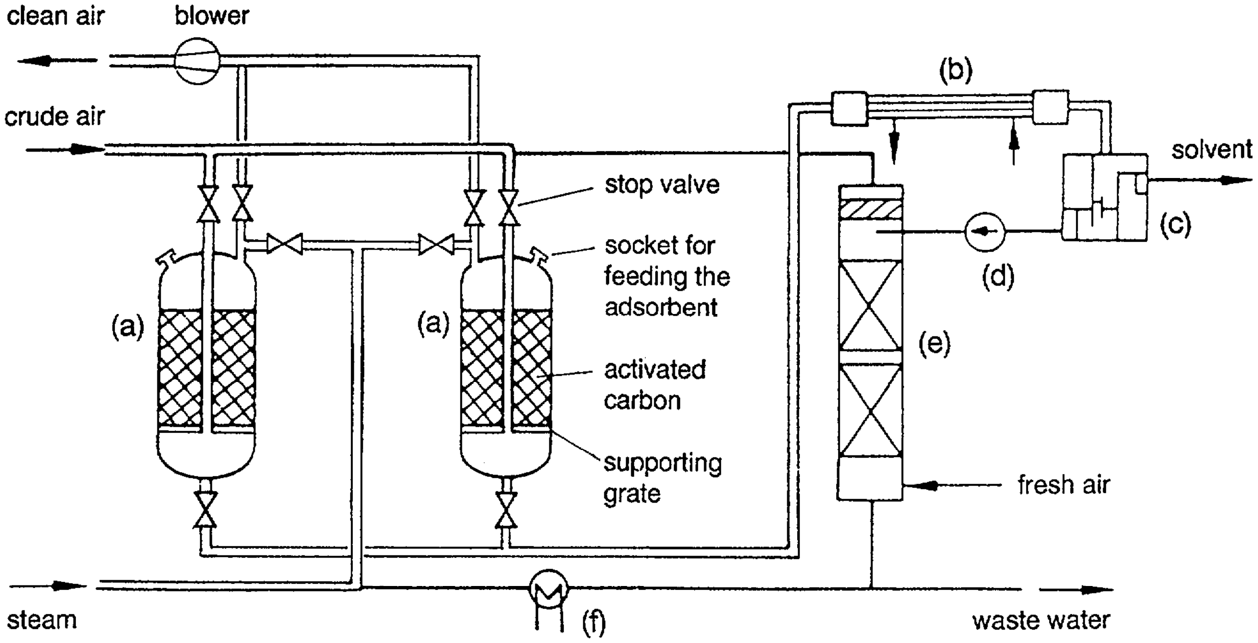
The exhaust air, containing organic material, flows from the bottom to the top through the bed of activated carbon. When the exit concentration reaches its limit value, the stream of exhaust air is directed to the regenerated adsorber. This is automatically done by a control signal coming from the clean air control instrument. Superheated steam flows countercurrently, from top to bottom, through the loaded fixed bed, displacing the organic mixture. The mixture of steam and organic vapour is liquefied in the condenser. The regenerated adsorber is then dried by means of a hot gas and later cooled with a cold gas.

Before it enters the adsorption unit, it is necessary to condition the off-gas stream to be cleaned, i.e. to remove dust, mist and aerosols, as they could plug the pores of the adsorber, leading to pressure losses, and as, at least partially, they cannot be removed in regeneration or reactivation. Therefore industrial adsorption plants are usually fitted with a pre-separator.

Sometimes the removal of water vapour is important to prevent the steaming out of already adsorbed harmful substances in the adsorption phase.

Conditioning is also necessary to keep the adsorption temperature below the temperature range of desorption. When using activated carbon the adsorption

Figure 2. Installation for purifying exhaust air



(a) Adsorber/desorber
(b) Condenser
(c) Separator
(d) Pump
(e) Stripping column
(f) Evaporator

temperature has to remain well below the self-ignition temperature.

The adsorption process has to be continuously controlled in order to maintain its effectiveness and to prevent any break-through of harmful substances, which can occur not only after the adsorbent is loaded, but also through the forming of channels, through a rise in temperature or steam penetration. Therefore the temperature in the adsorption bed is controlled (progression of the temperature zone caused by the adsorption heat also indicates the exhaustion of the adsorbent) as well as the remaining concentration of harmful substances in the cleaned air/gas stream.

Adsorbers for flammable solvents have to be fitted, for safety reasons, with connections for inert gas, sprinklers and water for fire fighting.

Some solvents like ester, ketons and carbon hydrochlorides suffer a small catalytic decomposition on the activated carbon, leading to acids with corroding effects. In such cases it may be necessary to use stainless steel adsorbers or a ceramic coating instead of painted steel.

A loaded adsorber is regenerated, i.e. the adsorbate is removed from the adsorbent by displacement from the active parts due to adsorption by a displacing agent, e.g. steam for the removal of organic substances from activated carbon. This is particularly advantageous if the organic substances are insoluble or difficult to dissolve in water, because the mixture formed during regeneration (steam and vapour of organic components) can then be separated readily into two liquid phases after condensation.

Choice of adsorbent and dimensioning of adsorbers

In practically no case can the adsorption behaviour be predicted on the basis of theoretical considerations. The most suitable adsorbent has therefore to be found by measuring the adsorption isotherms of the process gases and by determining the adsorption cinetics.

For the dimensioning of the adsorber installation, trials regarding flow, desorption and regeneration of the adsorbent are necessary.

The dimensioning depends mainly on the following various parameters:

Entry concentration and maximum allowed exit concentration;

Gas velocity and pressure loss;

Temperature and humidity of the gases;

Desired working time.

While entry and exit concentrations are generally fixed, gas velocity and pressure loss are decisively influenced by the measurements of the adsorbent bed and its grain sizes. The gas velocity has to stay below a certain limit, given by the equilibrium between the flow power and the weight power of the adsorbent grains.

In technical installations the flow velocity stays 30-40% below the critical velocity and lies at 0.2-0.4 m/s.

Description of the production process

The stainless steel plates are cut to size. Some of them are then rolled to form the cylindrical cases for the adsorbers, the condenser and the water separator. Others are prepared to form rings, flanges, air channels, baffles, the outer casing etc.; preparation means bending, cutting holes and preparation for welding. Also, in the rolled pieces, holes are cut to take up inlet or outlet pipes.

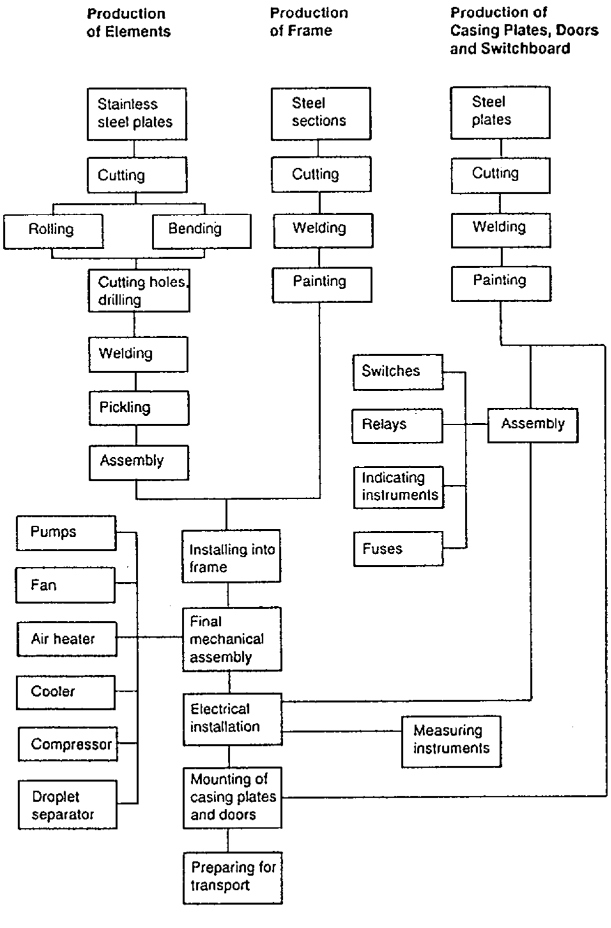
Parallel to this the necessary steel sections are cut to length and welded together to form a skeleton frame, in which the different elements are installed. This is then painted.

The next step is the welding of the different pieces to obtain the finished elements adsorbers, condenser, water separator and air channels. These elements are then pickled in a pickling tank and afterwards rinsed with water. When dry they are built into the skeleton frame. These elements are interconnected by pipes, valves incorporating pump, fan, air heater, cooler, compressor and droplet separator.

After the mechanical installation the electrical installation is carried out, fixing measuring instruments, installing the switchboard with switches, relays, indicating instruments, fuses, control lights etc. and connecting the electrical users (e.g. compressor, fan, pump) with the switchboard.

The final step is the mounting of the casing plates, already painted, and the preparation of the whole unit for transport, i.e. fixing it on a pallet and covering it with plastic foil for protection.

Figure 3. Flow chart



Example of a production plant

The firm being considered produces adsorption units for exhaust air cleaning. The exhaust air is loaded with a certain concentration of solvents, halided hydrocarbons, insoluble in water. The solvents are to be regained.

The following example is based on the assumption, that 50 adsorption units are produced per week with the amount of air to be cleaned being 240 m^3/h.

These adsorption units are manufactured from stainless steel plates (3 mm thick) for adsorbers, pipes, condenser, separator, casing and steel sections (U, T; L-shape etc.).

Required machinery and equipment

Description	*Pieces*
Circular saw	1
Shearing machine	1
Bending machine	1
Folding machine	1
Welding apparatus (protective gas)	6
Dipping tank (for pickling)	1
Workplaces (including necessary hand tools)	26
Painting equipment	1
Plastic foil welding machine	1
Fork lift truck (2 tonne)	1
Bridge crane (6 tonne)	1
FOB-price for machinery and equipment (1992)	Approx. US$ 2.1 million

Required manpower

Manager	1
Engineers	2
Foremen	2
Metalworkers	23
Welders	6
Electricians	10
Painters	2
Semi-skilled workers	4
Purchase/sales staff	8
Managerial and administrative staff	5

Required area

	Square metres
Production hall	1200
Machining section	250
Welding section	150
Assembly	500
Indoor storage	100
Facilities	200
Administration	150
Final storage/dispatch	350
Free area	300

Required energy

Electric power	150 kW
Argon bottles	
Air compressor (7.5 kW)	
Ventilation system (exhaust and filters)	

Required inputs

Stainless steel plates (3 mm)
Steel plates (for casing)
Steel sections (U, T, L-shaped etc.)
Pipes
Pipe elbows
Compressor motors
Pumps
Filters
Insulating wool
Electrodes
Small parts
Steel plates (1.5 mm for switchboard)
Relays
Switches
Indicating instruments
Measuring instruments for exhaust air
Fuses
Electric cable
Fans

Air heaters
Pneumatic valves
Droplet separators (plastic)
Cooler
Cooling pipes

Activated carbon (granulate, fibre)
Paint

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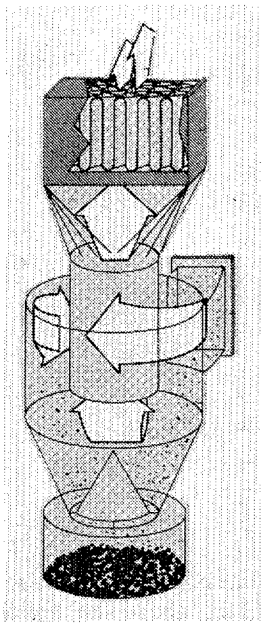
File: O 38
ISIC CODE 2811
May 1993

How to Start Manufacturing Industries

Dust removing plant



Introduction

From mixtures of gases and dust-laden air, that form during production processes, are additional foreign substances that must be removed. The foreign substances, i.e. the particles to be removed from gas mixtures, differ in their chemical composition, consistency and grain size and even extend into the realm of suspended matter or aerosols. Solid substances with particles smaller than 0.5 mm are defined as dust. Whether intended or not, dust results from mechanical tooling or crushing methods and from physico-chemical processes, such as drying, evaporation, combustion or melting. The fineness of the dust is determined by its mineral composition and process of formation. Treatment plants must be designed in line with these conditions.

Laws and legal regulations determine the cleaning for mixtures of gases and vitiated air. In practice, a variety of plants, that mainly differ in principle of operation, technical requirements and cost, are used for dust removal. The following describes a specific cleaning plant for these mixtures referred to as a "dust removing plant". Dust removing plants consists mainly of a cyclone and a set of filters connected in series.

Using one single cyclone to remove the dust is no longer state-of-the-art technology as it fails to attain the required degree of separation. It is now common practice to use cyclones as pre-separators for coarse-grained foreign substances, complemented by air filters connected in series for the subsequent separation of fine-grained particles. This type of dust removing plant can be of modular design, which means that several cyclones can be connected in series or in parallel and complemented by additional filters. This guarantees a high flexibility with regard to specific local requirements.

Dust removing plants can be used in the following main industries:

Chemical and ceramics industry;
Mining industry;
Pit and quarry industry;
Wood working industry;
Food processing industry.

The above type of dust removing plant is frequently used in cement works, metalworks, metalworking factories, sawmills, timber yards and furniture factories and also in food processing plants, especially sugar mills.

Dust removing plants composed of a cyclone as a pre-separator and several filter cells for fine-grained dust connected in series are particularly suitable for application and manufacture in developing countries. Due to their simple design they require low production costs, little maintenance work and are technically highly reliable.

The advantages of these dust removing plants are:

- They are suitable for high dust concentration.
- Their modular design allows for adapting cyclones and filters to given air quantities and degrees of separation.
- The layout of the individual plant is adaptable to specific substances, including toxic dust.
- Their high dust separating performance makes it possible to clean the air after the production processes and return it to the workrooms.
- The particularly high degree of separation is achieved by connecting coarse and fine filters in series after the cyclone.
- Filters can be replaced quickly and easily.
- Contamination-free replacement of filter cells and collecting basins for harmful dust is possible.
- For cleaning purposes the filters can be connected to an already existing compressed air system.

Description of the product and its operation

The main components of a dust removing plant are:

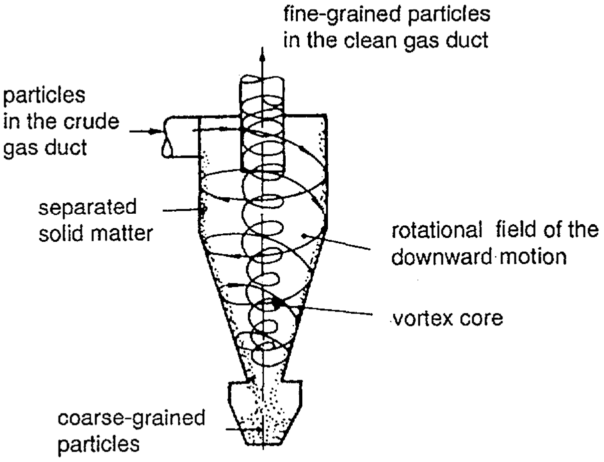
Cyclone as pre-separator;
Dust collecting basin;
Single-stage or multi-stage filter cell.

The following describes the function and mode of operation of the three main components:

The cyclone

Utilizing the centrifugal force of accelerated particles the cyclone is highly efficient in removing coarse-grained particles of dust. Pressure conditions and gas speed are decisive factors for its dimensioning and thus for the course of operations. This leads to complex flow patterns. The ideal pattern is shown in the following figure 1.

Figure 1. Flow characteristics in a cyclone



The main components of a cyclone are the inlet for the dust-laden air, the cylinder with its lower part shaped like a cone and the immersion tube.

Through the inlet the dust-laden air tangentially enters the cylindrical top and spirals downwards towards the cone. Coarse-grained particles of dust contained in the air are then flung to the cyclone wall by centrifugal force and are carried downwards along the wall by the rotating air current. Hitting the wall reduces the speed of the particles and thus the speed of the gas current and causes a powerful vortex motion inside the cyclone.

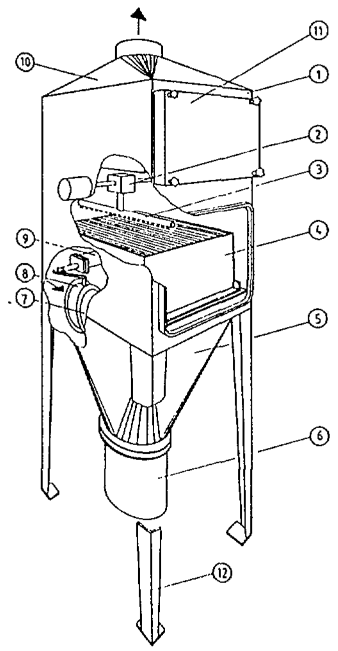
The high centrifugal acceleration of the particles of dust produces friction against the cyclone walls and the cone is therefore subject to increased wear.

The length of the immersion tube influences the secondary air current which splits away from the primary current. Lightening of particles would require an extension of the immersion tube in the cylinder to prevent the secondary current from transporting these particles, due to insufficient acceleration, directly through the immersion tube.

Dust collecting basin

Coarse-grained particles settle in the dust collecting basin connected below the cone. This happens when, caused by rotation, a ring of dust has formed on the cyclone wall, which discharges into the collecting basin as soon as it has reached its maximum dust absorbing capacity. The dust collecting basin should be positioned low enough under the cone, i.e. below the inversion areas of the primary air current, to prevent the collected dust from whirling up again. Figure 2 shows the necessary constructional measures such as the counter-cone and small ring opening.

Figure 2. Main components of a dust removing plant



Key:

1 Filter casing
2 Filter cleaning device
3 Sliding nozzle head
4 Filter cell
5 Dust cone
6 Dust collecting basin
7 Connection piece
8 Shutoff valve
9 Servomotor
10 Connection hood
11 Casing cover
12 Understructure

Filter cell

The filter cell, i.e. the third component, is fixed to the immersion tube above the cyclone. It serves to separate the fine-grained dust particles contained in the air current which moves up through the immersion tube. A variety of filter cells differing in design and material can be used. Particularly high degrees of separation can be achieved by connecting in series a number of filter cells which separate even very fine-grained dust particles.

If filters are connected in series the speed of the air current and the pressure which builds up require special attention as they must suffice to overcome the resistance of the filter media. Where toxic dust is involved a safe replacement of used filter cells is possible with the help of protective sacks. For this purpose a gas-tight aluminium collar can be fastened to the opening of the casing. The collar has two circular packing grooves to which a plastic maintenance sack can be fastened with elastic tightening straps.

Irreversible damage to the filter media caused by sticky and problematic dust, a frequent effect where conventional filter media are used, can be avoided if artificial dust is sprayed on to the filter surface thus forming a protective film which binds sticky particles and protects the cells.

Variants of dust removing plants

The air current which is to create the rotation needed for dust separation in a cyclone has to enter the air inlet at a defined speed. Two fundamentally different ways of air intake to the cyclone are known: the tangential and the axial intake.

If an air current hits the upper part of the cylinder tangentially, baffle plates cause the air to spiral downwards. An axial air current is diverted by axial or radial baffle plates fastened to the inside of the cyclone and is thereby caused to rotate. The intake for the dust-laden air need not be positioned in the upper part of the cyclone. Alternative designs are also possible, where the immersion tube through which the cleaned gas escapes is not fastened to the cyclone top.

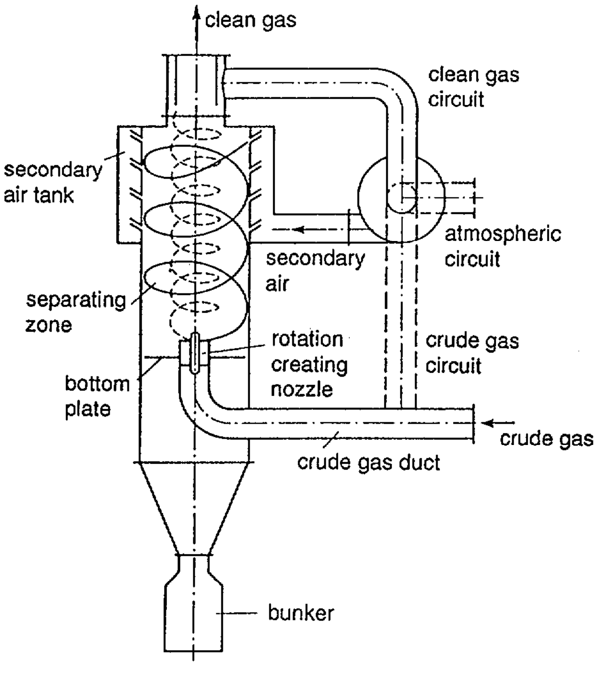
Tangential cyclones are primarily designed as large-scale cyclones with cylinder diameters of 2-6 m. They are mostly used separately but are sometimes connected in series. It can be necessary to connect cyclones in parallel in order to clean larger quantities of gas or to improve the treatment performance. In this case the dimensioning of the individual cyclone has to stay clearly below that of separately used cyclones.

The most common type of axial cyclone is the so-called multiclone (multiple centrifugal separator) consisting of a considerable number of axial cells connected in parallel. This allows for reduced cell diameters, preferably in the range of 0.1-0.25 m. Given a comparable speed of the air current, small diameters generate greater centrifugal forces and thus a higher degree of separation.

Hurriclones are an additional variant of cyclones. In contrast to the common type they use two air currents, i.e. the crude gas current and the secondary gas current (see figure 3). Varying the proportion of secondary air quantity to crude gas quantity influences the separating performance of the hurriclone. Larger quantities of secondary air lead to a higher degree of separation. As it is extremely difficult to record the flow process inside the cyclone, the exact calculation of its dimensions is more complicated than for the common type. Hurriclones are mainly applied where small quantities of waste gas occur.

The cyclone can be fitted with a special cleaning device. During the cleaning phase the cyclone is switched off and a sliding nozzle head moves to and fro over the filter surface. The continuous compressed air stream from the nozzles penetrates the filter medium in a downward direction and takes off the dust sticking to the lower side of the filter. The dust then falls down through the cyclone into the dust collecting basin.

Figure 3. Pattern of a hurriclone



Dimensioning

No reliable method has hitherto been developed for an exact calculation of cyclone dimensions. It is therefore common practice to proceed as follows:

Approximate values for the dimensions of the different cyclone components are worked out;

Values are correlated with the dimensions of other cyclones which the company has already constructed and gained experience with;

The performance specifications of the present cyclone are checked in a series of practical experiments.

The difficulties in calculating the dimensions of the individual components of a cyclone result from the variety of flow specific and material specific influencing factors. Due to the complexity of the relevant factors neither their combined effects nor their interaction are known well enough to have practicable formulae for their calculation available.

The most important factors influencing the dimensioning of a cyclone and thus the intended degree of separation of particles from the air current are:

The flow by volume of the gas to be cleaned in m^3/h;

The calculated speed of the gas in m/sec;

The concentration of dust in the gas in g/m^3;

The chemical composition of the dust and the specific weight of the individual dust components;

The distribution of dust particles according to grain size;

The critical grain size, i.e. the grain size, 50% of which is separated in the cyclone;

The fractional degree of separation indicating the proportion of particles of a given size contained in the gas stream that can be separated.

To illustrate the separating performance of a cyclone the following table 1 contains the characteristic values gained by experiment. It shows the grain size distribution within the dust fractions and the efficiency which can be achieved by the single fraction and by the entire system.

Table 1. Total separating performance of a cyclone for known dust grain-size

Grain size d (µm)	*Dust to be separated; proportion in percentage by weight*	*Fractional degree of dust separation*	*Total degree of dust separation*
0- 5	5	60	3.00
5-10	10	85	8.50
10-20	30	95	28.50
20-30	17	98	16.66
30-40	13	99.5	12.94
40-50	7	99.9	6.99
> 50	18	100	18.00
	100		94.59

The distribution of dust particles main dimensions for the components of a cyclone, the interaction between the dimensions and finally the configuration of the cyclone have been worked out in practical experiments and are listed below:

The cylindrical part of the cyclone has a diameter (D) of approximately 200-3500 mm.

Experience shows that the overall height of the cyclone ranges between 3D and 5D or 600 mm and 17,500 mm.

The inlet velocity of the gas to be cleaned lies between 10 m/sec and 24 m/sec.

As a result the velocity of flow at the cross-section area of the cylindrical part (= average load) ranges from 1-3.5 m/sec.

The exhaust speed of the cleaned gas, measured at the cross-section of the immersion tube is in the range of 8-13.5 m/sec.

The tapered inlet and the frictional resistance at the cyclone wall lead to a flow resistance of 500-1500 N/m³.

The maximum working temperature is 500 °C.

Figure 4 shows the main heights and diameters for the dimensioning of a cyclone.

Table 2 contains the main cyclone dimensions as a function of the different volumes of gas streams to be cleaned. Apart from these figures, the above range of main determinants including speed, dust content and fractions is valid for the cyclone dimensions described here.

Figure 4. Size relations for the dimensioning of cyclones

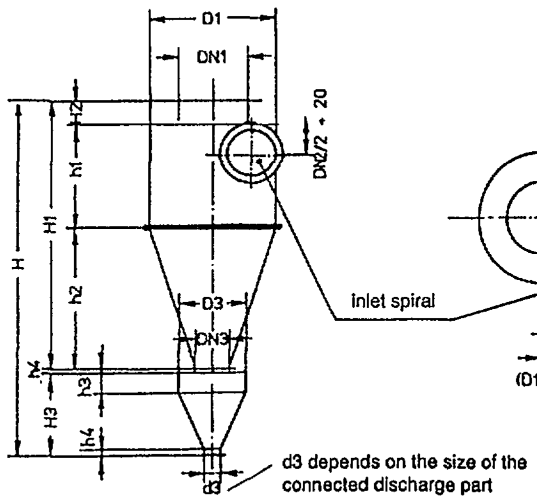


Table 2. Main cyclone dimensions as a function of the flow by volume

V	*Cyclone*							*Vortex Calming Chamber*			
(m3/h)	*D1*	*DN1*	*DN2*	*DN3*	*H1*	*h1*	*h2*	*D3*	*H3*	*h3*	*H*
225	203	83	65	83	505	190	285	—	—	—	505
350	253	103	83	103	620	235	335	175	225	55	895
500	303	128	103	128	735	285	400	200	250	65	1035
700	353	153	128	128	850	335	465	250	305	75	1205
900	403	153	128	153	980	380	530	300	360	90	1370
1150	453	178	153	178	1075	430	595	325	390	100	1515
1400	502	203	153	178	1190	475	665	350	415	105	1655
1700	552	228	178	203	1305	520	735	375	445	110	1800
2050	602	253	203	228	1420	570	800	400	470	120	1940
2750	702	278	228	228	1845	665	930	425	500	125	2195
3600	802	328	278	228	1875	780	1085	450	525	130	2450
4100	902	378	303	253	2100	855	1195	500	580	145	2730
5700	1002	403	328	278	2355	950	1330	550	855	165	3110
6650	1102	453	353	328	2585	1045	1465	600	710	180	3395
8150	1202	478	403	328	2780	1125	1580	650	785	190	3645
9550	1302	527	428	353	3040	1235	1730	700	820	205	3980
11100	1402	552	453	378	3265	1330	1880	750	875	220	4240
12700	1502	802	478	403	3495	1425	1995	800	930	235	4525
14500	1602	652	527	428	3725	1520	2130	830	955	240	4790
16350	1702	677	552	428	3925	1600	2250	850	985	245	5010
18300	1802	727	577	453	4205	1720	2410	900	1040	260	5345
20400	1902	752	627	478	4350	1780	2495	950	1090	275	5540
22800	2002	802	652	503	4635	1900	2660	1000	1250	315	5985

Note. All measurements in mm.

Description of the production process

The great height of a cyclone, and the necessity to install it in an upright position, calls for a supporting structure with at least four struts that may have either a steel sheeting or be constructed as an open type girder. Under the cyclone a space has to be left open for the dust collecting basin and the devices needed to empty the basin and to remove the dust. The end of the cylindrical part of the cyclone has to contain devices for the fitting, cleaning and replacing of filters. Additional arrangements should serve as a vent for the gases, which have been cleaned in the set of filters connected in series. This calls for a height of the supporting structure of approximately 1.3-2 H (H = height of the cyclone).

The construction of the total system requires plates made of stainless steel with a thickness of 0.5-2 mm and structural iron of different measurements. Pipes and flanges for intake and discharge of gas streams are also needed. As a general rule, these materials have to be purchased from suppliers. The same applies to the sets of filters connected in series, which can be obtained from only a few special firms.

The manufacturer of a cyclone has to ensure that:

Structural iron and steel sheets are cut accurately to size;

The sheets are bent in segments so that the circular sections are true to dimensions;

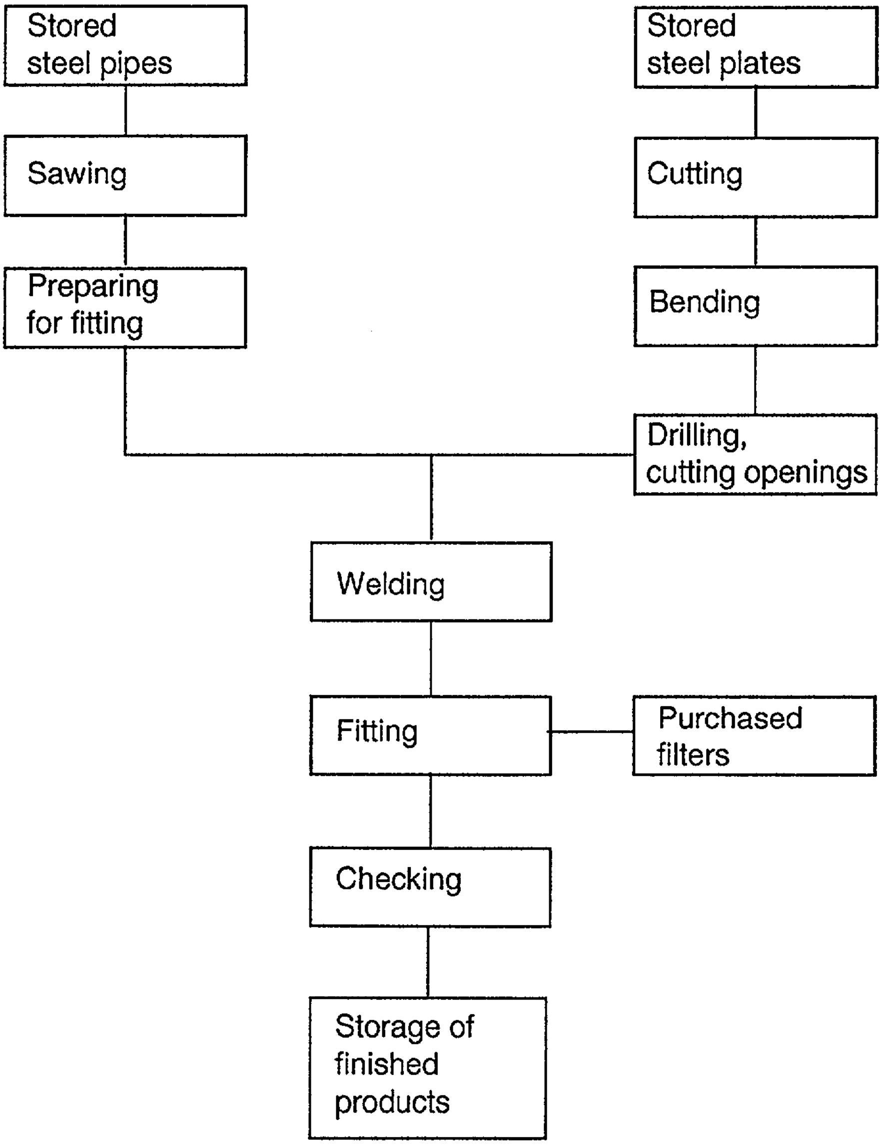
The sections of the stabilizing rings, which are needed to fix the bent and welded sheets, are perfectly circular;

The cone has a regular inclination;

The interior walls are perfectly smooth, especially near the welds.

The manufacturing process consists mainly of cutting and sawing the sheets and structural iron true to the dimensions given in the detail drawings, machining the parts, e.g. bending, folding and fixing the pretreated parts, and of welding, drilling and screwing, grinding and smoothing surfaces, and finally painting.

Figure 5. Flow chart



Example of a production plant

The following example illustrates the number of machinery, material, personnel and space required for a medium-sized production plant. Within six days this type of plant with approximately 13 workers working one shift per day can produce a medium-sized cyclone. The machinery, material and personnel listed below are not necessarily fully used. To reach full capacity an increase in production is necessary.

Required machinery and equipment

Description	*Pieces*
Cutting and folding bench	2
Guillotine shears	2
Folding press	1
Cutting torch	3
Metal cutting saw	2
Plate bending machine	2
Form bending machine	2
Electric welding unit	3
Autogenous welding unit	3
Cutting and grinding tools	4
Drilling machine	4
Shaping machine	2
Screw driver	6
Spraying gun	5
Transfer car	8
Crane and hoisting unit	5
Mounting frames	3
Small tools for metalworking	
FOB-price for machinery and equipment in US$	Approx. US$ 350.000

Personnel requirements

Managerial and administrative staff	5
Technical managers	2
Mechanical engineers	3
Designers	2
Skilled workers	6
Semi-skilled workers	10
Storemen	2
Quality control and maintenance staff	2

Space requirements

	Square metres
Administration	80
Production	800
Paint shop	400
Storage	800

Energy requirements

Electric power	75 kW

A stand-by unit for emergency power supply (50 kW) and devices for voltage stabilization should be provided.

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May 1993

How to Start Manufacturing Industries

Catalytic oxidation

Introduction

It is the highest environmental aim in industrial processes to reduce emissions as far as possible by applying more stringent measures to production processes themselves. However, in those cases where such measures are not adequate enough to keep emissions within the maximum allowed limits, then an "end-of-pipe" solution is unavoidable.

Catalytic waste air treatment is today a common procedure to reduce emissions that cannot be removed by applying more stringent measures to the production process. Catalytic waste air treatment removes organic harmful substances from waste air by transforming by means of a chemical reaction on the surface of a solid auxiliary material (catalyzer) polluted gaseous and vaporous substances into harmless substances. The harmful substances are oxidized in an exotherm reaction on the catalyzer at a raised temperature.

Industrial and craft waste air streams, containing oxidizable harmful substances, can be cleaned by catalytic oxidation. In practice adsorption as well as thermal oxidation are to be found in direct competition with catalytic oxidation. The application of catalytic oxidation is limited by the existence of toxic substances as well as by the possibilities of apparatus to prevent the overheating of the catalyzer in the case of extremely fluctuating pollution.

Principle of catalytic waste air treatment

Catalyzers are materials that increase the velocity of chemical reactions without themselves being used up. Technical catalyzers are highly porous materials that offer a vast surface for chemical reactions given that

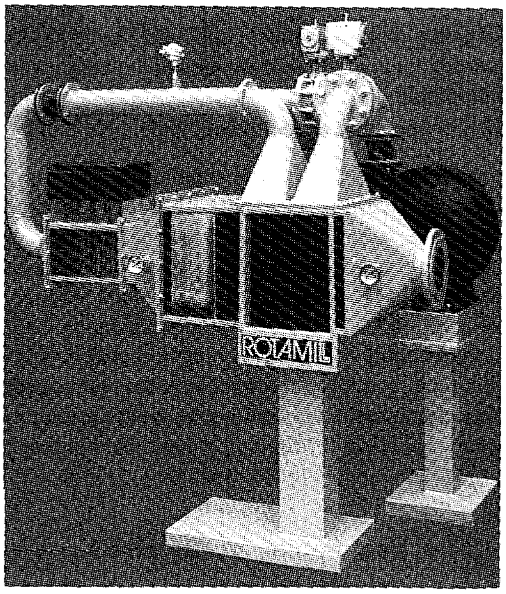


Table 1. Applications of catalytic waste air treatment

Area	*Problem*	*Examples*
Food industry Pharmaceutical industry	Odour emissions	Smoking works, mass animal production
	Removal of organic substances	Cleaning of food-CO_2-sterilization
Synthetics production and processing	Organic substances	Production of formaldehyde vinylchloride Maleinic acid anhydride PVC-profiles synthetic fibres
Fertilizer	Nitrous oxides	Nitric acid plants
Varnish processing	Organic solvents	Production of varnished wire, varnish drying
Processing of foil and profiles	Organic solvents	Lining, gluing, impregnating, paper coating, printing
Oil industry	H_2S_9, SO_2	Claus-plants
Energy production (steam, electricity)	Hydrocarbons Carbon monoxide Nitrous oxides	Cleaning of exhaust gases from engines Furnaces

offer a vast surface for chemical reactions given that the reaction partners (harmful substances and oxidizing or reducing agents) are present in a different state of aggregation than the catalyzer. The catalytic surface reaction consists of a number of succeeding partial steps:

Transport of the reaction partners to the contact surface of the catalyzer by the gas stream;

Diffusion of the reaction partners through the contact surface to the outer and inner surface of the catalyzer;

Adsorption of the reaction partners on the surface of the catalyzer;

Chemical transformation of the reaction products;

Desorption of the reaction products from the surface;

Diffusion of the products through the pores to the outer surface of the catalyzer and through the contact surface;

Further transport of the products by the gas stream.

Because desorption occurs together with succeeding diffusion and further transport, the active centres are ready for the transformation of further molecules.

The use of solid catalyzers increases the velocity of the gas reactions. Through this increased velocity, the transformation of air polluting substances by chemical reaction is achieved at lower temperatures and with smaller reactor sizes (shorter duration) as opposed to thermal processes. Catalytic waste air treatment can be differentiated from biological processes, however, by a higher temperature level as well as a shorter duration.

Functioning of the plant

For the technical realization of catalytic waste air treatment processes, special equipment components adapted to individual waste air problems are necessary (see figure 1). The process basically runs as explained in the following.

The polluted waste air is, after passing through a starting-up flap system and a dust filter for the separation of disturbing components, transported by a fan to an air/air heat exchanger (electrically or gas heated) for pre-heating. After this the waste air passes through a burner, where it is—if necessary—heated to reaction temperature. From here the waste air flows to the reactor, where the organic harmful substances are oxidized on a catalyzer. The reaction heat created heats the waste air. On passing through the air/air heat exchanger the pure gas stream gives up some of its heat to the crude gas stream, before leaving the plant by the stack.

The process selection in catalytic waste air treatment is dependent on the choice of active and stable catalyzers based on empirical factors or the execution of pilot trials. Basically the following technical catalyzers are to be found in waste air treatment:

Noble metal catalyzers (e.g. Pt, Pd);

Metal oxidation catalyzers (e.g. V, W, Cu, Mn, Fe);

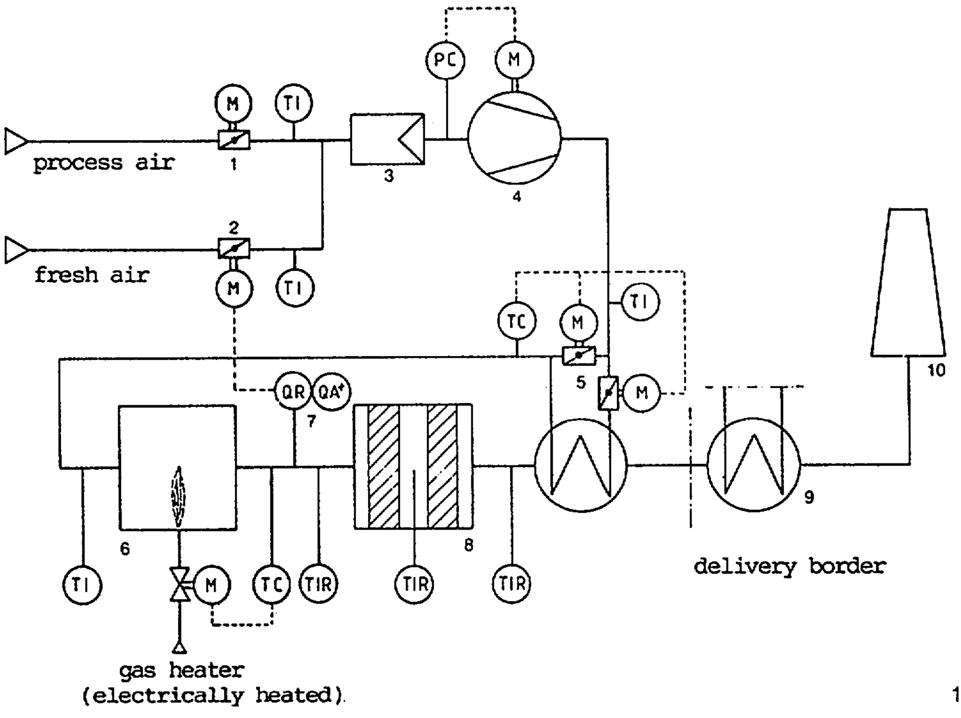
Oxidic catalyzers (e.g. zeolithes, Al_2O_3).

They occur as honeycomb or loose material catalyzers.

Dimensioning

The dimensioning of the catalyzer is mainly dependent on the technical details of the polluted air stream and the demanded degree of purity. Its characteristics are thereby determined by its material composition, its specific surface area, its pore distribution as well as its geometry.

Figure 1. Components of a catalytic waste air treatment plant



1 process air flap
2 fresh air/mixed air flap
3 dust filter
4 process air fan with underpressure control
5 air/air heat exchanger with temperature control
6 pre-heater (gas/electric)
7 concentration control
8 catalytic reactor
9 further energy recuperation
10 stack

The industrial equipment of the projected plant is determined by the following:

Composition of the crude gas;

Temperature of the crude gas;

Pressure of the crude gas;

Required degrees of transformation (admissible remaining emissions);

Type of catalyzer;

Possibilities of energy supply;

Possibilities of heat recovery.

For the dimensioning of the reactor two methods can be used:

(a) Pre-calculation on the basis of existing reactor models is a method when the kinetic data, necessary for the determination of the reactor velocity, and the conditions of flow and temperature are known and when there is no influence by disturbing components.

(b) Experimental simulation or pilot trial is a method of more practical importance, as for example: there are mixtures of harmful substances with often changing concentrations; conditions of flow and temperature vary considerably; no kinetic data are given; the influence of further crude gas components is not known; and a pilot run for the determination of toxic substances is often necessary. The results of these trials are registered in diagrams that show the dependency of transformation degrees of certain harmful substances on certain catalyzers on entry temperature, volume velocity, and entry concentration and which can be used as a basis for dimensioning.

In dimensioning the catalyzer it has to be taken into consideration that the speed of the total reaction is determined by the slowest step in the series of steps of the catalytic reaction. Every hindrance to any of the steps leads to a reduction of the total transformation. Therefore catalyzers should—if possible—allow high adsorption, reaction and desorption velocities. In addition they should be constructed in such a way, that the transport of the reaction products to and from the catalyzer is not hindered. The first demand is influenced by the chemical characteristics of the catalyzer, the second demand by its structure: under otherwise equal conditions reaction velocity increases proportionally with the effective surface of the catalyzer. Because of this as much catalyzer surface as possible should be contained in a reactor. This can, for example, be achieved by the use of fine-grained powder, which however leads to correspondingly high pressure losses.

If there is a high demand for small pressure losses then honeycomb pipes are used, as here the pressure loss is very small because of the laminar flow in the channels. Further advantages in using honeycomb pipes are:

Mechanical stability;

Simple exchangeability;

Steady afflux and throughflow;

Simple arrangements in boxes with different geometric cross-sections.

When catalyzers are used in technical processes their lifetime is not unlimited. The influence of excessive mechanical and thermal burdens on their lifetime can, nevertheless, be limited by conceptional measures of the plant. Toxic substances—on the other hand—like sulphur, halogens, phosphor and heavy metals have a stronger influence on their lifetime.

Construction and function of a catalytic waste air treatment plant

Example of application

In the solvent processing industry pollution is caused either by machines and devices containing solvent materials (e.g. adhesives, varnish, paints, synthetic resins, cleaning materials, etc.) or solvents themselves. The waste air from these aggregates is mostly loaded with a mixture of solvents, variable in composition. Problems arise when great amounts of air with only a small load of solvents have to be treated, as for example, in paint shops, printing works, and extraction of waste air from production halls, etc. In such cases waste air treatment by increasing the concentration and with succeeding catalytic oxidation is favourable for economic as well as environmental reasons. The increase in the concentration of the polluted waste air is achieved by a rotation adsorber.

The combined process is explained below using an example from the varnishing industry; its operation costs are compared with those used solely for catalytic oxidation.

Treatment of waste air from a varnishing plant

The solvent-laden air from an automatic varnishing plant should be cleaned to a concentration of < 100 mg/Nm³. The basic process data are as follows (see also table 2):

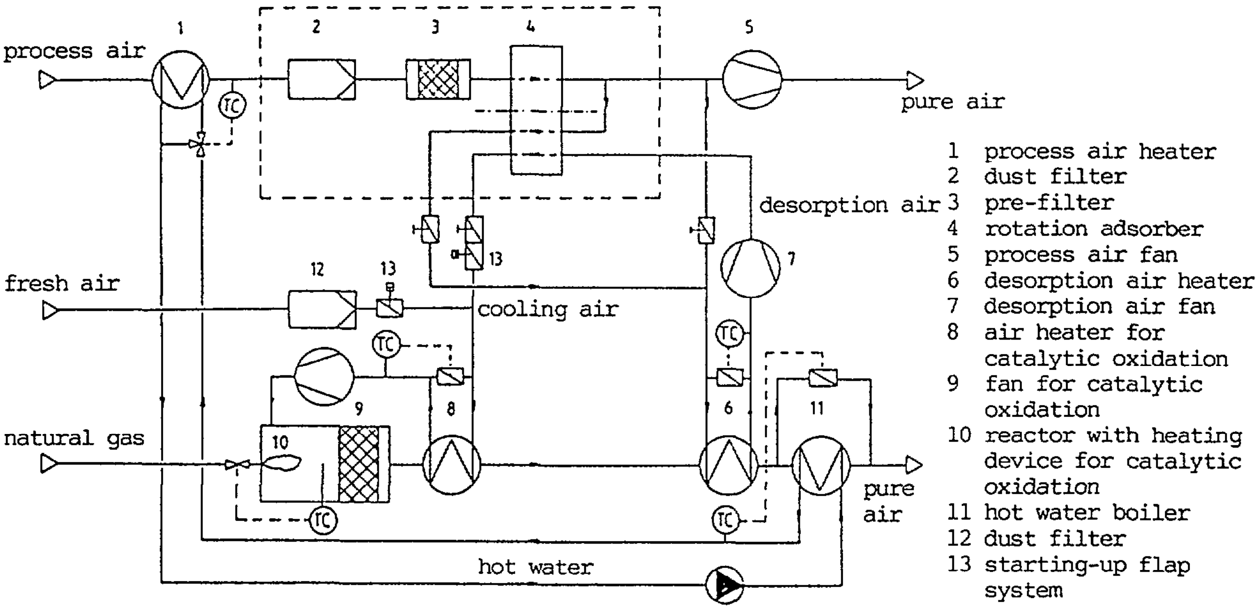
Amount of air	28000 Nm³/h
Temperature	< 25 °C
Relative humidity	max. 80%
Dust concentration	< 2 mg/Nm³

Table 2. Amount of solvent yield from a varnishing plant

	Amount	*Concentration*	*Operation time*
Standby	0.00 kg/h	0 mg/Nm³	400 h/a
Minimum	14.00 kg/h	500 mg/Nm³	1600 h/a
Maximum	21.00 kg/h	750 mg/Nm³	6000 h/a
Average	18.55 kg/h	663 mg/Nm³	8000 h/a

Solvent composition	*Percentage*	*Exotherme*
toluol	38	32.9 K/(g/Nm³)
xylol	38	33.7 K/(g/Nm³)
butylacetate	12	22.2 K/(g/Nm³)
ethylacetate	6	18.9 K/(g/Nm³)
methyl-ethylketon	6	24.7 K/(g/Nm³)
mixture	100	30.5 K/(g/Nm³)

Figure 2. Flow chart of total plant



To lower the relative humidity of the process air system to less than 60%, an air pre-heater is installed, working with hot water. The hot water is produced by using the waste heat of the catalytic oxidation plant. In front of the concentration plant a safety dust filter, as well as an activated carbon filter, are installed. The cold desorption air is taken from the cleaned air stream and is heated to desorption temperature in a heat exchanger by the hot pure gases of the catalytic oxidation before entering the concentration rotor. The cooling air is also taken from the cleaned air stream and is added to the desorption air stream. The highly concentrated desorption air coming from the concentrator is led into the catalytic oxidation plant which is fitted with noble-metal catalyzers. The hot pure gases from the catalyzer are used three times for energy purposes before they leave the plant via the stack.

Compilation of the most important plant data:

Process air amount	28000 Nm³/h
Desorption air amount	2500 Nm³/h
Air mixing relation	11.2 : 1
Solvent concentration:	
in the process air	0-750 mg/Nm³
in the desorption air	0-7800 mg/Nm³
in the pure air	< 100 mg/Nm³
Concentration limit for autothermic operation:	
with process air heating	approx. 600 mg/Nm³
without process air heating	approx. 400 mg/Nm³

It has to be taken into consideration that in the above example the autothermic operation for the total plant starts at a solvent concentration of 600 mg/Nm³. The complete waste air treatment plant can consequently, in the case of the given process data, be operated on an autothermic basis during 75% of its operation time. If the process air heating could be abandoned, the concentration limit would sink to 400 mg/Nm³. In comparison, the autothermic operation for treating the total waste air amount directly in a catalytic oxidation plant only begins at a solvent concentration of 2700 mg/Nm³.

If both plant types are compared in a calculation comprising operation costs and profitability, then the result shows that the annual total operation costs for a plant with concentration are only approx. 45% of the costs of a sole catalytic oxidation plant. This is based on the following factors:

Less need for electricity because of lower pressure losses;

Less need for gas because of the concentration;

Lower further operation costs because of other consumption materials;

Lower service of capital because of lower investment costs.

With the combined process of concentration/catalytic oxidation the treatment of large waste air streams with a low solvent load can be carried out with comparably low investment and operation costs.

Description of the production process

For the construction of the total plant steel plates with a thickness of 3 mm and structural steel of different measurements are needed as well as pipes and flanges for the gas and air streams. The manufacturing process consists mainly of the following activities:

Cutting and sawing of the sheets and of the structural steel according to given measurements;

Bending and folding of parts;

Drilling and cutting openings;

Welding of parts;

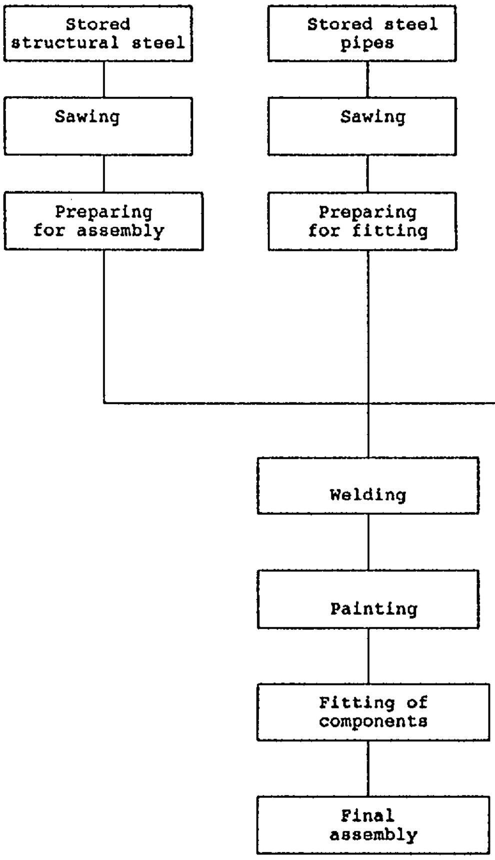
Grinding and smoothing of surfaces;

Painting;

Fitting of components;

Final assembly.

Figure 3. Production and assembly of the plant



Example of a production plant

The data given below is based on the assumption that one catalytic oxidation unit is manufactured within a month. In case a higher output is needed the number of some machines and equipment has to be increased proportionally.

Required machinery and equipment

Description	*Pieces*
Metal saw	1
Cutting machine	1
Folding bench	1
Pipe bending machine	1
Lathe	1
Electric welding unit	3
Hand cutting and grinding tools	3
Drilling machine	2
Workbench (including hand tools for metalworking)	4
Crane	1
Fork lift truck	1
FOB-price for machinery and equipment Approx. US$	120,000

Required personnel

Manager	1
Administration	1
Sales and projecting	1
Construction/work preparation	1
Skilled workers	4
Semi-skilled workers	2

Required area

	Square metres
Production hall including storage	1000
Administration and sales	30
Management	30
Construction/work preparation	30

Required energy

Electric power	25 kW

Required inputs

Steel plates (3 mm)
Steel pipes
Structural steel
Flanges
Fans for process air and catalytic reactor
Dust filter
Air/air heat exchanger
Catalyzer
Control instruments
Flaps, valves, fittings
Burner
Hot water boiler
Rotation adsorber

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

How to Start Manufacturing Industries

Waste gas cleaning using bag filters

Introduction

A large number of industrial processes contribute towards dust formation. The removal of dust from air and other gases is necessary for the following reasons:

The environment must be protected from the nuisance created by dust. This is the most important area of application for dust removal processes.

Gases e.g. throat gases from blast furnace plants, emitted from technical and chemical processes must often be cleaned before further use in order to safeguard subsequent installations and to fulfil further operational tasks.

Valuable materials e.g. copper, zinc, plastics, as well as intermediate or finished products, must be separated from the waste gases resulting from dryers, rotary furnaces, spray towers or pneumatic transporters.

Dust is defined as solid particles as well as, in the widest sense, liquid droplets, with grain sizes of predominantly 1-1000 μm. In all dust removal processes some kind of movement of the dispersed solid particles relative to the carrier gas is generated through external forces. Depending on the type of predominant force, the following principles of removal are to be differentiated:

Gravitational forces in settling chambers;

Rebounding, impacting and centrifugal forces in deflecting precipitators;

Centrifugal forces in centrifugal dust removal;

Electrostatic forces in electrostatic precipitators;

Impacting and bonding in fabric filters such as surface filters or bag filters.

Dust removal using fabric filters

Process

Dust removal using fabric filters can be divided into two areas. First, the removal of dust from air in production areas, working areas or living spaces; or the removal of dust from waste gas, emitted from some production processes, down to levels considered harmless to human beings, animals or plants. This area of application comprises of the removal of dust from the air supply, waste air or gas. Second, the removal of dispersed dust from gases during a production process. In this case, the task lies in collecting the dust or in cleaning the gases in the course of a production process.

In both cases, dust-removing fabric filters are used if high degrees of purity are required. The coarseness of the particles in this case is less important as with fabric filters only particles of up to 0.1 μm are retained. With the correct dimensioning and selection of a suitable fabric filter material over 99.9% separation can be achieved, as with the electrostatic precipitator, which corresponds to a pure air dust load of less than 30 mg/m^3.

The dust removal process is a separating operation based on the impact of dust particles hitting the filter element and diffusional, gravitational and electrostatic forces. What occurs during filtration is not a pure sieving process as the precipitated particles are often smaller than the pores of the filter medium. Close-mesh filters have a higher rate of efficiency than wide-mesh filters, however, at the cost of resistance, that is to say economy. In practice it has been observed, that, as a rule, the degree of precipitation rises along with the operating time until a constant value is reached. Basically the following factors should be considered regarding the degree of precipitation:

Physical and chemical properties of the dust particles and carrier gas;

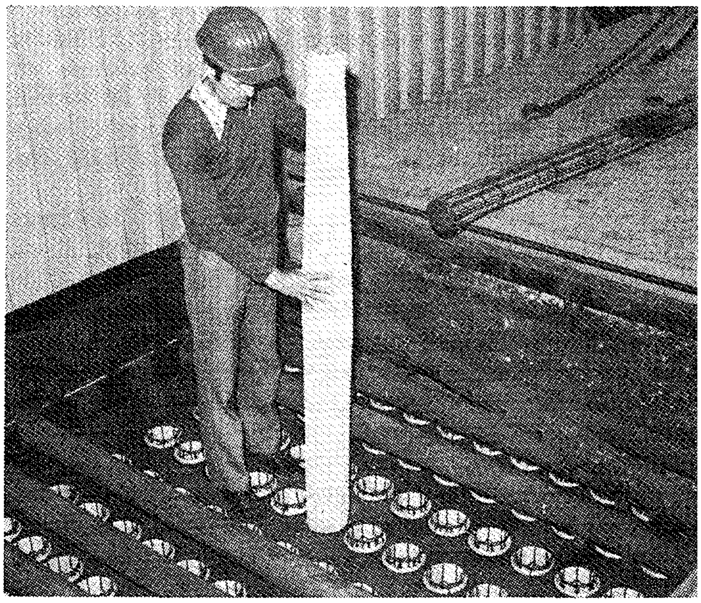
Dust load of crude gas;

Grain size distribution of the dust particles;

Characteristics of the filter mechanism;

Type and method of cleaning.

The precipitated dust layer that has been collected on the filter material increases the permeability resist-



ance of the filter element; in order to achieve a sufficiently constant filtration the precipitate must be removed from the filter material at specific time intervals. This process, referred to as deducting, can be carried out by means of:

Mechanical deducting (shaking, vibrating);

Low-pressure backwashing (pneumatic deducting);

High-pressure backwashing (pressure deducting).

Filter material

The precipitating quality of a filtration precipitator is subject above all to the filter material selected for use. Regarding filter materials, two features are of special interest. First, the geometry of the interstitial pores and thus the texture of the material; second, their properties of mechanical solidity, temperature constancy, and resistance against acids, lye, moisture and biological parasites.

Filter fabrics used for dust removal are divided into either natural fibres of plant/animal products such as cotton, wool, flax, natural silk and hemp; or synthetic fibres, such as polyamide, polyester and polyethylene.

In practice, depending on the temperature and chemical composition of the waste air (waste gas), cotton, polyvinylchloride and polyamide are used up to approx. 80 °C; wool up to approx. 100 °C; polyacrylnitrile (Orlon, Dralon) and polyester (Dacron) up to approx. 150 °C; Teflon up to approx. 220 °C, as well as siliconized glass fabrics up to 280 °C.

Apart from these fabrics radon felting (bonded fabrics) is more and more frequently being used because working at the same efficiency it is more economical than spun fabrics. It is mostly made from synthetic fibres and is fixed to a support cloth by a felting process or secured by means of binding agents.

Criteria for construction of dust filters

The basis for the construction of dust filters is knowing the volume flow that is to be cleaned, which either depends on the processes in use or is determined by the extraction conditions e.g. dust protection at the workplace.

An essential parameter of precipitation by filtration is the effective area; this is the ratio of the waste air volume flow (waste gas volume flow) to the surface load, which is experimentally determined or known from similar cases. In practice, this lies most frequently between 80 and 150 m^3/m^2h.

Examples of the surface loads of filtering separators using cloth or bonded fabrics as filter material are listed in table 1. In addition to the surface load to be selected, the following specifications regarding measurement, shape, operating mode, as well as choice of material are important for the construction of a dust precipitator.

Table 1. Surface loads of filtering separators

Production	*Surface load* m^3/m^2h
Power station (ash)	90-120
Foundry	75-95
Fish meal factory	90-100
Cocoa production	130-140
Flour production	110-120
Joinery	135-145
Feed stuff production	140-150
Cement factory	130-180
Fertilizer production	100-130

(a) General specifications

Type of installation, process, apparatus or machines for which the dust filter should be used.

Operating mode of the installation (e.g. continuous or in shifts).

Properties of the exhaust gas or air (e.g. health-hazardous, inflammable, etc.).

Properties of the dust (e.g. health-hazardous, inflammable, etc.).

(b) Specifications for construction

These relate to the intake of exhaust air (exhaust gas) into the dust filter and prescribe the operating conditions for which the dust separator is to be designed.

Specifications of the air or gas to be cleaned: temperature, composition, density, volume flow, desired pure air (pure gas) dust load.

Specifications of the dust: average dust load, minimum dust load, maximum load in the exhaust or crude gas; particle size distribution; density; composition regarding material components; water content.

Because these specifications are difficult to determine reliably it should always be verified whether or not test runs have to be conducted before a final decision on the construction of the dust filters is made.

Fields of use

As the above examples indicate, the use of dust filters made from cloth or woven fabrics extends over a large spectrum ranging from skilled trades (joineries, paint shops etc.) to large-scale industrial production plants in the chemical, metal-processing and other industries, to heating and power stations and waste incineration plants. In practice, there are advantages in using dust removing filters as opposed to electrostatic precipitators in terms of their working life, easy maintenance and cost efficiency, and more and more frequently fabric filters are being used for other dust removal processes. Consequently, baghouse filters are used wherever a low dust concentration in pure air is required.

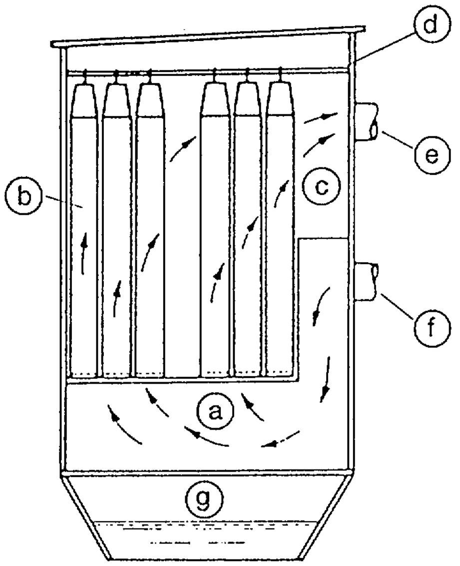
Bag filter

Bag filters are used not only due to their high rate of dust removal, but also because they save space as compared to a surface filter, for example. The basic structure of a bag filter can be seen in figure 1.

A bag filter consists essentially of the following elements:

The exhaust air space (a): this is the part of the filter installation through which the exhaust air (exhaust

Figure 1. Structure of a bag filter



Key:
a Exhaust air space
b Bag filter
c Pure air space
d Dust collection area
e Inlet connecting piece
f Outlet connecting piece
g Suspension frame

gas) flows and which serves to distribute the air to be cleaned onto the bag filters (b);

The pure air space (c): purified air (gas) passes through this part of the installation, which serves to collect the purified air or gases;

The dust collection area (d): dust detached from the filter elements through deducting is collected here. At the lower side it is equipped with a dust discharger;

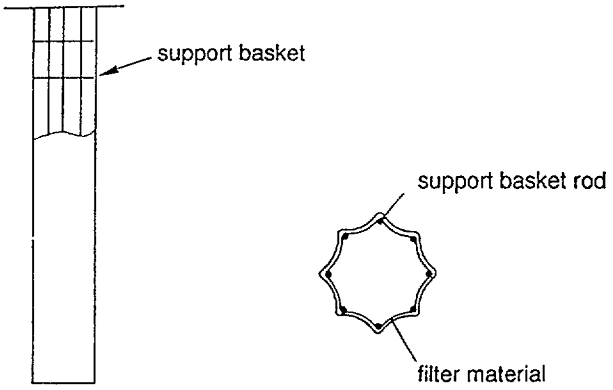
The bag filters (b): the required filter surface is attained by assembling a certain number of standardized bag filters into a unit;

Suspension frame (g): this consists of steel tubes to which the bag filters are attached;

The tapping/rapping equipment.

It is important that in the filter installation the exhaust air space and the pure air space are linked only through the filter elements. Bag filters are the most common filters at the moment (see figure 2); the filter element consists of a cylindrical fabric bag mounted on a support basket made from stainless steel rods. Depending on the required filter surface, the corresponding number of filters are installed in a filter chamber.

Figure 2. Bag filter



As can be seen from figure 1 dust is removed when exhaust air (crude gas) is admitted into the waste air space (a) by means of a ventilator located above an inlet connecting piece (e). The exhaust air then flows through the bag filter (closed on top) from bottom to top, whereby dust particles in the air to be cleaned collect on the inner sides of the filter elements (b). The purified exhaust air collected in the pure air space (c) then leaves the filter installation through an outlet connecting piece (f).

The dust layer collected on the filter material is referred to as filter cake, which increases the permeability resistance of the filter element and therefore must be removed at specific time intervals; this process, referred to as deducting, is usually done by mechanical devices, such as tapping and rapping machines and vibrators, supported by scavenging air.

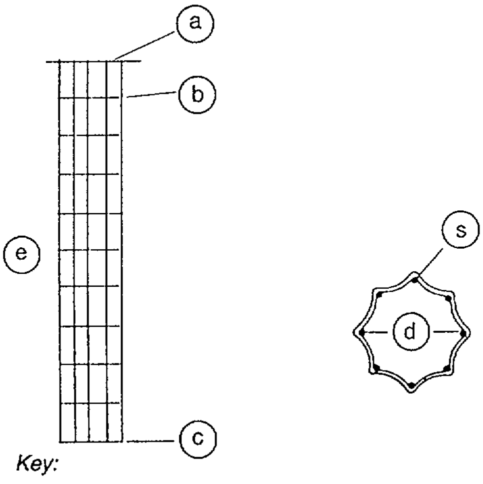
The process most frequently used at the moment is deducting by tapping the suspension frame, which holds the bag filters. The detached filter cakes then fall down into a dust collecting area (d), that is emptied continuously or periodically using a dust discharger.

To clean the filter, filtering (in single-chamber installations) must be interrupted; to avoid this, multichamber installations are increasingly preferred for use, whereby only one baghouse chamber is cleaned while the other chambers can be kept operational.

Description of the bag filters

Various factors determine the measurements of a bag filter. As it is costly to produce filter fabrics from natural and chemical fibres, or as technically difficult processes are demanded, filter fabrics are supplied from outside; what is produced is a support or bag basket with the following standard measurements: diameter 30 cm; length 2 m. Thus the filter surface encompasses approx. 2 m^2.

Figure 3. Support basket



Key:
a Head ring
b Spacing ring
c Sealing ring
d Diameter
e Length
s Support basket rod

The support basket consists of the following individual components (see figure 3):

8 stainless steel support basket rods (s), length 2 m, diameter 1 cm (a);

1 head ring (diameter 30 cm) (a) of stainless steel wire (length 95 cm, diameter 0.5 cm) at the upper rim;

1 sealing ring (diameter 30 cm) (c) of stainless steel wire (length 95 cm, diameter 0.5 cm) at the lower rim;

9 octagonal, star-shaped spacing rings (diameter 30 cm) (b) of stainless steel wire (length 93 cm, diameter 0.5 cm), affixed to the steel rods between the head ring and sealing ring positioned 20 cm apart.

Parallel to the support basket, the filter chamber (see figure 4) can also be manufactured from steel plates, into which the bag filters (c) mounted on a supporting frame (b) are inserted. The rapping devised (d) is supplied from outside.

Description of the production process

The following description and flow chart of the production process refer to the production of bag or support baskets, the suspension frame and the filter body. These parts are usually produced to order in larger quantities by metal or iron processing factories, which also manufacture other products.

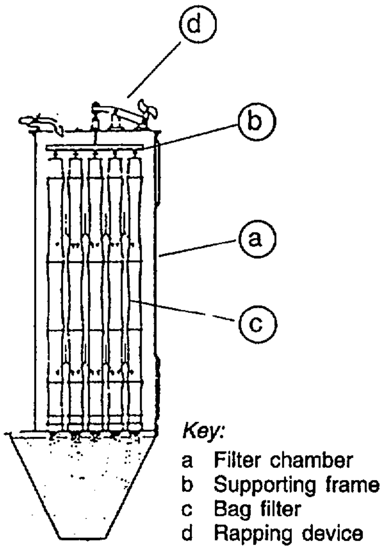


Figure 4. Filter chamber

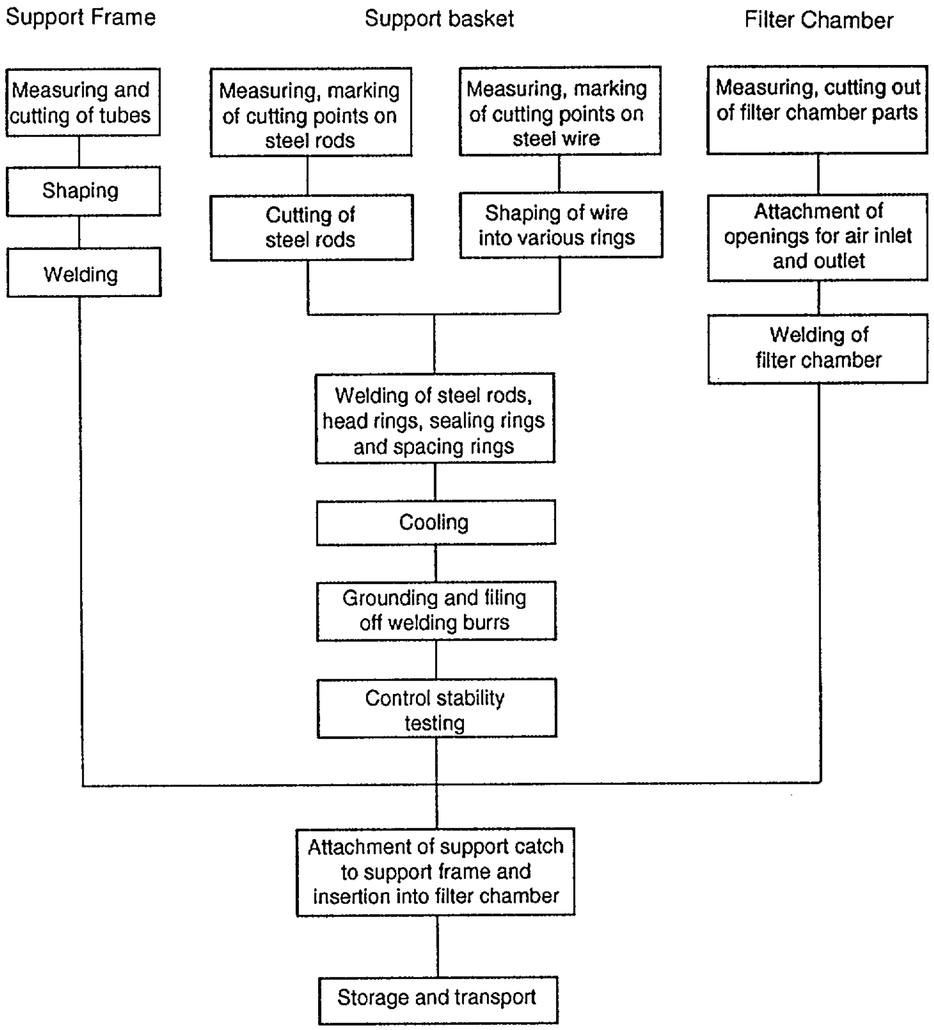


Figure 5. Flow chart

The production of bag baskets begins with the determination of the required total length of steel rods and steel wire, as well as with the calculation of the length and number of single steel rods and wire parts needed for the head rings, sealing rings and star-shaped spacing rings. Following this, the steel rods are cut to specific size and number on a cutting machine. At the same time, the steel wires are shaped into head rings and sealing rings, while spacing rings are shaped according to a prepared model.

Points are then marked on the head and sealing rings at which the steel rods are to be fixed by welding. Welding of the steel rods to both rings creates a cylindrical basket; the star-shaped spacing rings are then welded to the marked points on the basket.

After cooling, the weld points can be checked, and protruding welding burrs are ground or filed off. Finally, the product should be tested for stability (no stress).

Parallel to the production of bag baskets is that of the suspension frame and filter chamber. Tubes, cut to length, shaped to size and welded to an over-all frame, are used. The filter chamber itself is made from steel plates, which, after being cut to size and attached with inlet and outlet openings, are welded together.

Following this, the support baskets are attached to the suspension frame in the filter chamber. The filter can now be stored or transported to its place of use. To avoid damage to the filter bags during transport, they are not mounted to the support basket until they have reached their place of use.

Example of a production plant

It has already been mentioned that the filter components, as well as the support baskets for bag filters, are produced only on request and then accommodated by the production programme in operation. For this reason, it is not possible to enumerate specific details regarding energy and personnel requirements etc. for the production of a single bag filter.

Working on the premise of a metal-processing factory operating an eight-hour workday to exclusively produce support baskets, suspension frames and filter chambers on special order, it can be assumed that well-trained personnel with professional working experience and skills would require 60-70 minutes to produce one support basket; in which case, 7 support baskets can be produced in one workday.

The production of a complete middle-sized baghouse filter (16 support baskets) will require approx. 6 workdays.

Required machinery and equipment

Description	*Pieces*
Plate shears	1
Metal saw	1
Workbench (including hand tools)	4
Welding unit	3
Cutting machine	1
Bending device with model	1
Grinder	1
Folding machine	1
Pipe bending device	1
Lifting gear	1
Fork-lift truck	1
FOB-price for machinery and equipment (1991) Approx. US$	100,000

Required personnel

Manager	1
Business supervisor (also responsible for administration, accounts, advertising, etc.)	1
Administrative personnel	1
Foreman	1
Skilled workers (welder, mechanic)	4
Semi-skilled workers	5

Required area

	Square metres
Production hall	400
Management and administration	80
Social facilities	30
Storage	100

Required energy

Electricity approx.	25 kW
Water	
Oxygen, acetylene	

Required materials

Stainless steel rods	1 cm diameter, 112 m
Stainless steel wire	0.5 cm diameter, 73 m
Stainless steel plates	
Stainless steel pipes	
Welding material	

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How to Start Manufacturing Industries

Granular bed filter

Introduction

For waste gases loaded with gaseous, vaporous or solid pollutants, and arising from industrial production, a granular bed filter can be used in certain circumstances for the cleaning of the waste gases.

Granular bed filters are today preferably employed for unusual dust removing tasks. They are often used in those cases where other dust removing devices, such as bag filters or electrical precipitators for example, do not have favourable conditions or are insufficient. Granular bed filters are mainly used for the removal of dust from hot waste gases, for the removal of abrasive, chemically aggressive and/or sticky types of dust as well as in those cases where there is a danger of smouldering fires or of a drop in temperature to below the point of condensation.

Granular bed filters are used either as primary or as final filters. Up to now they are to be found in special branches of industry, chiefly in the ceramics industry, the lime and cement industry, after kilns, in the pit and quarry industry as well as in the chemical industry. In the United States granular bed filters have been successfully used to clean the waste air coming from nuclear power stations.

Principle of granular bed filters

Granular bed filters are normally used for the removal of gaseous pollutants from waste air, especially hydrogen fluoride, and solid pollutants under suitable marginal conditions from flue gases with a temperature of up to approx. 400 °C. Furthermore, granular bed filters can also be used for the sorption of other gaseous or vaporous pollutants from flue gases under suitable marginal conditions.

Granular bed filters use the filtration effect whereby the dust laden gas stream passes through a granular layer and is thus cleaned. The granular layer can be made up of materials of various sorts and sizes; quite often gravel, sand, ceramic materials, activated carbon or filling material of different shapes (rings, balls etc.) are used. The employment possibilities of granular bed filters are essentially determined by the characteristics of the granular material used. Of importance are their chemical and mechanical stability, their resistance against high pressure and high temperature as well as their regeneration behaviour.

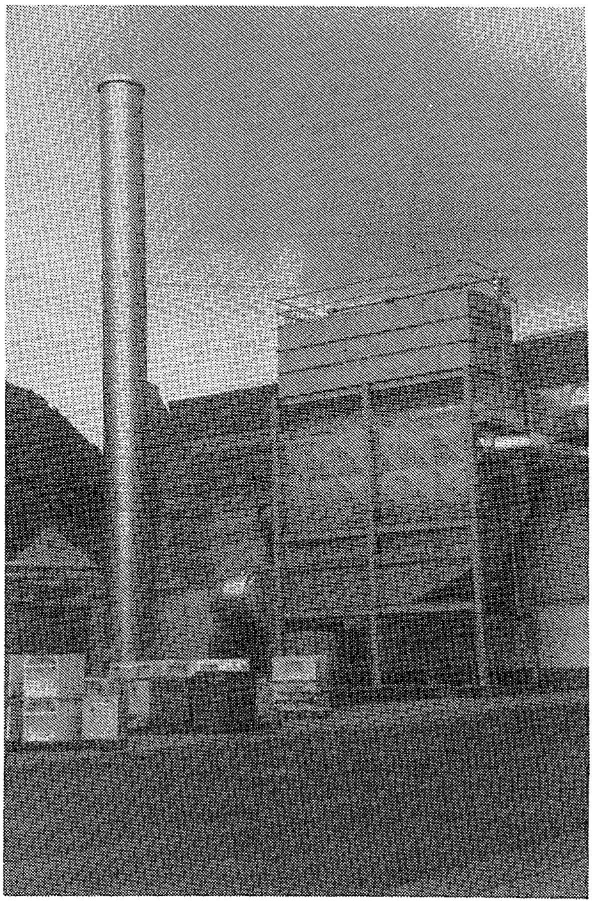
In principle the removal of solid particles by granular bed particles can take place either in a fixed bed; a moving bed; or in a bed carried by the gas stream (turbulent bed).

Corresponding to this three different types of granular bed filters can be distinguished.

Particle removal in granular beds

The removal of particles in granular beds is a complicated process depending on numerous influencing variables. In an unloaded granular bed the removal of solid particles takes place first of all inside the bed on individual granules. In this case the particles have to be transported by special mechanisms to the surface of the separation particles and retained there by adhesion. This process is basically the same as with storage filters, the difference being higher packing densities in the granular bed, i.e. smaller distances between the removing particles.

As a result of the settling of the dust particles, dust layers are formed on the granules of the bed, which leads to an improvement in the adhesive conditions and thus to a higher degree of separation. In a fixed granular bed the empty spaces between the granules gradually clog up as filtration progresses. The removal location of the particles shifts more and more from the inside of the granular bed to the surface. Even a dust cake can form on the surface. If the granular bed continues to be loaded, then the degree of removal will diminish. After exceeding a critical load, or a critical



pressure loss, flow channels are formed through which dust particles can pass directly to the clean gas side.

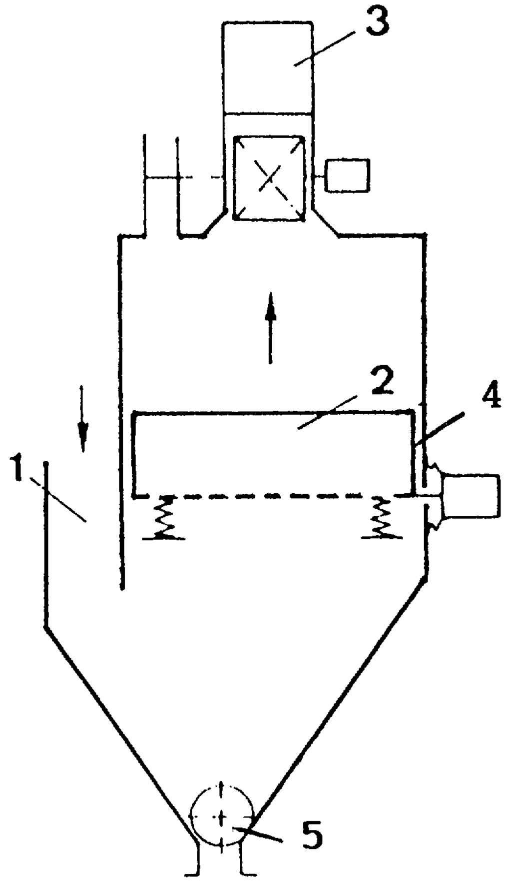
The situation is different in the case of moving or turbulent granular bed filters. Because of the continuous movement it is impossible for a dust cake to form. The removal mainly takes place directly on the granular bed particles. Because of the friction between the granules in the moving bed or because of the particle collisions in the turbulent bed, particles already removed can, to a certain extent, again become detached and can reach the clean gas.

Functioning of a plant

In the following the functioning of a granular bed filter installation is described. There is a distinction between granular bed filters with a fixed bed and those with a moving bed.

The construction of a fixed granular bed filter is shown in figure 1. The gas stream loaded with dust particles enters the filter by the crude gas inlet (1) and is guided through the granular bed situated in filter trays (2). In passing through the porous granular bed the dust particles are removed. According to the dust concentration and the porosity of the bed, the removal takes place either inside the bed or on the surface. In the case of very high crude gas concentrations even dust cakes can form. The cleaned gas leaves the filter by the clean gas channel (3). The filter trays provided with a sieve floor (4) are installed in several rows next to each other or—in the case of multi-stage plants—also on top of each other thus forming a filter chamber. Often several filter chambers are installed in parallel and commonly operated as one filter installation. This multi-chamber construction corresponds to that of bag filter or pocket filter installations. In the bottom of the filter casing a feed screw (5) is installed to transport the filtrate to the outside.

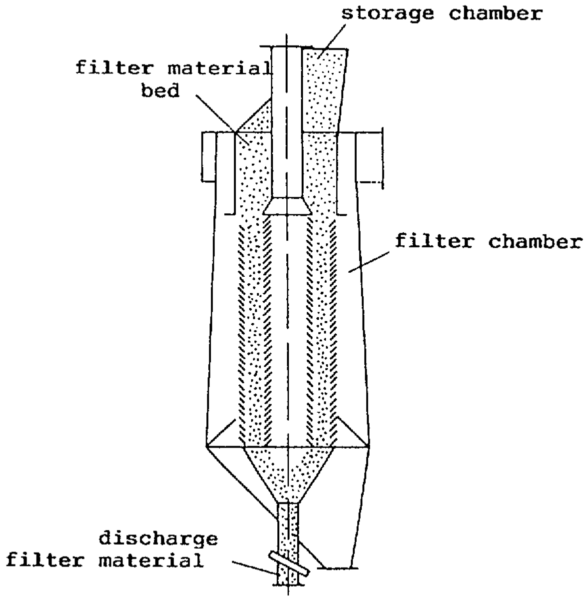
Figure 1. Fixed granular bed filter



As the removed particles become embedded in the granular bed, pressure loss increases during the filtration phase. After reaching a permitted maximum pressure loss, the granular beds have to be cleaned. This process repeats itself at certain intervals. In many granular bed filters it is still necessary to cut off the filter chamber to be cleaned from the crude gas stream. The cleaning of the filter bed is, however, carried out in most cases within the filter chamber by using backflowing scavenging air. The cleaning process is mostly supported by a mechanical loosening of the granular bed (e.g. by rotating rakes or vibration of the filter trays). When using this type of construction several filter chambers have to be installed in parallel in order to maintain a continuous filtration operation. These individual filter chambers are then regenerated in rotation.

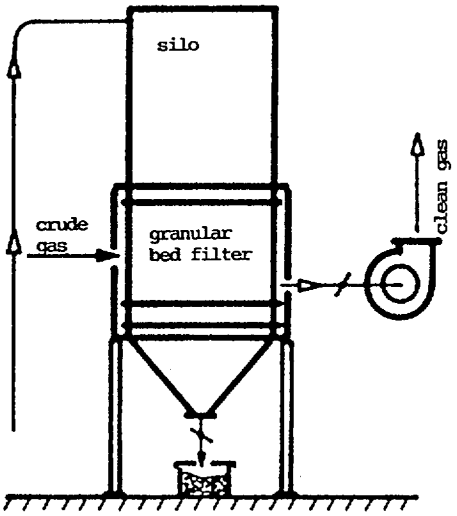
Besides these batch-type constructions also continuously working granular bed filters also exist (see figures 2-3), where the filter bed moves steadily through the filter chamber. During operation new packed bed granules are steadily added from a storage chamber. The used material is taken out at the bottom of the filter. The regeneration of the granular bed material takes place outside the apparatus. Because of this external regeneration a multi-chamber construction is not necessary.

Figure 2. Moving granular bed filter

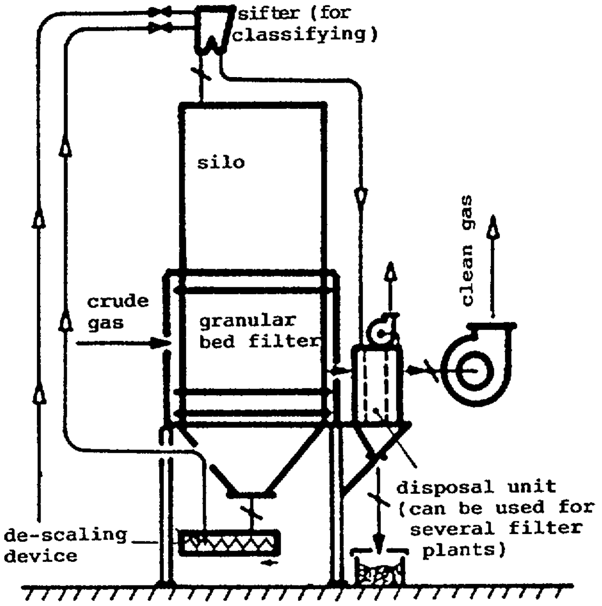


In principle, dust particles can also be removed in a turbulent bed where particles are carried along by the gas stream. However this process is hardly used nowadays on an industrial scale.

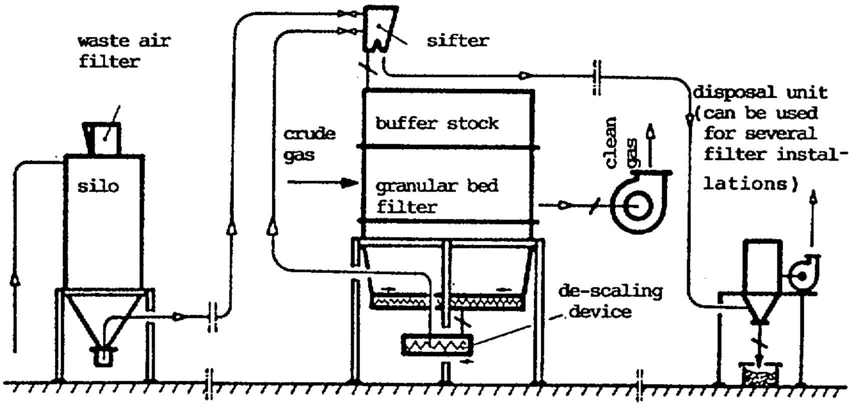
Figure 3. Example of different granular bed filter construction



A. Waste gas amounts up to approx. 100 000 m³/h in one unit, hydrogen fluoride contents up to approx. 50 mg/Nm³



B. Waste gas amounts up to approx. 60 000 m³/h in one unit with limestone gravel de-scaling, hydrogen fluoride contents > approx. 50 mg/Nm³



C. Waste gas amounts up to approx. 100 000 m³/h in one unit with separate silo and limestone gravel de-scaling, hydrogen fluoride contents > approx. 50 mg/Nm³

Dimensioning

The following technical details are necessary for the dimensioning of a granular bed filter:

Type of furnace: tunnel kiln, shuttle kiln
Type of fuel: gas, oil, etc.
Amount of waste gas, minimum and maximum, in m_n^3/h
Temperatures, minimum and maximum
Water content of the waste gases in g/m_n^3
HF content in mg/m_n^3
SO_3 and SO_2 content in mg/m_n^3
HCl content in mg/m_n^3
O_2 content in % of volume
Desired guarantees.

Necessary characteristics of the sorbent:

Share of $CaCO_3$	< 96% in mass
Amorphous part approx.	70%
H_2O content	< 0.5%
Average granule diameter approx.	3 mm
Share of granules under 2 mm	< 5%

Construction and function of a plant

A granular bed filter installation is described as used in the ceramics industry for the removal of fluorine from flue gases (chemical sorption).

Figure 4 shows a schematic representation of a granular bed filter installation in operation with the following design data:

Flue gas volume	100000 m^3/h at 150 °C
Flue gas temperature	up to 350 °C
HF content of untreated gas	≤ 100 mg/m^3
Fluorine content in the clean gas	< 5 mg/m^3_n for 3% CO_2
Dust content in the clean gas	< 50 mg/m^3_n
Filter area	20 m^2
Granular bed thickness	180 mm

The kiln off-gases are diverted after the kiln fans into a common pipeline to the sorption filter. Fluorine sorption takes place inside the filter, as the gas flows through a number of granular bed layers consisting of a limestone material ($CaCO_3$). After passing through the filter, the flue gases are conducted via a fan to a 25 m high steel chimney stack and discharged into the atmosphere. The necessary volume flow control is done by a valve providing a constant over-pressure at a suitable point in the flue gas flow before the filter.

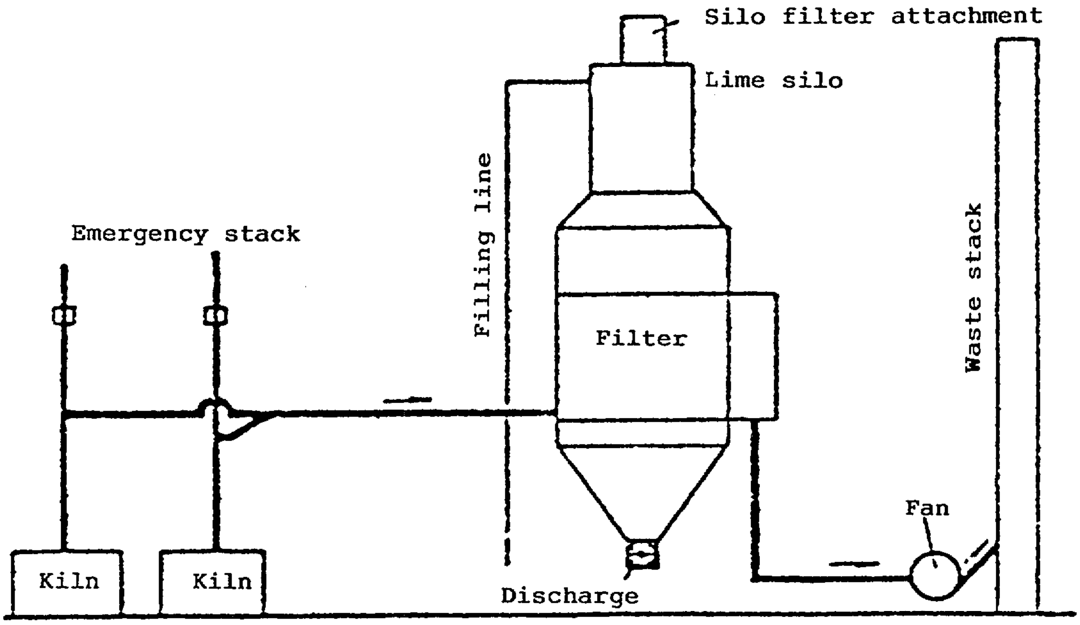
The sorption filter employed is a granular bed filter with limestone storage hopper. The four individual granular bed layers are arranged vertically. They are bounded by gas-permeable separating walls. The filter is supplied with fresh limestone material from a storage hopper which is mounted above the filter. The hourly lime consumption amounts to 4 kg. The used sorption material is passed via a feed screw and a discharge device into a de-scaling screw conveyor or immediately into a container.

The limestone silo is supplied with milled limestone from a silo transporter. To the fresh limestone re-activated limestone is added coming from a de-scaling device situated under the discharge of the filter. The de-scaling device consists of a de-scaling screw conveyor inside a slightly inclined steel cylinder. As the screw conveyor revolves, it moves the granules about. The friction created by the granules being rubbed against each other leads to the abrasion of their used surfaces enabling the residual grain to be re-activated and rendered ready for re-use.

From the de-scaling device the particles and the dust are pneumatically lifted into a sifter on top of the silo, where the two materials are separated. The reusable residual granules (> 3 mm) are returned to the silo, while the dust produced in de-scaling is conveyed to a disposal station and discharged at regular intervals into a container.

The level of the granular material in the silo is regulated by a level control unit. From the silo the granules slide down into the filter shafts automatically. This movement takes place each time the pneumatically controlled moving grates under the filter are opened.

Figure 4. Design of a granular bed filter installation



This is in most cases controlled by a time switch, whereby the intervals are determined by experience, and then corrected by results from samples taken from time to time from the clean gas stream. For economic reasons (high price of measuring instrument) there are only very few cases where the movement is controlled by a measuring device in the clean gas channel.

The system is designed for an untreated gas volume of 10000 m^3_n/h.

Capital and running costs

Capital cost ($)	
(a) Plant	115,000
(b) Erection	12,500
(c) Connection services	12,500
Total	140,000
Running costs ($/a)	
(a) Electricity	2,800
(b) Maintenance	1,500
(c) Sorption medium	900
Total	5,200

Production of a granular bed filter

Granular bed filters are usually not the only product manufactured by a firm, but one of several. That is why it is rather difficult to give precise figures on the production of granular bed filters.

For the production of granular bed filters or of a granular bed filter installation it is important to estimate production requirements and the existing production possibilities for the manufacturing of different components. For economic reasons it is recommended that individual components, necessary for the production of a complete installation, be ordered from outside firms. It is even possible to limit the production entirely to the manufacture of the granular material.

If a firm wants to produce a complete filter installation itself, it has to have possibilities for the machining of steel plates and pipes.

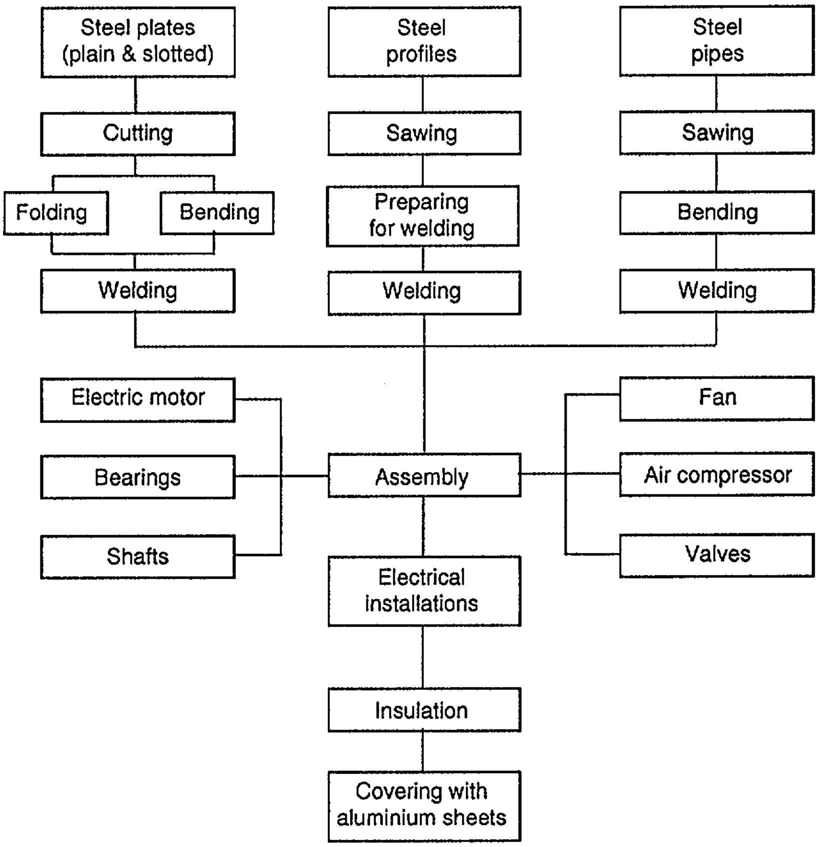
The steel plates, ordered from outside, are cut by a plate shearing machine to the necessary shapes and sizes. The plate pieces are, when necessary, folded to serve as outside sheets for the filter casing, as limestone silo, as collecting hopper or as gas channels. They are bent into curved shapes to form the limestone de-scaling cylinder or the pipes for the crude or clean gas. These elements are welded together to transportable units.

The slotted steel plates, ordered from outside, are cut to size by a plate shearing machine; they are used as gas-permeable separating walls, forming the granular bed shafts.

Parallel to this, rolled steel sections for the supporting framework as well as for strengthening the filter casing are sawn to length, prepared for joining and welded together into transportable units.

The final assembly takes place at the site. After completion, the outside of the filter installation is painted to protect it from corrosion, then insulated with mineral wool against heat loss in order to prevent a temperature drop of below the point of condensation. The insulated filter is finally enclosed by aluminium metal sheets for water protection and better appearance.

Figure 5. Flow chart



Example of a production plant

The following data are based on the assumption that a firm only produces granular bed filters at a certain time. For the production and assembly of one medium-sized granular bed filter installation of the type shown earlier, five workers will need approximately 1 week (1 shift operation). Including the limestone silo the complete installation has a height of 11 m, a depth of 3.5 m and a length of 5-6 m.

Required machinery and equipment

Description	*Pieces*
Plate shears	1
Folding machine	1
Bending machine	1
Metal saw	1
Drilling machine	1
Welding machine	2
Workbench (incl. hand tools)	3
Crane (5 tonne)	1
Fork lift truck (2 tonne)	1
FOB-price for machinery andequipment (1992) Approx. US$	150,000

Required personnel

Manager	1
Administration staff	1
Salesman	1
Works engineer	1
Skilled workers	3
Semi-skilled workers	2

Required area

	Square metres
Production hall	300
Storage	50
Facilities	30
Management and administration	40
Covered outside working area (5 m height)	50

Required energy

Electric power	75 kW

Required inputs

- Steel plates (3 mm)
- Slotted steel plates (3 mm)
- Steel profiles
- Steel pipes
  - for limestone transport
  - for compressed air
- Valves (snap valve, cylinder valve)
- Fan
- Welding material
- Granular material
- Shafts for de-scaling device
- Bearings for de-scaling device
- Air-compressor
- Electrical motor
- Aluminium plates
- Insulation material (100 mm mineral wool)
- Electrical equipment
- Primer
- Paint

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How to Start Manufacturing Industries

Thermal oxidation

Introduction

Depending on the kind of exhaust constituents a variety of processes exist to reduce the emission of air polluting substances. Basically a classification of the processes is made according to combustible and non-combustible exhaust constituents. Combustible (oxidizable) substances are compounds of the elements C, H, O and N, including organic matters, nuisant odours, and anorganic gases like carbon monoxide and ammonia. On the other hand the non-combustible substances include sulphur dioxide, nitrous oxides, halides and their derivates, and ash containing dust. Exhaust cleaning by thermal processing cannot be carried out for the non-combustibles and is of course limited if the exhaust contains constituents such as S, P, halides and dust. A classification of purification processes for combustible and non-combustible emissions is given by the following figure (figure 1).

Oxidizing processes reducing air polluting emissions

Flame oxidation

Flame oxidation is applicable when the energy content of the exhausts is sufficient so that the flame is burning without an additional burner. The reaction takes place in a very confined place at temperatures > 1200 °C. A difference is made between ground

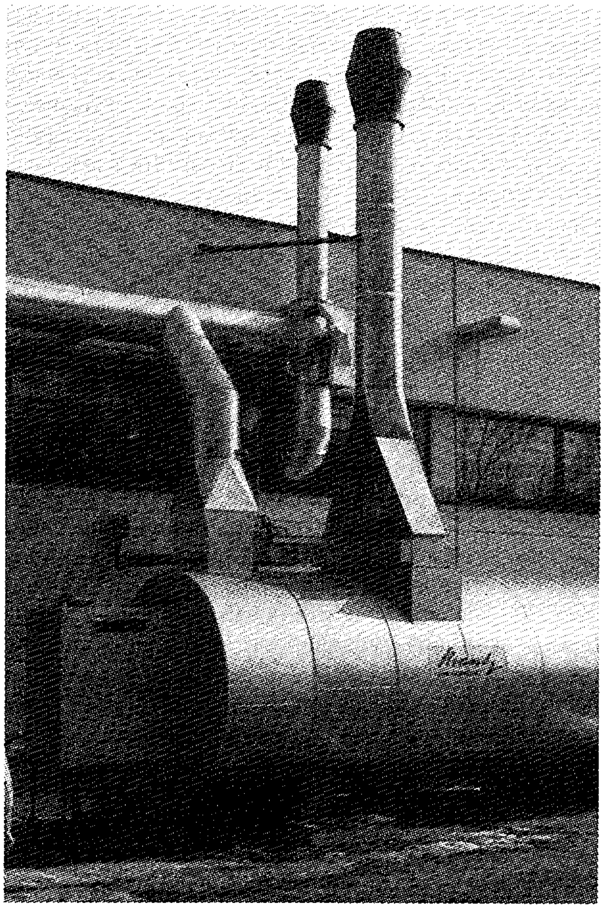
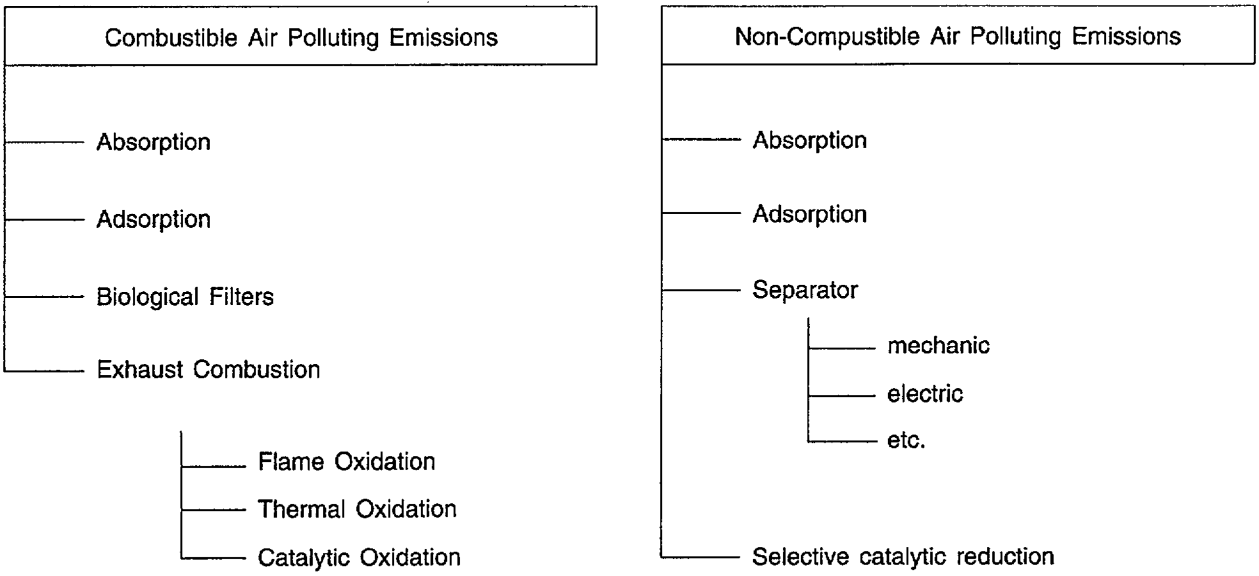


Figure 1. Classification of air purification processes



flares and high flares. The latter serve mainly for the combustion of oxygen free exhausts that arise from start-up and throttle processes, or in cases of process breakdowns when exhausts flow discontinuously. Flame oxidation is mainly applicable in the petrochemical industry.

Catalytic oxidation

In cases of high quantities of exhausts and low contents of organic constituents catalytic oxidation processes are applied, as well as in cases when specific heats of the constituents are too low and heat recovery is not planned. A substantial advantage of catalytic oxidation is the transformation of harmful substances into inert components. No secondary waste management problems arise from this purification process and energy costs and choice of construction material are a further advantage as well as the low temperature range (80-500 °C) in which reactions take place.

Thermal oxidation

Thermal oxidation is applied in many industry branches like petroleum, printing, food processing, the pharmaceutical industry, the chemical industry, and in synthetic material processing and metal processing. Thermal processing for exhaust purification operates within a temperature range between 600 °C and 1000 °C. The objective is to transform oxidizable pollutants, especially hydrocarbons, other hydrogen compounds and carbon monoxide, arising from industrial production by combustion without catalysator into non-polluting materials or into precipitable materials that can then be cleaned with a flue gas purification unit. Basically, thermal oxidation is applied when exhaust quantities are small with high concentrations of organic substances.

Universal applicability of thermal processing and almost complete transformation of air polluting substances into CO_2 and H_2O are to be faced by high energy costs of the thermal oxidation process. The costs arise due to high reaction temperatures which have to be supported and regulated by an additional burner and in cases when exhausts are poor on calorific value. The objective of the construction of thermal exhaust air cleaning units is to minimize size and heat loss—by integrating exhaust preheating and heat recovery with heat converters—in order to guarantee optimal conversion. Therefore optimization of thermal exhaust air cleaning units has the improvement of burning concepts and heat conversion concepts (approximately 38% of the investment costs) as its aim.

Process

Thermal exhaust air cleaning units consist principally of a burner system, a combustion chamber, and a heat converter for heat recovery and/or exhaust preheating (figure 2). Exhausts escaping, for example a coating unit, are transferred to the combustion chamber by an exhaust air fan guiding them along the tubes of the heat converter where hot cleaned exhaust coming from the combustion chamber transmit their heat in order to preheat the exhausts to be cleaned. The functions of the burner system are: the supply of as much heat energy as necessary to the preheated exhausts by fuel feeding in order to achieve the ignition temperature before entering the combustion chamber; the ignition of the exhaust-fuel-mixture; the regulation of the combustion chamber at constant temperatures; and the compensation of fluctuations in calorific power due to operating conditions. Leaving the burner system the exhaust-fuel-mixture is commonly accelerated by a venturi tube for intimate mixture.

In the combustion chamber the oxidation of hydrocarbons is given by the combustion equation for complete oxidation:

$$C_m H_n + (m + n/2)\ O_2 \rightarrow mCO_2 + n/4\ H_2O$$

Combustion equations for frequently occurring pollutants and corresponding nascent enthalpies are listed in table 1. In order to avoid incomplete combustion, which produces by-products such as carbon monoxide and formaldehyde, complete combustion is mainly dependent on the following:

The necessary oxygen quantity;

The combustion chamber final temperature;

The duration of the exhausts in the combustion chamber;

The flow conditions in the combustion chamber;

The ignitability of the fuel-exhaust-air-mixture;

The grading up and conversion of the fuel-exhaust-air-mixture;

The preheating of the exhausts up to ignition temperature.

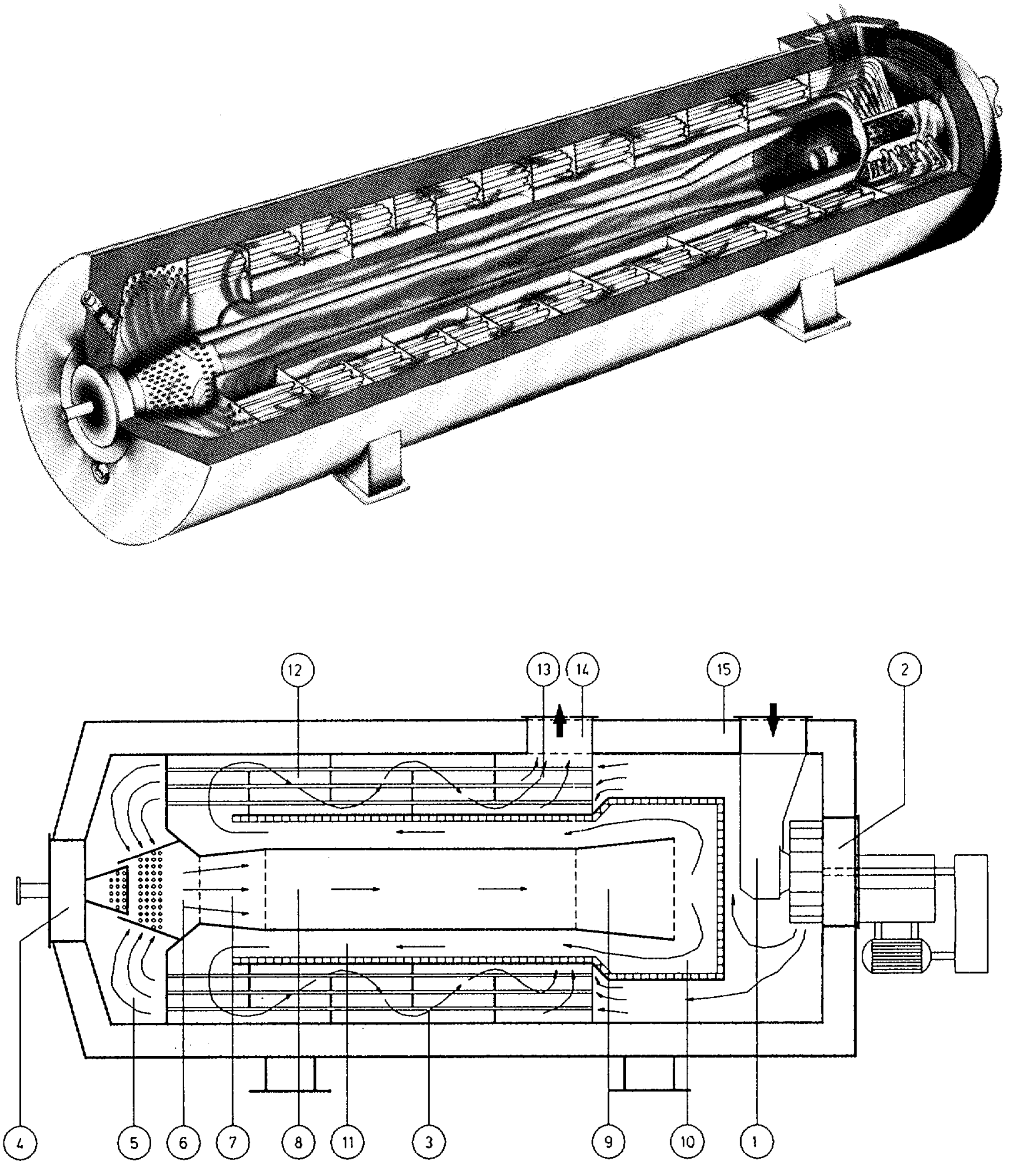
After leaving the combustion chamber the hot cleaned gases enter the tubes of the heat converter succeeded by the outlet where further purifying steps may follow.

The fields of application of thermal exhaust air cleaning processes for exhaust purification are listed in table 2. The table also provides information about additional fuels, exhaust volumes, temperatures at exhaust inlet, after-preheating and after-combustion as well as the minimization of pollutants.

Table 1. Combustion equations for frequently occurring pollutants

Compound	*Combustion equation*		*Calorific power H_{ncp} at 25 °C 1013 mbar kJ/mol*
Methane	$CH_4 + 2O_2$	$\rightarrow CO_2 + 2H_2O$	802.1
Benzol	$C_6H_6 + 7.5O_2$	$\rightarrow 6CO_2 + 3H_2O$	3167.9
Toluol	$C_7H_8 + 9O_2$	$\rightarrow 7CO_2 + 4H_2O$	3770.1
Methanol	$CH_3OH + 1.5O_2$	$\rightarrow CO_2 + 2H_2O$	675.8
Acetone	$C_3H_6O + 4O_2$	$\rightarrow 3CO_2 + 3H_2O$	1688.7
Acetaldehyde	$C_2H_4O + 2.5O_2$	$\rightarrow 2CO_2 + 2H_2O$	1104.0
Ammonia	$NH_3 + 0.75O_2$	$\rightarrow N + 1.5H_2O$	313.2
Hydrogen sulfide	$H_2S + 1.5O_2$	$\rightarrow SO_2 + H_2O$	523.6

Figure 2. Design and function of a thermal exhaust air cleaning system



1 Exhaust gas inlet with condensate evaporator
2 Integrated exhaust air fan
3 Straight tubes
4 Burner with conical front
5 Pre combustion chamber
6 Venturi inlet cone
7 Pressure recovery section
8 High velocity mixing tube
9 Pressure recovery section
10 Turbulence zone*
11 Final oxydation zone*
12 Cross counter flow heat-exchanger
13 Outlet collector
14 Exhaust outlet
15 Heat insulation

*covered with a ceramic fibrous coating

Table 2. Examples and results of measurement from ceramic insulated thermal exhaust air cleaning units

						Concentrations		
			Temperatures			*Carbon in combustion chamber*		
Pollutants and their origin	*Additional fuel*	*Exhaust Volume* m^3/h	*Inlet °C*	*After Preheating °C*	*Combustion °C*	*Inlet* mg/m^3	*Outlet* mg/m^3	*CO-Emission ppm*
Coating plant a) Ethylacetate b) Ethylglycol acetate	Nat. gas	17500	150	470	a) 755 b) 770	a) 5500 b) 5500	a) 3 b) <2	a) 300 b) 50
Acetone + Methanol + MEK	Nat. gas	5000	70	520 750	750	5600	5 <2	300 80
DOP (Softener) from drying channel	Nat. gas	19000	200	550	700 750	800 800	10 <2	200 35
Softener from drying channel	Propane	8000	160	510	745 760	1110 1110	3 <2	30 10
Firebrick prod. Tar vapours	Fuel oil	6000	200	450	740	500	15	250
Sludge Combustion Odours — CO	Fuel oil	7500	50	600	740 770	CO: 4200 C: 350	3 3	100 400
Offset printing Offset exhaust	Nat. gas	6000	160	420	700	2070	7	25
Formaldehyde CO Methanol	Nat. gas	24000	40	500	780	C: 4840 CO: 11700	68	<100
Solvent vapours	Sewer Gas	30000	120	450	780	8760	<5	70

Dimensioning of thermal exhaust air cleaning units

For the dimensioning of thermal exhaust air cleaning units several essential data treated below are required which will be taken up in the design example.

Production process producing exhausts. For optimal treatment of the exhausts the characteristics of the production process which creates the pollutant exhausts have to be well-known.

Exhaust gas quantity. The volume of arising exhausts decides essentially on the dimensions of additional burner, combustion chamber and heat converter.

Exhaust gas temperature. Experience show that the inlet temperatures of the exhausts are between 80 °C to 200 °C. The inlet temperature determines the necessary temperature increase of the fuel-exhaust-air-mixture by additional burner and heat converter.

Type and quantity of harmful substances. Type and quantity of harmful constituents in the exhausts determine first of all the selection between oxidizing or catalytic combustion. Furthermore, they determine the necessary combustion chamber final temperature, where all pollutants are converted to the largest extent into CO_2 and H_2O. The conversion sets free the enthalpies of the pollutants which leads to a temperature increase of:

$$\Delta t_{cp} = \frac{H_{ncp}}{C_{ash}}$$

H_{ncp} = net caloric power
C_{ash} = average specific heat

and represents an energy share to attain the final combustion chamber temperature. This has to be considered when determinating the exhaust preheating by additional burner and heat converter.

Other contamination. Dusts, fibres, halides and sulphur compounds lead to soiling and wearing of the surfaces of the heat converter and the mantle surfaces. Therefore soiling must be known and is to be taken into account by corresponding soiling factors when calculating the coefficient of heat transmission (which is needed for the calculation of the heat converter surface).

Relative moisture of the exhaust gas, underpressure at the exhaust suction point and stipulated exhaust purity. The required exhaust purity ensues from environmental regulations concerning the content of pollutants in cleaned exhausts that have to be taken into consideration when designing the unit. These regulations determine the minimum conversion of the pollutants into CO_2 and H_2O, and from that the combustion chamber final temperature.

Permissible noise level. Thermal exhaust air cleaning units are commonly isolated in order to reduce noise to attain the permissible level and to prevent heat loss.

Available operating media. Operating media would include: additional fuel; power supply; instrument air; steam; pressure air; and availability of the plant (e.g. coating unit).

Ignition temperature of the exhaust-additional fuel-air-mixture. The initiation of the combustion requires a certain minimum temperature to activate the fuel and oxygen molecules, called ignition temperature. Since the pollutant containing exhausts coming from the production plant enter the thermal exhaust air cleaning unit with temperatures between 80 °C and 200 °C they have to be heated up to their ignition temperature. This is done by indirect heat conversion and with additional burner systems. The ignition temperatures can be taken from literature about investigated triangular systems (pollutant-oxygen-nitrogen).

Combustion chamber final temperature. The combustion chamber final temperature (t_{ft}) consists of the following energy shares:

$$t_{ft} = t_{ie} + t_{hc} + t_{af} + t_{cp}$$

t_{ie}	Inlet temperature of the exhausts
Δt_{hc}	Temperature increase by heat converter
Δt_{af}	Temperature increase by additional fuel
Δt_{cp}	Temperature increase by net calorific power of the exhausts

Temperature increase by net calorific power and inlet temperature of the exhausts are largely determined, whereas the temperature increase by heat conversion and additional fuel are variable so that they can be tuned in order to ensure complete conversion of the pollutants. Facing raising energy costs exhausts should mainly be heated by heat converters so that additional burners only regulate and initiate the combustion process.

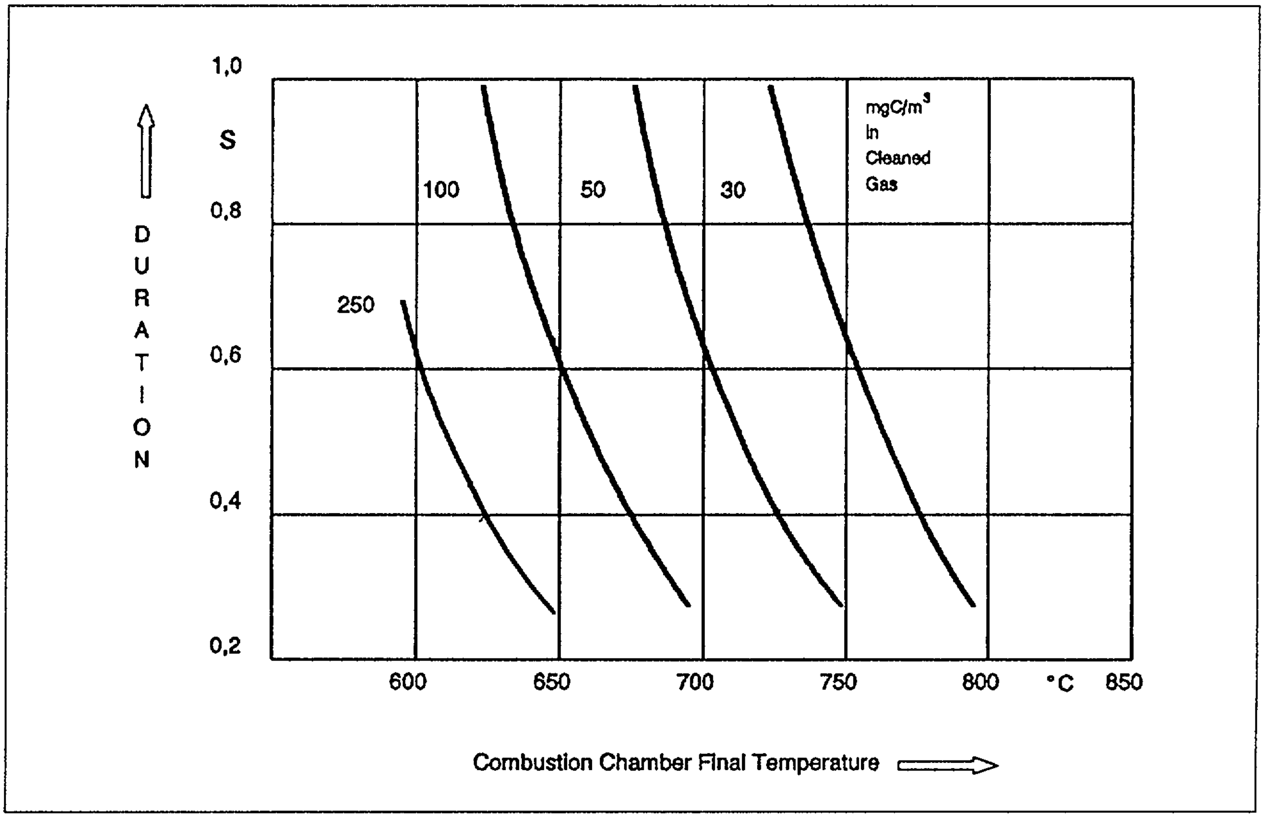
Duration of the exhaust-additional fuel-air-mixture in the combustion chamber. Conversion of the pollutants and their residual concentration depend on the final combustion chamber temperature and on the duration of the mixture in the combustion chamber. The duration (τ) is calculated with the following equation:

$$\tau = \frac{V_{cc}}{V_g}$$

V_{cc}	Volume of combustion chamber
V_g	Effective gas throughput

The higher the combustion chamber final temperature is the shorter can be the duration of the preheated mixture (figure 3). Since the effective gas throughput (V_g) and the necessary final combustion chamber temperature are known the duration determines then the size of the combustion chamber. At constant gas throughput (V_g) a longer duration requires a longer combustion chamber, which means higher investment costs; on the other hand a shorter duration requires a shorter combustion chamber but higher operating costs because of then necessary higher combustion temperatures. At sufficiently high temperatures and long duration every conversion rate of pollutants desired can be attained.

Figure 3. Residual concentration of organic carbon (at 2000 mgC/m³ in exhaust gas)



Capacity and layout of additional burner. Empirically, exhausts show strong fluctuations in their concentration of combustible pollutants, i.e. the calorific power of the exhausts vary considerably. Correspondingly, variability burner systems need a wide range of adjustment of about 1:20 (today 1:40 are realized) to adjust the temperature to the defined combustion chamber conditions. For interests of stable operating conditions, in most cases the capacity of additional burners cannot be throttled below 75-80% of their maximum capacity.

The necessary capacity of the additional burner is determined by the volume of exhausts arising from the production plant (V), the average specific calorific power of the exhausts (c_{pm}) and the temperature difference (Δt_{af}) necessary to heat the exhaust-additional fuel-air-mixture up to ignition temperature:

$$Q = V \times c_{pm} \times \Delta t_{af} \; [kJ / h]$$

The layout of the burner system results from conceptional requirements of the unit, depending on whether liquid and/or gaseous pollutants have to be combusted and whether liquid and/or gaseous additional fuel will be used. Therefore, the following burners can be distinguished:

Nozzle burner:	Commonly used for liquid additional fuels;
Binary mixture burner:	Commonly used for gaseous and liquid additional fuels;
Sheet burner:	Commonly used to reduce operating costs when the minimum oxygen content is not below 16%, the exhausts contain no solid particles and preferably natural gas is used as additional fuel. Modular construction of several sheet burners allows division of the overall capacity of the burner system into several segments, like start up burner, partial load burner, and full load burner for better adjustment to the operating conditions;
Return burner:	Commonly used when high combustion temperatures have to be attained within little space. For better thermal upgrading of the exhaust-additional fuel-air-mixture hot combustion gases from the combustion chamber are returned to the venturi pipe after passing the nozzle area;
Turbulence burner:	Commonly used when high turbulence of combustion air and intensive combustion is required with high specific charges (up to 21 × 10^6 kJ / m^3h) of the combustion chamber.

Coefficient of heat transmission and transmission surface. The layout of the heat converter is determined by the coefficient of heat transmission and resulting from that by the transmission surface. The coefficient of heat transmission (k) represents the heat transferred from the tube and mantle walls to the exhaust-additional fuel-air-mixture which basically depends on the surface heat transfer coefficients of the tube (a_1) and mantle (a_2) walls [kJ m^2 h °C] and with that from the flow conditions. The heat transmission resistance (s/λ) of the tube material (s = thickness of tube; λ = coefficient of thermal conductivity) has only little influence on the heat transmission. On the other hand fouling of both converter surface sides have to be taken into account by corresponding fouling factors (f_1; tubeside) and (f_2; wallside), so that the coefficient of heat transmission k is calculated with the following equation:

$$k = \frac{1}{\frac{1}{a_1} + \frac{1}{a_2} + \frac{s}{\lambda} + f_1 + f_2} \left[\frac{kJ}{m_2 \, h \, °C}\right]$$

The heat converter surface (A) then results from the latent heat (Q) out of the combustion, the coefficient of heat transmission (k) and the intended temperature increase by heat conversion (Δt_{hc}):

$$A = \frac{Q}{k \cdot \Delta t_{hc}} \; [m^2]$$

Dimensioning of the combustion chamber. Length and volume of the combustion chamber result from arising exhaust quantities and exhaust duration in the combustion chamber. To calculate the volume of the combustion chamber the effective gas throughput is multiplied with the duration. The length of the combustion chamber is then calculated by the ratio of the volume to the selected inside diameter of the combustion chamber. The ratio commonly used is ≈ 2.5 : 1. To resist the high thermal stress in many cases steel-mantles of combustion chambers are coated with ceramic materials which have to be treated very carefully and above all absolutely jointless in order to avoid condensation and corrosion.

Capacity of exhaust air fan. Operating costs of thermal exhaust air cleaning units are essentially dependent on the consumption of additional fuel and on power consumption by the exhaust air fan. The power consumption of the exhaust air fan results from the exhaust quantity to be transported and from overcoming the loss of pressure. The total loss of pressure (Δp) consists of:

Underpressure at the exhaust suction point;
Pressure loss in the tubes and armatures;
Pressure loss in the combustion chamber;
Pressure loss in the heat converter.

The capacity of the exhaust air fan is calculated as follows:

$$N = \frac{V \cdot \Delta p}{\eta} \; [KW]$$

V volume of gas arising from production plant
Δp total pressure loss
μ efficiency of exhaust air fan

Design example

With this example the most important steps of dimensioning shall be explained.

Production process: paper coating
Exhaust gas quantity: 22.000 m^3/h
Exhaust gas temperature: 120 °C
Type and quantity of
harmful substances:
Ethyl acetate $C_4H_8O_2$ 6g/m^3
Methyl ethyl ketone C_4H_8O 7g/m^3
Toluol C_7H_8 4g/m^3
Total concentration 17g/m^3
Other contamination: paper dust

Relative moisture of the exhaust gas: 55% at 55 °C

Underpressure on the suction point: 60 mm column of water

Stipulated exhaust purity:
Ethyl acetate 300 mg/m^3
Methyl ethyl ketone 300 mg/m^3
Toluol 150 mg/m^3
CO 1000 mg/m^3; with natural gas as supplement fuel 1250 mg/m^3

Admissible noise level: 45 dB A

Available operating media:
Additional fuel natural gas; H_{ncp} = 35196 kJ/m^3; pressure = 3 bar
Power supply 220 V; 50 Hz
Instrument air 3 bar; dew point–30 °C
Steam 4.5 bar, 150 °C
Pressure air 10 bar; 150 °C
Availability of the production plant abt. 6000 working hours p.a.

Ignition temperature: t_i = 450 °C

Combustion chamber final temperature: t_{ft} = 900 °C (1173 K)

Duration: τ = 0.6 sec

Calorific power per standard cubic metre:
Ethyl acetate $6 \cdot 10^{-3}$ kg/m^3 × 24218 kJ/kg = 145.31 kJ/m^3
Methyl ethyl ketone $7 \cdot 10^{-3}$ kg/m^3 × 31928 kJ/kg = 223.49 kJ/m^3
Toluol $4 \cdot 10^{-3}$ kg/m^3 × 40978 kJ/kg = 163.91 kJ/m^3
Total net calorific power H_{ncp} = 532.71 kJ/m^3

Temperature Δt_{cp} by total net calorific power H_{ncp}:

$$\Delta t_{cp} = \frac{H_{ncp}}{C_{ash}} = \frac{532.62 \ \frac{kJ}{m^3}}{1.4 \ \frac{kJ}{m^3 \cdot °C}} = 380.66\ °C$$

H_{ncp}...net calorific power; c_{ash}...average specific heat

Temperature increase by heat converter:

$$\Delta t_{hc} = t_{ft} - \Delta t_{cp} = 519\ °C$$

Considering the temperature of the exhaust gases of 120 °C due to fabrication (Δt_{hc}) results in:

$$\Delta t_{hc} = 519\ °C - 120\ °C = 399.34 °C$$

For reasons of safe operation the additional gas burner should be proportioned this way that its power amounts to at least about 5% of the latent exhaust gas heat. This is equivalent to a temperature increase by the additional gas burner of Δt_{af} = 20 °C. Therefore the heat converter is to be laid out for an initial heating by:

$$\Delta t_{hc} = 399.34\ °C - 20\ °C = 379.34\ °C$$

At this temperature (379.34 °C) the following quantity of heat (Q) has to be transmitted:

$$Q = 22000\ m^3/h \times 1.4\ kJ/m^3 \cdot °C \times 379.34\ °C = 11.69 \cdot 10^6\ kJ/h$$

Capacity of the additional gas burner:

In order to attain a temperature increase of Δt_{af} = 20 °C the additional gas burner has to show the following power or to transmit the quantity of heat (Q):

$$Q = 22000\ m^3/h \times 1.4\ kJ/m^3 \cdot °C \times 20\ °C = 0.62 \cdot 10^6\ kJ/h$$

Dimensioning of heat converter:

As coefficient of heat transmission k = 104.75 kJ/m^3 · h · °C forms the basis. The transmission surface of the heat converter results in:

$$A = \frac{Q_{hc}}{k \cdot (\Delta t_{cp} + Dt_{af})} = \frac{11.69 \cdot 10^8\ kJ \cdot m^2 \cdot h \cdot °C}{h \cdot 104.75\ kJ \cdot 400.66\ °C} = 278.54\ m^2$$

Dimensioning of combustion chamber:

Effective gas throughput:

$$V_{eff} = \frac{22000\ m^3 \cdot 1173\ K \cdot h}{h \cdot 273\ K \cdot 3600\ sec} = 26.26\ \frac{m^3}{sec}$$

Required combustion chamber volume:

$$V_{cc} = V_{eff} \cdot Duration = 26.26\ \frac{m^3}{sec} \cdot 0.6\ sec = 15.76\ m^3$$

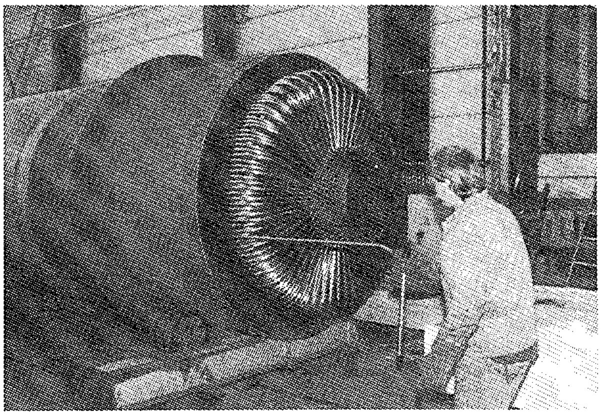
At a chosen inside diameter of 1.50 m the combustion chamber volume results in a combustion chamber length L_{cc} of:

$$L_{cc} = \frac{15.73\ m^3}{1.88\ m^3} = 6.69\ m$$

If the heat converter consists of single tubes, through which the exhaust gases are lead, with a diameter of 2 cm per tube and 7.19 m length (6.69 m + 0.5 m for the bend, see figure 4) it comes to the following number of heat converter tubes:

$$\frac{A_{hc}}{A_t} = \frac{278.54\ m^2}{7.19\ m \cdot 0.0314\ m^2} = 1233.13 = 1234\ tubes$$

Figure 4. Thermal exhaust air cleaning unit in construction; bended tubes can be seen



Exhaust air fan capacity

If the basis of the total pressure loss for the projected plant is Δp = 600 mm water column, an intake temperature of 120 °C, an efficiency of = 65% and a torsional moment of 102 mkp it comes to the following:

$$N = \frac{V\ (\frac{m^3}{sec}) \cdot \Delta p\ (\frac{kp}{m^2})}{\eta} =$$

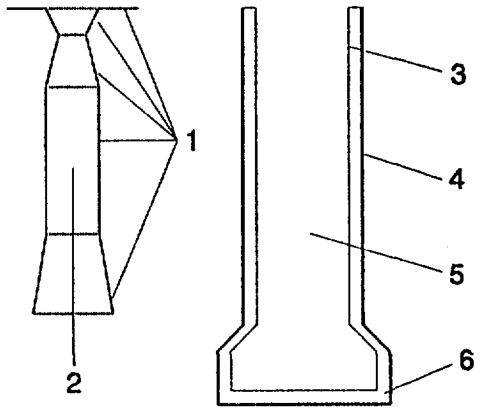
$$\frac{22000\ m3 \cdot 393\ K \cdot 0.06 \cdot 104\ kp \cdot sec \cdot KW}{3600\ sec \cdot 273 \cdot 102\ MKP \cdot 0.65} = 79.6\ KW$$

Description of the production process

The assembly of the single components begins with the inner components followed by the outer components. Manufacturing precision is necessary to avoid high tension and shearing forces which could then arise at operation and lead to disruption of the whole thermal exhaust air cleaning unit. It has to be considered that all parts expand by volume and longitudinal direction. Starting-up operation causes first an expansion of the combustion chamber and the heat converter tubes in longitudinal direction and second an expansion of the whole unit by volume. From that combustion tube, combustion chamber and heat converter tubes have to be supported in a way that they can move in any direction. The stand surfaces of the whole unit is conceived to avoid tension by having one stand fixed and one stand that allows sliding/expansion in all directions.

The description of the assembly relates to the sketches in figures 2, 5 and 6. Before assembling, components like the combustion chamber and tube (figure 5) and burner can be build first. The burner consists of a socket of firebricks with inlets for additional fuel, start-up flame and infrared sensor, on which a mixing cone is mounted. For the cone, a steel plate with drilled holes is formed to a cone whose wider opening shows in the direction of the combustion tube. Before forming, holes having different diameters are drilled with a NC machine. The allocation and the different diameters of the holes are important for the flow conditions in the cone, the combustion characteristic of the flame, and for the feeding of the flame with additional fuel and preheated exhaust gas. This demands high standards in conception and construction of the burner unit and requires extensive investigations.

Figure 5. Combustion chamber

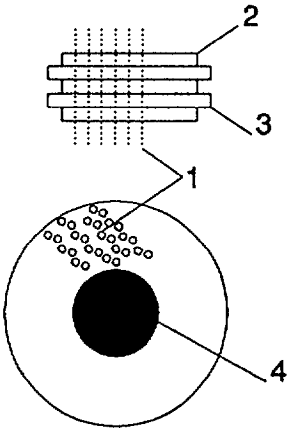


1 Segments of combustion tube
2 Combustion tube
3 Inner wall
4 Outer wall of combustion chamber
5 Combustion chamber
6 Ceramic fibre wool coating

Assembly after projecting and construction by CAD

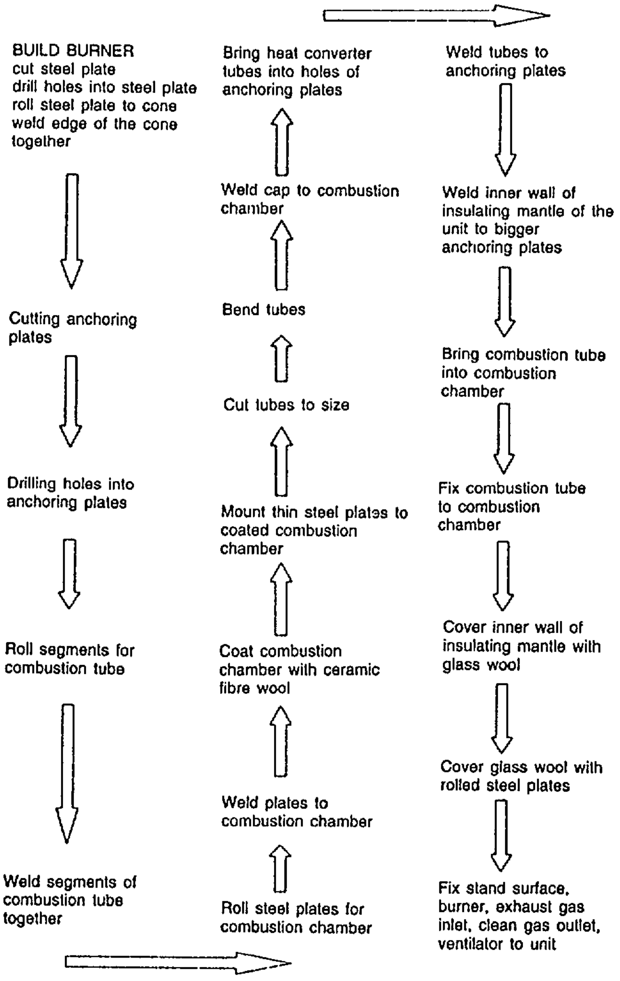
First the outer mantle of the combustion chamber (figure 5) is welded together with single rolled steel plates. Subsequently, the single anchoring plates (figures 2 and 6), for the heat converter tubes, are cut out of steel plates with the plasma cutting machine, with smaller diameters fitting to the combustion chambers outer diameter and with bigger diameters fitting to inner diameter of the insulating mantle of the unit. Out of these plates, openings are cut which fit to the diameters of the circumference of the combustion chamber and bigger openings for those anchoring plates on which the inner side of the insulating mantle is welded. After fixing the plates together (figure 6), to prevent them slipping, the holes for the heat converter tubes are drilled with the NC machine. Subsequently the anchoring plates are pushed onto the combustion chamber, aligned and fixed to avoid slipping. For exact alignment adapting tubes are brought into the holes to guarantee later true alignment of the heat converter tubes. After aligning the anchoring plates are welded to the outer mantle of the combustion chamber. Around this arrangement the inner wall of the insulating mantle of the thermal exhaust air cleaning unit is welded to the anchoring plates with bigger diameter segment-wise. The segments are made of rolled steel plates. The next step is the coating of the combustion chamber with ceramic fibre wool on which again rolled thin steel plates are mounted. Subsequently the combustion tube, welded together from five segments (see figure 5), is brought into the combustion chamber and fixed to it with movable suspension points. After truing the combustion tube, the end of the still open combustion chamber is closed by welding a cap with the same sequence (steel plate-ceramic fibre coating-thin steel plate) as the combustion chamber mantle to the end of the combustion chamber. The heat converter tubes are then cut to size and exactly bent to compensate for heat expansion. After bringing the tubes into the holes of the anchoring plates, they are welded to the anchoring plate of the combustion tube and on the opposite side to the anchoring plate on the combustion chamber end side. This is followed by covering the inner wall of the insulating mantle of the thermal exhaust air cleaning unit with glass wool. The glass wool is then covered segment-wise by rolled steel plates. At the end of the assembly, the stand surfaces, the burner, the exhaust gas inlet, the clean gas outlet and the ventilator are fixed to the unit.

Figure 6. Anchoring plate



1 Drilled holes for heat converter tubes
2 Smaller anchoring plates
3 Bigger anchoring plates
4 Openings

Figure 7. Flow chart of assembly for a thermal exhaust air cleaning unit



Example of Production Facilities

The manufacturing of plants for thermal exhaust air cleaning requires, besides from expertise, a series of tools and machines, as well as thoroughly trained personnel. The manufacturing of a plant, as calculated in the example, takes about five months to build.

Required machinery and equipment

Description	*Pieces*
Welding equipment for Ni-steel	1
Plasma cutting machine	1
Rolling mills for circular shapes	2
Crane with a lifting power up to 70 tonnes	1
Rubber-tired auxiliary gun carriages for heavy pieces	4
Electric drill table	1
NC machine	1
Personal computer with CAD software	1

Necessary tools, equipment and machinery are available in the simplest version for approx. US$ 500,000 (1993 prices)

Required manpower

Managers	2
Engineers	10
Welders (Ni-steel specialized)	3
Skilled locksmiths	3

Required area

	Square metres
Production area	500
Storage capacity	150
Recreation area, WC, washing facilities	40
Office space, managers	30
Office space, engineers	100

Required power and utilities

Electric power	100 KW
Pressure air	
Welding gas	

Required material

Ni-Steel plates 1-10 mm, hexagon screws M10, infrared thermo-sensors, thermo-regulators, pressure regulators, compression supervisor, insulating material, ceramic fibrous coating, exhaust air fans.

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Processing of filter and flue dust

Introduction

Filter and flue dust occurs in industry in large amounts; their substance matter is, however, different, depending on their origin. A large part of the filter dust creates no problems from an environmental point of view: this part can be immediately, i.e. in the same firm, either re-used, led to other employment possibilities or dumped. Examples of this are dust filtered from the air of work-rooms or halls, or filtered from machines like mills, grinding machines or others.

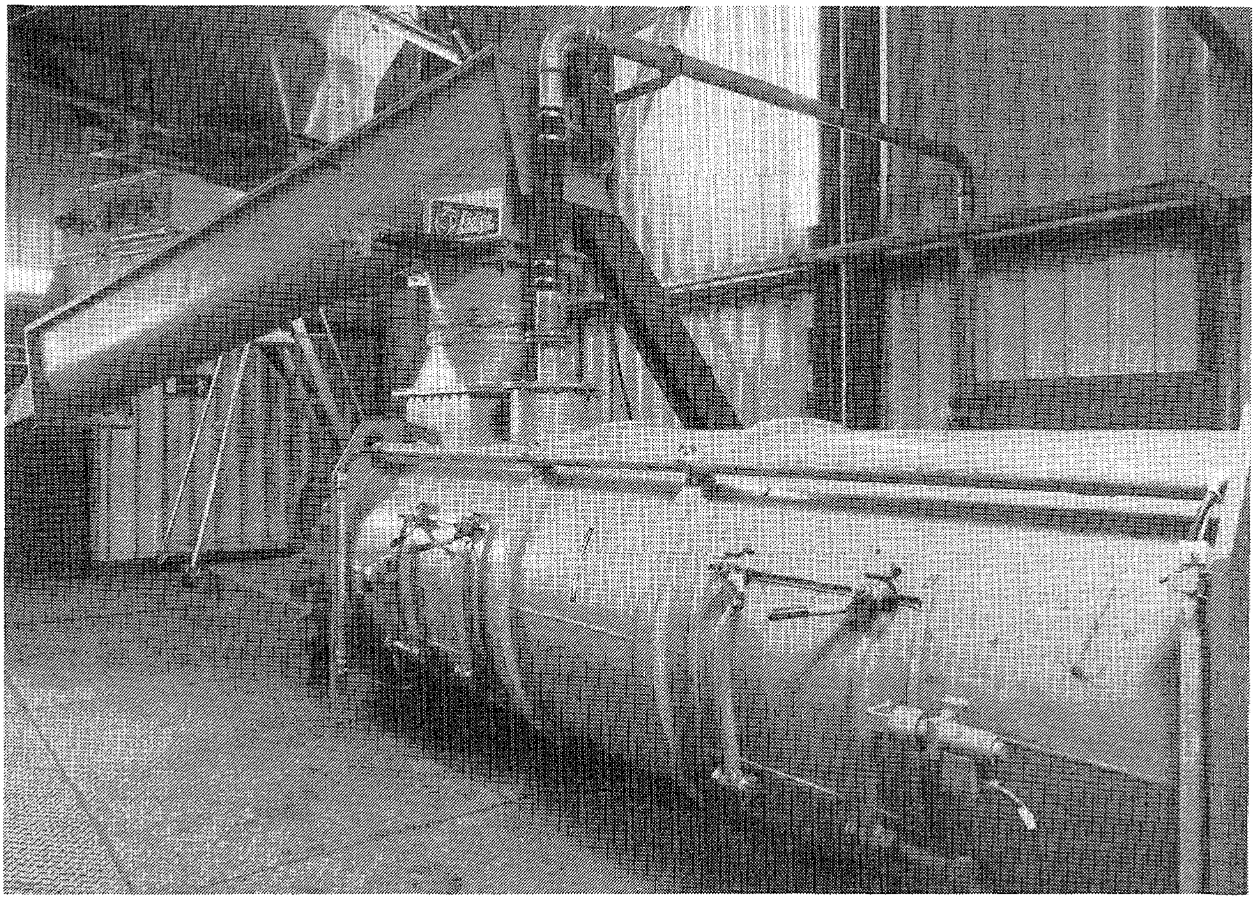
Flue dust from combustion is a greater problem, as—even in the case of optimal process control—residue concentrations of harmful substances could remain in the dust which would then have to be reduced or rendered harmless by certain techniques.

Flue dust from refuse incineration plants is a special problem as it contains (besides metallic oxides, silicates and salts) mainly heavy metals like cadmium and lead for example. Dumping without a corresponding treatment can lead to contamination of the ground-water.

In the following, only flue dust from combustion plants is considered and, first, fly ash from the dry combustion of coal-fired power stations. This fly ash can, for the greater part, be used after relevant processing (see table 1). The concrete and building material industry represents the main area of employment.

Table 1. Possible applications of fly ash

Industry/product	*Application of fly ash*
Concrete and building	Additive
Cement	Additive, raw material
Mortar, plaster	Additive
Bricks	Grogging of rich clay
Aerated concrete	Partial replacement of quartz sand (lightweight aggregate, colouring
Lime sand brick	Purposeful colouring
Road building material	Bank building, production of hydraulicly bound base courses (up to 50% of the sand)



Industry/product	*Application of fly ash*
Road building material *(continued)*	Filler in bituminous layers, replacement of stone chips or pebbles
Landscaping	Soil improvement
Earthmoving	Filling material (for noise protection dams, around buildings, for pipe ditches)
Mining mortar	Additive

Basic processing procedures

Filter and flue dust is defined as fine grained solid particles with the main grain spectrum between 1-100 µm. Into this category falls mainly fly ash from coal-fired power stations and from refuse incineration plants, in as far as it is separated immediately behind the boiler and before entering the absorber.

Flue dust is a grey material in powder form, mainly consisting of little glass balls, of which silicon oxide and aluminium oxide are the main components. Regarding heavy metals only chromium has to be mentioned.

In order to be safely deposited or further used, the harmful substances must be permanently and safely bonded in a stabilizing agent. This stabilization should prevent the extraction of the harmful substances by water.

There are three process alternatives for stabilizing: melting down; pelletizing; and consolidation by adding a binding agent.

Only the last process fulfils most of today's environmental regulations; the melting down process leaves the problem of water-soluble substances, and the pellets formed at low temperatures can easily be eluted.

Consolidation is a chemo-physical treatment with the aim of bonding the harmful substances left in the remaining material, so as to immobilize them as much as possible. Four reaction mechanisms occur:

Chemical or mineral bonding or conversion of the harmful substances respectively;

Diminishing the solubility, e.g. by adjusting the pH-value;

Adsorption of harmful substances, dissolved in the interstitial water, on the surface of the solid material or on the binding agent;

Physical bonding into a fixed, hardly permeable matrix.

In consolidating fly ash, mainly the physical bonding of the harmful substances takes place. After setting, through mixing with water and having added binding agents (mostly lime), a mechanically stable monolithic body with only a slight water permeability arises from the remaining powdery material.

If consolidation is done with cement as a binding agent, the high content of chlorides (4-8%) interferes with the binding process in the case of fly ash, which makes one of two alternative measures necessary: either an increased input of binding agents to reach a satisfactory immobilization; or a washing with washing water from the flue gas washing process (metals are dissolved because of the low pH-value).

Besides cement (adding 5-30% by weight) also additives like sodium sulfide (Na_2S up to 2%) and calcium hydroxide (up to 4%) can be used; the amount of water needed is 20-25%.

A new development is the use of the wet-dry product coming from the wet-dry lime-based absorption process, an alternative to the wet flue gas desulphurization process. This wet-dry product, obtained after a significant pre-collection of the fly ash from the gas before it enters the reactor, can take the place of cement in mixing with and activation of pozzolanic fly ash.

The material is produced with well defined strength properties and develops into a chemically inert material. It is weather resistant with regard to water and also has freeze-thaw properties. The material's significant environmental properties cover very low permeabilities as well as a high buffering capacity for acid and low release rates for chlorides. An optimum mixing ratio is approx. 2 parts of fly ash to 1 part of wet-dry product. The end-product is called "stabilisate" and is used for landscaping, road construction and structural filling.

Other product properties can be obtained by adding cement, which involves, however, a higher proportion of fly ash. With the properties then reached, the mixture can be used for the production of a structural filling material (containing small quantities of various surface-active agents), for the production of bricks or of concrete (containing also aggregate/ground silica sand).

Fly ash from coal has a high content of vitreous components. The pozzolaneous reactions, which lead to the formation of stable mineral phases and by this to a consolidated product, are introduced by stimulation with calcium oxide or by adding water. The amorphous components, consisting of silicic acid and alumina, react to consolidating calcium silicate and calcium aluminate hydrate. The crystalline components do not take part in the reaction.

Flue dust treatment

One type of flue dust treatment is the consolidation of the dust in a cylindrical mixer. The dry flue dust, coming from the electrical precipitator either directly at approx. 250 °C or via a bunker, enters the cylindrical mixer through a connection piece, situated on one end of the cylinder at the top. The binding agent, coming from a separate bunker, is added through the same piece. As flue dust and binding agent have to be kept at a certain ratio to each other, both material streams pass over separate belt weighers. Further down towards the output end of the drum, water is sprayed onto the mixture. This is necessary to moisten the mixture, to assist compacting and to cool the mixture down.

Within the cylindrical drum, plough plates rotate on the inside surface of the casing. Rotation speed and geometric form of the plates have to be designed in such a way that they throw the bulk material out of the material bed into the free mixing area and lift the material again from the drum wall, working against the centrifugal force. The mechanical turbulence bed thus

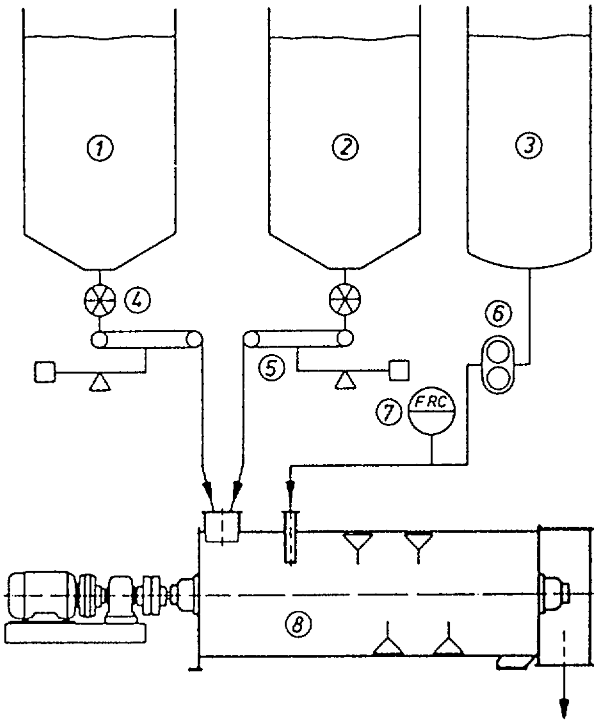


Figure 1. Outline of plant

1 Bunker I
2 Bunker II
3 Water container
4 Rotary valve
5 Belt weigher
6 Gear pump
7 Flow meter
8 Plough plate mixer

created leads to a very intensive mixing even with high material flows or short duration times respectively.

To avoid clusters or to make purposeful agglomerations additional blades can be installed in the casing of the drum. These blades rotate at high speed and are driven separately by electric motors.

The shaft with the plough plates is driven by a heavy electric motor, situated at the input end of the drum. For small propulsive power a V-belt-drive with direct gear reduction is used, for higher propulsive power an additional reducing spur gearbox is installed. For propulsive power over 20 kW a direct reducing spur gearbox without V-belt-drive is employed.

On the output face end of the drum is the outflow opening, provided with a slide gate for altitude adjustment or with an adjustable segment piece. The granulated product leaves the drum at a temperature of < 100 °C.

Mixing system and water adding installation are designed in such a way that the forming of clusters or dry nests is avoided and a granulation of the dust product is reached.

Dust moistening and granulating is usually done on a continuous basis, but also batch-wise operation is possible. The retention times of the product in the mixer are very short, so that relatively small mixers can be used, handling large amounts of dust, however, on a continuous basis.

Dimensioning

Depending on the type of dust or fly ash (grain spectrum, grain structure, temperature, powder density) and later use, retention times of 30-120 seconds are sufficient to bind the material; for granulation processes the retention times increase to 3-6 minutes.

The precise retention time has to be gained from mixing trials or determined on the basis of empirical data, stemming from the treatment of the same or similar products.

The effective volume content of the drum depends on the product to be mixed or the mixing procedure and lies usually between 25-50% of the gross volume content. Table 2 shows the ratio of gross volume content, effective volume content and quantity of throughflow, under certain parameters, of a cylindrical drum.

Table 2. Output of a cylindrical drum

Gross volume content in litres	*Effective volume content in litres (50% filling degree)*	*Amount of throughflow in l/h at a retention time of 1 min.*
150	75	4500
300	150	9000
600	300	18000
1200	600	36000
2000	1000	60000
3000	1500	90000
4200	2100	126000
6000	3000	180000
8000	4000	240000
10000	5000	300000
13500	6750	405000
15000	7500	450000

Description of the manufacturing process

Depending on the size of the mixer steel plates of 5 to over 20 mm are cut to shape and size by a plate shearing machine, or flame cutting machine in the case of thicker plates. A planing machine prepares the edges for welding. The plate pieces are, where necessary, bent into curved shapes to form the casing of the drum, the casing for the bunkers and the water container or the pipes and the round connection pieces on top of the drum.

Openings are cut out, holes are drilled and flanges are welded on. Then the pieces of the casing are welded together; the strengthening pieces as well as the square and round connection pieces are welded on and the previously prepared service flaps installed.

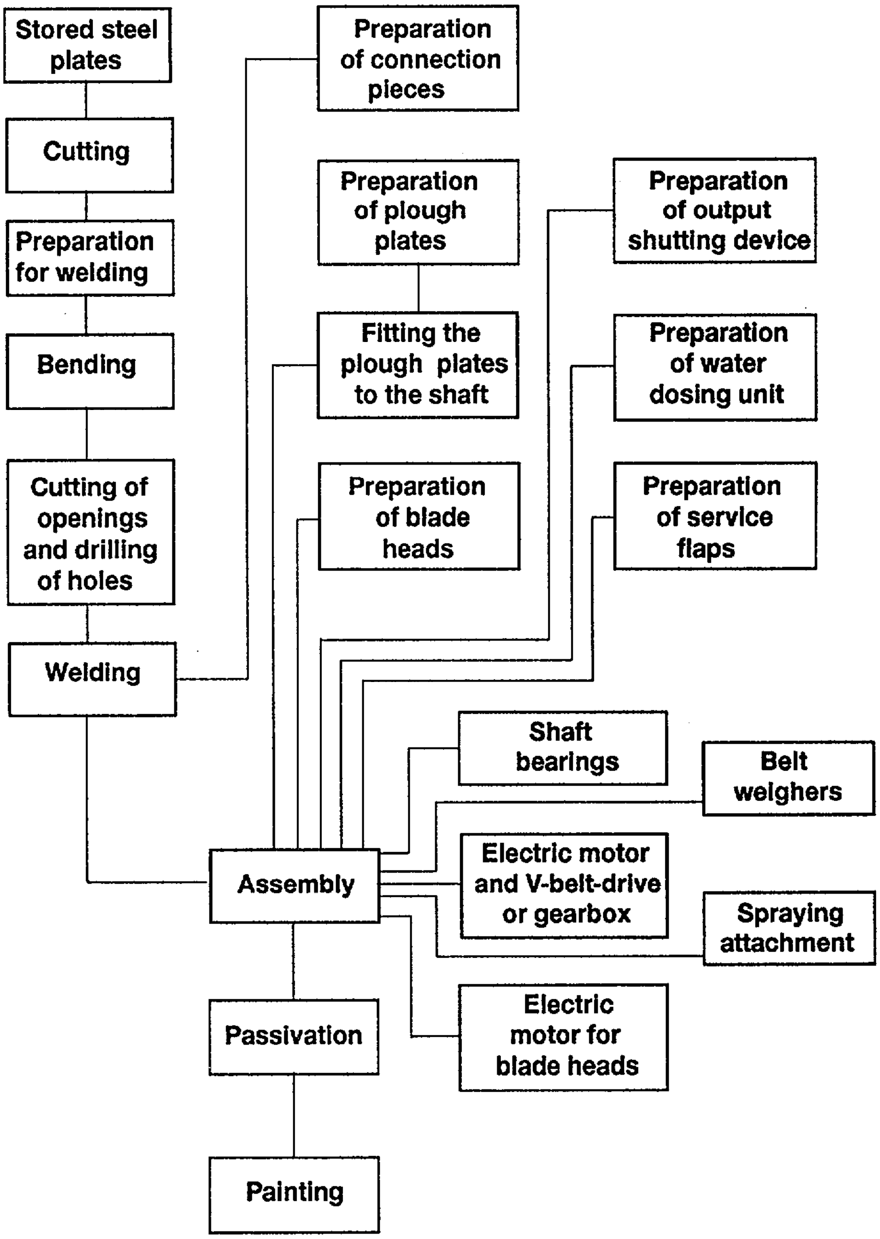
During assembly and welding of and on the casing a shape-keeping device is clamped inside the cylinder to avoid warpage and to retain the casing's perfect round shape. This is necessary in order to guarantee a small and equal distance between plough plates and casing.

The plough plates, which have been cut from metal plates and formed into their bent shape, are welded together. They are fitted to the shaft, usually ordered from outside, either by being screwed directly into the shaft, by being screwed onto foot plates, which have to be welded onto the shaft beforehand, or by being directly welded onto the shaft. The latter procedure is only advisable in the case of minimal wear.

The completed shaft is installed into the drum using shaft bearings supplied from other firms and fitted onto the head plates of the drum, which are strengthened by plate stiffeners to form the stands for the mixer. The blade heads, also manufactured in the works, are installed into the outside casing of the drum.

Finally the electric motor with V-belt-drive or gearbox is mounted onto the mixer. The bunkers, water container and pipes are welded parallel to the mixer. The finished mixer, the bunkers, water container, pipes etc. are painted to ensure protection from corrosion. The final assembly of the complete flue dust treatment plant usually takes place on the site.

Figure 2. Flow chart



Example of a manufacturing plant

This example is based on the assumption that the firm produces the main steel components itself, i.e. the mixer, bunkers, water container, plough plates, blade heads and pipes. The electric motors, V-belt-drive, gearbox, shaft, shaft bearings, water dosing unit, belt weighers, gear pumps, star feeder, flow meter etc. are supplied by outside firms.

The listings below have been made on the basis, that 4 to 5 mixing units of different sizes are produced every month.

Required machinery and equipment

Description	*Pieces*
Plate shearing machine	1
Flame cutting machine	1
Bending machine	1
Planing machine	1
Saw	1
Lathe	1
Drilling machine	1
Welding apparatus	4
Acetylene cutter	1
Hand grinding machine	3
Hand drilling machine	2
Workplace (including standard tools)	6
Bridge crane (5 tonne)	1
Fork lift truck (2 tonne)	1
FOB-price for machinery and equipment (1992) Approx. US$	950,000

Required manpower

Manager	1
Works engineer	1
Managerial and administrative staff	2
Foreman	1
Welders	4
Metalworkers	4
Semi-skilled workers	4

Required area

	Square metres
Production hall	1,500
inside storage	500
Facilities	50
Administration	100

Required energy

Electric power	250 kW
Acetylene cylinders	
Oxygen cylinders	
Compressed air	10 bar

Required inputs

Steel plates	Flow meter
Pipes and pipe bends	Shafts
Welding material	Shaft bearings
Paints	Belt weighers
Electric motors	Water dosing units
V-belt-drives	Rotary valves
Gearboxes	Gear pumps

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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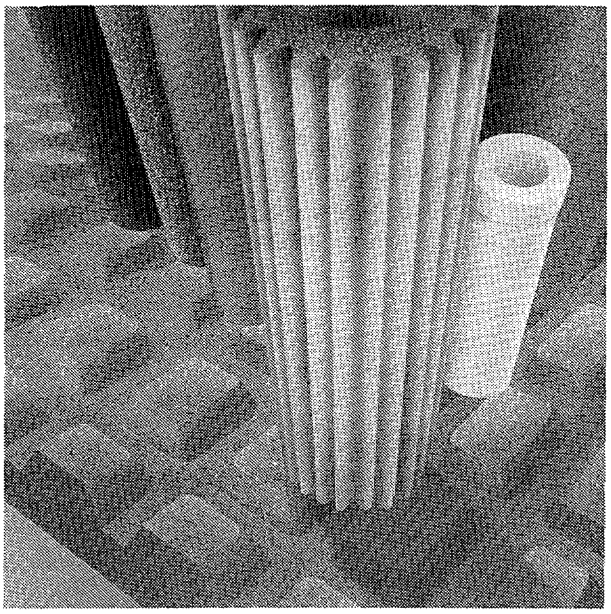
May 1993

How to Start Manufacturing Industries

Dust separation using ceramic filters



Introduction

Increasing industrialization in both developed and developing countries has resulted in a degree of air pollution never before encountered that has now in part reached such levels especially in densely populated industrial centres as to present a serious health threat or health hazard to the people living there.

The formation of air pollutants is linked to two conditions: air-strange matter existing in a finely-dispersed or easily fine-dispersable state, for instance, as gas, steam, vapour or, in this case, dust; and the existence of a carrier gas in motion (in this case, air) to absorb this matter, which is largely dispersed and carried along by the gas.

Depending on how they appear, air-contaminating substances can basically be divided into three groups. First, substances such as dust which inevitably accompany processes but which do not particularly affect the process course or quality and thus do not have to be filtered out. They do, however, cause pollution of the environment (e.g. combined heating and power stations, commercial and industrial production processes). Second, substances which are valuable main products (dust from dyes, pesticides) or by-products (e.g. solvent vapours, blast furnace gases). Third, substances which must be removed from a part of the production cycle to prevent its obstruction (e.g. arsenic oxide vapours produced from roasting gases during the production of sulphuric acid).

There are generally two methods of fighting air-contaminating dust: either by avoiding the formation of dust-air mixtures; or, by cleaning existing dust-air mixtures using special technical devices such as dust separators.

Technical devices used for dust separation, depending on their operating principle, can be grouped as: gravity separators; inertial separators; centrifugal separators (cyclones); or filters equipped with various filter materials, such as natural fabrics, synthetic fibres, felt, fleece and ceramic.

Dust separation using ceramic filters

The removal of air-strange particles using filters belongs to the oldest of cleaning methods. During filtration the dust-separating space is formed by the filter medium, a solid, permeable, porous material. While dust-laden air flows through this system, dust particles are retained due to two essentially different effects, namely by blocking or screening, or by moving the particles to the surface of the porous material by means of inertia, electrical forces and molecular diffusion.

Separation occurs when dust particles adhere to the filter medium, thereby forming a dust layer on the outer side of the material, that must be regularly or periodically removed (cleaned) so as to prevent obstruction of effective filtration. The filtering quality of a dust-filtering separator depends above all on the filter materials pore structure (geometry of the interstices), or its material properties (mechanical strength; temperature resistance; resistance against acids, lye, moisture and biological parasites).

In addition to dust filters made from natural and synthetic fibres (or paper, fleece or felt), filters made from porous (compound) ceramics are increasingly coming into use because of their suitability for fine cleaning; that is, for reducing dust contents from waste air and gas, or process gases, to values below 0.1 mg/m^3. Furthermore, in comparison to filters made from other materials such as felt, fabric and metal, ceramic filters have better material properties relating to not only resistance against moisture, acids, lye, etc., but also to temperature resistance, as can be seen in the comparative overview in table 1.

Dimensioning

The basis for the construction of ceramic filters is knowing the volume flow to be cleaned, which either depends on the process or on the conditions under which extraction takes place. An essential parameter of

Table 1. Material resistance to temperature
(centigrade)

Filter material	*Constant temperature*	*Possible short-term peak temperatures*
Polyamide	180	220
Felt	200	250
Fabric	250	300
Metal fibres	400	450
Quartz	600	800
Ceramic	1000	> 1300

separation by filtration is the effective filter surface, which is the ratio of waste gas or waste air volume flow to surface load determined experimentally or known from similar cases. Examples of surface loads corresponding to filtering separators using ceramic filters are given in table 2.

Table 2. Surface load in relation to production and filtering

Production	*Surface Load* m^3/m^2h
Asbestos	90-120
Cellulose	170-190
Spun glass	120-140
Glass wool	170-200
Wood grinding dust	155-165
Fine carbon	110-140
Non-ferrous metals and non-ferrous metal compounds	110-120
Quartz powder	80-110
Viscose staple fibre	190-200

In addition to the most important parameter in constructing dust-filtering separators, namely the effective filter surface, there are other factors to consider, such as:

The type of installation, process, apparatus or machines for which the filter is to be used;

The properties of the waste gas or waste air (combustible, health-hazardous, etc.), as well as those of their dust content (e.g. particle size distribution, composition, amount of dust content);

The operating mode of the installation (e.g. in shifts, seasonal, continuous).

In practice, these specifications are always difficult to determine reliably. It should therefore be determined if pilot experiments are necessary before a final decision on filter construction is made.

Fields of use

The different fields in which ceramic dust filters are used are due to the better material properties of ceramics compared to other filter materials, above all, regarding their performance in fine dust separation and resistance against high temperatures. Their use extends over various industrial sectors, from skilled trades and large-scale industrial production processes to the incineration of slightly radioactive waste.

Structure of a ceramic filter

A ceramic filter consists of modular units which can be used either individually or assembled in larger groups. Figure 1 shows the basic structure of a single ceramic dust filter. The filter element consists essentially of the following parts:

The suspension hood (c): The ceramic filter (f) is attached to the suspension hood, which is equipped with the inlet (a) and outlet (b) connecting pieces, and is then screwed to the cylindrical filter housing (e).

The waste air space (d): Waste air flows through this part of the filter system before entering the ceramic filter (f).

The clean air space (h): Air which has been cleaned flows through this part of the installation.

The dust collecting space (i): Dissolved dust from the cleaning of filter elements is collected here and discharged.

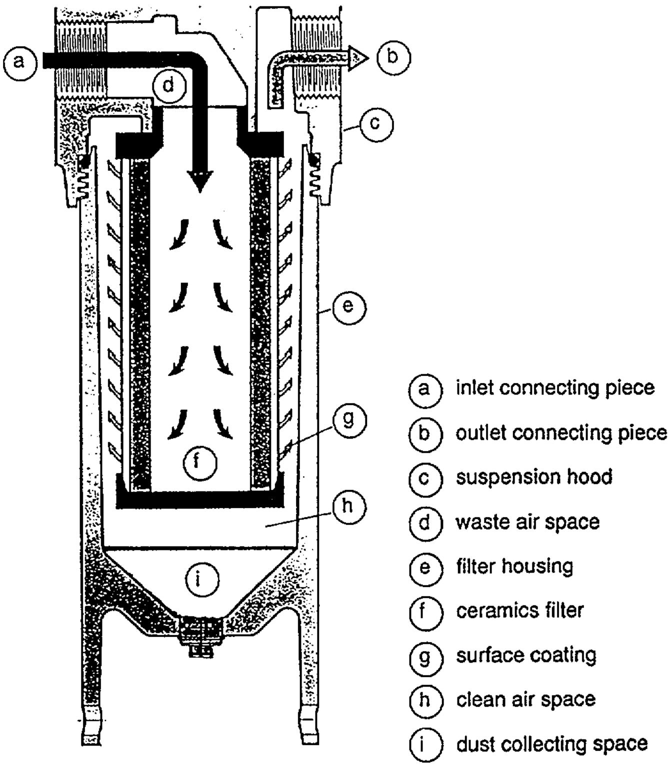
The ceramic filter (f): Depending on the effective filter surface required, one filter element suffices, otherwise a certain number of standardized filter elements are assembled into one unit.

For a smooth operation of the installation it is essential that the waste air and clean air spaces make contact only via the filter element.

Filtering process

During filtering (i.e. dust separation) waste air (crude gas) enters the waste air space (d) through the inlet connecting piece (a), assisted by a fan or ventila-

Figure 1. Components of a single ceramic dust filter



tor. It then flows through the ceramic filter from top to bottom, its bottom being closed. This causes the waste air to filter through the pores of the ceramic filter, where separation of dust particles occurs at the filter surface, which is coated with inorganic minerals.

The dust layer that forms on the outer side of the filter increases the filter element's permeability resistance; therefore, collected dust must be removed from the filter medium at certain time intervals. This procedure (cleaning) can be done using mechanical devices (tapping or shaking machines, vibrators) or by scavenging with compressed air. With ceramic dust filters cleaning, as described above, is in most cases done by high-pressure scavenging.

The dust layer dissolved in this way falls down into the dust collecting space (i), which is emptied using a dust discharger.

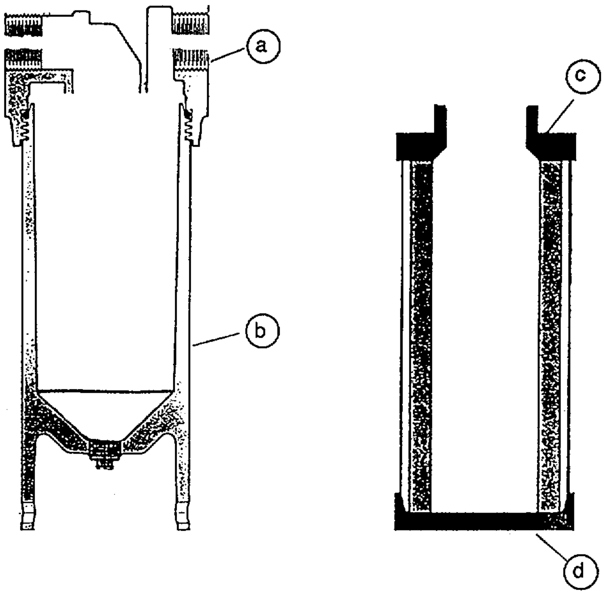
Description of a manufactured ceramic filter

As described above, the construction of dust-separating ceramic filters depends on several factors; correspondingly, ceramic filters can be differently sized. For a description of the production process and installation, a filter with the following measurements has been selected as an example (see figure 2).

In order to gain as large an effective surface as possible, while at the same time requiring relatively little space, the ceramic filter is given a star-shaped profile. The filter is produced from porous aluminium oxide ceramic; it is largely made from synthetic raw materials and additives in order to guarantee as high a reproducibility of porosity, pore diameter and pore shape as possible. An inorganic mineral substance is used for the filter coating.

The filter housing is one part of the ceramic filter system (see figure 3). The housing (b) is a cylindrical structure constructed from approx. 5 mm thick steel sheets. The suspension hood (a), plastic crown (c) and sealing pieces (d) for the filter are supplied from external sources.

Figure 3. Filter housing

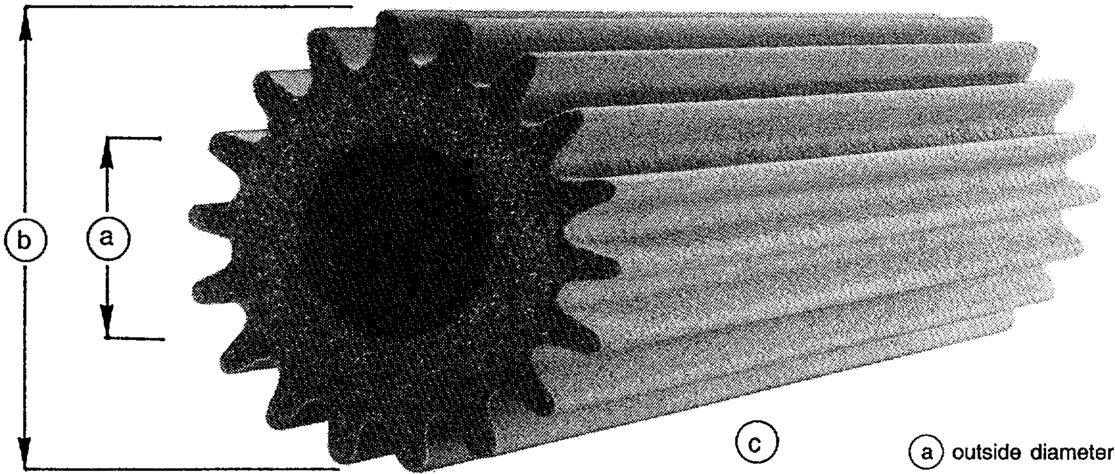


Description of the production process

The description of the production process refers to that of a ceramic filter with the specifications given above together with its filter housing. It should be noted that these products are usually produced to order in economically justifiable quantities and integrated into the regular production programme of the factory.

The production of ceramic filters begins by determining the required amount of raw materials and additives which affect, among other things, porosity and temperature resistance. These are mixed to a pulpy substance in a mixer and then poured into a pre-prepared mould. This is then put into a furnace where the substance is converted into ceramic at high temperatures for approximately three hours. Following this, the mould is loaded into a cooling chamber, where

Figure 2. Ceramic filter



cooling is slow and uniform to prevent fissures and tears. After the mould has cooled it is removed. Before it is immersed in a coating bath the ceramic filter is quality checked to determine whether the baking process was successful.

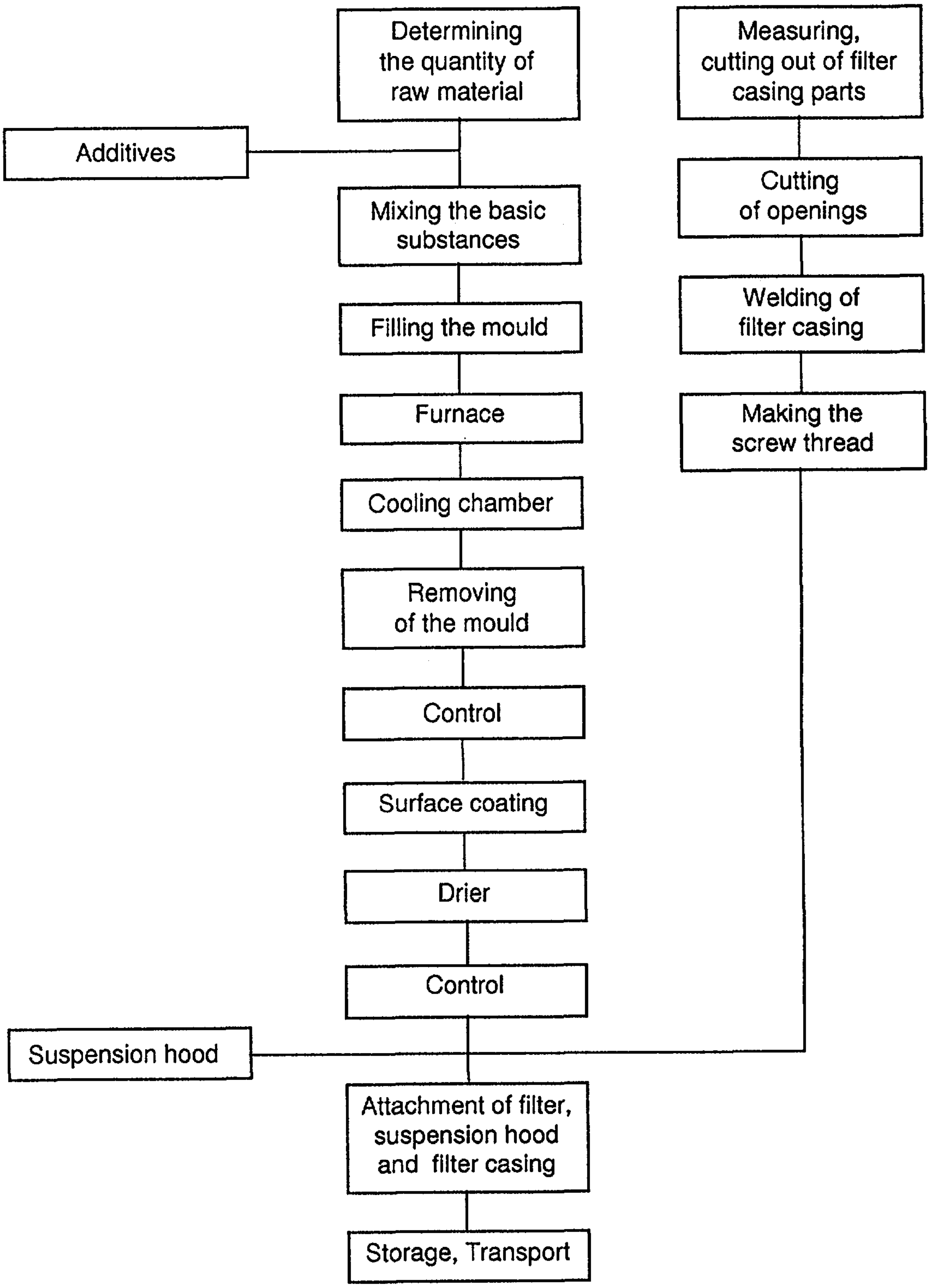
After it has been coated the filter is transported into a dryer to harden the coating as quickly as possible.

Following a further check the filter can be fitted with the crown and sealing pieces and attached to the suspension hood. The hood is then inserted along with the filter into the filter housing which is produced parallel to the filter.

The filter housing is made from steel sheets which, after being cut to size and equipped with the dust outlet and screw thread for the hanging floor, are welded together.

The filter system can now be transported to its place of use or storage.

Figure 4. Flow chart



Example of a production plant

It has already been noted that ceramic filters and filter housings are produced exclusively upon order and then integrated into the regular production programme of a factory. It is therefore not possible to list here exact figures regarding required energy and personnel etc. for the production of a single filter and filter housing.

Nevertheless, assuming that a factory produces only the filter and filter housing described here, due to the high cost in time required for the baking and cooling phases of production, only a maximum of 2 filters can be produced in one eight-hour workday, given that the production progresses without incident and the filters meet the required quality standard.

Required machinery and equipment

Description	*Number*
Mixer	1
Furnace	1
Cooling box	1
Drying installation	1
Coating bath	1
Welding unit	1
Crane	1
Workbench (with assembly tools)	1
Thread cutter	1
Fork-lift	1

FOB-price for machinery and equipment
Approx. US$ 1,100,000

Required personnel

Manager	1
Business supervisor (also responsible for administration, accounts, advertising, etc.)	1
Administrative personnel	1
Foreman	2
Skilled worker (mechanic, welder)	6
Workers (semi-skilled)	8

Required area

	Square metres
Production area	550
Management and administration	90
Social facilities	40
Storage	120

Required energy

Electricity	approx. 50 kW
Compressed air	
pressure	8-12 bar
volume	2000 l/h
Water	
Acetylene, oxygen	

Required materials

Aluminium oxide (Al_2O_3)
Additives
Steel plates

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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May 1993

How to Start Manufacturing Industries

Biological waste air treatment

Biofiltration

Introduction

Every year more than 100 million tonnes of carbonhydroxides and other organic compounds are emitted world-wide. The emission is caused by road traffic, industry, trade and households. To treat such off-gas components quite a number of processes exist, as, for example, adsorption with activated carbon, absorption with scrubbers, thermal and catalytic oxidation. Besides these physico-chemical methods, there is also the possibility of biological waste air treatment, using micro-organisms. Two processes are mostly used, bioscrubbing and biofiltration. Both processes offer, when compared with other methods, several advantages:

There is no further environmental pollution as no additional chemicals are used;

The organic substances in the waste air are, in the most favourable case, reduced to carbon dioxide and water;

There is little displacement into other environmental areas (e.g. waste water, solid waste);

The biological processes are in most cases low in cost and are hardly energy-intensive.

The areas where biofiltration is used have steadily expanded over the last decade. First used for the treatment of unliked odours biofiltration today is also used for the removal of numerous organic and some anorganic components from industrial waste air.

The process of biological waste air treatment

Biological waste air treatment is based on the activity of micro-organisms which can biochemically oxidize organic and some anorganic gaseous compounds and can convert them into hardly noticeable compounds.

As nowadays there are hardly any modern waste water treatment plants without a biological treatment phase, based on the natural process of the self-cleaning of water, so too is biological waste air treatment based on widespread natural processes. For biofiltration it is important that the living conditions for the micro-organisms concerned are optimal in order to achieve a good cleaning efficiency. With biological processes only that waste air can be treated which contains microbially degradable or bio-chemically oxidizable components and which does not act in a toxic manner as, for example, sulphur dioxide (SO_2).

To remove harmful substances from the waste air, they have to be brought into contact with a sorptive medium. This is achieved through two different processes:

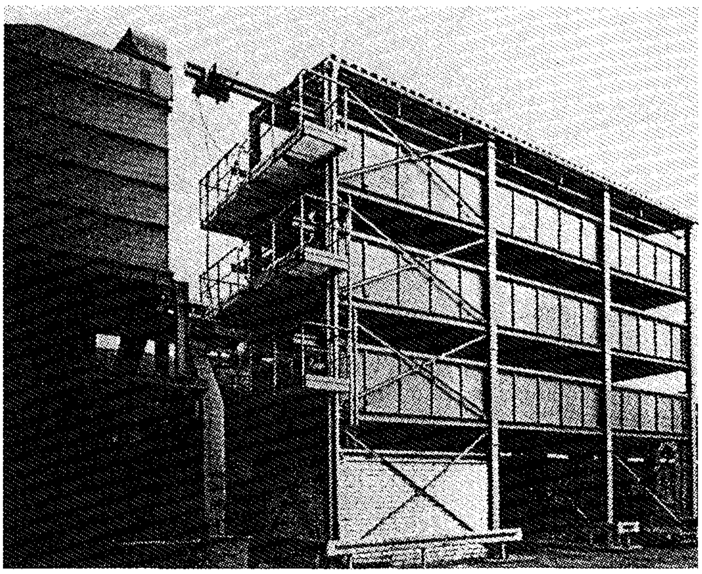
Bio-scrubbers, where the waste air is brought into contact with a washing liquid which washes out the harmful substances resulting in the elimination of these substances through the use of micro-organisms;

Biofilters, in which the waste air loaded with harmful substances flows through biologically active material where it is absorbed and afterwards microbially removed.

Both processes have relatively low investment costs as well as operation costs, whilst high-cleaning efficiency and price stability are maintained.

Bio-scrubber

Bio-scrubbers are used for the de-odourization of odour-intensive waste air streams as well as for the removal of organic gaseous substances from the waste air of industrial plants of very different production branches. In a bio-scrubber the substances contained in the waste air are absorbed by a washing liquid (absorbent) which acts selectively. This process is technically realized in an absorber. The substances absorbed by the washing liquid have to be removed from the absorbent after the absorption process. This process stage, defined as the regeneration of the absorbent, takes place through micro-organisms which use the



washed-out air components as a substrate. The micro-organisms are either finely dispersed in the washing water (bio-scrubber working according to the activated sludge process) or they settle on the scrubber installation as a biological lawn (bio-scrubber working according to the trickling filter process).

Bio-scrubber working according to activated sludge process

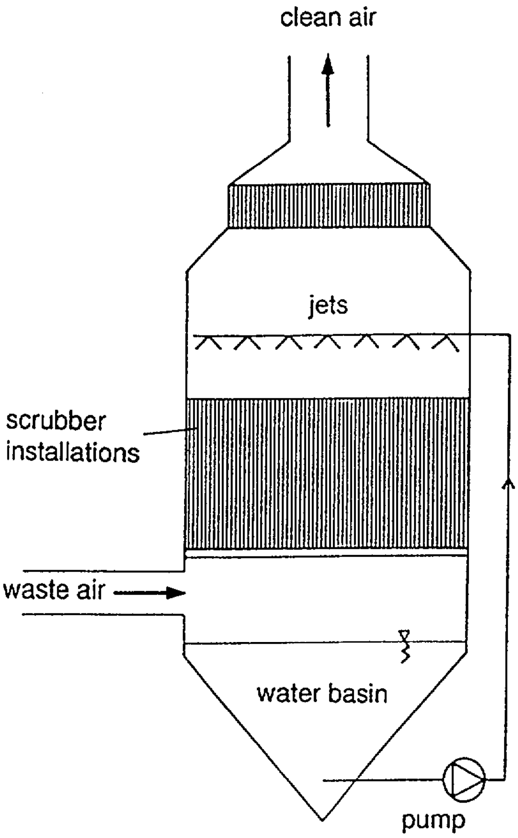
A fan conveys the waste air to the absorber or scrubber (see figure 1). An activated sludge suspension, acting as absorbent, is pumped from the activated sludge basin to the absorber and is distributed over the whole cross-section of the absorber by means of spray jets. To avoid sludge sedimentation the basin is aerated to cause sufficient turbulence. The waste air moving upwards in the absorber, which is generally made of synthetic material like PVC or PE, is cleaned on the one hand by the downward flowing absorbent containing micro-organisms, and on the other hand by the micro-organisms themselves, which have settled in the absorber.

The absorbent, together with the absorbed material, is fed into the activated sludge basin, in which the necessary regeneration of the washing liquid takes place. This is done by oxygen using (aerobic) micro-organisms, which use the impurities as a substrate and thus remove them from the water.

Bio-scrubber working according to the trickling filter process

The functioning of this bio-scrubber corresponds to that known from waste water treatment. Figure 2 shows that the waste air is fed to the scrubber by a fan. Water is pumped from a water basin to the scrubber where it is sprayed by jets over the whole cross-section of the scrubber installations. These are made of synthetic material like PVC or PE, and is where the waste air and the washing liquid meet.

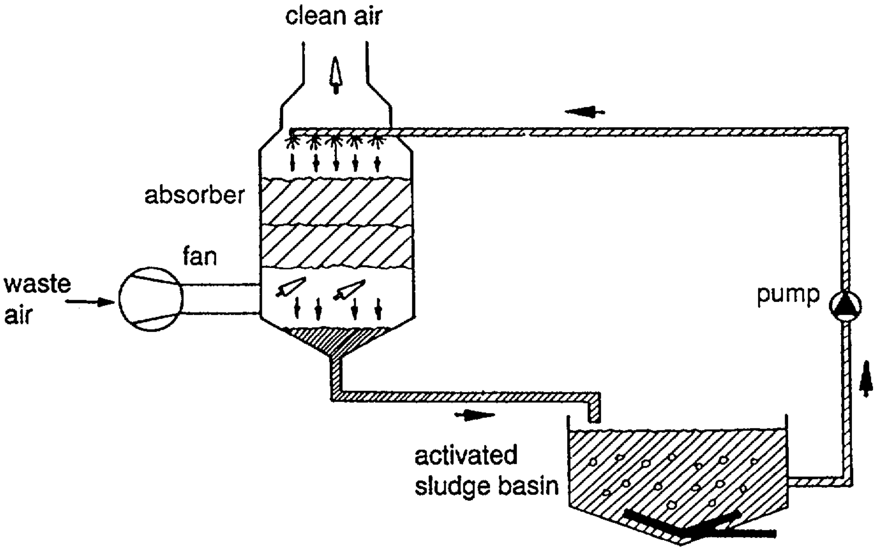
Figure 2. Components of a bio-scrubber



The surface of these installations is covered with micro-organisms in the form of a biological lawn. The micro-organisms are supplied with a substrate, stemming from the washing water loaded with the harmful substances, and with oxygen so that a biological decomposition occurs. The off-flowing and regenerated washing water is collected in a basin where solid material is deposited and from where the water is recycled to the scrubber.

The use of a bio-scrubber is mainly dependent on the following conditions:

Figure 1. Flow chart of a bio-scrubber working according to activated sludge process



The substances contained in the waste-air have to be water-soluble;

These substances should be able to serve as a substrate to the micro-organisms, i.e. should be biologically decomposable;

The waste air should be free of properties or components interfering with the biological decomposition, such as dust, grease or toxic substances;

The micro-organisms need sufficient (at least 1 mg/l) oxygen in the washing liquid to be able to absorb the harmful substances contained in the waste air;

Micro-organisms need small amounts of phosphor or nitrogen besides oxygen. Should there not be a sufficient amount of these substances in the waste air, then they have to be added in the form of corresponding salts.

Biofilter

The areas for the application of biofiltration have steadily increased over the last decade. After only being used initially for the treatment of unwanted odours, biofilters are today also used for the removal of numerous organic and anorganic compounds from waste air. The application of biofiltration is dependent on some important preconditions:

The substances contained in the waste air have to be water-soluble;

These substances have to be biologically decomposable;

The temperature of the waste air should lie between 5 °C and 60 °C;

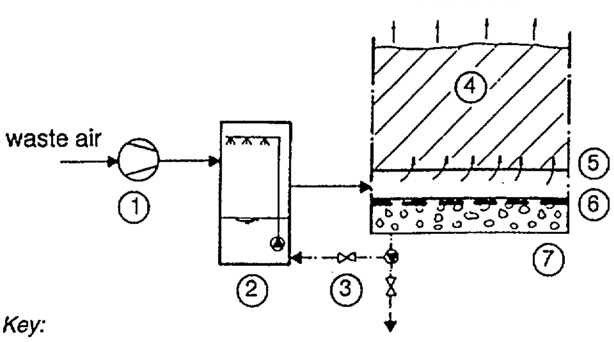
The waste air should be free of toxic substances;

The waste air should also be free of larger amounts of dust and grease.

Construction, process procedure

The essential construction elements and the process procedure are shown in figure 3. The waste air is fed by a fan (1) into a conditioning unit (2), where the air is moisturized to at least 95% in order to avoid any drying out of the biofilter material (4). This material could be compost (refuse, bark, foliage, paper), heather, brushwood, bark chippings, peat, polystyrene, lava or light expanded clay aggregate. The waste air is fed into the filter material from underneath by means of a suitable air distribution system (e.g. aeration floor consisting of perforated hollow tiles) (3).

Figure 3. Flow chart of a biofilter



Key:

1 = fan
2 = conditioning
3 = drainage system
4 = biofilter material
5 = air distribution system
6 = ground seal
7 = base

The filter material, normally arranged in several layers, is passed by the air to be cleaned where the substances contained in the air are removed by sorption and subsequently microbially decomposed. Here the filter material regenerates itself.

A drainage system (6) is responsible for the efflux of the surplus condensation and surface water.

The plant is installed on a stable base (concrete, stainless steel, partly also synthetics), which should be sealed sufficiently (e.g. PE foils) to prevent leakage water from getting into the ground water.

Biofiltration has relatively low investment and operation costs whilst—at the same time—a high cleaning efficiency and process stability are maintained. An important advantage is that there are no continuous secondary problems attached to these almost natural processes, as, for example, surplus water in the case of chemical scrubbers, flue gases etc.

Variants, dimensioning, areas of application

Variants. For waste air treatment with biofilters a relatively large filter volume is necessary compared with other processes; the reason for this being the limited decomposition efficiency of the micro-organisms. This great need for space often prevents the application of biofilters especially in the industrial field, although biological processes would be possible because of the composition of the exhaust air. During the last few years quite a number of biofilter variants have been developed, facilitating the use of biofilters because less space is needed and in some cases they are even transportable. According to the manner of their construction the following types of biofilters can be distinguished:

Single-level filters—they are the most commonly built form;

Multi-level filters—several filter layers (single-level) are arranged on top of each other;

Container filters—these are, in principle, transportable single-level filters which can also be arranged on top of each other and can be operated in parallel or in series;

Tower filters—these are filters with high fillings of filter material of about 2-6 m.

Dimensioning. The space needed and the construction of a biofilter are essentially dependent on the maximum amount of waste air to be cleaned; the types of harmful substances as well as their concentration; and the sort of filter material.

For the calculation of the filter dimensions the filter load (area or volume load) is an important factor. In most cases the area load is used for dimensioning; this is the waste air volume stream in relation to the filter area (m^3/m^2h).

Example:

Waste air volume stream	10 000 m^3/h
Chosen area load	200 m^3/m^2h
Resulting filter area	50 m^2

A dimensioning through calculation of the filter volume load (waste air volume stream in relation to the filter volume (m^3/m^3h)) is used in practice, whenever the filter is higher than one metre.

Example:

Waste air volume stream	10 000 m^3/h
Filter height	1.8 m
Chosen volume load	200 m^3/m^3h
Resulting filter volume	50 m^3
Ground space approx.	28 m^2

Areas of application. Areas, where biofilters can successfully be used for waste air treatment, are cited below:

- Adhesive production
- Animal feed production
- Aroma extraction
- Beer yeast drying
- Blood meal production
- Bone processing
- Bristle drying
- Cacao roasting
- Coffee roasting
- Composting facilities
- Crematorium
- Dump gas removal
- Fat processing
- Feather drying
- Fish meal production
- Fish roasting
- Gelatine production
- Glue production
- Lacquer production
- Livestock farming
- Maggot cultures
- Manure drying
- Plastics processing
- Polyester manufacture
- Production of friction-linings
- Production of oils and greases
- Refuse processing
- Rendering plants
- Sewage treatment, municipal
- Sewage treatment, industrial
- Sewage sludge drying
- Slaughter-houses
- Sugar-beet drying
- Tank farms
- Tobacco processing
- Used oil processing
- Vulcanizing plants

Description of a manufactured biofilter

From the numerous biofilter types described above the production of a single-level filter has been chosen, consisting of the components shown in figure 4.

From the calculation of the volume load the following measurements can be deducted:

(a) filter chamber (1)

length	600 cm
width	230 cm
height	150 cm
wall thickness	4 cm

(b) slotted floor (2)

length	600 cm
width	230 cm
height	2.5 cm

The slotted floor has 22 rows of air inlet slots (2 cm wide, 10 cm long) (3), the distance between the individual slots being 5 cm.

All other parts belonging to a functioning biofilter system, like fan, conditioning unit, waste air feeding system, clean air discharge system, leakage water system, ground seals, are delivered and integrated into the system at the site.

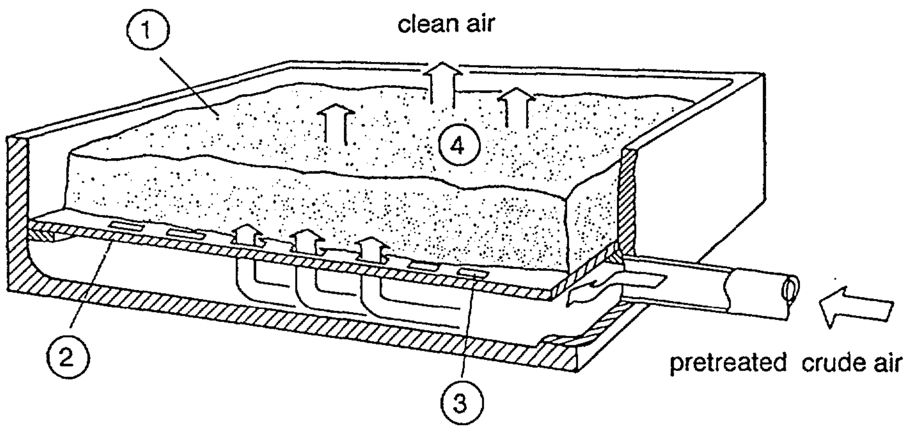
Description of the production process

The production process describes the production of the filter chamber and the slotted floor. These products are usually manufactured at a concrete works, however, they represent only a part of the much wider production programme of the works.

The production process starts with the determination of the amount of cement, gravel and sand needed for the concrete mixing plant. The moulds for the filter chamber and the slotted floor are prepared, i.e. the different parts giving the openings for the waste air intake and for the drainage system in the filter chamber are fixed. With regard to the slotted floor, special attention has to be given to the openings for the air intake slots i.e. a sufficient distance from the steel reinforcements is necessary.

When the concrete has reached the required quality, it is poured by means of a vessel hanging from a crane into the prepared moulds and compressed under constant rapping. After the concrete has set (approx. 48 hours), the moulds can be carefully removed and the cast products be cured, i.e. any remaining seams removed. Special attention has again to be given to the

Figure 4. Components of a biofilter

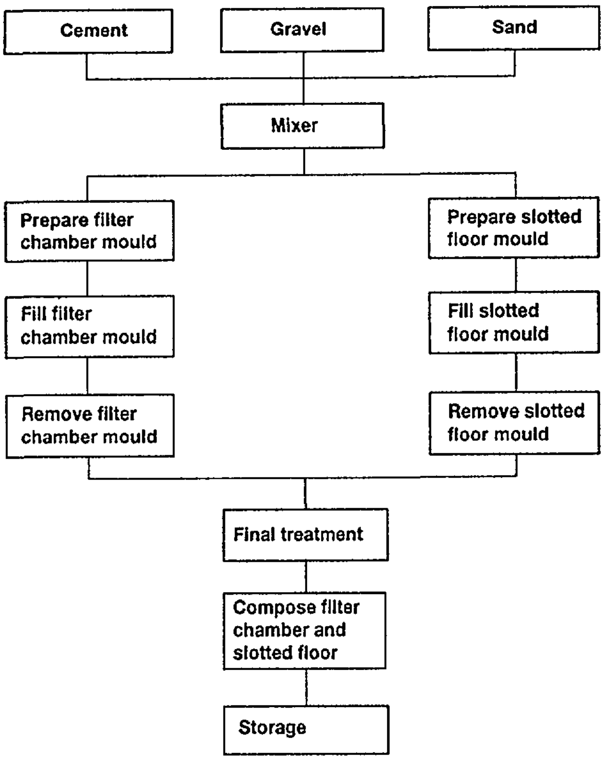


Key:

1 Filter chamber from concrete
2 Slotted floor from concrete
3 Air intake slots for waste air
4 Filter material

openings in the filter chamber and in the slotted floor. Following this, the filter chamber and the slotted floor are covered with a concrete protection paint; because of the relatively large areas a paint roller or a spray gun are used in most cases. After the protection paint has soaked into the concrete, the slotted floor is fitted into the filter chamber. The single-level filter is now either stored or prepared for transport.

Figure 5. Flow chart



Example of a production plant

As already indicated, the filter chamber and the slotted floor are only two items of a much wider production programme, produced daily by a concrete works. Normally the parts of a biofilter are only produced according to need and then integrated into the running production programme. It is therefore quite difficult to give exact details on energy and personnel demands etc. for the sole production of biofilters.

To give some idea it is assumed that the concrete works produces four units per day with the specification given above.

Required machinery and equipment

Description	*Pieces*
Cement silo	1
Gravel/sand silo	1
Mixing plant	1
Moulds	24
Rapping machine	2
Crane with pouring vessel	1
Workbenches	4
FOB-price for machinery and equipment (1991) Approx. US$	1.9 million

Required personnel

Manager	1
Works engineer	1
Foremen	1
Skilled workers	3
Semi-skilled workers	4
Managerial and administrative staff	3

Required area

	Square metres
Production, total	630
silos and mixing plant, the latter under a roof	330
curing, treatment, assembly (in production hall)	300
Management and administration	100
Social facilities	110
Storage	200

Required energy

Electricity	210 kW
Water	40 m^3

Required components and raw materials

Concrete (50% gravel, 30% sand, 20% cement)	20 t/day
Steel	1.3 t/day

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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ISIC CODE 2694
December 1993

How to Start Manufacturing Industries

Gypsum production

Introduction

Because of increasing environmental pollution caused by industrial solid wastes, the increasing difficulty and cost of dumping and limitations in finding new dump grounds, due to harsher environmental laws and increasing environmental costs in general, industry tries to find ways to reduce solid waste by utilizing residue material or by recycling it. Industry is today looking for cost effective production processes with minimal negative environmental effects, or, in the case of tail-end environmental measures, for the possibilities of simple, low cost recovery, recycling or the utilization of residue material through corresponding process design or the use of suitable reagents.

This last aspect, of finding a suitable process design, is illustrated by the case of wet flue gas desulphurization process at power stations. For example, in the fly ash being separated from the reagent cycle and the creation of the possibility of an easy conversion to forced oxidation; by so doing the use of lime milk results in a final product that can be further processed into gypsum in a relatively simple technical and economical basis.

The main advantage of gypsum production as part of the wet desulphurization process is that no solid materials occur which have to be disposed of. In most cases it can be stated that the additional investment (approx. 30% more) plus the energy costs for the gypsum production minus the income from the gypsum sales pays off either in the short or in the long run, when compared with the disposal costs.

However, there is one important condition to be noted: the gypsum coming from flue gas desulphurization (FGD) plants must have a secured and long-term use in as widely diversified applications as possible.

The quality of the gypsum coming from a flue gas desulphurization plant is comparable to that of natural gypsum and is also recognized to be as safe healthwise. It can be used as a building material especially as: building plaster; plaster board; plaster wall plates; plaster slabs; and mortar for the mining industry. In addition it can be used as an additive in the cement industry (solidification control) or it can be further processed to a cement-like binding agent in the concrete and building material industry.

Further applications are at present being examined, for example: as a binding agent in chip board production; as an aggregate in road and landscape works; as a pneumatic packing in mining; and for soil improvement in agriculture. In order to avoid high transport costs factories using gypsum as an input are best built in the vicinity of power stations. If FGD gypsum is used in the plaster industry a larger amount of reagents or set-up agents is necessary because of the fineness and grain form of the crystals in contrast to natural gypsum.

Basic process steps

In order to prepare the flue gas desulphurization plant for the production of gypsum, the calcium sulphide created in the flue gas washing process has to be oxidized to sulphate. The SO_2 in the flue gas reacts in the washer with the lime milk to sulphide. In a further step the calcium sulphide is transferred to hydrogen sulphide. Then by adding air in a final step the oxidation to sulphate takes place.

The single process steps are as follows:

(1) lime milk preparation

$CaO + H_2O \rightarrow Ca(OH)_2$

(2) flue gas washer

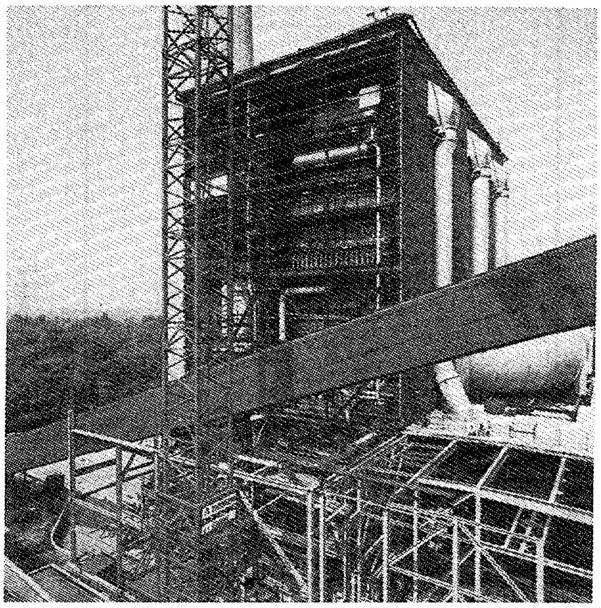
$Ca(OH)_2 + SO_2 \rightarrow Ca\,SO_3 \cdot 1/2\,H_2O + 1/2\,H_2O$

(3) gypsum process

$CaSO_3 \cdot 1/2\,H_2O + SO_2 + 1/2\,H_2O \rightarrow Ca(HSO_3)_2$

$Ca(HSO_3)_2 + 1/2\,O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + H_2SO_3$

Should a very pure gypsum be required as the end-product of the process, then a double-phase desulphurization process is needed where the flue gases are first cooled down to saturation temperature by water in a gas cooler and then freed from any remaining dust and gaseous components like chlorine and fluorine. Here the fly ash can be further processed, for example to improve the quality of cement in the cement industry. If there are not such high demands on the quality of the gypsum, a one-phase desulphurization process might be sufficient, where the cooling of the flue gases takes place in the reactor itself.



Description of the production process

As mentioned earlier, the flue gas desulphurization system has to be designed for forced oxidation in order to convert practically all of the dissolved calcium sulphide into calcium sulphate, which crystallizes as gypsum ($CaSO_4 \cdot 2H_2O$). To achieve this, air has to be blown into the absorber, or a separate oxidation tank has to be installed fitted with air spargers, into which a certain part of the washing cycle is fed.

By feeding the washing liquid with the calcium sulphide through the washer again, the pH value of the liquid is lowered by the flue gas stream, a precondition to reach a complete transformation into gypsum. The gypsum suspension, produced in the absorber, which has a solid material concentration of 8-12% by weight, is first thickened by using a conventional thickener and a battery of hydrocyclones or centrifuges. At this stage the gypsum crystal growth takes place. Using a thickener has the following advantages:

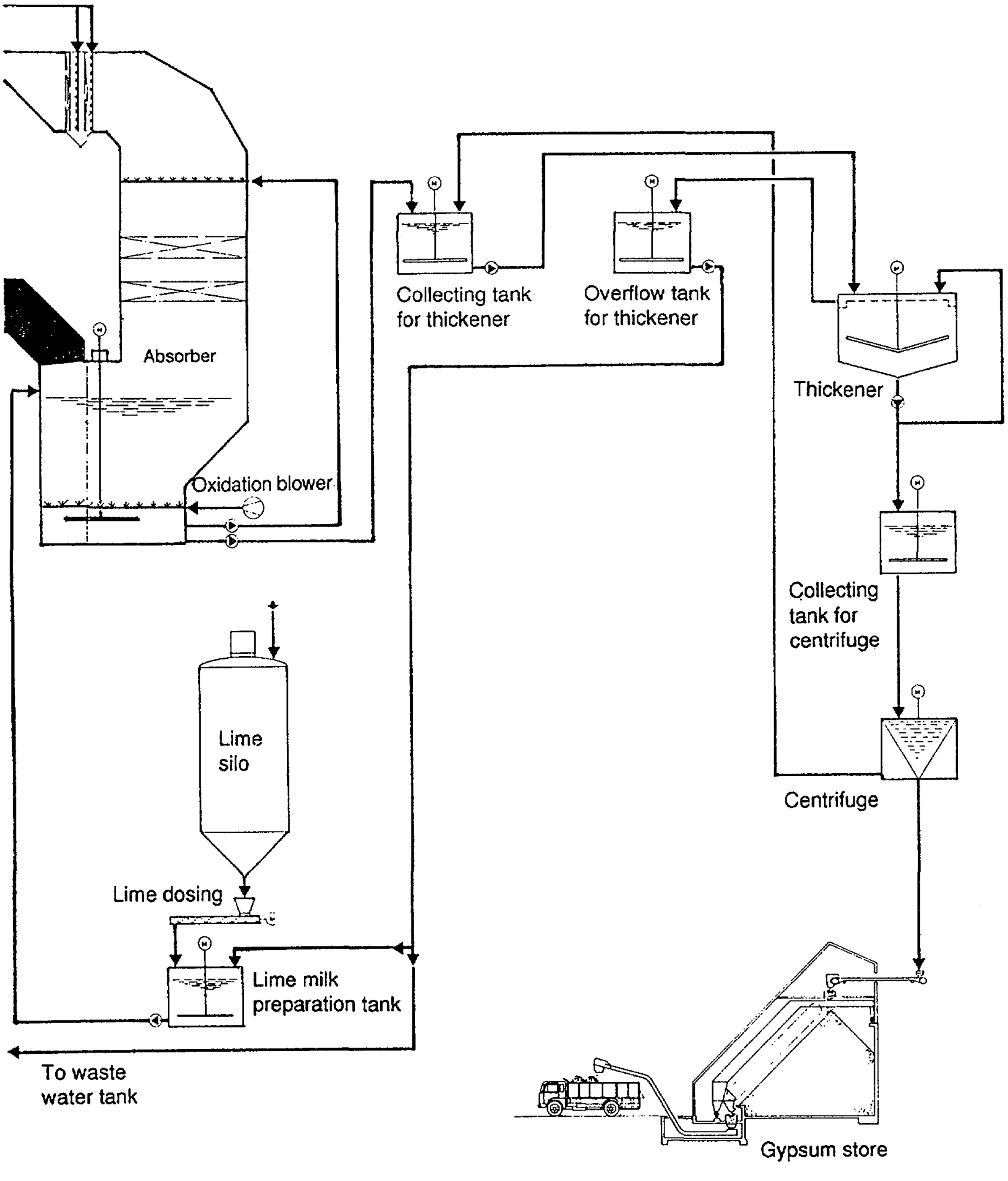
Buffer stock for
- failures in the FGD-process;
- light load operation;

Constant volume flow to the hydrocyclones, also in the case of alternations in the load;

Constant solid material concentration;

Possibility to draw-off waste water relatively poor in solid material.

Figure 1. Production process



In the following step, dewatering aggregates, like vacuum band filters or centrifuges, separate the gypsum which then has a maximum residue moisture of 10% by weight. The product can now either go directly into a nearby processing plant or be prepared for storage or for longer transportation.

In the latter case the still slightly humid gypsum cake is directly fed into a dryer. It is transported through the dryer by hot air (max. 140 °C), making contact with the steam-heated case of the dryer. The now dust-dry gypsum is separated in dust filters and conveyed continuously via a buffer silo onto a double roller press, which forms the gypsum into egg-shaped briquets.

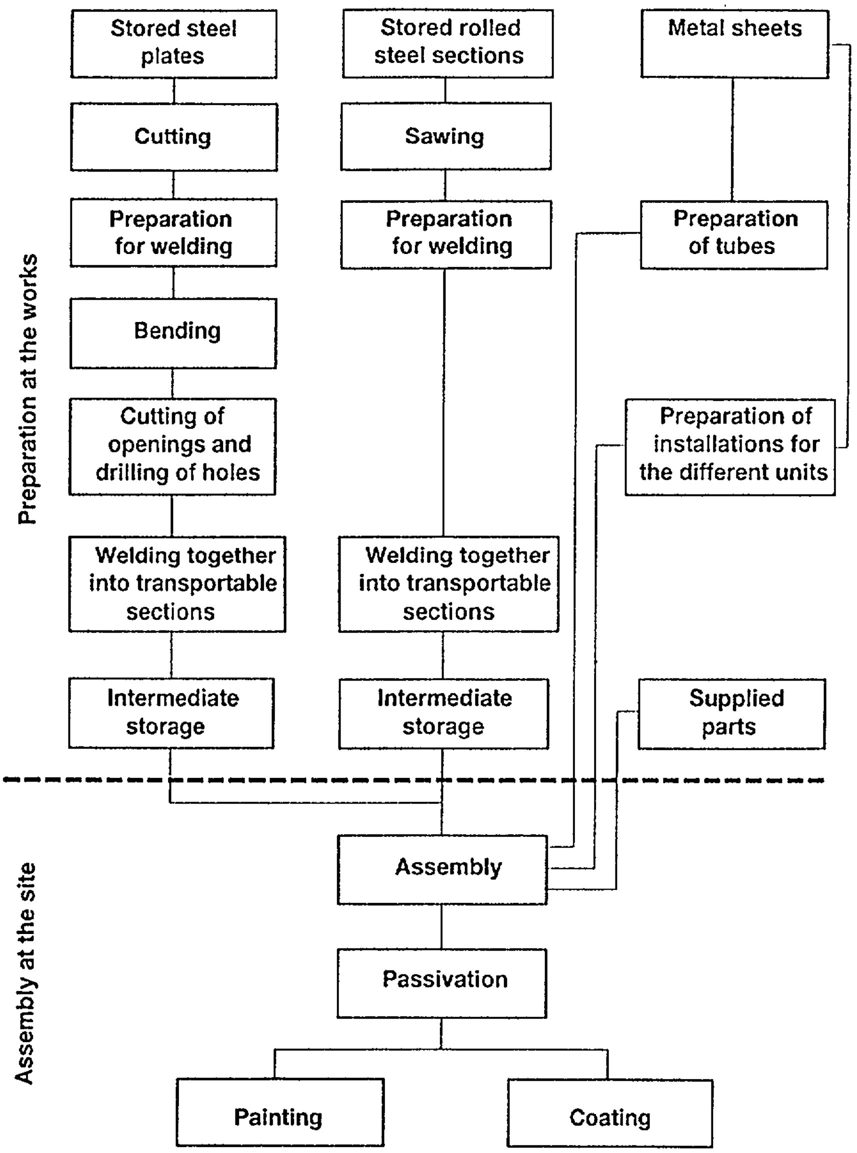
The pure gypsum produced is equivalent to natural gypsum and immediately suitable for further industrial processing as, for example, for plaster board production. The remaining water from the gypsum plant is fed back to the FGD-plant.

The following example gives an idea of how much gypsum can be produced by desulphurizing the flue gas of a power station: a modern coal-fired power station with a capacity of 750 MWe and the attached flue gas desulphurization plant with the necessary gypsum producing facilities will produce approx. 90,000 tonnes of gypsum of commercial quality per year.

Description of the plant manufacturing process

The basic materials are steel plates of 8-20 mm thickness and rolled steel sections ordered from outside. The steel plates are first sand-blasted and then cut into the necessary shape by a flame cutting machine. A longitudinal planing machine prepares the edges for welding. Some of the plate pieces will be bent into curved shapes according to given radii. They will serve as the casing for the collecting tank and overflow tank for the thickener, as casing for the thickener itself, as casing for the collecting tank for the centrifuge and for the centrifuge itself. Also the pieces for the connecting tubes and bigger pipes will be prepared in the same way. The casings are stiffened by rolled sections welded on the outside. Openings are cut, holes are drilled and flanges are welded on.

Figure 2. Flow chart



The units mentioned so far need a supporting framework. The necessary pieces for this are sawn to length, prepared for joining and welded together to transportable sections where appropriate.

Finally the installations for the different tanks, thickener and centrifuge are prepared. These installations consist of the bridges on top of the units onto which the stirring devices are mounted, the toothed channel to draw off the surplus water from the thickener, and the rotor of the centrifuge. All pieces and prepared sections are then transported to the site and assembled according to the construction plan. The finished units are, after being lightly sandblasted, painted to protect them against corrosion. The insides are often coated with rubber or a special protective paint in accordance with the particular needs.

Example of a manufacturing plant

Gypsum producing installations have to be adapted to the size and type of the FGD-plant, itself depending on the size of the power station. Therefore different installation sizes have to be produced. Production includes: thickener with collecting tank and overflow tank, centrifuge with collecting tank, and the necessary piping. Not included is the production of the gypsum store.

With the machines and workforce given below, the plant should be able to produce approx. 4 to 5 large-sized gypsum plants per year. However, it should be stated, that machine-loading is under-optimal in quite a number of cases. The figures quoted include the machinery and personnel necessary for the assembly on the site. Not included are transport facilities, lifting gear, scaffolding and living quarters for the workers. Pumps, valves, wheel shafts, bearings, flanges all electrical equipment, such as electric motors, control and measuring instruments, are ordered from outside firms.

Required machinery and equipment

Description	*Pieces*
Flame-cutting machine	1
Longitudinal planing machine	1
Bending machine	1
Folding machine	1
Column-type drilling machine	1
Horizontal multipurpose drilling machine	1
Circular metal saw	1
Plate shearing machine	1
Roller bed	4
Welding apparatus	15
Flame cutter	3
Hand drilling machine	4
Hand grinding machine	15
Workbench with hand tools, measuring tools, templates etc.	5
Bridge crane (15 and 10 tonne)	2
Fork lift truck (5 tonne)	2
Sandblasting installation	1
Mobile sandblasting unit	1
Air compressor (10 m^3/h)	1

FOB-price for machinery and equipment (1993) Approx. US$ 1,200,000

Required manpower

Manager	1
Works engineer	1
Engineer (works preparation and control)	1
Managerial and administrative staff	2
Foremen	2
Welders	15
Metalworkers	12
Semi-skilled workers	14
Painters	2

Required area

	Square metres
Production hall	6,000
inside storage	1,500
sandblasting room	200
Outside storage	1,500
Facilities	150
Administration	200

Required energy

Electric power	250 kW
Acetylene cylinders	
Oxygen cylinders	

Required inputs

Steel plates (8-20 mm)
Rolled steel sections
Tubes
Tube bends
Flanges
Plastic pipes (different diameters)
Pumps
Valves
Wheel shafts
Shaft bearings
Control and measuring instruments
Electric motors
Stirrer
Centrifuge rotors
Conveyor belts
Welding and cutting gases
Welding material
Sandblasting material
Paints
Coating material

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WATER PURIFICATION

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ISIC CODE 9000
October 1992

How to Start Manufacturing Industries

Industry briefing paper:
Water purification

Introduction

The 1980s have been declared the United Nations International Drinking Water Supply and Sanitation Decade (1980 - 1990) to draw attention to one of the most serious environmental problems: the supply of clean drinking water for a steadily growing population.

Water supply activities include more and more waste water purification. Since the overall water resources are limited, the recycling of waste water becomes more and more important. Producers of waste water are all kinds of industry, but increasingly urban districts and rural areas.

In reality, water supply and waste water treatment have many specific, regional problems caused by geological conditions of a particular area, by socio-cultural aspects of human life and by the technology used in small, medium or large industry.

The small and medium scale industry in developing countries is the core target group of the environmental technology profiles presented in this publication. Taking this orientation into account, certain priority is given to waste water management and water purification in mining, food processing, textile and leather manufacturing, and the paper industry.

Waste water composition

Water in the municipal sewerage system consists mainly of domestic sewage and industrial (or commercial) waste water. Additional minor sources are rainwater and some agricultural waste water. Industrial waste water is produced by medium scale to large scale industry. In urban areas it is treated, recycled, purified or discharged into the municipal sewerage system. Commercial waste water is produced by small manufacturers, slaughterhouses or public facilities.

The industrial and commercial waste waters contain different substances of natural or processing origin and treatment is required before discharge into a sewerage system. Waste water can be classified according to the degree of pollution and some indicators have been established to represent the type of waste water. The five most important indicators are:

Biochemical oxygen demand (BOD): the amount of oxygen consumed in 20 days (BOD_{20}) or 5 days (BOD_5) by micro-organisms at a temperature of 20 °C;

Chemical oxygen demand (COD): the amount of oxygen used to oxidize inorganic and organic matter in the sewage (usual oxidation agent: $KMnO_4$);

Total oxygen demand (TOD): the theoretical amount of oxygen needed for the oxidation of all oxidizable substances contained in the sewage;

Total organic carbon (TOC): the overall volume of organic carbon in the sewage;

The ammonia nitrogen content: ammonia usually originates from fertilizers used in agriculture, but commercial waste water can also carry small amounts of ammonia nitrogen. Even small amounts are toxic for fish.

Industrial waste water with the following components can cause major toxic effects on humans:

Organic halogen (Cl, F) and phosphorous compounds;

Heavy metals such as mercury, lead and cadmium;

Hydrogen sulphide;

Cyanides and fluorides.

Major sources of industrial waste water

Fresh water used in industry and other commercial business is *(a)* a raw material, *(b)* process water and *(c)* a cooling medium. Cooling water is contaminated only to a minor degree, mainly by air pollutants, but its quality is lowered by warming. The pollution of process water is much more serious. The type of contamination depends on the industrial process but can be classified into two distinct areas: pollution by organic substances and by inorganic material. Waste water treatment is geared to this distinction.

Inorganic industrial waste water

The main producer of waste water with various inorganic substances is the mining industry and all subsequent processing of minerals and metals.

The *mining industry* consumes large quantities of water for coal washing and coke quenching, ore dressing and saltbrine refining. In addition to this process water requirement, water is discharged as pit waters or pithead bathing waters. The pit water quantity varies between litres and 10 m³ per tonne of run of mine coal or ore. The pit waters are acidic and contain dissolved chlorides ($NaCl$, $CaCl_2$, $MgCl_2$), sulphates and metal salts (Fe, Ni, Mn, Cu, As etc.). The pithead bath water derives from miners' showers and toilets and contains soap, dirt and coal dust and amounts to about 50 l per man per day. Waste water from coal washing contains suspended coal and clay particles, dissolved salts and organic substances. The amount of water required for coal washing depends on the type of coal and on the end product but is in the range of 4-5 m^3 per tonne fine coal. Waste water from coal coking plants are polluted by condensates, washing and steam stripping waters and contains harmful components such as ammonia, phenols, cyanides and sulphides.

Tailing waters from ore dressing plants have various contaminations according to the dressing process used and the composition of the ore. Complex ores with sulphides usually contain trace metals (e.g. Cu, Zn, Pb, Ag, Cd, Hg, As). Small amounts of these metals are discharged in tailings. Mineral flotation and swim-sink processes consume chemicals and pollute the tailing waters with (mainly organic) compounds. In the non-metallic ("industrial") mineral industry, there are some processing activities which consume a considerably high amount of water and produce waste water. Common examples are cement factories where limestone or clay or cement dust is removed by water, or ceramic factories where cleaning waters contain suspended solids of kaolin, other clay minerals, very fine-grained quartz or feldspar. In porcelain factories, waste water containing phenol may occur. Other examples of industrial mineral processing are brick factories and glass factories. The very fine-grained minerals suspended in the waste water are very hard to clarify because the sedimentation of this material in water takes many days, sometimes weeks.

The *metallurgical industry* is another producer of inorganic waste water. In iron and steel plants, large quantities of water are used for cooling, ore washing, granulation or blast-furnace gases washing and converter rinsing. The waste water contains coke dust or metal traces but also chemicals like ammonia, cyanide and naphthalene. Iron, steel and other metals are processed in mills by rolling for the manufacture of sheets, plates and strips. Waste waters from metal rolling mills contain lubricants, metal particles and acids (sulphuric, nitric, hydrochloric).

Mechanical workshops produce highly polluted waste water (or even emulsion) mainly from metal cutting, drilling, sawing or grinding and contain additives like soap, resins, oils or phosphates and require a very careful purification process or special disposal.

Larger metal processing plants which manufacture industrial goods for vehicles, tools, machines or metallic household goods treat the metals in many ways and produce waste waters with various substances such as acids and metals or detergents, soaps, naphthene and naphthenosulphonates.

All waste waters from the metal processing industry containing more than 100 g/l dissolved substances are classified as concentrates, solutions with less than 100 g/l as semi-concentrates.

Very special waste waters and sometimes very harmful polluted solutions are discharged by metal eloxal works and electrolytic plating works. Electrolytic oxidation of aluminium (eloxal) is an anodic oxidation process which requires precleaning, grinding, polishing, degreasing and acid bath oxidation. The discharge of the processes contains fluoride, sulphate and aluminium hydroxide in large quantities and produces large amounts of sludge. Galvanization processes using metals like Cu, Zn, Cr, Ni and Cd discharge solutions with cyanides and metals.

The *chemical industry* discharges waste waters with inorganic pollutants from works producing acids or alkalis. Most important in this respect are the fertilizer plants. They use sulphuric acid, ammonia, phosphates and potassium salts for the production of inorganic nitrogen, phosphate and potash fertilizers. Washing water in processing raw salts or in gas cleaning is required in large quantities and will be contaminated by various salts (phosphates, chlorides, sulphates)

Organic industrial waste water

Waste waters contaminated by organic substances are mainly produced and discharged by the food processing industry, textile and leather industry, paper industry and cosmetics industry. These industries process organic material and use organic acids for chemical reactions. In most cases, biological treatment of the waste water is necessary for water purification.

Waste waters from *food processing plants* have certain characteristics: they flow irregularly, often seasonally, in high quantities, containing energy-rich proteins, fats, alcohols, sugar and other carbohydrates. The amount of waste water depends on the process and the raw material. Large quantities of water are used from washing and boiling of agricultural produce (fruits, vegetables, meat, fish), for the cleaning of containers and machines (including bottles, tanks, sterilizers, evaporators) and for cooling (see table 1).

Table 1. Amount of waste produced by selected food processing plants

Processing plant	*m^3/t per product*
Fish processing plants	20-25
Cattle slaughterhouse	1-10
Dairy factory	0.5-3
Ice-cream factory	4-6
Brewery	0.5-1.2
Canning industry	10-25
Potato industry	5-8
Sugar refinery	0.5-1

In *dairies* between 0.5 and 2.0% of the milk is lost during processing, mainly by leaks in filling-taps and accidents in pouring milk. Process waters contaminated by milk and rinsing or purification waters additionally contaminated by acid and alkaline solutions and disinfectants are the main sources of waste waters in dairies processing cheese, butter, yoghurts etc.

The production of beer in *breweries* has three main steps: production of malt from barley (or rice), preparation of beer wort and fermentation of beer. Waste waters are discharged during the bottle cleaning (mainly rinsing water, 35 m^3 per 100 hl beer), filter cloth washing (15 m^3/100 hl) and vat cleaning (fermenting vat, storage vat, etc.: 2 - 3 m^3/100 hl).

In *fish canning* factories, the waste water contains large amounts of scales, fins, bones, flanks, etc. In addition, canned fish is marinated and prepared with vegetables. From vegetable cleaning and processing as well as from marinate processing, large amounts of waste waters containing salt, acetic acid and vegetable residuals are discharged.

The composition of waste waters from *slaughterhouses* depends on the size of the operation, on the process used and on the amount of fresh water available. Cleaning the animals, removal of hair and collection of blood are the major sources for solid and liquid waste substances in discharged waters.

Waste waters from *textile plants* contain both organic and inorganic waste. Textile factories prefabricating raw materials for final textile products process cotton, wool, silk, hemp or flax and have waste waters with mainly organic material. Finishing plants like cloth factories produce waste waters with both organic and inorganic substances. Waste waters come from washing and other treatment processes as well as from bleaching and dyeing. The volume discharged goes up to 1000 m^3 per tonne finished product. Some processes like cotton bleaching, wool washing, cloth preparation (dye works) and pulp production contain various acid and alkaline solutions, fibrous material, wool fats and aniline dyes.

A special producer of large amounts of contaminated waste water are leather factories. Preliminary treatment of animal hides and skins takes place in water workshops while the leather finishing process takes place in tanneries. The soaking waters of the preliminary treatment contain agents such as caustic soda and lactic acid. The waste waters are very salty with many organic substances. Tanning agents on the other side are formaldehyde, cresols, anthracene and their sulphuric acids. Chrome tanning is done with chromic salts, other tanning processes also use metallic salts. A medium size tannery discharges 1000-2000 m^3 highly contaminated waste water per day.

Sewage purification technology

Industrial water purification is undertaken in three main steps: extraction of pollutant and recyclable substances; treatment of water; and treatment of sludge. A common flowsheet of an industrial waste water purification plant consists of:

Screening unit (with coarse and fine grating);
Sand traps;
Oil (and fat) separation.

A pre-treatment operation (or mechanical purification) is followed by biological (hygienic) purification in ponds. The sludge from the mechanical separation process is deposited in ponds and must be removed every two to five years. It is often spread as fertilizer on fields. Sludge from biological treatment is also digested in the ponds and used as fertilizers or, when highly contaminated, discharged to specific waste disposals.

Methods

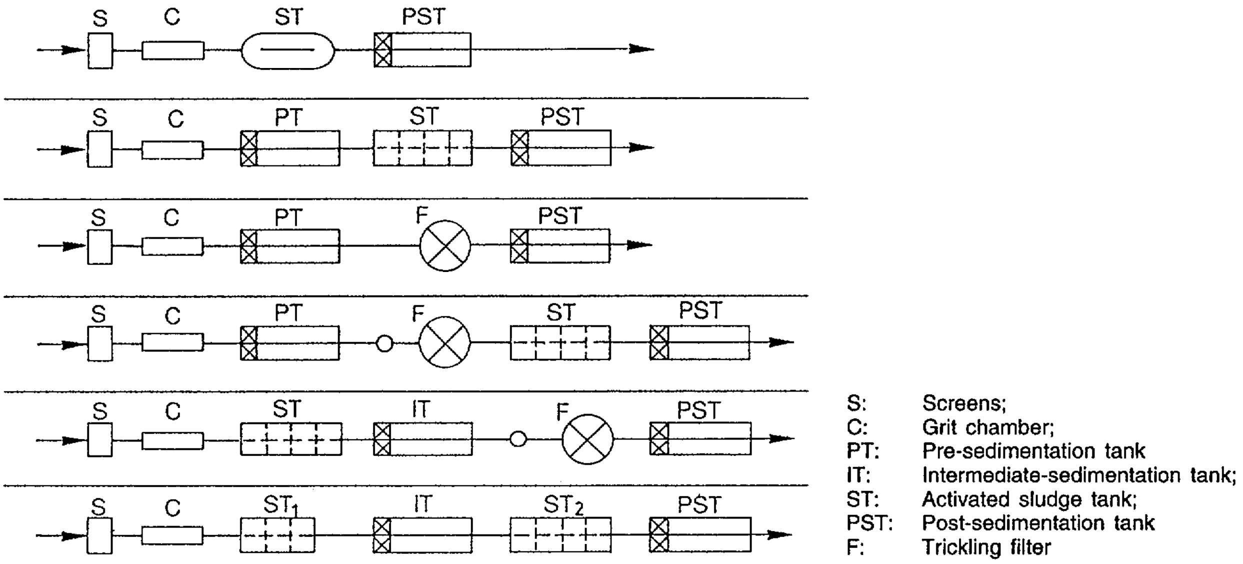
The removal of all settleable solids takes place by *mechanical* purification methods. Normally mechanical purification is used to prepurify the sewage. The methods that can be applied are: separation by sedimentation tanks or by screens and jigs; or by sorting; desliming; decanting; centrifugal separation; filtering and flotation.

Chemical purification of sewage is to remove the suspended matter or dissolved substances with the help of chemicals. In industry, this chemical purification is used in particular where dissolved substances or solvents are to be retrieved from the sewage.

Biological purification of sewage is primarily suited to removing organic contamination. Micro-organisms in the activated sludge of the biological stage (activated sludge basin or trickling filter) are used to oxidize organic substances.

In most cases a combination of mechanical and biological methods is used for sewage treatment. Usual combinations are outlined in figure 1.

Figure 1. Combination of mechanical-biological sewage treatment



Equipment

The major components of purification systems are:

Screens and sieves: In order to separate coarse material (wood, leaves, gravel, sand, paper, metal parts), wire nets, perforated metal sheets or slotted sheets can be used. The sieve holes vary from 0.02-1 mm. Distinctions are drawn between flushing screens, dry screens and vibrations sieves.

Filters: Sewage contents are not removed by two-dimensional means, but three-dimensionally. The filters are made up of a bed of sand, gravel, anthracite or similar material. While sieves are largely employed for the prepurification of sewage, filters are largely used for post-purification. The main types of filter are high rate filters, multilayer filters, disc filters, drum filters, suction filters and pressure filters.

Trickling filters: Containers 2-4 m or 5-20 m high and 2-5 m wide are filled with rubble, pumice stone, slag or plastic in which a biofilm is formed of aerobic bacteria that degrade pollutants and which is used to biologically purify the sewage. The sewage in the trickling filter is distributed by means of nozzles.

Absorbers: A physical-chemical treatment is used to purify the sewage of material that cannot be degraded by means of bacteria. Then the purification is effected by means of activated carbon. This is produced from wood or bones by dehydration and carbonization at high temperature in a vacuum. The activated carbon is inserted into the absorber as powder or granules. There are three main types:

Fixed bed absorber with activated carbon in a cylindrical container which must be put out of operation for regeneration and washing;

Slide bed absorber with an outlet for the coal which is continually removed from the floor of the container and can be regenerated and then refilled;

Fluidized bed absorber filled with high water pressure via a perforated floor which keeps the activated carbon suspended.

Water purification management in developing countries

The Action Plan of the United Nations Water Conference, held in March 1977 in Mar de Plata, called for the application of modern technology and basic management principles in the water resources supply. The Mar de Plata Action Plan forms a comprehensive guideline on water resources policy. However since the conference, political and economic developments have produced considerable changes in the framework conditions for water management in developing countries, such as:

- An adverse economic situation arose in Latin America and the Caribbean due to the external debt crisis, and in Africa due to low commodity prices, drought and public sector mismanagement.
- A considerable reduction of the public sector and a subsequent increase in all kinds of private investment and management took place in many countries.
- In general, private sector in industry focuses more on small and medium size units, processing local raw materials and applying appropriate technology.
- In many countries environmental awareness is growing in government and in society as a whole. This includes adequate water legislation and regulations on waste water treatment.
- Institutional systems reflect more and more the importance of local conditions for water supply and water treatment and give them priority over centrally imposed water management. Some common problems of water management still remain. These include:

  Unregulated use of water resources;

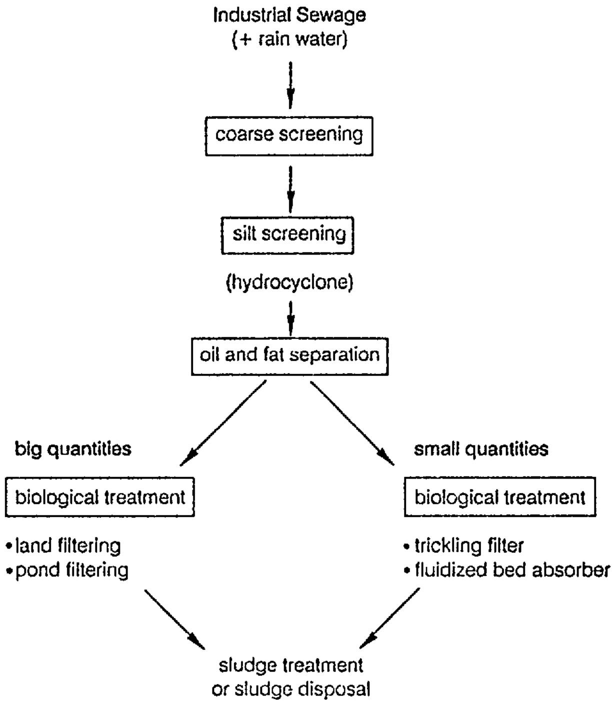
  Inadequate and ineffective purification of industrial waste water;

  Insufficient technology available for water treatment;

  Lack of trained staff at all levels;

  Inappropriate environment (water pollution) control.

Figure 2. Flow sheet of sewage treatment plants



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How to Start Manufacturing Industries

Fixed bed cascade bioreactor for sewage pre-purification

Introduction

Sewage with mechanical, organic or chemical impurities has to be purified before being released into the sewerage system or main canal. The sewage treatment requires several process steps and the use of different technologies. One of these technologies is the biological treatment of sewage after mechanical purification. During this treatment the remaining, decomposed organic particles of the sewage are degraded with the help of micro-organisms while a supply of oxygen sustains the process.

The following methodes of oxygen supply for the biological treatment of sewage can be distinguished:

Mechanical aeration, where water is brought into contact with air by means of circulation;

Pneumatic aeration, where compressed air is supplied; and

Combined mechanical-pneumatic aeration.

In addition to the oxygen supply, the geometry of the sewage basins is decisive for the purification process.

The fixed bed cascade bioreactor (FBC-reactor), dealt with here, works with pneumatic aeration. Compared to other methods of biological purification, that operate according to the principle of mechanical aeration, such as the activated sludge process (ASP), the percolating filter process (PFP) and the immersion percolating filter process (IPFP), the FBC-reactor has the following advantages:

Reduction of the sludge disposal costs due to the distinctly lower volume of surplus sludge;

Normally there is no need for secondary sedimentation basins with indirect dischargers;

Smaller reactor volumes save space and reduce the construction costs thanks to their higher purification performance;

A higher operational efficiency, and lower maintenance and repair costs are achieved as there are no movable parts installed;

A return flow mechanism for sludge is not required;

An optimal adaptability between the bacteria and the reactor sections allows, for example, the degradation of easily degradable sewage materials in the front section of the reactor and the degradation sewage materials difficult to be degraded in the following reactor sections (cascade);

The biomass adapts itself well to the hydraulic and stock pollution loads;

The biomass can survive without problems for 2-3 days without any sewage flowing and there is no risk of desiccation (as for the PFP);

The biomass, fixed on the fixed bed, is, immediately after the plant has been shut down for a certain time, fully operational (the ASP is not);

Due to the cascade design short circuiting currents can be largely excluded and the specified contact time for each sewage particle with the biomass is assured;

The reactor is movable and can be easily adapted to changes in the operating conditions because of its modular construction;

The FBC bioreactor can be used everywhere where commercial and industrial waste water containing biological pollutants is produced:

Food-stuff processing factories, where sewage is produced during the product purification as well as during the purification of granaries and storage plants (e.g. vegetables and tinned fruits);

Slaughter-houses and meat processing factories, where faecal, slaughter, clean-up and mixed sewage occurs;

Fat melting plants, where process water, condensed vapours and surface water occur;

Wine pressing factories and fruit-juice factories, where sewage occurs due to the cleaning of inputs, storage tanks and production equipment;

Large kitchens, where sewage occurs during the washing of foodstuffs, during meat and fish processing and dishwashing;

Textile processing industry, where sewage is polluted with dyestuff;

Chemical industry, cosmetics manufacturers, the pharmaceutical industry, where different volumes of sewage containing organic pollutants occur;

Tips, where highly toxic sewage occurs in the form of percolating water.

Furthermore, the reactor can be used for the biological treatment of exhaust air in order to remove washer waste from exhaust air cleaners and to treat condensation products from biofilters.

Product description

FBC-reactors are sewage purification plants which operate with an aerobic biological purification process. During this process the aerobic carbon user decomposes glucose with the help of elementary oxygen glucose, according to the equation:

$$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+2822\ \text{kJ}.$$

During this process carbohydrates, fats and proteins are used up within a short period of time for growth and metabolism and are removed in this way from the sewage. This causes a decrease in the chemical oxygen demand (COD) and the biological oxygen demand for a period of five days (BOD_5). There is a conversion mainly to carbon dioxide, water and cell substance. The originally organically bound nitrogen is then mainly in the form of ammonium.

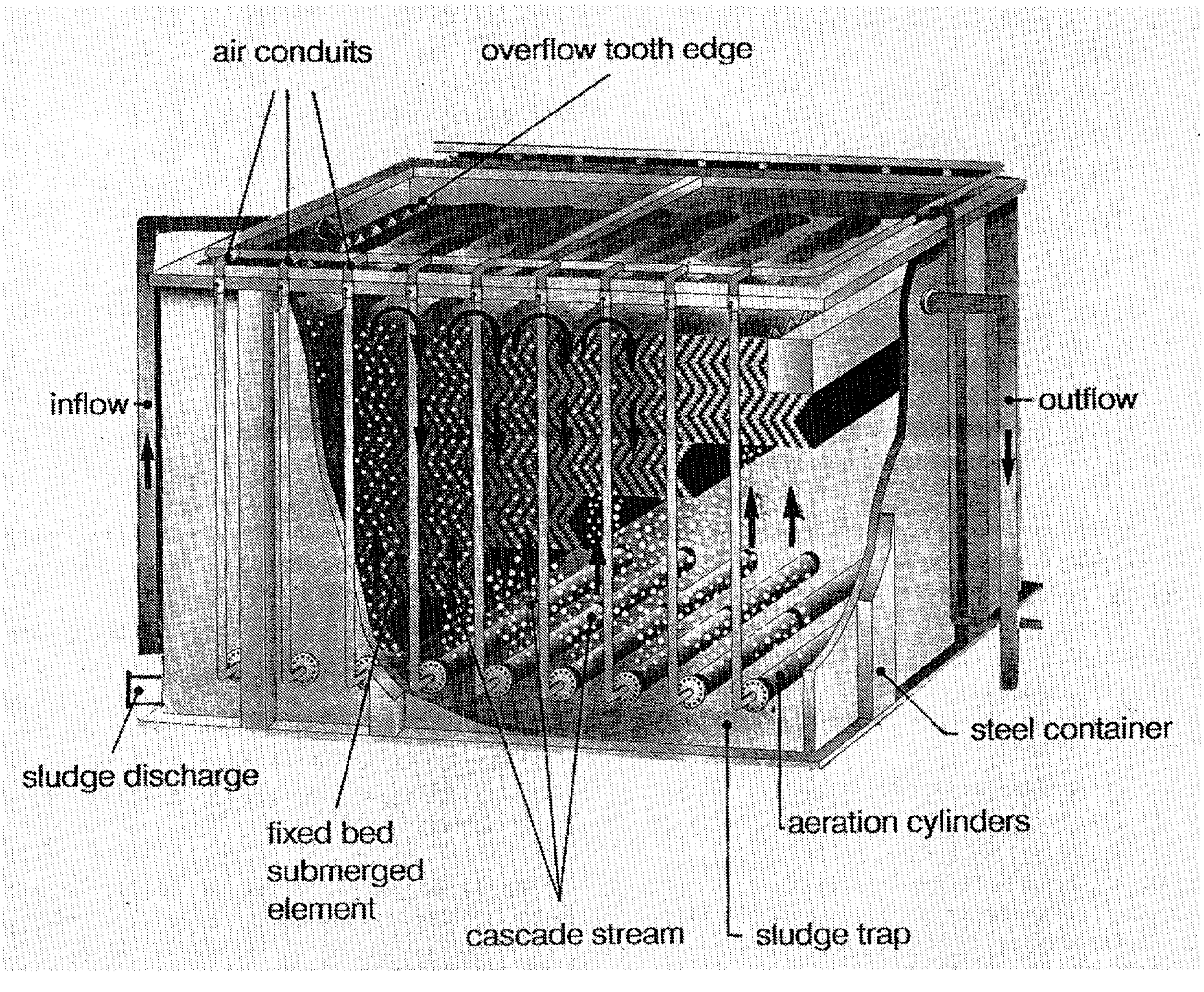
The reactor consists of a stainless steel container filled with plastic packing. The plastic packing is so arranged that it can only be passed in a vertical direction. The packing consists of numerous thin-walled plastic sheets arranged in a parallel order at small intervals that correspond in length and breadth to the internal dimensions of the reactor. At the vertical longitudinal sides of the reactor there is a sealed occlusion between the wall and the plastic packing in order to guarantee the forced circulation of the sewage.

The surface of the plastic sheets is structured so that an optimum "biological lawn" can be built up. From the construction point of view the plastic elements are so arranged that the surface presents as large a contact zone as possible for the passing sewage. The optimization task is to design, in the case of a given volume of the FBC-reactor the surface of the plastic sheets in such a way that it is large enough to minimize flow resistances and to ensure that mechanical impurifications in the water do not block the flow routes between the plates.

A plastic element with a volume of 1 m^3 has a surface of between 150-200 m^2. This ratio of "surface to volume" must be optimized and adapted to the specific sewage profile. On the narrow side of the rectangular container the inflow and outflow are respectively arranged. Inflow and outflow are at the same heights, so that the flow direction adjusts itself automatically to an afflux of sewage.

Below the plastic packing are the aeration cylinders which are consistently filled with compressed air from a fan or a compressor. The bottom of the reactor serves as a sludge collecting basin.

Figure 1. FBC-reactor



Functional description

The inflow and outflow of the sewage is directed over toothed edges which retain solid matter and ensure the even distribution of the water over the overall surface of the reactor. The plastic packing is submerged and surface micro-organisms settle on its surface as a "biological lawn".

The oxygen is supplied by pumping air via compressors or fans that are located outside the reactor. The air is emitted into the reactor with the help of ceramic aeration cylinders. They are arranged underneath the plastic packing sections and parallel to these at defined intervals. This ensures an optimum supply of air and oxygen.

Due to the design of the fixed bed and the arrangement of the aeration cylinders in the reactor the sewage flows in cascades through the fixed bed with upstreams and downstreams. Here, use is made of the physical principle whereby the specific weight of the air-water-mixture is lighter than in the parallel sections, where without air supply the heavier water sinks.

The cascade flow through the reactor allows long flow routes for the sewage and thus contact with the "biological lawn". Solid matter and the remaining surplus sludge are collected in the sludge trap. The dimensions of the sludge trap are so designed that emptying is only necessary twice or four times a year, depending on the sewage profile. The sludge is removed by a sludge discharge pipe located in the sludge basin. The reactor must be emptied and cleaned once a year.

The biological activity in the reactor is induced by adding specially cultivated micro-organisms into the reactor filled with sewage. Within a few days an active biomass is built up. If there are any substances in the sewage that are difficult to degrade, then the efficiency of the sewage purification can be increased by the regular addition of specially cultivated micro-organisms.

The regular maintenance of the reactor requires:

Control of the pumps and fans;

Inspection of the water consistency and of the inflow and outflow.

Operational conditions

In order to avoid the blocking of the plastic packing by mechanical impurities a separation of the crude matter from the water is necessary with the help of filtering. The fineness of the filtering depends on the composition of the sewage.

Sewage that is very fatty should be prepurified with the help of a flotation or other prepurification process. The following parameters have to be kept for an optimum biological decomposition of the organic sewage contents:

pH-value: 5-9;

Sewage temperature: 8-40 °C (ideal: 30 °C);

Nutritive substances: addition of nitrogen and phosphate in the case of insufficient nutritive substances;

Toxic substances should not exceed a limit as the decomposition only takes place in the case of low concentration.

The reactor can be installed inside and outside. Due to the complete encapsulation of the reactor, exhaust air treatment (e.g. with biofilter, peat or bark filter) is possible without complicated installations. An insulation of the reactor is advisable, if it is installed in locations with temperatures below 10 °C.

Layout of FBC-reactors

The layout of FBC-reactors, i.e. the dimensions of the container as well as the fixed bed, inclusive of the related components (pipelines, fan, compressor) depends mostly on the following parameters:

Hourly, daily and peak sewage volumes;

Qualitative specific sewage profile;

Efficiency and adaptability of the micro-organisms and nutrients used;

Statutory regulations for the inflow of the prepurified sewage.

Figure 3 shows the dependence between the reactor's efficiency and the volume load for different easily degradable industrial sewages.

Figure 2. FBC-reactor with upstream and downstream components

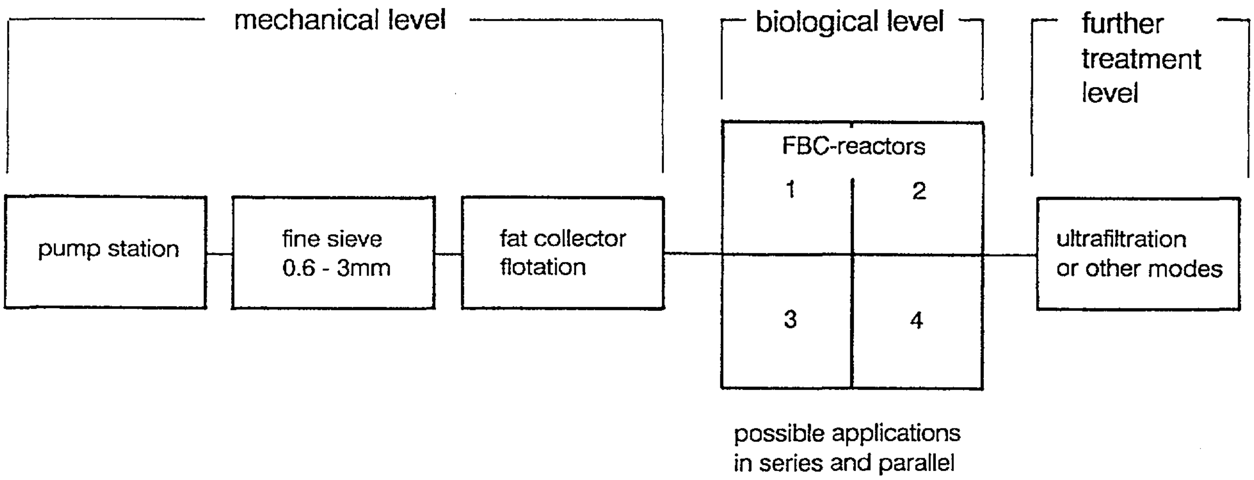
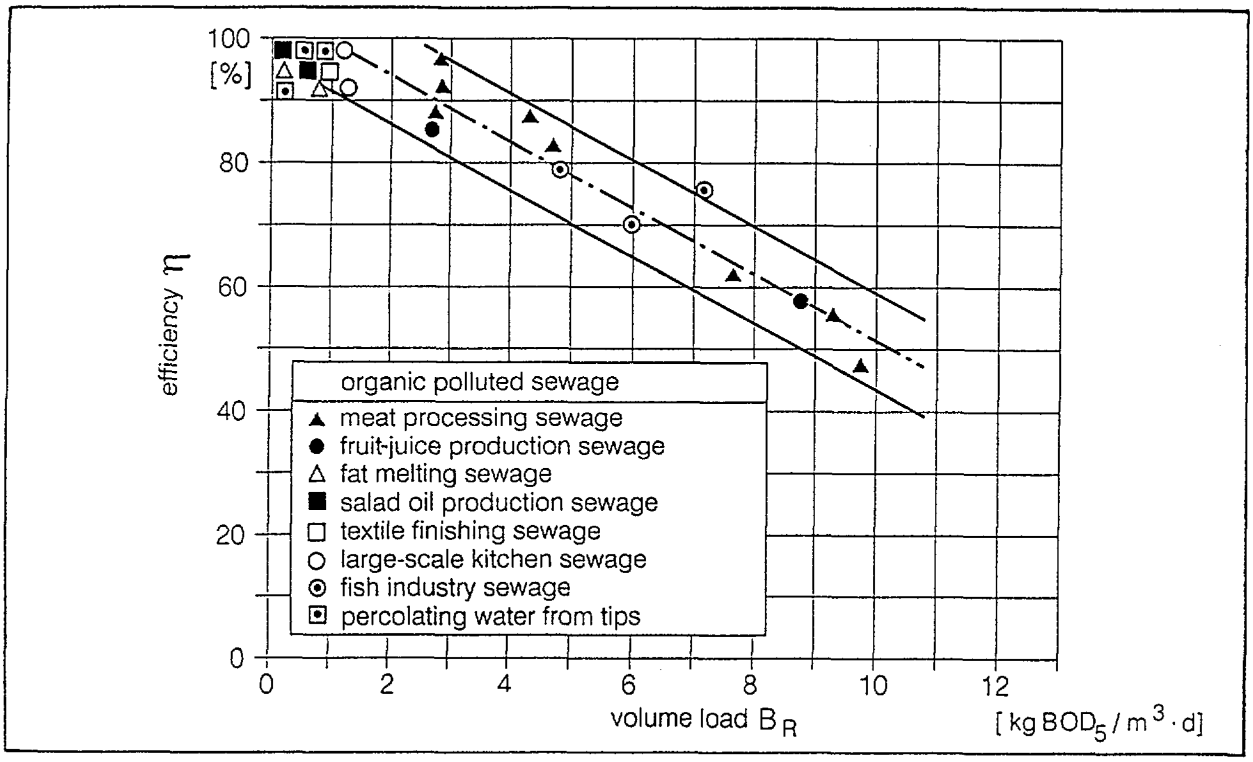


Figure 3. FBC-reactor efficiency rating chart



The design of bioreactors is in line with this degradation diagram. It must be ascertained whether the sewage that has to be prepurified, corresponds to the above-mentioned application examples and which grade of purification has to be aimed at in accordance with the statutory regulations.

If the sewage to be treated cannot be classified into one of those categories, further analysis is necessary. Normally, preliminary tests have to be conducted to minimize possible risks.

The specification for the FBC-reactor and the parameters for the sewage load are shown in table 1. Table 1 shows that FBC-reactors are constructed in dimensions of 3-50 m^3. The measurements of the container are also given.

Production process

The reactors are produced in the form of containers from stainless steel sheets. According to the container size support struts are necessary because of the structural requirements. These should be attached to the outside of the reactor. In order to guarantee the desired mobility, carrying and transport facilities have to be planned. The connections have to be simple and leakproof (i.e. DIN-flanged).

The supply industry delivers pipes in different sizes for the aeration and sewage inflow and outflow. The pipes should be made of rustproof material. If a shorter service period is accepted, it is also possible to use normal steel and to provide, if necessary, corrosion protection. The plastic packing to be installed in the container is also provided by supply firms. Instead of plastic packing it is possible to use normal materials (i.e. lignite coke or basalt stone beds) with large surfaces.

The aeration cylinders must also be supplied. They normally consist of fine-pored ceramic materials. Instead of these, fine-perforated pipes can also be used. It is important that as many air bubbles as possible are emitted with a low individual volume.

Table 1. Specifications and handling load of FBC-reactors

Effective volume	m^3	3.5	5.5	11.5	22.5	31.9	42.6	50.2
Length	m	2.45	3.65	3.90	3.90	5.40	7.15	8.40
Breath	m	1.45	1.45	1.45	2.65	2.65	2.65	2.65
Height	m	1.80	1.80	2.80	2.80	2.80	2.80	2.80
Transport weight	t	0.6	0.8	1.3	3.0	3.8	5.0	5.6
Operational weight	t	4.1	6.3	12.8	25.5	35.7	47.6	55.8
Connected load	kW	1.0	1.5	1.5	3.0	3.0	5.5	7.5
Max. hyd. load	m^3/d	35*	60*	120*	240*	360*	480*	600*
Max. BOD_5-load	kg/d	3-25**	5-40**	10-80**	20-160**	30-240**	40-320**	50-400**

*Dependent on the organic load and required efficiency.
**Dependent on the degradability of the contents.

The following equipment and machinery are needed for production:

Cutting and folding machines to cross-cut sheets and pipes;

Sheet bending machine for the shaping of the steel sheets;

Lifting gear, such as crane, rail or chain hoists;

welding tools to weld the steelpipe sheets and braces;

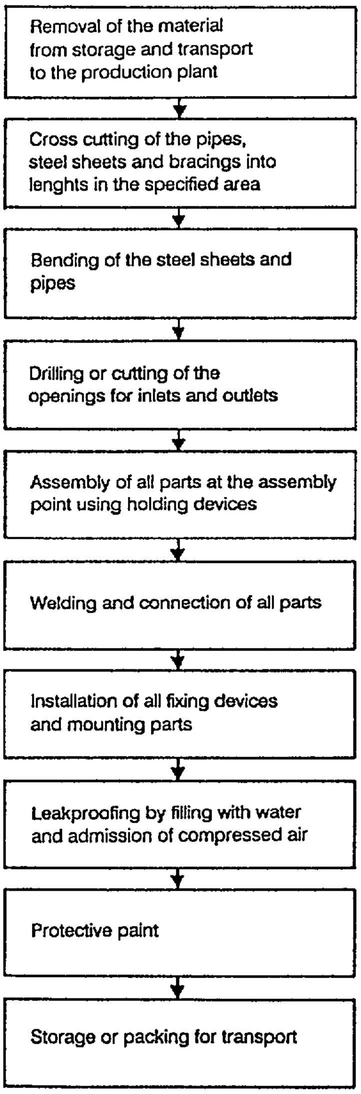
Drilling machines, cutting and grinding tools (cutt-off saw, flame cutter, angle grinder) and spray gun;

Variable assembly points and holding devices.

If stainless steel is used then the finished parts have to be pickled in a special plant (waste disposal problems arise during pickling). If materials other than stainless steel are used the container must be given a protective coating.

The flow chart (figure 4) shows the most important production steps. The technical requirements for producers who want to produce FBC-reactors are similar to those of a construction engineer. Special knowledge is necessary in the field of process and analytical techniques and metal working, especially welding.

Figure 4. Processing flow chart



Examples for different scales of production plants

The following machines and equipments are needed for the different yearly outputs:

Required machinery and equipment

	Pieces		
	Quantity of FBC-reactors/year		
Description	*25*	*50*	*100*
Cutting and folding machine	1	1	2
Plate shears	1	1	2
Folding press	1	1	1
Folding machine for sheet metal	1	1	1
Folding machine for profiles	1	1	2
Crane installation	1	1	3
Welding devices	2	3	2
Flame cutter	2	3	3
Drilling machine	2	4	4
Grinding tools	2	4	4
Spray gun	2	4	6
Extraction and cleaning equipment	—	—	1
Assembly point for painting	1	3	5
Set of tools	1	2	4
FOB-price for machinery and equipment Approx. US$	208,000	210,000	250,000

Required manpower

	Quantity of FBC-reactors/year		
	25	*50*	*100*
Management and administration	3	4	5
Technical manager	1	1	2
Engineer	1	1	3
Skilled workers	3	5	9
Semi-skilled workers	3	6	9
Quality control and maintenance	—	—	1
Chemical engineer	—	—	1
Total	11	17	30

Required area

	Quantity of FBC-reactors/year		
	25	*50*	*100*
Administration	50	50	100
Production	450	650	800
Painting	200	200	200
Storage	400	600	800
Total (in square metres)	1 100	1 500	1 900

Required energy

Electric power (25 units)	50 kW
Electric power (50 units)	75 kW
Electric power (100 units)	100 kW

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

Conventional type separator for light liquids

Introduction

Light liquids are fluids with a lower density than water (up to 0.95 g/cm^3), that do not usually dissolve in water; they include petrol, diesel and fuel oils, filter oils and other oils with mineral origins. These fluids do not include emulsions or grease and oils from plants or animals.

The aim of the separator is to separate and hold back, solely by means of gravitational force, light liquids from water in order to prevent pollution of the soil, waterways and ground water.

Light liquid separators are used in plants which maintain, refuel and clean vehicles, and in plants which store, rack and load motor fuels, oils or lubricants as well as store and load materials involving mineral oils. The market for such separators is very large.

Areas of application include the following:

Petrol stations;

Washing facilities for motor vehicles;

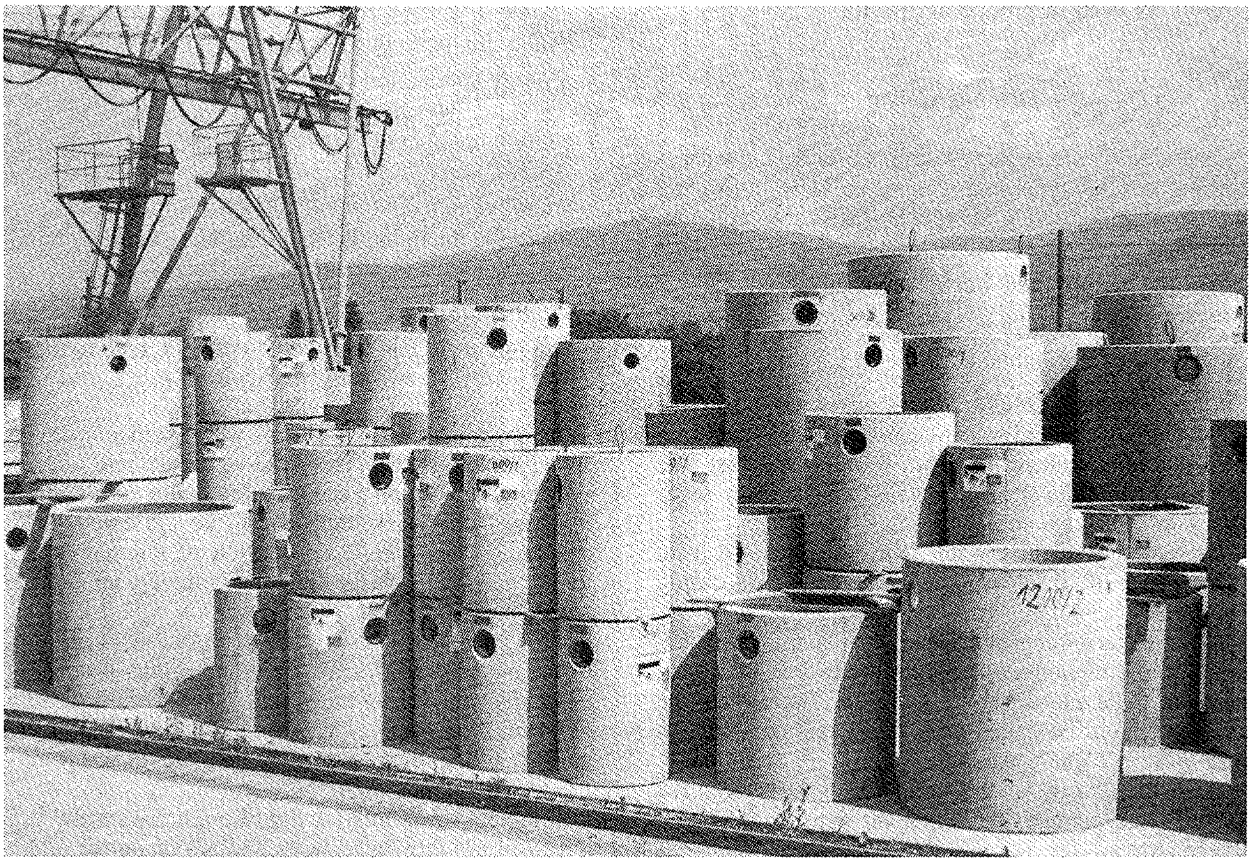
Workshops for cars, lorries, busses, cranes, building machines, agricultural machines, trams, railway vehicles (rolling stock);

Storage and loading stations for petrol, diesel and fuel oil.

Description of the product

Separators of light liquids, which work according to the principle of gravity, are appliances for the removal of free oil from water. Free oil is oil in the form of small drops that, because of its low density, rises to the surface of the water from where it can then be mechanically removed.

Such a separator consists usually of a superposed *sludge trap,* in order to hold back depositable materials, and the actual *separating chamber,* in which the light liquids are separated and collected until removal. Sometimes, however, a special storage tank is attached.



To increase the safety of the unit the separator is fitted with an automatic seal. The point of this device is that, when the storage limit has been reached, the separator outlet is closed down automatically, in order to prevent unpurified fluids entering the waste water.

All parts of the separator must be made of durable and non-inflammable materials. Pipes, connecting pieces and sealing materials, as well as the inner surfaces of the separator must all be resistant to light liquids. The separator is made either of cast iron, impermeable concrete, coated steel or stainless steel.

The fluids should pass through the separating chamber at a constant rate to prevent an escape without separation or a stirring-up of the separated light liquids. Two points are of particular importance, namely:

The time, that the fluids are in the separator; the greater the quantity of flow, the longer the time;

The surface area of the separator; this should increase proportionally to the quantity of flow.

Furthermore, light liquids should be prevented from flowing back into the inlet pipe as well as entering the outlet pipe.

Concerning the design of the separator, there are two basic possibilities: either separate units for the sludge trap and separator/oil storage chamber; or integration in one unit (steel or concrete container). In addition a difference is to be made between:

Underground installation (in petrol stations, washing facilities, workshops, etc.); here a concrete construction is necessary, i.e. the steel elements are put into a concrete chamber; for very small units cast iron can also be used;

Free-standing construction in steel (coated or stainless), as used in production plants.

Dimensioning

The size of the separator is to be dimensioned according to the type and volume of the in-flowing liquids. The following should be taken into consideration:

Volume of rain and waste water;

Density of the light liquids;

Volume of the light liquids.

Concerning the volume of rain-water, only the rainfall on the working area in question is to be taken into consideration. Rain-water from roofs and yards, free from light liquids, should be able to flow away separately into the sewerage system.

The volume of dirty water is to be calculated from the amount of dirty water actually occurring during operation.

When determining the size of the separator, the actual volume of rain-water should be taken into consideration, whereas in the case of the dirty water the volume should be counted twice, as this contains the light liquids to be separated.

Also the density of the light liquids influences the size of the separator: the higher the density, the larger the separator.

For further details concerning conditions, principles of construction or size calculation see for example DIN 1999 and DIN 4043 or comparable standards.

In order to guarantee a constant flow through the separating chamber and maintain the longest possible period in the separator to achieve the highest possible separating effect, the surface of the separating chamber should be a certain size in area and the width should be in relationship to the length, according to certain values.

These values will be influenced by the prescribed degree of separation to be achieved, in particular so that the surface area will increase in proportion to the quantity of flow.

The same separating effect can, however, also be achieved through appropriate constructional measures in the separator, which makes smaller measurements possible.

In the case of the conventional separator the storage capacity is determined by the total size of the separator. The storage capacity cannot be adapted to the volume of light liquids; the latter can only determine the period of time before the separator is emptied.

The size of the superposed sludge trap varies according to the actual amount of sludge. This can be classified as follows:

Small

Waste water with a defined small amount of sludge;

Rain-water catchment-areas without wear and tear from roads and traffic;

Medium

Petrol stations;

Washing facilities for cars and busses;

Repair workshops;

Areas for parking vehicles;

Energy production plants;

Machine factories.

Large

Washing facilities for lorries;

Washing facilities for building-site vehicles, building machines, agricultural machines.

Design and function of concrete separators for light liquids

Because of the similarity of the design of conventional separators for light liquids, grease and oil, and starch, and also on account of the use of the same materials, only one material will be presented in the following. However, a description of alternative materials can be found in the corresponding sections on other separator types.

Moreover, it is important to point out that according to the material used, and depending on the production technique employed there will be different minimal sizes of production. This can be clearly seen in the corresponding section dealing with the example of a production plant.

Concrete separators for light liquids are mostly produced in pre-fabricated units and are made for underground installation. In the simplest form they are offered in an integrated or two chamber design, in which the first chamber serves as the sludge trap and the second as the separator.

The conventional two chamber unit consists of two separate, rectangular or circular concrete parts, each of which is covered by a concrete slab with an opening for entry; on these, tubbing rings rest up to the surface level. The units must be completely water-tight and oil resistant. Both units are sealed by cover slabs with entry and ventilation openings.

Every unit should be linked up to a sampling manhole, so that it is possible to control the liquids flowing off.

The first chamber is the sludge trap, which has an elbow-shaped inlet pipe for better sedimentation. The diameters of the inlet, of the outlet and of the connecting pipes are all the same; the diameter is calculated according to the maximum amount of water flowing in.

From the sludge trap the liquid, now free of solid particles, goes into the separator. A downflow baffle at the inlet prevents the possibility of an oil backflow. At the outlet a float has been built in as an automatic stop, to prevent the flowing off of untreated liquids in the case of a full storage chamber.

When the storage chamber is full, the separator must be pumped empty, so that it can then start functioning again fully. The sludge trap is also to be emptied at regular intervals. The liquids removed from the separator are to be disposed of properly.

Coalescence separators

Gravitational separators are able only to a restricted degree, on account of the short time that the liquid is in the separator, to achieve high separating values, or to remove dispersed oils. A dispersion occurs, when oil is divided into fine drops as a result of mechanical stress in pumps or through high-pressure cleaners. These fine drops float in the water, a separation takes place only very slowly. Coalescence separators support this separation, by causing the light liquid drops, finely distributed in the water, to unite into separable drops.

Coalescence separators are usually added to the traditional separator units, but can also be integrated into the separator.

For a coalescence separator various models are possible: either as a parallel plate pack or corrugated plate pack separator, in which the separated oil drops rise to the surface of the water on the under side of the plate pack, which is built in at an angle, or, more popular today, through the introduction of a coalescent material out of small plastic parts, or a filter membrane, in the second separating chamber.

This separator also should be regularly pumped out, preferably at the same time as the first separator, and the filter membrane should be cleaned. The contents pumped out of the separator should be disposed of properly.

Figure 1 illustrates a complete conventional separator unit, consisting of four units: the sludge trap; petrol and oil separator; coalescence separator; and the sampling manhole.

If the waste water contains materials which impair the separating capability of the light liquids or which act in an emulsifying way, then special units, for example, an emulsion separating unit, should be added to the gravity separators.

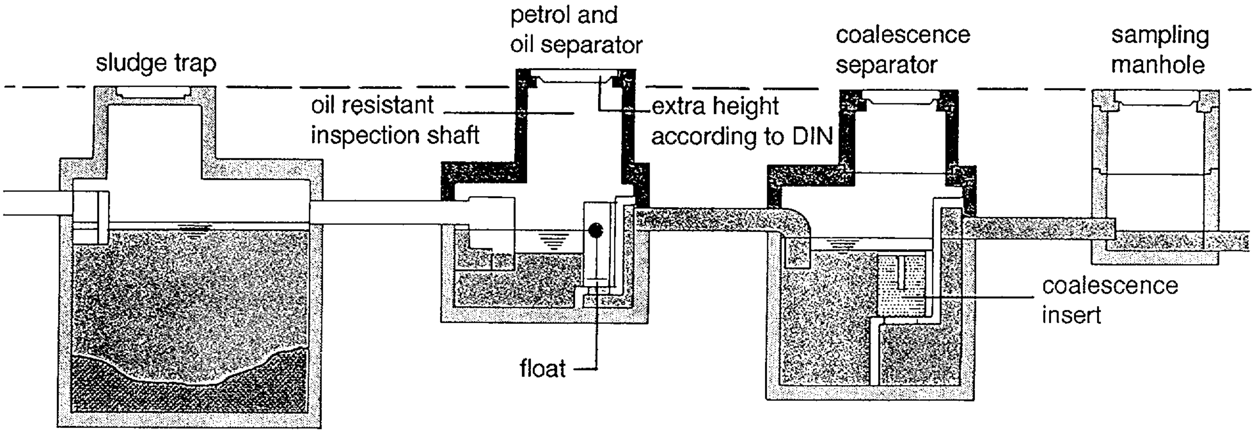
Furthermore, it should be taken into consideration that when cleaners are used, in particular cold cleaners (e.g. deprocessors, floor cleaners, other cleaning materials) these cleaners must not inhibit the separation process.

Description of the production process of concrete separators

Normally for the chambers monolithic reinforced concrete containers are used, i.e. circular or rectangular containers of various sizes made in one piece. These can either be obtained from a concrete factory, made according to a prescribed design, or they can be self-produced.

If the concrete containers are acquired from outside, the separator producer concentrates on the insertion of the pipe ducts (in so far as these have not been inserted during casting at the concrete factory), for which a diamond drill is necessary, on the fitting of the inlet

Figure 1. Conventional separator unit



and outlet pipes, the baffles and the float, or of the coalescence element.

The cover and shaft rings are not fitted until on the building-site.

If the concrete containers are self-produced, then it should be taken into consideration that in the production of light liquid separators a concrete mixing plant is not by any means utilized to the full. For this reason a concrete factory will only produce separators as an additional element to its current programme, although it is usual for parts of the underground structures programme to be used also for the separator programme.

Figure 2. Pre-production of concrete separator

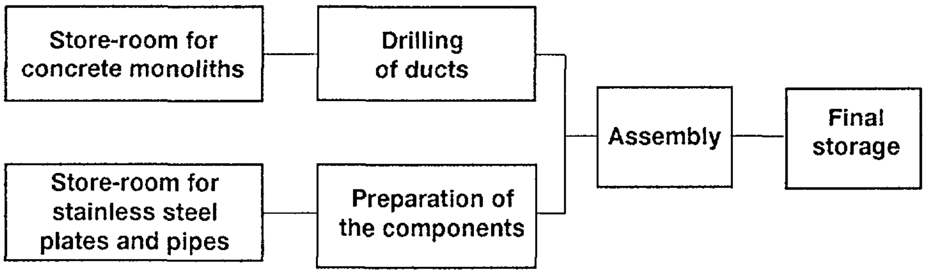
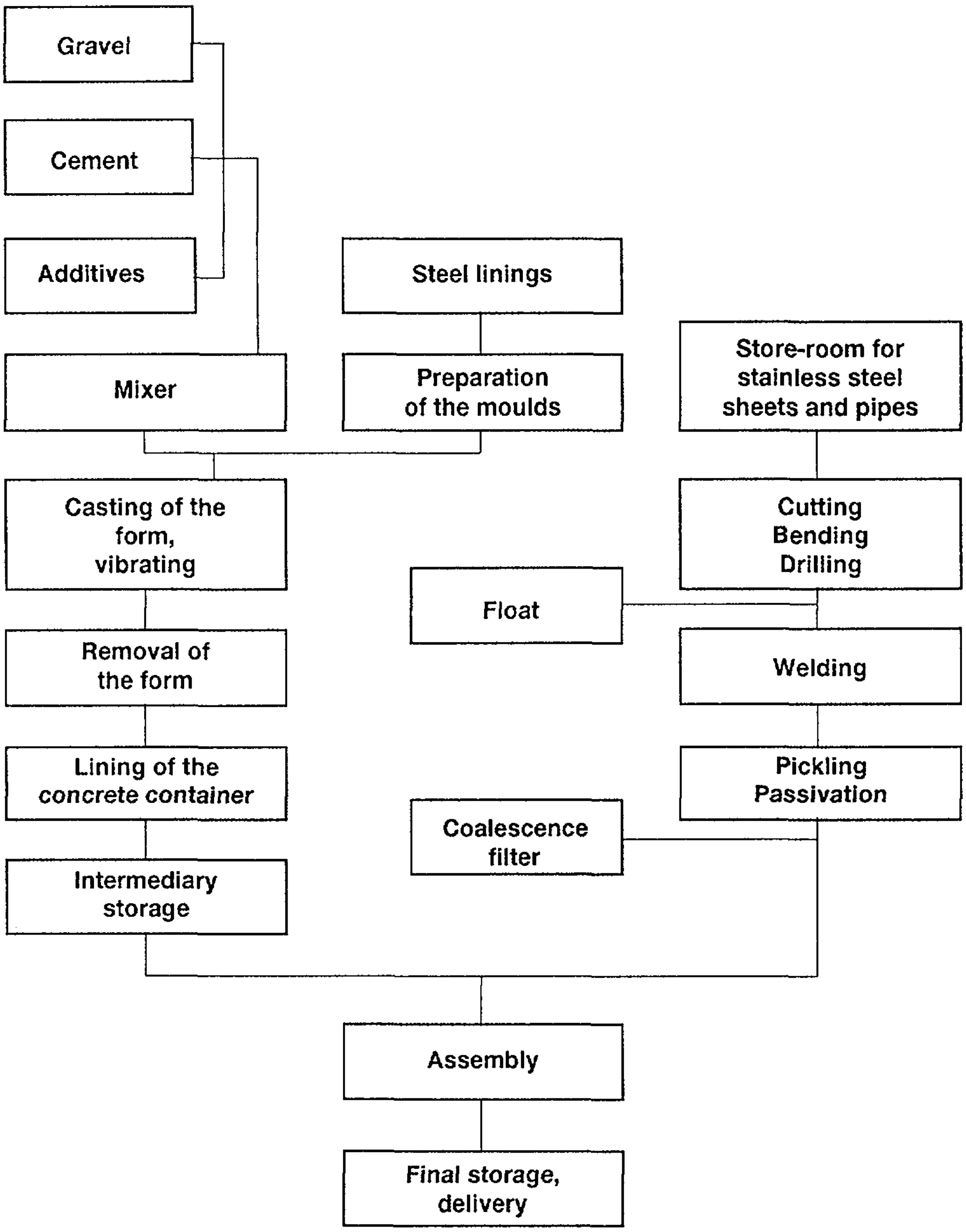


Figure 3. Production and assembly of a conventional separator unit



As it leaves the mixer, the concrete made out of gravel, cement and additives (to achieve watertightness) is poured, with the help of a crane and large-size pouring ladle, into the prepared forms and is then compressed by means of a jarring moulding machine. "Prepared forms" means that the steel reinforcement and the channels for the pipe ducts have been put into place. When the cement has set, the containers are lined with a light liquid resistant material (paint-brush or roller) and are then brought to the intermediary storage area.

The final stage to complete the separator only occurs according to demand. Then in the metal workshop the baffles for the sludge trap, oil or coalescence separator, are cut to shape out of stainless steel sheets, bent into the necessary form and provided with the holes required for assembly. The inlet and outlet pipes, or the elbow-shaped pipes, are cut to length, and the float, ordered from outside, is welded to the outlet waste pipe.

These prepared parts are built into the concrete sections; the baffles and coalescence filters (obtained as pre-fabricated units) are fastened with dowels, and the inlet and outlet pipes are plastered in.

The completed containers are brought to the building-site by special lorries and are mounted there in the intended position. This assembly work can be carried out either by the people on the building-site or by the separator producer.

Example of a production plant

Production of 40 units of various sizes (flow of up to 30 l/sec) per week, whereby each unit consists of a sludge trap, separator and sampling manhole. This is a hypothetical value, made, assuming that the mixing plant is working at full capacity and only producing separators. In reality a concrete factory has a diversified production programme (e.g. pipes, shaft rings, shaft covers, cones, pump and filter shafts), only a small part of which is devoted to separators.

The use of a mixing plant makes it almost impossible to reduce capacity. Only manual working allows a smaller capacity.

In conclusion it should be said, that the same moulds can also be used for the production of grease and starch separators, as these are indentical in their basic design.

Required machinery and equipment

Description	*Pieces*
Gravel silo	1
Cement silo	1
Concrete mixing plant	1
Casting moulds with vibrator	10
Hand percussion drill	1
Fork lift truck (8 tonnes)	1
Crane	1
Lorry with its own lifting tackle (8 tonnes)	2
FOB-price for machinery and equipment (1990)	Approx. US$ 1,200,000

Required manpower

Management and administration	4
Technical manager	1
Engineer	1
Sales personnel	3
Skilled workers	4
Unskilled workers	5
Maintenance	1
Lorry drivers	2
Total	21

Required area

	Square metres
Concrete mixing plant	200
Production	400
Covered storage (delivered goods)	110
Open air storage (completed units)	500
Maintenance	40
Administration and social rooms	150

Required power and utilities

Electric power	100 kW
Water	3/4'
Gas (resp. oil) (winter heating)	

Required components and raw materials

	Tonnes/week
Steel linings	10
Gravel	250
Cement	40
Lining material	
Parts for assembly/delivered parts	

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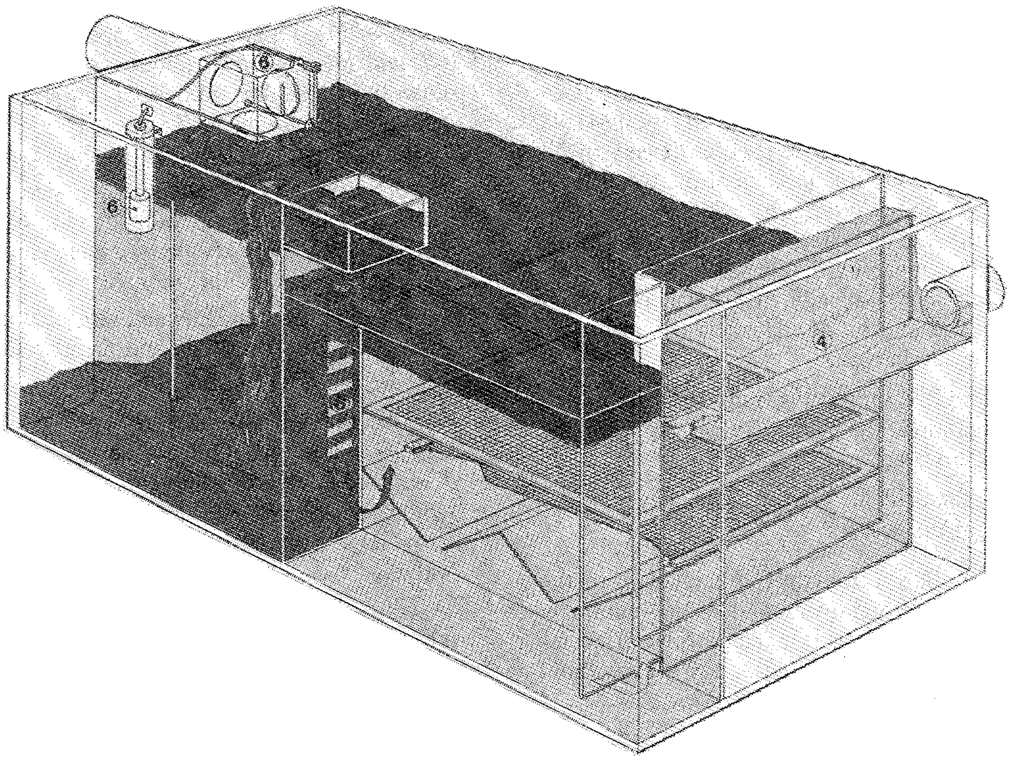
October 1990

How to Start Manufacturing Industries

High performance separator for light liquids



Introduction

Light liquids are fluids with a lower density than water (up to 0.95 g/cm^3) that do not usually dissolve in water; they include petrol, diesel, fuel oils, filter oils as well as other oils with mineral origins. These fluids do not include emulsions, or grease and oils from plants or animals.

The aim of the separator is to separate, by gravitational force, light liquids from water in order to prevent pollution of the soil, waterways and ground water.

Light liquid separators are used in plants which maintain, refuel and clean vehicles, and in plants which store, rack and load motor fuels, oils or lubricants as well as store and load materials involving mineral oils. The market for such separators is very large.

Areas of application include the following:

Petrol stations;

Washing facilities for motor vehicles;

Workshops for cars, lorries, busses, cranes, building machines, agricultural machines, trams, railway vehicles (rolling stock);

Storage and loading stations for petrol, diesel and fuel oil.

In addition there are the following special areas of application:

Metal industry;

Machine building;

Vehicle building;

Refineries, petro-chemical industry;

Mining;

Shipbuilding;

Plants for the production of energy.

In machine and vehicle production, as well as in the car industry, metal sheets, metal parts, machines and machine parts, for example, have to be cleaned and degreased before further processing or assembly. The cleaning fluid is then processed in order to avoid polluting the waste water and to enable a recirculation of the cleaning fluid, which in turn lowers the costs.

The processing of the dirty cleaning fluid usually involves several stages, whereby the gravitational oil separator forms the first phase. To achieve a greater cleaning effect the following can also be included in the process: centrifuges, ultrafiltration, thin-film evaporators, etc.

Description of the product

Separators of light liquids, that work according to the principle of gravitation, are appliances for the removal of free oil from water. Free oil is oil in the form of small drops. Because of its low density it rises to the surface of the water from where it can then be removed.

A separator usually consists of a superposed *sludge trap,* in order to hold back depositable materials, and a *separating chamber,* where the light liquids are separated and collected until removal. Sometimes, however, a special storage tank is attached.

The most modern separator, that is patented, is characterized by the fact that it does not need any movable parts. The system uses the difference in density of oil and water as well as the fluctuations of the water level for hydraulic pumping processes, which continually pump off the oil free of water. Every alteration in the flow (putting the apparatus into operation, operation, standstill) results automatically in the water-free discharge of oil. The density of the oil is useful in two respects for the discharge:

When putting the apparatus into operation, and when in operation, by having an oil layer on the surface of the water;

When at a standstill, by having an oil layer below the surface of the water.

The oil flows into a container separated from the water; it cannot be carried over and does not require an automatic cut-off valve. The collected oil can be removed from the storage container at any time without disturbing the operation of the separator.

With this system it is possible to achieve for free oil very high separating values of up to almost 100%.

The main characteristics of this modern separator, as shown in figure 2, are:

In the event of a full oil storage chamber or a greater oil spillage the inlet is closed by means of a valve (7), thus protecting the sewerage system and the main canal. (When the full amount is reached, no float is required to cut off the system.)

High separating results from the coalescence effect caused by the hydraulic action, thereby making it unnecessary to clean or exchange clogged up filters.

Integration of the sludge trap (13), multi-functional chamber (1), separator (2), inspection compartment (4) and oil storage chamber (6) in one container; thus the separator will need only a very small amount of space.

Separate oil storage chamber, which can be adjusted to actual need, independent of the size of the separator. Thereby longer periods of time between each emptying, and the execution of each emptying without interruption of operation.

Fine sediments, paraffins and other harmful materials stick to the oil drops and thereby flow directly into the oil storage chamber (6).

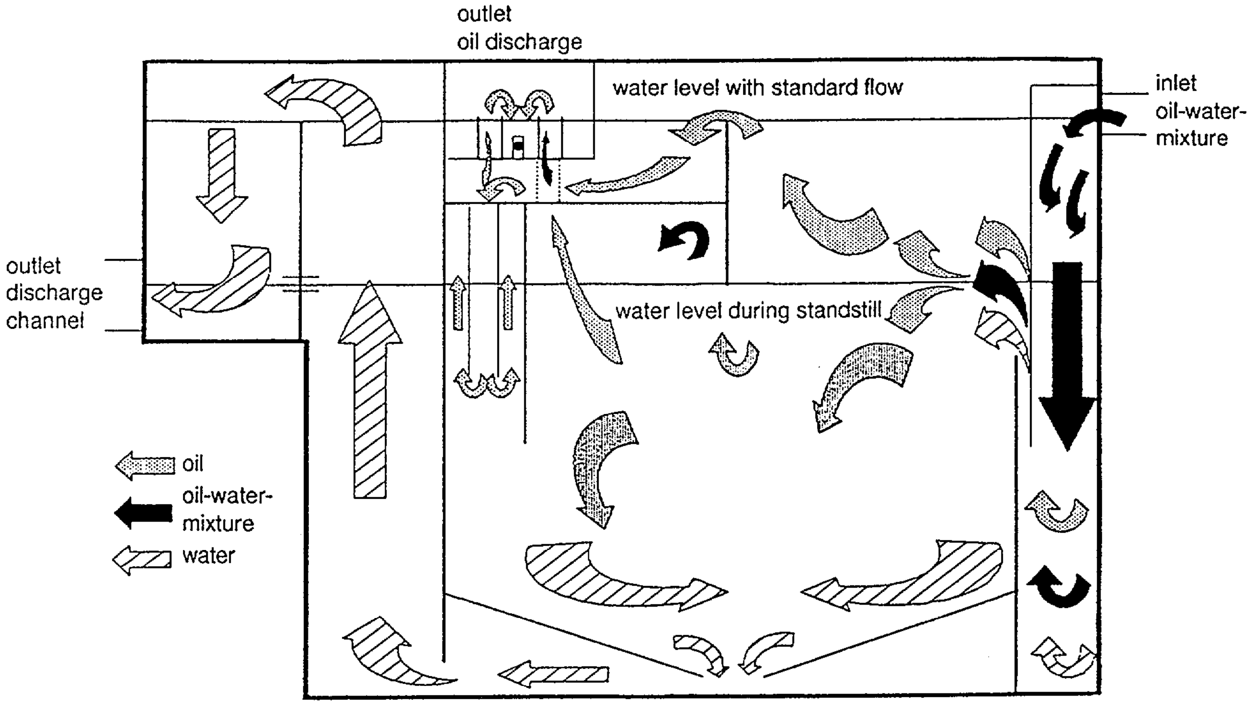
Low costs for emptying, as only the water-free oil is pumped off.

Clear separation of rough and fine sedimentation within the separator; the rough separator chamber also takes on the function of the oil backwash safety valve.

A constant flow of the oily waste water over the entire width of the baffle by means of turbulence breakers in the inlet section.

The coalescence action of the separator can be increased by inserting (also at a later stage) filling material.

Figure 1. The principle of a modern light liquid separator



The following materials can be used for the containers: steel, coated, or stainless steel for free-standing position; and reinforced concrete for underground installation, namely in the form of monolithic rings. The individual elements, to be built in, are exclusively made out of stainless steel.

Dimensioning

The size of the separator depends on the sort and actual amount of waste water. The following factors have to be considered:

Volume of rain and waste water;

Density of the light liquids;

Volume of the light liquids.

In the case of the volume of rainwater only the actual working area should be taken into consideration. Rainwater from surfaces, free of light liquids, should be directed separately into the sewerage system. The volume of waste water results from the sum of all the sources of waste water.

When calculating the size of the separator the volume of *rainwater* should be considered at its actual amount, whereas the volume of *waste water* should be considered two-fold, as the light liquids to be separated are contained in it. The density of the light liquids also has an influence on the calculation of the size of the separator: the higher the density values, the larger the size of the separator.

Because of the integrated space-saving method of construction and of the special design only a few standardized sizes are needed for the separator.

The size of the oil storage tanks, in the case of a high performance separator, no longer depends upon the dimensions of the complete separator, but can be adapted according to the volume of the light liquids to be separated and the period of time between each emptying. Of prime importance are suitability and rentability.

Construction and function of high performance separators for light liquids

Concrete design

These separators are produced to a certain size in pre-fabricated units and are intended for underground installation. They are offered in an integrated design, whereby the separator is built into a monolithic concrete container which is reinforced to prevent cracking and lined with a material resistant to light liquids. The container is sealed with a reinforced concrete cover plate which has two openings on which two shaft rings with shaft covers are mounted.

The separator, made entirely of stainless steel, is built into these monoliths. The resulting separator system is distinguished by the following:

Integrated sludge trap;

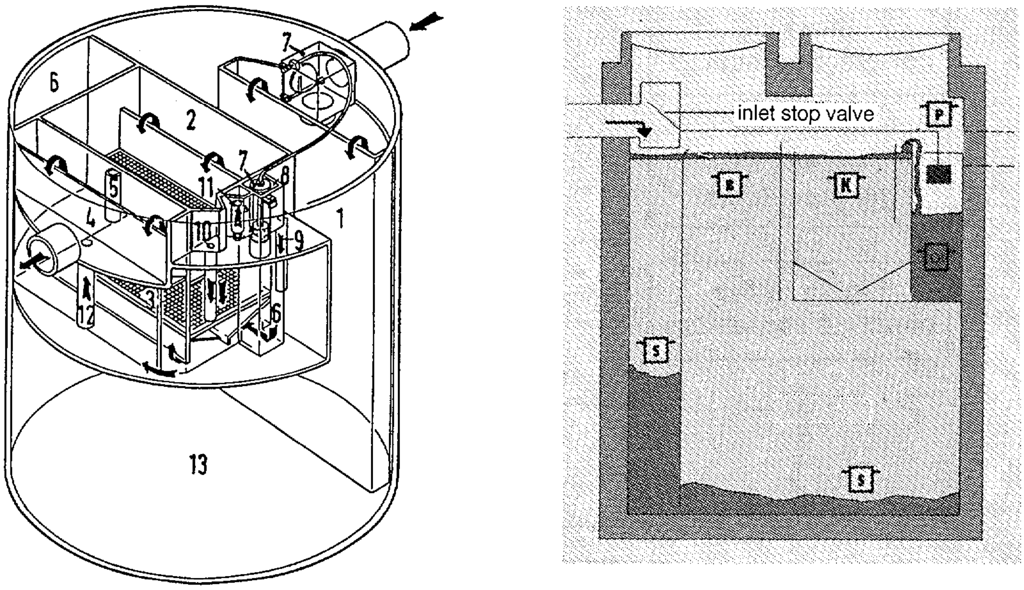
Oil backflow safety valve;

Automatic water-free oil discharge;

Integrated oil storage container with an opening for emptying;

Integrated sampling manhole.

Figure 2. High performance separator



Key:

1 multi-purpose chamber
2 separating chamber
3 chamber with tilling material
4 outflow channel/sampling possibility
5 separator ventilation
6 oil storage tank ⩾ 250 litres
7 inlet stop valve with oil float control

8 opening for emptying of the oil
9 oil-water-dip pipe antechamber
10 oil-water-dip separator
11 oil release pipe (adjustable)
12 dip pipe outflow channel
13 sludge trap ⩾ 5000 litres, integrated

S sludge trap
B petrol separator
K coalescence separator
P sampling possibility
Oil oil storage tank

The waste water flows through an elbow-shaped inlet pipe, which has an inlet stop valve, into the multipurpose chamber, which serves as a rough sludge trap. After flowing over a baffle the liquid reaches the separating chamber, where the light liquids float and the remaining solid particles sink.

The remaining liquid flows through the chamber intended for the filling material, whereby further separation is achieved.

The separated light liquids from the separating chamber and the chamber intended for the filling material are pumped hydraulically into the oil storage tank, from where they can be pumped off at certain times through an opening.

When the oil storage tank is full, the inlet stop valve automatically closes by means of a mechanical unlocking device: stopping the inflow into the separator.

The sediments in the multi-purpose chamber, and in the separating chamber, are pumped off at regular intervals and sediments and light liquids are disposed of in the proper manner.

Figure 2 shows the high performance separator built into a steel concrete shaft.

Steel design

In contrast to the concrete design this separator is built into a rectangular steel casing, which is either made of stainless steel or - in the case of steel being used - is lined with a material resistant to light liquids. This type of construction is intended to be used in a free-standing position.

Description of the production process of high performance separators for light liquids

Concrete design

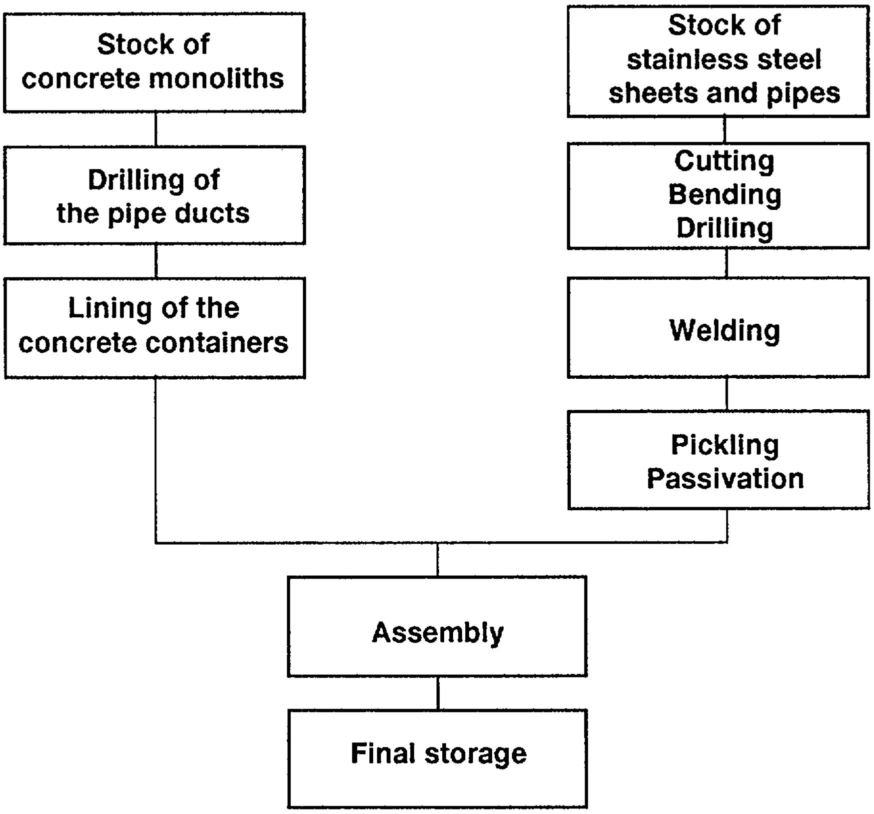
The cylindrical monolithic reinforced concrete containers are made according to prescribed design, and obtained from a concrete factory. The separator producer has to add the necessary pipe ducts for which a diamond drill is required. He also has to line the concrete containers with a material, which is resistant to light liquids.

For the actual separating system the stainless steel plates, ordered from an outside firm, have to be cut and bent to required sizes and shapes, and the holes for the pipe ducts and pipe connections have to be drilled or cut out. Equally, the necessary pipes, also obtained from an outside firm, have to be cut to the required lengths.

The stainless steel sheets are welded together and the inlet, outlet, overflow and elbow-shaped pipes are welded into the container. The inlet and outlet pipes are prepared for sleeve coupling.

The completed stainless steel separator is built into the prepared concrete container; the inlet and outlet pipes are then put in and welded to the built-in separator. Finally the pipe ducts are sealed.

Figure 3. Pre-production of a high performance separator



Stainless steel design

The stainless steel sheets, the thickness of which is determined by the size of the separator, are cut to given sizes on a cutting machine and by means of a bending press are brought into the required shapes; the necessary holes for the pipe ducts and pipe connections are cut out with a flame-cutter. The sheets are welded together and the prepared inlet and outlet pipes, fitted with flanges, are welded in.

The completed separator unit (see concrete design) is built into the stainless steel container. Finally the whole unit is pickled and passivated (bath or brush).

Example of a production plant for stainless steel separators

In the case of medium sized separators, heavy fork lift trucks (> 5 tonnes) are required for transportation within the plant; for large-size separators a crane is unavoidable.

Required machinery and equipment

Description	*Pieces*
Cutting machine (up to 4mm thickness)	1
Bending machine (up to 4mm thickness)	1
Flame-cutter	1
Bow-saw	1
Workbenches with tools	2
Welding apparatus	2
FOB-price for machinery and equipment (1990)	Approx. US$ 100,000

Required manpower

Commercial manager	1
Technical factory manager	1
Skilled workers	3
Unskilled workers	2
Draftsman	1
Administration	1

Required area

	Square metres
Production area	200
Storage	
Material (covered)	100
Finished parts	500
Administration and facilities	100
Free space	1100

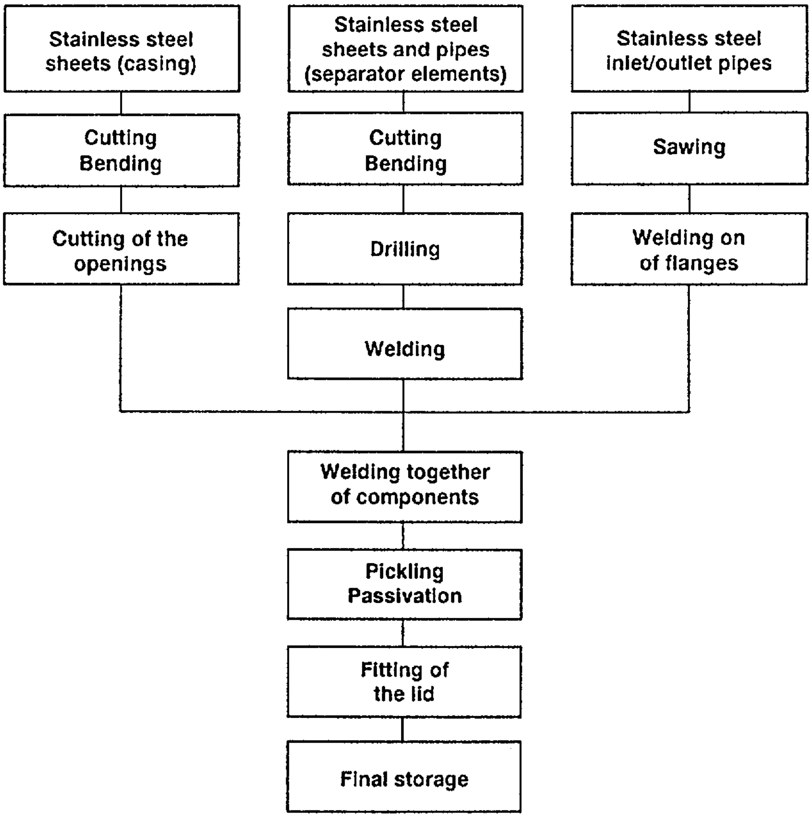
Required power and utilities

Electric power	100 kW
Water	
Acetylene cylinders	
Oxygen cylinders	

Required inputs

Stainless steel sheets
Stainless steel plates
Stainless steel pipes and elbows
Welding electrodes

Figure 4. Production and assembly of a high performance separator



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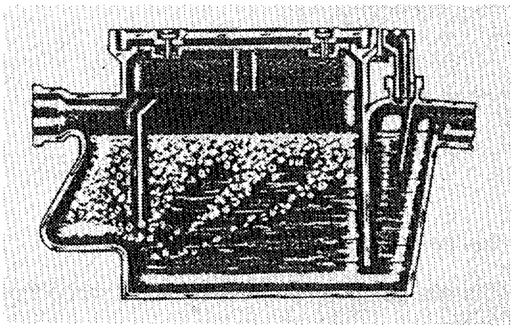
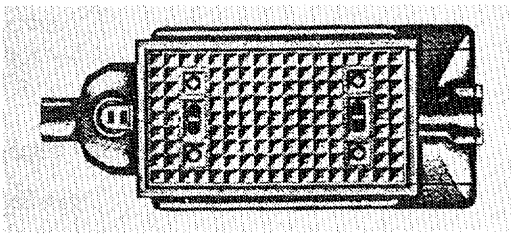
File: Z 6
ISIC CODE 9000
October 1990

How to Start Manufacturing Industries

Separator for organic grease and oil





Introduction

Organic grease and oil stem from animals or plants; they are not, or only slightly, soluble and saponifiable in water. Animal grease includes for example suet, butter, lard, grease and oil of bones, wool fat, blubber and fish oil. Vegetable fat and oil includes olive oil, linseed oil, hemp-seed oil, nut and kernel oil, palm oil and margarine.

It is the aim of the separator to separate and hold back organic grease and oil from waste water because they solidify, while cooling, and settle on the pipe walls. Through binding other contaminants they can cause an obstruction and finally a blockage. Besides this, they quickly start to decompose, forming aggressive fatty acids and producing a dreadful smell. Separators for organic grease and oil are used in trading and industrial enterprises, as for example:

Kitchens of restaurants, hotels, canteens etc.;
Hot meal services, where the plates and dishes are returned;
Butchers;
Meat factories;
Abbatoirs;
Gut preparing factories;
Carcass utilization works;
Bone and glue boiling factories;
Soap and stearin factories;
Fish utilization works;
Oil mills;
Edible oil refineries;
Margarine factories;
Tinned goods factories;
Producers of ready meals;
Plants producing potato chips and crisps;
Peanut roasting plants.

Separators for grease and oil can only be used to a certain extent in dairies and cheese producing factories. Also, for fish utilization works, special criteria have to be observed; parts of grease can take an emulsified form, thus requiring special emulsion separating units. At the same time quickly rotting sediments can be contained in the waste water, thus preventing the use of a sludge trap. Rough particles should in this case be held back by sieves, built-in in front of the separator.

Product description

A separator for organic grease and oil normally consists of a *sludge trap* and the actual oil *separator.* The waste water first runs through the sludge trap, in which the sediments settle. The partially cleaned water then enters the grease separator, where grease and oil are eliminated. As both are lighter than water they rise to the surface. Within the grease separator a grease collection chamber is formed by baffles separating the collecting space from the inflow area (to prevent a backflow) and the discharge area (to prevent any oil spilling into the sewage system). The flow through the separator should be even.

Materials used for casing as well as for fitted parts are:

Cast iron (only for small sizes);
Steel or stainless steel;
Concrete;
Certain plastics.

Materials, which are not resistant against waste water at temperatures up to 70° C, must be given a lasting protection by relevant coatings, linings etc.

For separators of simple design the basic construction is the same as for separators for light liquids or starch; that is why firms normally offer all three types of separators at the same time.

Figures 1 and 2 show two different grease separators; they can be rectangular or round, undivided or divided into two pieces, free-standing or made for underground installation.

Figure 1. An undivided, free-standing separator

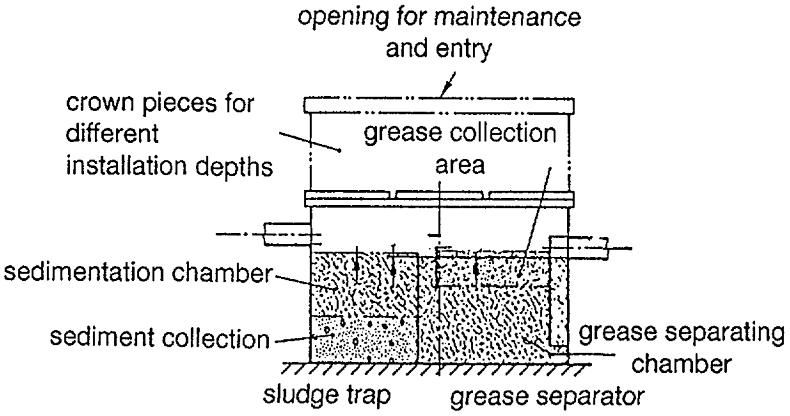
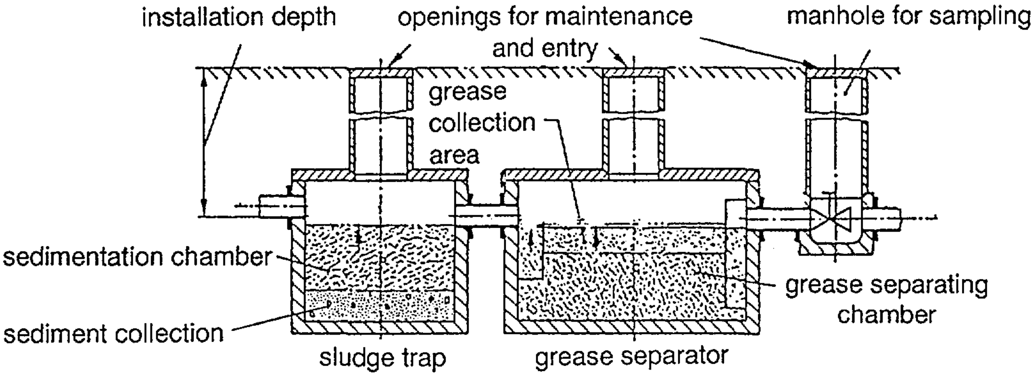


Figure 2. A divided separator for an underground installation



The efficiency of the grease separator depends on the surface area between the two baffles, the collection capacity therefore is depending on the depth.

Dimensioning

The size of the separator depends on the sort and actual amount of waste water.

The following factors have to be considered:

Volume of waste water;

Density of grease to be separated;

Temperature of waste water;

Influence of rinsing and cleaning materials;

Amount of grease and floating materials to be separated.

The volume of waste water results from the sum of all the various waste water sources. To determine the size of the separator, those factors, which make the process of separation more difficult, have to be considered. This is done by multiplying the volume of waste water by the various aggravating factors.

The aggravating factors are:

Density factor of the relevant grease material;

Factor of higher temperature;

Factor of the influence of rinsing and cleaning materials;

Factor of extraordinary masses of grease and floating material.

These aggravating factors have the value 1 under usual or standard conditions. They become > 1 (but stay < 2):

With increasing density of the grease material;

With increasing temperature;

With the adding of rinsing and cleaning materials;

With the increasing amount of grease material.

The aggravating factors increase the size of the unit and therefore prolong the time of the waste water in the separation area.

Instead of the calculation described, simplified calculation methods can be used in frequently occurring cases, as for example meals portions, livestock units.

For further details concerning conditions, principles of construction or size calculation see for example DIN 4040/4041 or comparable standards.

Before being used for the first time, the sludge trap and grease separator should be filled with water. Both should be emptied and cleaned regularly.

Construction and functioning of cast iron separators for organic grease and oil

Because of the similar basic construction of separators for grease and oil, light liquids and starch, as well as the use of the same materials, only one material is presented in the following. The descriptions of alternative materials can be found in the corresponding sections on the other separator types.

Moreover, it is important to point out that according to the material used and depending on the production technique employed, there will be different minimal sizes of production. This can be clearly seen in the corresponding section dealing with the example of a production plant.

Cast iron separators for organic grease and oil are usually only produced in smaller sizes. They are offered—as already mentioned—as undivided or divided units in two parts. In the case of the divided units the first part is the sludge trap, mostly produced from concrete, and the second part is the actual cast iron separator.

If cast iron separators are installed underground they must have a minimal installation depth in order to reach free-of-frost conditions.

The separator is a cast iron container with two baffles, one behind the inlet the other in front of the outlet, thus forming the grease collection area. The grease and oil particles, being lighter than water, rise to the surface and form an increasing grease, or respectively an increasing oil layer. In order to prevent any trouble from smell, the lid of the separator is screwed down to the casing in such a way that no smell can escape.

The separator has to be emptied before the grease collection area is filled completely. In contrast to the separators for light liquids, the separator for organic grease and oil has no float closing the outlet automatically. A manhole for sampling and controlling the outflowing water is also to be recommended in the case of a grease separator.

Description of the production process for cast iron separators

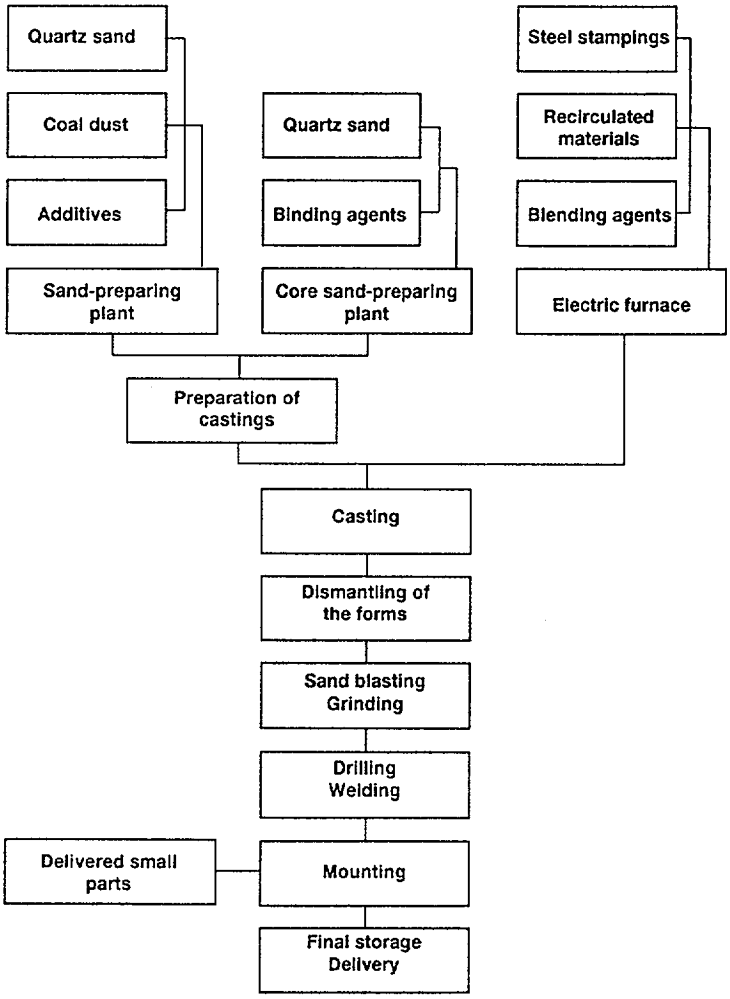
A foundry will always have a diversified production programme; the production of cast iron separators will only form a small part of the production programme.

In the sand-preparing plant quartz sand, coal dust and additives, taken from the storage bins, are put into the mixer and converted into moulding sand. With this the outer forms are produced by filling a moulding box, around a model, with moulding sand which is then compressed (pneumatic hammer or squeezer).

In a parallel operation the cores are produced: special core sand comes from the core sand-preparing plant where quartz sand and binding agents are mixed. The finished cores are then fitted into the outer forms and the complete form is prepared for casting.

The electric furnace is charged with the necessary materials (steel stampings, recirculated materials, blending agents) and brought up to temperature. When the charge is ready it is poured into the prepared forms by means of a ladle and a crane.

Figure 3. Flow chart



When the castings are cold they are taken out of the forms and sandblasted. They are then reground at the assembly site, where the boreholes are drilled and the necessary fitting and welding work is carried out. Finally the finished parts are given a protective coating and are mounted and prepared for delivery. A fork lift truck is used for the transportation from the foundry via the assembly-site to the outside storage area.

Example of a production plant

The following example describes a small foundry, assuming that only separators are produced. The foundry has an electric furnace with a capacity of 1 t/hr corresponding to a production of 3 separators per hour.

Required machinery and equipment

Description	*Pieces*
Electric furnace	1
Sand-preparing plant (mixer and storage bins)	1
Moulding machine	1
Core sand-preparing plant (mixer and storage bins)	1
Bridge crane (3 tonnes minimum)	1
Ladle	1
Pneumatic hammer	3
Sandblasting apparatus	1
Hand grinder	3
Welding appliance	1
Radial drilling machine	1
Work places with bench	2
Fork lift truck (1.5 tonnes)	1
FOB-price for machinery and equipment (1990)	Approx. US$ 1,250,000

Required manpower

Management and administration	5
Production engineer	1
Foreman	1
Skilled workers	4
Unskilled workers	10
Maintenance	2
Sales personnel	2
Construction engineer	1

Required buldings and areas

	Square metres
Production hall	1700
Stores (raw materials, delivered parts)	150
Outside storage (finished products)	600
Work places	100
Maintenance	50
Administration and social rooms	200
Open area	2000

Required power and utilities

Electric power	1300 kW
Compressed air (at 6 bar)	720 Nm^3/hr

Required components and raw materials

Steel stampings and recirculated materials	1 t/hr
Blending agents (foundry auxiliaries)	
Initial issue of sand (for forms)	36 t
Core sand	10 t/day
Sand binding agents	
Delivered parts	

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How to Start Manufacturing Industries

Separator for waste water with a starch content

Introduction

Enterprises producing waste water with a starch content should use starch separators to remove starch from the waste water. This would prevent it from settling on the pipe walls, leading to blocked pipes within a short space of time.

Starch separators are used especially in the following areas:

Potato pealing enterprises;

Kitchens of restaurants, hotels, guest houses and canteens.

Product description

Starch separators are units built into waste water pipes to hold back sediments, as for example potato starch in the waste water of potato peeling machines. Starch separators do not therefore need a superposed sludge trap.

A sludge trap, however, should certainly be used in conjunction with a starch separator in order to clean the waste water arising from potato washing. In this case the inlet into the waste water system lies behind the separator.

Starch separators are, in their simplest form, designed as an integrated two-chamber system consisting of an antechamber and the actual settling chamber. The waste water first flows into the antechamber, where the arising starch foam is precipitated by a built-in sprinkler. In addition, the antechamber often takes on the task of collecting solid materials carried along with the water, e.g. potato peelings. For this purpose a fitting bucket, which can easily be emptied after the peeling process has been finished, is quite often put into the chamber.

The waste water, now free of solid materials, then flows below the surface of the liquid into the settling chamber passing the buffer plate. The size of this chamber should be large enough to allow the rate of flow of the water to be slowed down, enabling the starch to settle. The outlet, on the opposite side of the chamber, is reached via a baffle and a siphon which has a special safety mechanism preventing suction.

The following materials are used for the casing and built-in parts of the separator:

Stainless steel;

Steel, lined;

Concrete (for casing only).

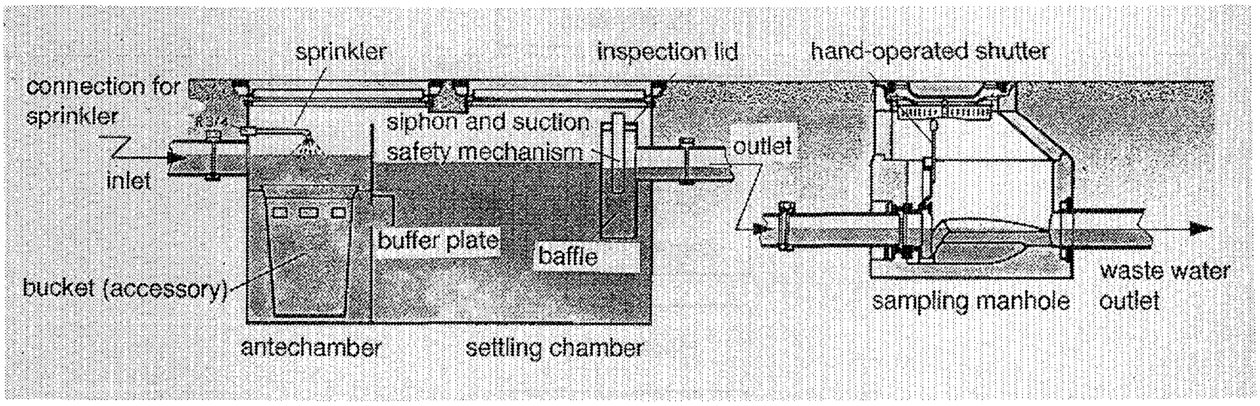
Starch separators are to be found as free-standing units or are built underground. In the first case steel or stainless steel is used, in the second case all three materials are employed.

Stainless steel has distinct advantages; it can easily be cleaned and is, in general, resistant to aggressive waste water. It is not necessary to control or renew the lining and therefore no interruption in operation occurs.

It is recommended that a sampling manhole be connected to the outside of the separator outlet. Both the antechamber and the settling chamber should be emptied regularly, at least once a fortnight. The pumped off starch should be disposed of properly. The inside walls of the chambers should be rinsed with clean water before the unit is sealed again. The unit has to be refilled with water before operation is restarted.

Because of the comparable basic design of conventional separators for starch, grease and oil as well as light liquids and also because of the use of the same

Figure 1. A conventional starch separator



materials, only one material is dealt with in the following presentation. The descriptions of alternative materials can be found in the corresponding sections on the other separator types.

Moreover, it is important to point out that according to the material used and depending on the production technique employed there will be different minimal sizes of production. This can be clearly seen in the corresponding section dealing with the example of a production plant.

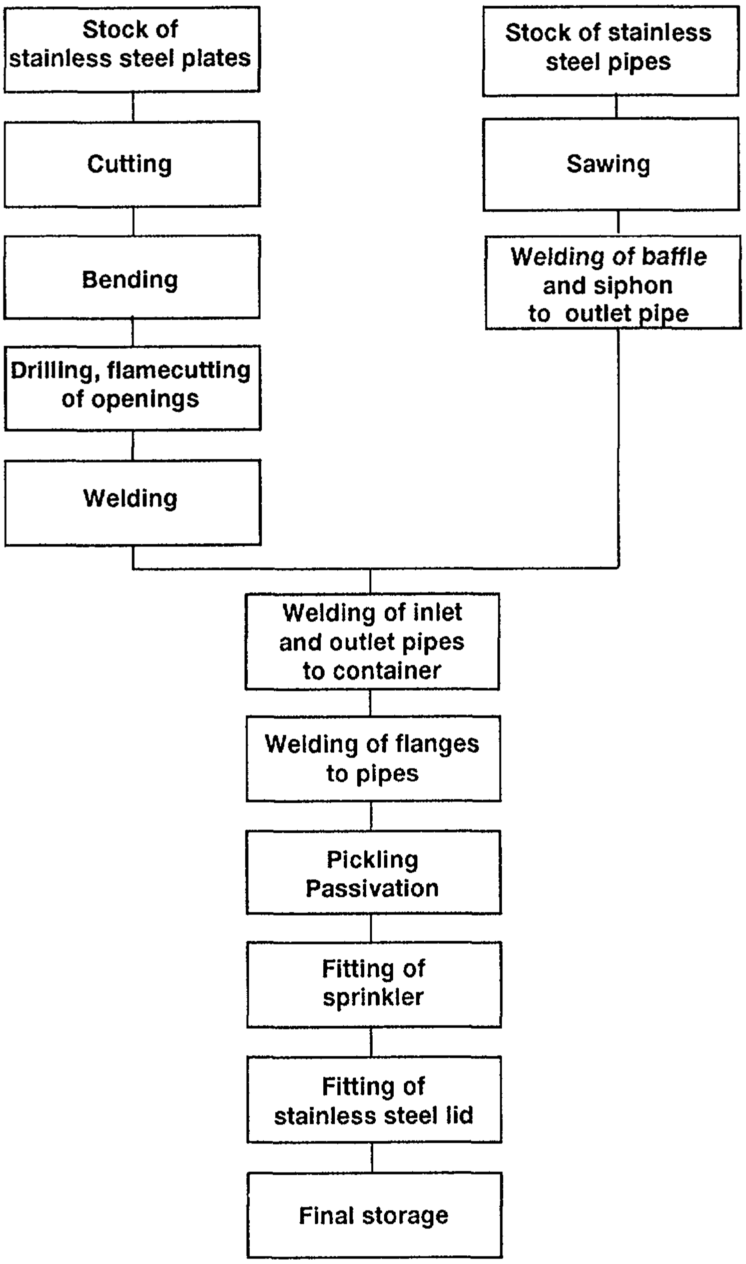
Dimensioning

The size of the separator is determined by the maximum amount of waste water. In order to allow the starch to settle satisfactorily, the separator should have a very large capacity. A capacity of 700 litres for a flow rate of 1 l/s is a common empirical value; it should not be smaller.

Description of the production process of stainless steel separators for starch

The stainless steel plates, the thickness of which is determined by the size of the separator, are cut to size and brought into the intended shape by means of a bending machine; the necessary holes for the pipe ducts and pipe connections are drilled or cut out by a flame-cutter. The plates are welded together and the inlet and outlet pipes are welded on after the outlet pipe has been fitted with the baffle and the siphon with its special suction safety mechanism.

Figure 2. Flow chart



Flanges are welded onto the inlet and outlet pipes, and the separating wall, fitted with the buffer plate, is welded into the container, thus forming the antechamber and the settling chamber.

After pickling and passivating the stainless steel unit with a bath or brush, the sprinkler is fitted. The final production stage is the sealing of the container with a stainless steel lid, which has two openings for entry.

Example of a production plant

The plant produces five separators, of different sizes, per day. However, the machinery, personnel and area, as given below, are underutilized. To achieve better usage and to have all the facilities needed production has to be greater and/or more diversified.

Required machinery and equipment

Description	*Pieces*
Cutting machine	1
Bending machine	1
Flame-cutter	1
Bow-saw	1
Workbench with tools	2
Welding apparatus	2
Fork lift truck	1
FOB-price for machinery and equipment (1990)	Approx. US$ 150,000

Required manpower

Management	2
Skilled workers	3
Unskilled workers	3
Draftsman	1
Administration	1

Required buldings and areas

	Square metres
Production hall	300
Stores (materials)	100
Outside storage (finished products)	400
Administration and facilities	150
Free area	1000

Required power and utilities

- Electric power 100 kW
- Water
- Acetylene cylinders
- Oxygen cylinders

Required inputs

- Stainless steel plates (different thicknesses)
- Stainless steel pipes
- Welding electrodes
- Sprinkler

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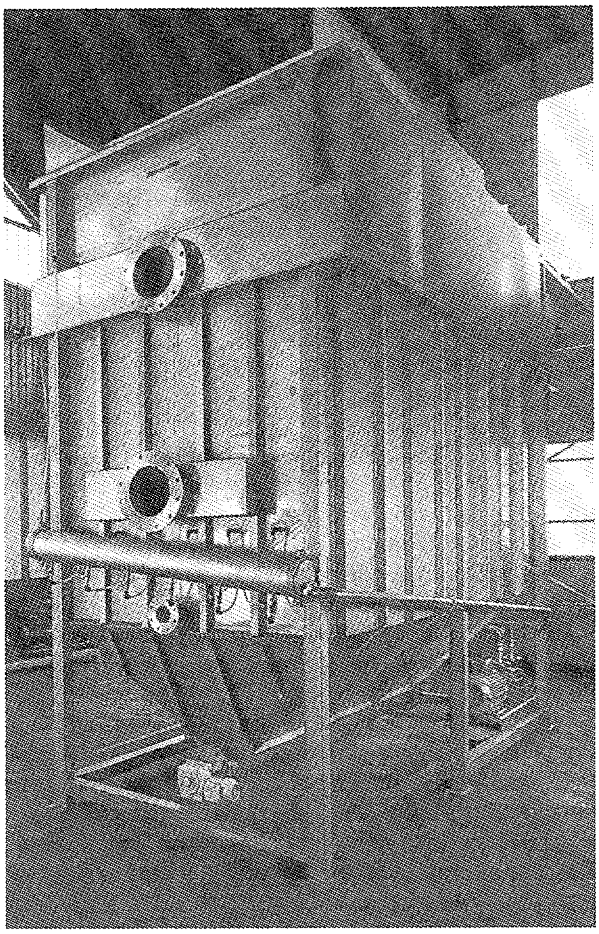
How to Start Manufacturing Industries

Sedimentation/flotation unit



Introduction

Depending on the pollutional load of the waste water i.e. size, shape, density and solubility in water of the impurities, several special separating techniques are used, mostly requiring separate units. These are then organized in series, as only occasionally can different separating techniques be combined in one unit, comprising of:

- Rough screens for the mechanical separation of coarse material;
- Sedimentation units for the removal of quickly and/or slowly settling or rising particles;
- Flotation units for the separation of impurities, which separate extremely slowly;
- Flocculation/coagulation for the chemical separation of emulsions and some dissolved components;
- Biological treatment.

The decision on the optimal choice from the different existing techniques has to be based on a thorough analysis. The design of a waste water treatment installation is especially difficult if components, sort and concentration of the load, as well as the through-flow of water are changing continuously.

Sedimentation/flotation units, as considered here, are built in a compact form and are used for the mechanical treatment of waste water mainly in the industrial field.

Sedimentation/flotation units can be found in a number of industries, occasionally combined with flocculation/coagulation units for improved performance and efficiency.

These units are applied in:

Refineries
Slaughter-houses
Meat-packing industry
Carcass utilization plants
Papermaking industry
Vegetable oil processing industry
Oil production fields
Tank cleaning
Laundries
Purification of fruit juices.

Sedimentation/flotation units, as described below, are intended for the treatment of large quantities of waste water (> 25m^3/hr).

Product description

A sedimentation/flotation unit is a compactly built system which is designed for the efficient removal of settling as well as floating particles.

The basic structure of the unit is the same for sedimentation or for flotation; it becomes a sedimentation or flotation unit by changing the dimensions of the unit (see "Dimensioning") and the position of the built-in plate pack:

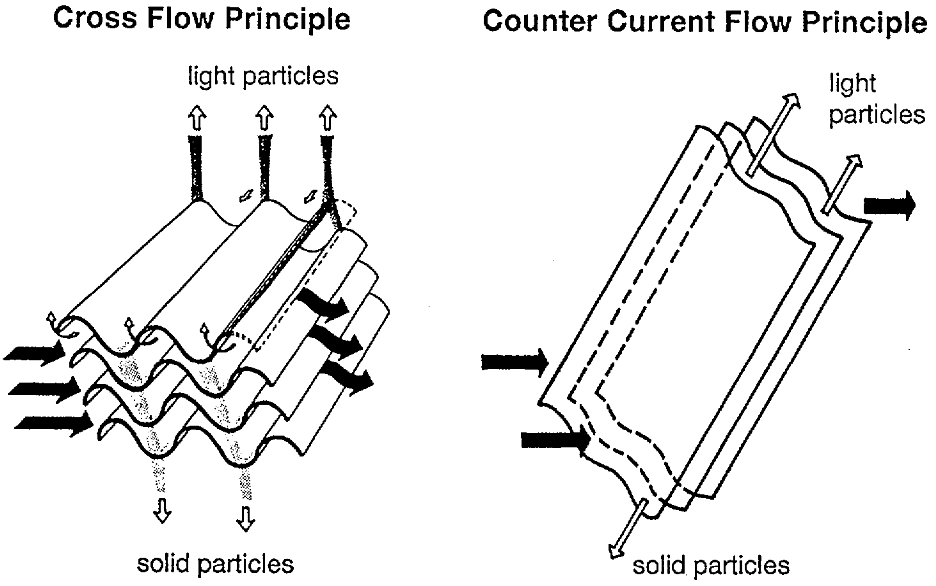
Sedimentation unit: long, low-built unit, using the cross flow principle in order to assist the downward movement of particles; used for waste water flows with high solid loadings.

Flotation unit: short, high-built unit, using the counter current flow principle to increase the upward movement of particles; used to handle highly contaminated waste water flows.

The waste water enters the sedimentation/flotation unit through a distribution pipe which takes care of the initial distribution. A complete flow distribution is then reached by flow distribution baffles. Distribution by changing the flow directions a few times rather than by using restrictions prevents the floating or settling parts breaking down in the flow distribution baffles.

The water then flows in a horizontal direction through the plate pack section, where the corrugated

Figure 1. Waste removal by sedimentation/flotation method



plates are mounted in such a way that they form a parallel system and are built in at an angle declining to the side (cross flow) or ascending to the back (counter current flow).

The short distance between the plates results in a perfect laminar flow within which an efficient separation can take place. Settling solids slide down the plates and floating particles move upwards.

The settling particles are collected in the sludgecone under the plate pack. The sludge has to be removed regularly through the de-sludging valve which can be operated automatically or manually.

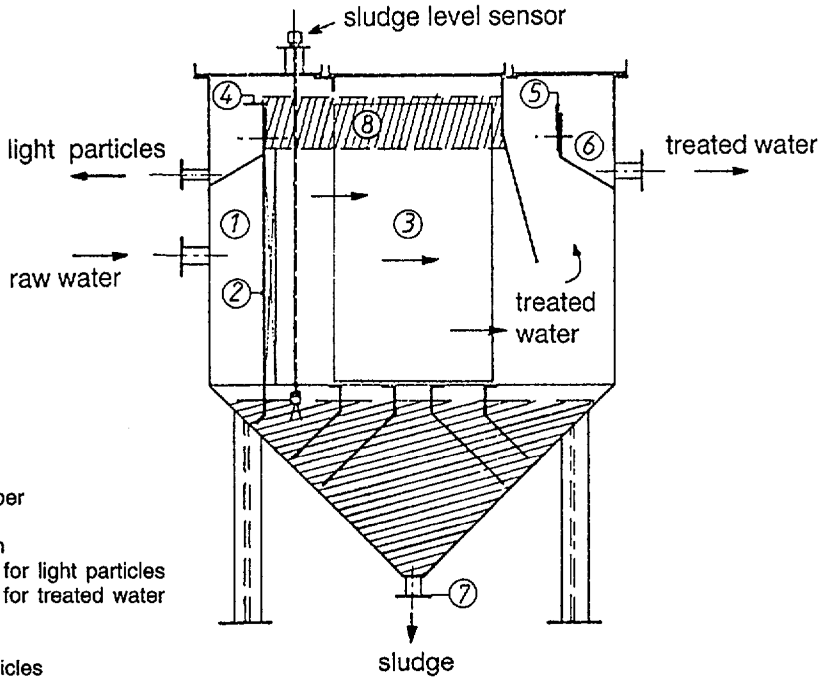
The de-sludging will result in a downward movement of the liquid in the separator. This causes particles which have become stuck to the plates to be released and continue their path. Because of this "self-cleaning" system, the plate pack will not usually clog up. The clean water will leave the separator by means of an underflow and an overflow partition.

Floating particles (oils, grease, fibres etc.) can be removed by the skimming pipe. This means that the water level in the sedimentation unit must be raised for a while. This happens by restricting or closing the clean water discharge.

If the floating particles are fibres or solids and cannot be removed by a skimming pipe, a special mechanical skimmer has to be installed to move the swimming sludge onto a mechanical de-sludging device.

If the separation is extremely slow and difficult, flotation is improved by pressing a highly condensed

Figure 2. Sedimentation/flotation unit



Key:

1 Distribution chamber
2 Baffle
3 Plate pack section
4 Overflow partition for light particles
5 Overflow partition for treated water
6 Effluent chamber
7 De-sludging valve
8 Layer of light particles

water/air mixture into the system (approx. 5 bar). This is achieved by a pump taking cleaned water from the outflow and mixing it with sucked-in air. The injected air relaxes to 1 bar and the micron-sized air bubbles take the floating particles to the surface because of their adherence to them. This process results in a sufficient difference in density leading to a fast flotation and efficient separation.

A sedimentation/flotation unit is a rectangular (sometimes round) container with a cone underneath, made out of stainless steel. The unit is delivered ready for installation in the waste water treatment section of the relevant industry. It is normally directly mounted on a concrete foundation.

Dimensioning

The efficiency of a sedimentation/flotation unit is determined by the liquid volume Q (m^3/hr) flowing over the horizontal component of the separating surface F (m^2), the so-called overflow rate (OR):

$$OR = Q/F \text{ (m/hr)}$$

Under usual separating conditions therefore the retention time is of minor importance. The sedimentation/flotation unit can separate all those particles, the rising or settling rate of which is equal or greater than the overflow rate.

The separating surface area can, however, be substantially expanded by passing the liquid through a set of parallel corrugated plates. The profitability of such a feature can easily be seen in the drastic reduction of the distance over which the particles have to rise or fall before interception.

To make separation by means of gravity economically feasible, the impurities should be sufficiently large and have a minimum difference in density with the carrier liquid.

The following gives some idea of the actual sizes of units, according to capacity:

Sedimentation unit

capacity (m^3/hr)	*measurements (mm) (l × w × h)*
15	3800 × 2400 × 2400
50	7300 × 2400 × 2400
100	11300 × 2400 × 2400

Flotation unit

capacity (m^3/hr)	*measurements (mm) (l × w × h)*
20	2700 × 1300 × 2800
50	2700 × 2400 × 2800
100	4600 × 2200 × 3970

Description of the production process

The stainless steel plates, ordered from other firms, are brought into the required shape and size by a cutting machine; the openings for the pipe culverts and pipe connections are cut out by a flame-cutter and the holes for the necessary screw connections are drilled.

Figure 3. Flow chart

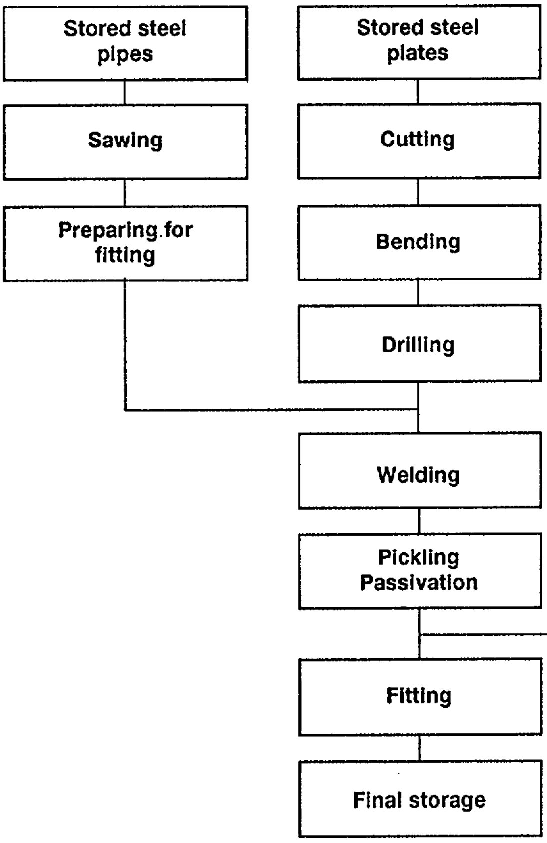
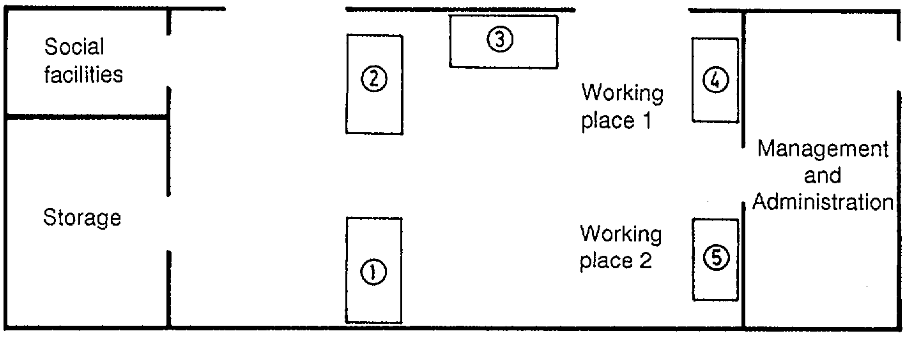


Figure 4. Plant layout



① Cutting machine
② Bending machine
③ Engineer
④ Workbench
⑤ Workbench

The stainless steel pipes, also ordered from outside firms, are cut to length and prepared for fitting.

The outside plates are welded together, the prepared separation, baffle and overflow plates as well as the inflow and effluent pipes are welded into place and the four legs are fixed.

At the same time the corrugated plastic plates, ordered from other firms, are sawn to size and mounted together to form a pack of parallel plates. This pack is then fitted inside the finished container.

Example of a plant

A small plant with two workers in the production team is able to produce one sedimentation unit per week with a capacity of 25-50 m^3/hr.

It has to be stated, that the machinery, personnel and area as given below are underutilized. To achieve a better use on the one side and to have all the facilities needed on the other, the production has to be greater and/or more diversified.

Required machinery and equipment

Description	*Pieces*
Cutting machine	1
Bending machine	1
Drilling machine	1
Welding apparatus	2
Flame cutter	1
Workbench for assembly (incl. tools)	1
Crane	1
FOB-price for machinery and equipment (1990)	Approx. US$ 140,000

Required manpower

Commercial manager	1
Engineer	1
Locksmith	1
Welder	1
Draftsman	1
Administration	2

Required area

	Square metres
Production	100
Storage	
Raw materials (covered)	20
Finished parts (outside)	50
Facilities	150
Open area	500

Required power and utilities

Electrical power	20 kW
Water	

Required components and raw materials

Stainless steel plates (3 mm)
Stainless steel pipes (diff. diameters)
Elbow-shaped pipes
Corrugated plates (polyester, plastics)
Incidentals

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Filter plates for filter presses used in sludge drainage

Introduction

Waste water treatment is presently one of the major environmental problems. This situation is prevalent not only in the industrial countries of Europe and overseas but also increasingly in developing countries, especially those on the threshold of industrial development.

The most serious pollution of water occurs when untreated waste water is drained off from cities, communities and industrial areas. Because this causes a drastic alteration of the water's properties (e.g. a decrease in oxygen content, mud sedimentation, algae growth), waste water must first be purified, so that contamination and overloading by pollutants and toxic agents introduced into the water are prevented. In this way, in densely populated and industrial areas, it is thus possible to use the water several times over.

The purification of both domestic and industrial waste water generally includes:

Retention of pollutants, toxins or recyclable materials that are contained in the water;

Subsequent treatment of waste water;

Separate sludge treatment.

Because waste water sludge is, as a rule, highly aqueous, it must be reduced in volume for treatment and for storage in waste dumps, as well as for recycling. If the water content of sludge is reduced (e.g. from 95-85%), then the amount of sludge is reduced considerably.

To reduce the water content in waste water sludge, natural and artificial drainage methods can be used. To naturally drain sludge, dry sludge beds and sludge ponds are used, while centrifuges, vacuum filters, screen belt presses and filter presses are available methods for artificial drainage. Compared to natural methods artificial drainage has the advantage of requiring less space and time for operation.

Filter plates as parts of a filter press

Where solid matter is to be separated from liquid matter filter presses can generally be successfully used. The range of application is, therefore, correspondingly extensive, including the drainage of industrial and domestic sludge. Filter presses are also used in chemical and food production plants, synthetic fibre and viscose production, as well as in mining.

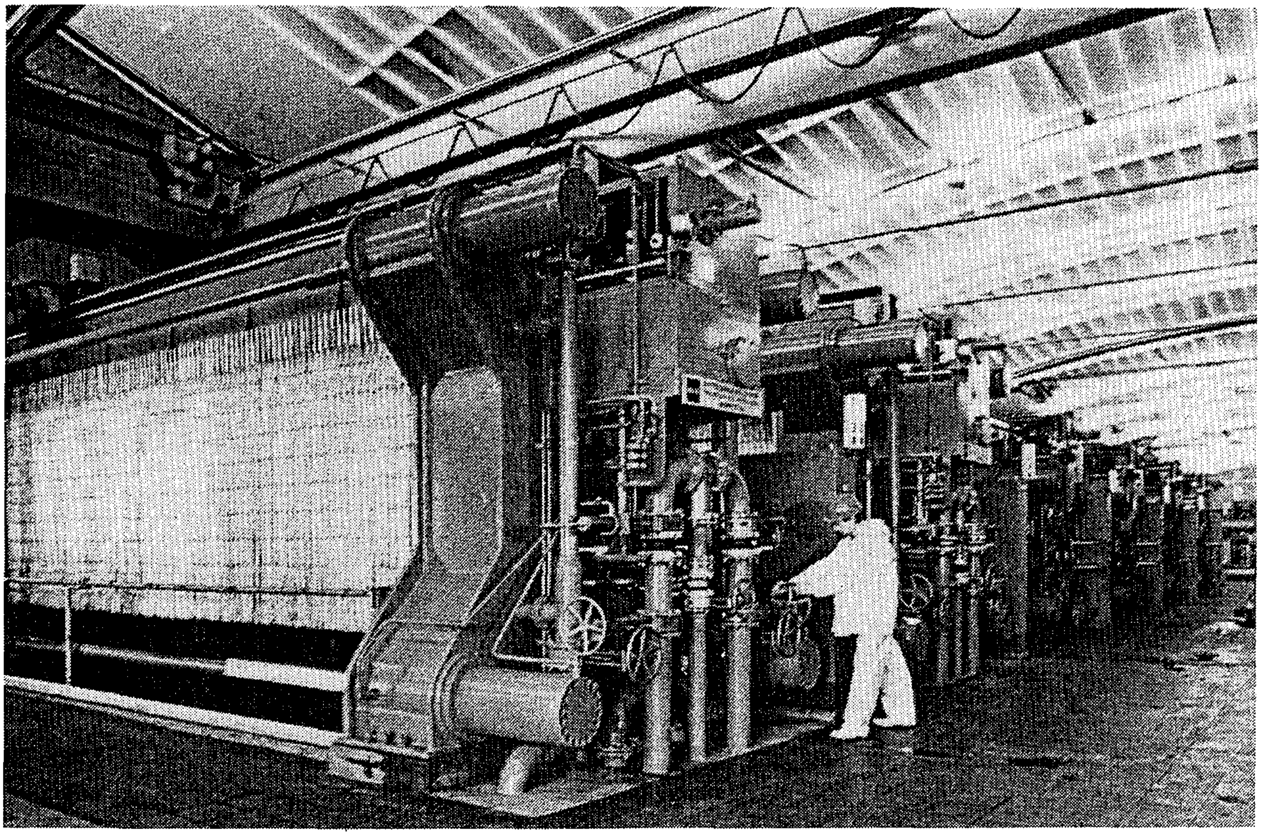
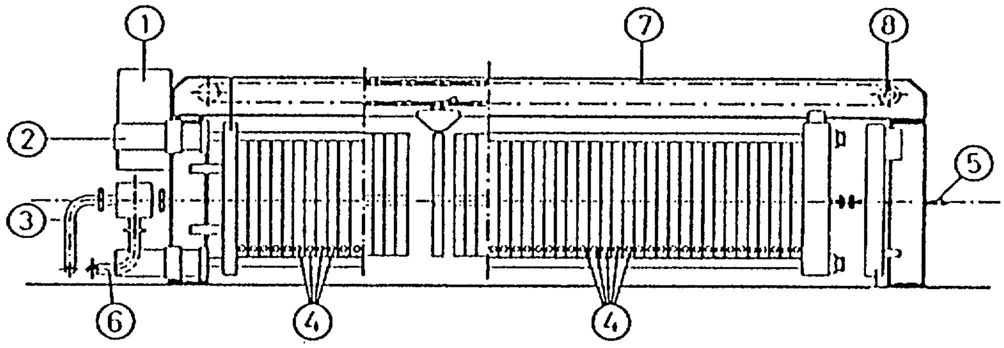


Figure 1. Filter press



Key:

1 Hydraulic device	5 Pressurized air canal
2 Hydraulic piston	6 Filtrate escape canal
3 Delivery canal	7 Conveyor chain
4 Filtrate openings	8 Motor

Filter presses are used for pressure filtration. They are composed of a variable number of filter plates which are suspended and aligned parallel to one another and are covered on top and at the sides by a filter cloth that functions as a separating membrane. This so-called plate packet is sealed at one end by a headplate and at the other end by a pressure plate. The required number of filter plates and their sizes depend on the total filter area desired, which can have any size from 0.2-1,600 m^2.

During the filtration process the sludge, which is to be drained, is pressed by pumps through the delivery canal into the cavities between the filter plates. Then the plate packet is pressed together by hydraulic or electro-hydraulic power, whereby filter pressures of up to 1.75 psi can be reached. The cavities between the single filters form the so-called cake chambers in which solid matter (cake), that has been filtered out, is deposited 20-30 mm thick. The liquid (filtrate) flows away from the slightly webbed surface of the filter plates through the filtrate escape canals down into a collecting tank.

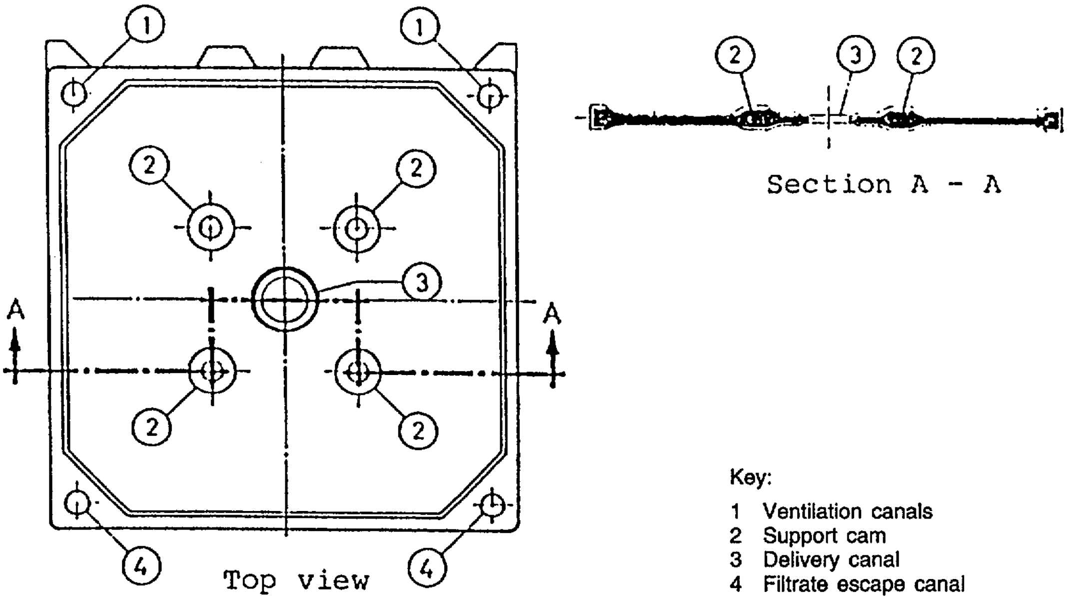
When the filtrate volume reaches its minimum after the filling and compression process (approx. 2-3 hours), the filtration process is discontinued and the filter press is emptied. To empty the filter plates, they are automatically separated, which causes the sludge cake to fall down onto a conveyor belt. After emptying the filter press is closed and another filtration run can begin.

With drainage in filter presses the concentration of solid matter in the drained sludge can reach 60-80%.

Product description

In waste water technology square filter plates are predominantly used, which vary in size from 100 × 100 mm to 2600 × 2600 mm. The choice of material for the filter plates is based on three criteria;

Figure 2. Filter plate



Key:

1 Ventilation canals
2 Support cam
3 Delivery canal
4 Filtrate escape canal

Mechanical stress;

Thermal stress;

Chemical stress.

Experience has demonstrated that, apart from those made of hard rubber and light metal, filter plates made above all from spheroidal graphite cast iron and polypropylene meet these criteria; in most cases, polypropylene plates are used because of its high resistance to corrosion. Furthermore, these plastic plates can be produced quickly and with relatively little expense for machines, production sites and personnel.

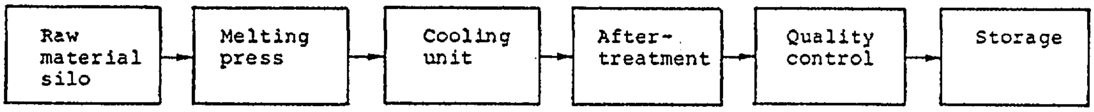
Apart from the delivery canal, through which the sludge to be drained is pressed into the filter plates, and apart from the filtrate escape canals, through which predominantly residue-free filtrate flows out, the filter plates also have support cams. These are necessary to maintain the distance between the plates during operation and to prevent warping, as blockage is easily caused by course matter contained in the sludge, which can lead to additional stress on the filter plates and perhaps breakage of the plates.

Description of the production process

In the following description of the production process for filter plates made from polypropylene, the required machines, specifications for production sites and personnel apply to the manufacturing of all types of filter plates. However, the data for energy and raw materials required is based on the production of middle-sized filter plates (from 400 × 400 mm to approx. 800 x 800 mm), of which approx. 200-220 units can be produced per 8-hour day at full production capacity.

The starting point of the production process outlined below is the raw material silo, from which polypropylene moves to the melting press via a pipe. In the melting press the raw material is melted, homogenized and shaped into the desired plate forms. Following this, they are then transported by conveyor belt to the cooling unit, where the filter plates are quickly cooled off to fix their shape. Then they move by conveyor belt to the after-treatment centre where, for instance, excess material from the production process along edges and in orifices are removed. After passing quality control the filter plates are transported into storage.

Figure 3. Flow chart



Example of a production plant

Required machinery and equipment

Description	*Pieces*
Raw material silo	1
Melting press	1
Cooling unit	1
Conveyor	3
FOB-price for machinery and equipment (1989)	Approx. US$ 500,000

Additionally, tools, instruments for quality testing and simple storage and transport facilities are required.

Required manpower

The production of all types of filter plates is covered by the following personnel

Commercial and technical manager	1
Secretary	1
Foremen	2
Unskilled workers	6

Required buldings and areas

Simple production sites with an adequate supply of electricity and water are sufficient.

	Square metres
Production building	120
Storage	100
Offices and social rooms	80

Required power and utilities

Electricity	100 kW
Pressurized air consumption	
Pressure	6-10 bar
Consumption	2000 l/hr
Water	4 m^3/hr

Required inputs

Polypropylene	300,000 kg/year
Also lubricants and other expendable materials	

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

Fine-mesh filter for filter cartridges used in micropurification of waste water

Introduction

The treatment of domestic and industrial waste water usually takes place in three phases:

Mechanical purification where insoluble materials are separated physically from the waste water;

Biological purification/clarification; as waste water contains solid or dissolved substances needed by micro-organisms for their growth and metabolism, these substances are removed from the waste water;

Advanced treatment by application techniques supplementary to conventional mechanical or biological purification methods.

In the advanced treatment of waste water such materials as those which are still contained in the waste water after a run through the mechanical-biological purification plant, are eliminated by microsieves and special filters (fine-mesh filters). The advanced treatment of waste water is also referred to as tertiary treatment. This supplementary phase is frequently used after the mechanical-biological purification of domestic waste water, as well as for the special treatment of industrial waste water.

Using the third purification phase depends essentially on the properties of the waste water. This technique is used if the waste water contains high levels of nitrogen and phosphate, as well as organic, inorganic and suspended materials.

To reduce, or rather to eliminate, these materials micro-sieves and special fine-mesh filters are effectively used.

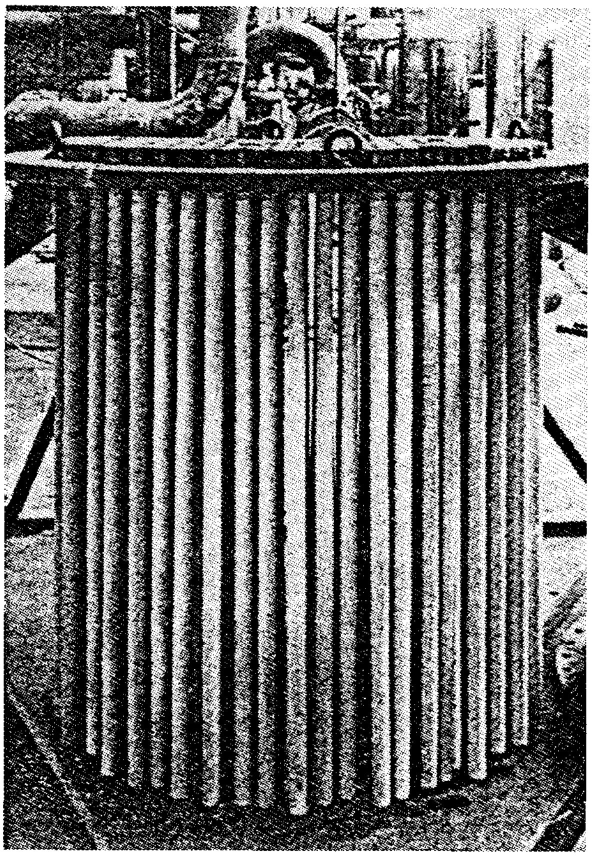
Apart from its use in waste water purification, advanced treatment is also used in industry when hygienically pure water is necessary for the production process.

A fine-mesh filter as an element of a filter cartridge

At purification plants filters for micro filtration or fine filtration are used above all in filter cartridges. A filter cartridge consists of a cylindrical steel casing which is sealed by a steel cover plate and base. Under the cover plate is a separate carrier plate on to which a varying number of "candles", depending on the diameter of the steel casing, are fixed vertically next to each other. These candles are hollow, pierced cylinders made of either stainless steel or reinforced plastic. A fine-mesh filter is fitted over each of these candles.

The water that is to be treated is pumped into the space surrounding the candles by a feeding pipe connected to the cover plate. The water flows through the candles and leaves the filter cartridge purified through another duct in the base plate. During this process material deposits settle on the outside of the fine-mesh filters, which are fitted over the candles. When the maximum permissible filter resistance is reached the fine-mesh filter is changed.

Figure 1. Application of a filter cartridge



As in many countries, above all in developing countries, the third purification phase is still not used, but is, however, necessary for the manufacture of beer, mineral water, food stuffs, medicine etc., this advanced treatment is carried out in the production installations themselves. Here, too, water is passed through filter cartridges before its use in the production process.

The sizes of the cartridges (i.e. the length, diameter and quantity of the candles used and the filters fitted over them) are different. The sizes depend overall on: the volume of water to be purified; the materials contained in the water; as well as on the volume of the required (i.e. necessary for a certain production process) microfiltered water. In municipal purification plants filter cartridges with a diameter of 2200 mm are usually used, each comprising of approx. 40-60 candles with a length of 1000 mm and a diameter of 60 mm. Those filter cartridges used by industrial companies are usually of smaller dimensions.

Product description

A fine-mesh filter is used for safety reasons, when the water to be treated must be constantly free of all substances, which are either created during, or remain after, previous processing and purification phases. Fine-mesh filters are made from unfolded pulp paper, but if for technical reasons in production, for example, a minimum filter volume and a maximum filter area are desired, then they are made from folded pulp paper several millimetres thick. To achieve a specific porosity the filter paper is impregnated with resin.

Fine-mesh filters are usually in the shape of a cylinder which tapers to a point at its lower end. They are fitted over each filter candle and in this way form a microporous filter layer on a solid base. The length and diameter of a fine-mesh filter depend on the throughput capacity expected. These sizes are determined partly by calculation and partly by trial. The types of fine-mesh filters currently in use enable operation capacities of a few litres to approx. 500 m^3/hr. Throughput capacity depends on the type and concentration of the substances contained in the water to be filtered out.

The production of fine-mesh filters can be carried out in simple production installations with relatively little expense required for machines, equipment, personnel and know-how. Moreover, there is a constant demand as fine-mesh filters must be changed upon reaching their maximum permissible resistance, and used filters cannot be re-used.

Description of the production process

The production line described is flexible so as to be able to produce all types of fine-mesh filters with only minimum equipment change-over. Different types of fine-mesh filters in varying quotas are usually produced in one workday.

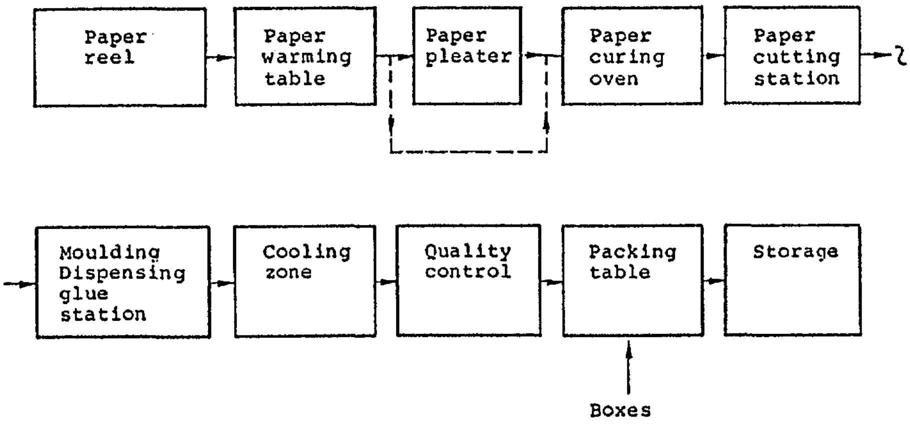
The starting point of the production process is the special pulp paper reel. From the reel the paper is fed over a warming table into the paper pleater by conveyor belt, where the filter surface is enlarged by folding the paper lengthwise.

Should fine-mesh filters with smooth surfaces be required, the filter paper is directly transported into the curing oven on a conveyor belt, where resin in the filter paper is burned out to open the pores. The filter paper is then transported by conveyor belt over a cutting station, where it is cut to size according to the given fine-mesh filter type, into the moulding press. Here the pulp paper receives its cylindrical shape and is simultaneously glued together with a special glue. From the moulding press the fine-mesh filters reach the cooling zone by means of another conveyor belt, where their temperature is reduced to approximately room temperature. After passing quality control the finished fine-mesh filters can be packed into supplied boxes at the packing table and then put into storage.

Example of a production plant

An exact assessment of the required raw materials, personnel and energy for the production of a single fine-mesh filter type is not possible because, in practice, varying quantities (depending on demand) of several fine-mesh filter types are produced daily. The following lists of particulars referring to personnel, raw materials and energy are based, therefore, on an average production rate of 650 units (filters of different types and sizes) per hour.

Figure 2. Flow chart



Required machinery and equipment

Description	*Pieces*
Paper reel	1
Paper warming table	1
Paper pleater	1
Paper curing oven	1
Paper cutting station	1
Moulding, dispensing glue station	1
Cooling zone	1
Table for quality control	1
Packing table	1
Conveyor	7
FOB-price for machinery and equipment (1989)	Approx. US$ 800,000

Additionally, simple facilities for storage and transport, as well as for tools and instruments for simple maintenance and repairs are required.

Required manpower

The following personnel is necessary for the described production process

Manager (technical and commercial)	1
Secretary	1
Foremen	2
Skilled workers	4
Unskilled workers	6

Required area and buildings

The erection of simple buildings is sufficient

	Square metres
Production area (including offices)	400
Storage	150
Social rooms	80

Required power and utilities

A reliable and adequate supply of electricity and water is necessary for the production process

Electric power	220 kW
Water	5 m^3/hr

Required inputs

Filter paper	50 t/year
PVC-glue	12 t/year
Boxes	1.1 million/year

In addition, incidentals such as lubricants, replacement parts etc. are required.

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How to Start Manufacturing Industries

Filter sand

Introduction

In the purification process of waste water filtration plays an important role and is classified as a method of mechanical waste water purification. Filtration is understood to be the retention of suspendable solids in waste water by suitable filter materials.

Suspendable solids contain both organic (BOD_5 = Biochemical Oxygen Demand; COD = Chemical Oxygen Demand) and inorganic substances (P,N), which may lead to the accumulation of mud in the water. This in turn can cause considerable contamination, the outcome of which is that water use becomes limited. Domestic and industrial waste water, in particular, are the essential sources of such contamination in water, as are precipitation, erosion and damage incurred through agricultural use.

Various materials are suitable as filter media, depending on their area of application and intended use. The essential operative range in waste water treatment lies in the purification of industrial and domestic waste water; a clear advantage of this system is that several purification effects can be combined, for example:

Elimination of dissolved, biologically degradable organic residue;

Elimination of substances which are difficult to degrade or not degradable at all;

Elimination of nitrogen and phosphate compounds;

Removal of suspended matter;

Elimination of toxic compounds (e.g. heavy metals).

Because domestic, commercial and industrial waste water can contain very diverse substances in various proportions, filtration is, as a rule, supplemented by other purification methods.

Principle of dry filtration

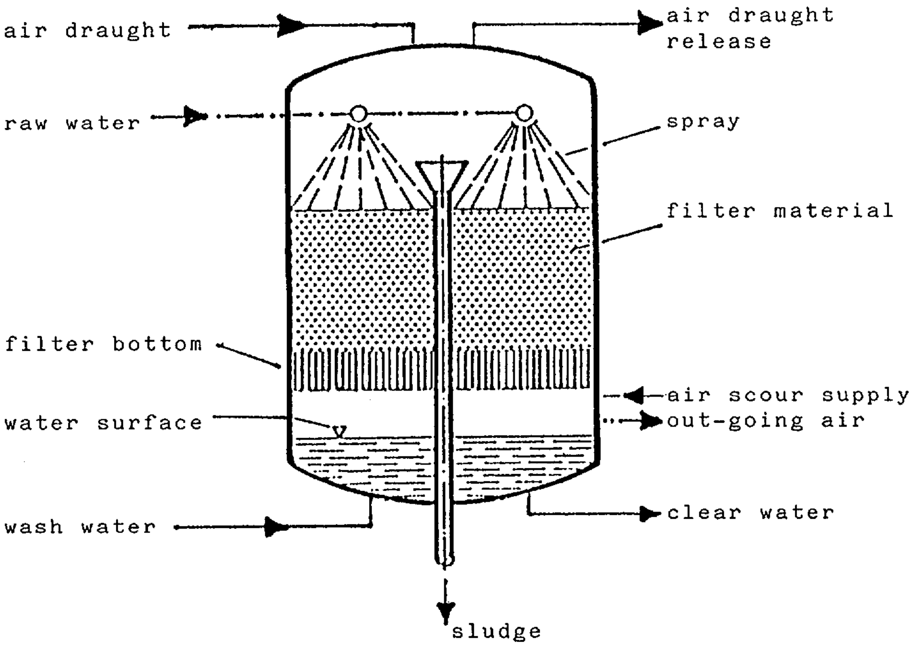
In dry filtration the waste water, that is to be treated, is uniformly distributed by spraying it over the entire filter bed surface. Water trickles thinly over the surface of the filter material, and air is channelled in either a direct or a countercurrent direction through the filter bed by suction or pressure.

Apart from retaining suspended matter, this procedure also eliminates dissolved organic materials which might be difficult to decompose, and enables nitrification. Thus dry filtration has increasingly found use in the field of advanced waste water purification as a biologically intensified method of filtration. The use of multi-layer filters allows a higher capacity of filtration. The solids, which have been filtered out, are removed by backwashing with air and water after the filter material is saturated with suspended matter.

Principle and application of double-layer filtration

The efficiency of deep bed filters multiplies when the filter bed is made up of more than one layer. Double-layer filters are usually used, for example, with anthracite and sand, whereby filter-anthracite forms the upper filter layer. Its granulation is coarser and its

Figure 1. Closed type filter



density lower than the underlying sand and thus marks a precisely defined plane above the heavier sand.

The double-layer arrangement of the filter materials offers obvious advantages: instead of filtration occurring on the surface, as in a single-layer filter, a volume filtration occurs over the entire depth of the filter bed. Thus the effectiveness of the filter is improved due to:

Higher retention capacity for solids;

Lower pressure loss;

Lower initial filter resistance;

Longer filter-runs;

Higher filter velocity;

Better filtrate quality;

Lowered backwash frequency;

Less space requirement.

All of which together have the positive economic effect of lower running costs.

Dry filtration by dual-media structure is possible with both the open and the closed type filters. Backwashing, as in dry filtration, occurs for the most part as a combined air scouring and flushing against the direction of filtration, upwards from bottom to top.

The advantages of double-layer filtration are seen in the treatment of very different types of water in particular good results and practical experience have been gained not only in the treatment of waste water, but also of well water, spring water and river water.

Double-layer filtration is used, for example, in:

The purification of drinking water;

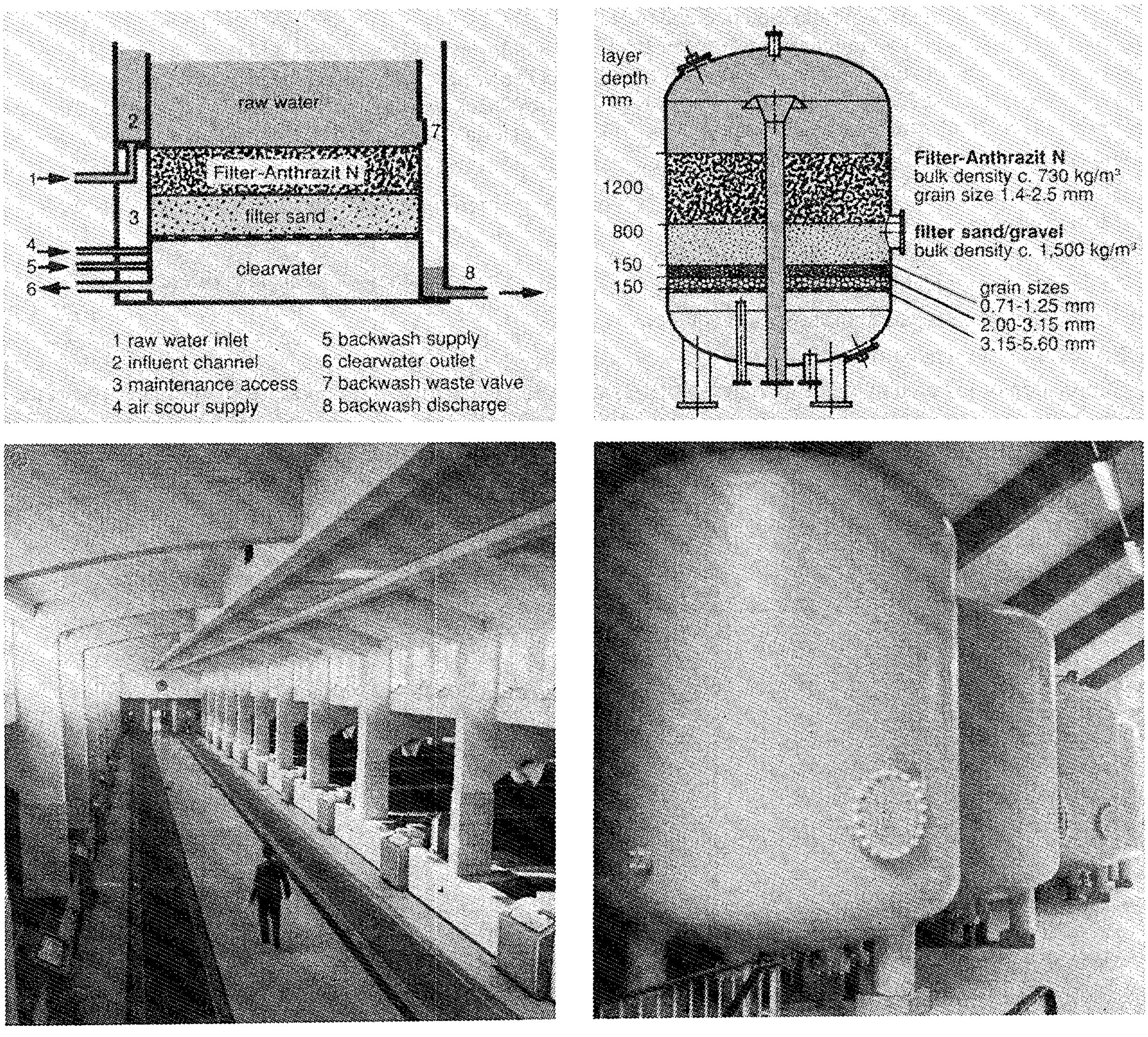
The purification of waste water;

The treatment of industrial water, for example, in food manufacturing enterprises, paper factories and breweries;

Community sewage treatment, especially as the final procedure after a mechanical-biological treatment to remove suspended matter, if necessary after precipitation chemicals are added.

Multi-layer, especially double-layer, filtration is increasingly winning recognition and being accepted for

Figure 2. Filtration type systems



Open type double-layer filtration

Closed type double-layer filtration

use by virtue of its particular economic and technical advantages. It can also be used much more in developing countries than has hitherto been the case.

Product description

Depending on the type and volume of the dirt particles found in the waste water, different filter materials are necessary to achieve the desired refinement effects. In double-layer filtration the following filter materials can be used:

As upper-layer material	*As lower-layer material*
Anthracite	Basalt
Carbonized lignite	Quartz sand
Oil coke	
Swelling shale	
Sintered glass	

In selecting the suitable filter materials, knowledge of their grain shape and stability, surface finish, grain porousness, density, bulk density, are of particular importance in assessing their filtration capacity. Further calculations (e.g. of the specific filter bed surfaces) are based on these initial values.

Quartz sand is generally understood to be a type of sand containing a high proportion of quartz and a low content of other minerals. Quartz sand deposits are rather common, around 90% of developing countries possess potential deposits.

The use of double-layer filtration could play a more significant role in developing countries, if the import of filter materials and the resulting outflow of foreign currency were considerably reduced. As it is, costs for imported filter materials are from three to five times their actual value due to shipping expenses.

Thus, apart from environmental aspects, the political significance in development of saving foreign currency becomes obvious. Filter materials, such as quartz sand and gravel, could be exported to other countries. Treating water internally would thus not only reduce the outflow of foreign currency but could also trigger its influx. Furthermore, the life span of filter materials is usually seven to ten years; this demands investment in replacement parts, which must be included in market potential evaluations.

Description of the production process

The regulations governing the use of quartz sand as water purification filters vary from country to country. In Germany special requirements are effective as set by the "DIN-Norm".

The essential steps in the production process of filter sand are presented in figure 3.

Extraction

Depending on the type of deposits, dry or wet extraction methods used. *Dry extraction* is done by shovel loader, dredger or bucket wheel excavator. In *wet extraction* the grain size of the deposit determines which method of extraction will be used: if the proportion of fine grains is high, suction dredges are used; if the proportion of fine grains is low, then floating bucket line dredgers are used.

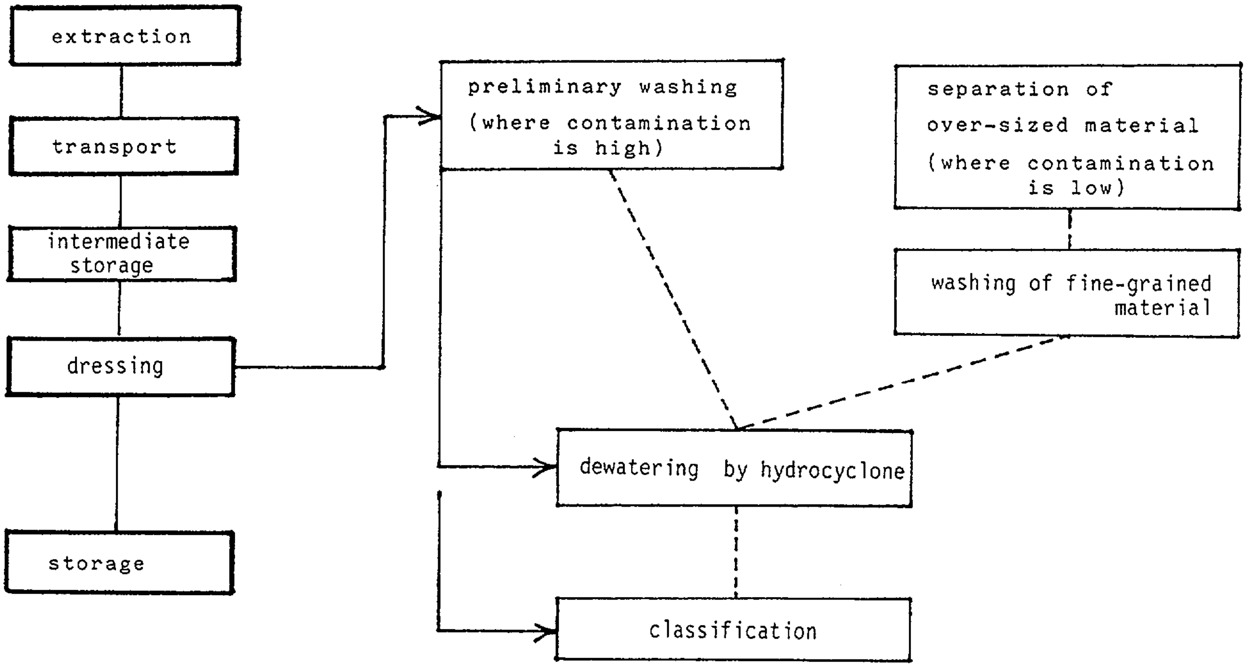


Figure 3. Flow chart showing the major steps in the "production" of filter sand

Transport

In *dry extraction* the deposit material is fed onto a conveyor belt. In *wet extraction* the mixture of sand and water is pumped through pipes to cyclones and the dewatered sand then transported by conveyor belt.

Intermediate Storage

The installation of a temporary sand-bin levels out fluctuations in the material flow.

Dressing

Preliminary washing: necessary if materials are contaminated, is done by a washing drum or log washers, that is, by dissolving and washing out particles other than quartz. The washed quartz sand is then further transported by conveyor belt. Preliminary washing is not necessary for those slightly contaminated materials which are dry extracted.

Separation: of over-sized materials, carried out if contamination is low, is done on a vibration screen and the washing out of fine materials in a washing trough.

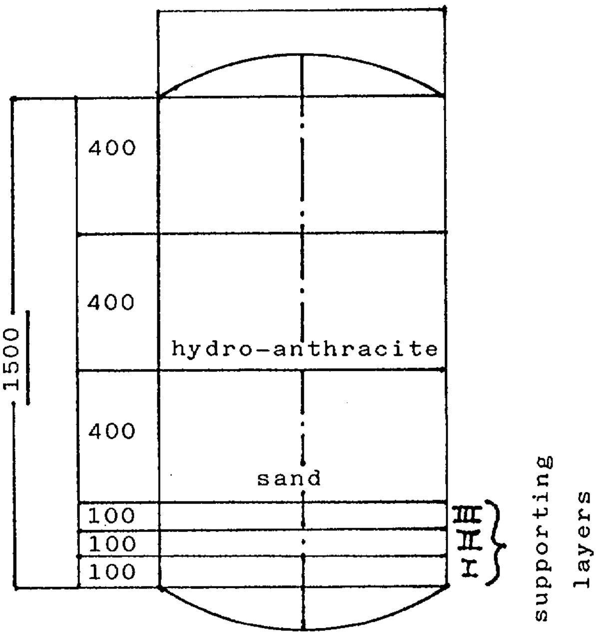
Dewatering: the mixture of sand and water is dewatered in sand traps or hydrocyclones.

Classification: the classification of the quartz sand into different grain-size classes is done in screening drums.

Storage

Finished products are stored in stockpiles or silos. Over-sized particles, which are screened out during the dressing process, can be diverted for use in plants which produce gravel and sand.

Figure 4. Standard installation



Dimensioning

For a standard type installation with a filter of 2800 mm in diameter and 6.158 m^2 filter area the following filter materials are required:

1 tonne of gravel (supporting layer) with varying granulation from 1 -0.7 mm;

4 tonnes of sand (filter layer 1) with granulation from 0.4-0.7 mm;

2.5 m^3 anthracite.

In such an installation with a flow rate of 12 m/hr there is a flow volume of approx. 74 m^3/hr.

Examples of alternative dressing plants

Example 1:
Standard equipment of a dressing plant with a capacity of 40 t/d at 8 hr/d = 5 t/hr

Required machinery and equipment

Description	*Pieces*
Screens	6
Silos	2
Packing installation	1
FOB-price for machinery and equipment (1990)	Approx. US$ 350,000

Required manpower

Foreman	1
Locksmith	1
Unskilled workers	3

Required area

	Square metres
Covered area	300-500
Outside storage area	5000
Total	6000

Required Power and Water

No detailed data available

Example 2:
Standard equipment of a dressing plant with a capacity of 1800 t/s at 24 hr/d = 75 t/hr

Required machinery and equipment

Wet sand production:

Three wet screening equipments for coarse sand with four screening machines each, a hydrosizer and two screening drums;

An installation for fine sand screening with a hydrosizer and plane filters.

Drying installation with dry screens for coarse sand and for fine sand.

Silos and bunkers for finished products, packaging facilities, and loading areas for trucks and railcars.

FOB-price for machinery and equipment (1990):
Approx. US$ 10 mill.

Required manpower

Total: 20 employees per shift

Required area

	Square metres
Covered area with 3 to 4 floors for dressing and silo installations	1500
Open storage area	10000
Total	11500

Required power and water

No detailed data available

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How to Start Manufacturing Industries

Screens

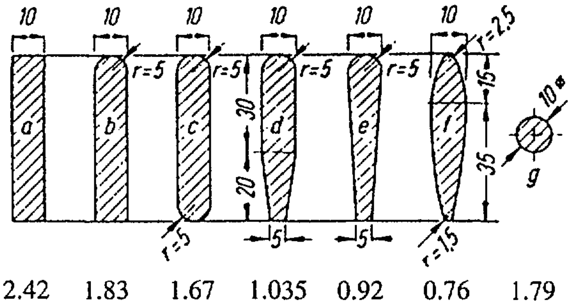
Introduction

Screening is normally the first unit operation used at waste-water treatment plants. The general purpose of screens is to remove large objects such as rags, paper, plastics, metals etc. These objects, if not removed, may damage the pumping and sludge removal equipment, overhang weirs, block valves, nozzles, channels, pipelines and appurtenances, thus creating serious plant operation and maintenance problems. Furthermore, the removal of screened material is a condition for the efficiency and continuity of the following water purification process.

The type and layout of a screening unit is mainly dependent on the expected kind and amount of industrial sewage discharge, the topographic conditions, the climate and the local society. Concepts for screening units as well as for the whole waste-water treatment plant should take into consideration the coordination between the preceding sewerage system and the adjacent drainage system. Without this coordination, serious and costly problems will be the consequence.

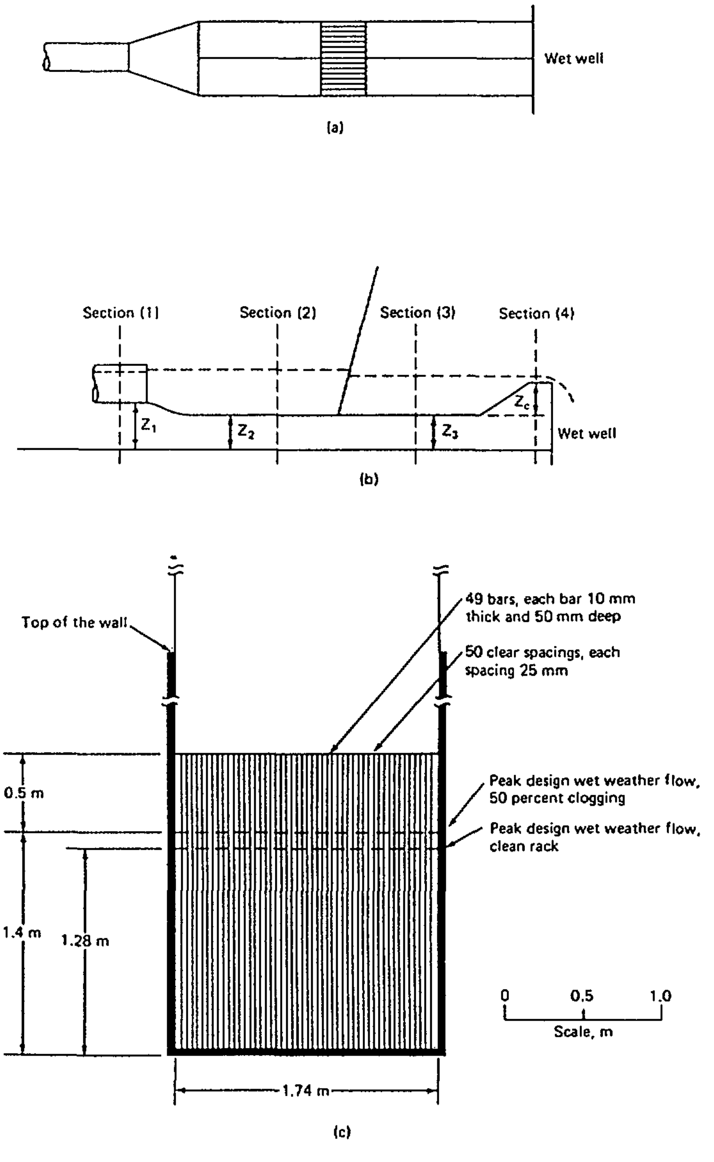
An important functional and basic element of a screening unit is the screen consisting of a frame with, commonly, steel bars inside (figure 2c). The bars have the same distance between each other, whereby different forms are used (figure 1) in order to obtain different flow resistance. This frame is fixed in the inflow channel with, according to its design, different angles of inclination relating to the flow direction. In the 1970s, the use of sieves instead of screens became more popular because of material restrictions that did not allow tighter spacing (< 10 mm) between the bars.

Figure 1. Different forms of steel with formfactor β



Nowadays, higher hydraulic efficiency and higher efficiency of the rake systems make spacing of as little as 1 mm possible. Positive experiences have been noted with finest screens (≤ 6 mm) as well as with finest sieves (≤ 10 mm).

Figure 2. Details of rack chamber. (a) Plan. (b) Longitudinal section through the rack chamber. (c) Cross section showing bar arrangement, channel section, and depth of flow.



Types of screen

The various types of screen can be subdivided into:

Manually or mechanically cleaned screens;

Front or back cleaned screens;

Moving or fixed screens;

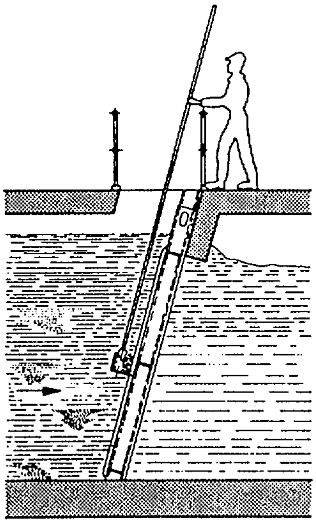
Coarse (40-100 mm), fine (10-30 mm) and finest (1-10 mm) screens;

Screens in combination with comminutors.

Manually cleaned screens

Today, manually cleaned screens (figure 3) are used primarily as protective devices with bar distances > 50 mm (coarse) at main collectors located at riverbanks, where the inflow of large objects like tyres, driftwood or mattresses etc. is expected. Fine (10-30 mm), manually cleaned screens are used in small water treatment plants and as preliminary protection in emergency cycles.

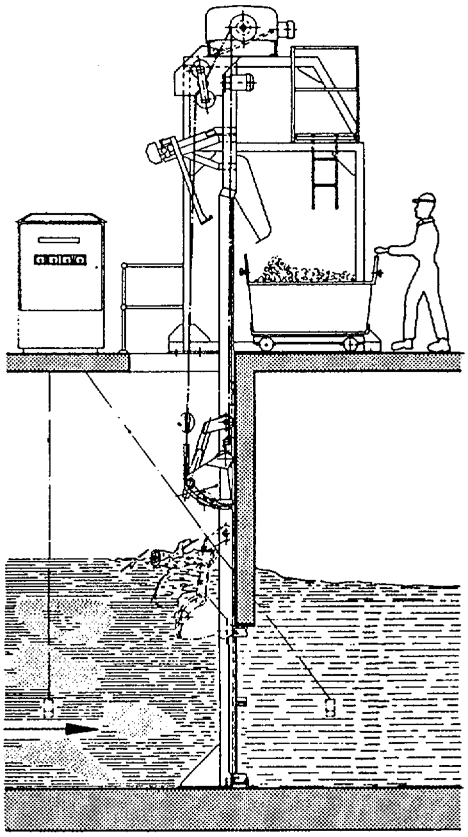
Figure 3. Manually cleaned screen



Mechanically cleaned screens

Mechanical cleaned screens are widely used and show a wide range of variation relating to the above mentioned subdivision. Here as well, coarse screens are used as protective devices whereas finer screens are used as a first cleaning step. A basic design of a mechanically cleaned screen is shown in figure 4. The three principal elements are: (a) the screen chamber, (b) the screen and (c) the rake construction.

Figure 4. Mechanically cleaned screen



Manually cleaned fine screens—function and design

Screens are dimensioned in accordance with the volume of water to be treated, water levels, the bar spacing selected, and the degree of pollution, whilst a guide to many of the parameters is supplied by experience. Manually cleaned fine (10-30 mm) screens are commonly installed in small water treatment plants with a capacity designed for medium-scale industries or small communities. The following information is required for this purpose:

Nature of the water and any abnormal characteristics (pH, temperature), its origin and the purpose for which it is to be used, and details of the impurities contained;

Water flows;

The relevant water levels, and where applicable, the design capacity of the plant for specific water levels;

Inlet cross-section;

Required bar spacing;

Heights of inlet channel floor, terrain and service deck;

Kind of debris material.

Bar racks are the most commonly used devices at waste-water treatment plants. They contain a screen chamber with inlet and outlet structures, and a screening device. A screen chamber consists of a rectangular channel. The floor of the channel is normally 7-15 cm lower than the invert of the incoming sewer. Also, the channel floor may be flat or at a desired slope. The screen is designed to prevent accumulation of grit and other heavy materials into the channel. The channel is normally provided with a straight approach, perpendicular to the screen, to assure uniform distribution of screenings over the entire screen area.

The yield of screenings can be subject to large fluctuations relating to local conditions (time dependence of sewage inlet by industry) and the weather. Heavy rains after long dry periods, as in many developing countries, will often result in high peak values and a higher tendency towards clogging. Therefore, at least two bar racks, each designed to carry the designed peak flow, must be provided in case one is out of operation. Arrangements for stopping the flow and draining the channel should be made for routine maintenance.

Manually cleaned bar racks have sloping bars that facilitate hand racking. The screenings are placed on a perforated plate for drainage. After drainage, disposal in a stationary screenings container or a further processing by comminutors is possible in order to use the comminuted screenings for compost disposals. In former times, comminutors were used in combination with screens, thus the screenings were only comminuted but not eliminated from the further waste-water treatment process, making the protective sense of such a screen arrangement doubtful, as well as the efficiency of following processing steps (biological and chemical treatment).

Stationary screening containers should be covered for reasons of climate influences (high temperatures in tropical countries create, for example, unpleasant odours), hygienic and aesthetic aspects and emissions.

Design example

The following design example is introduced to demonstrate how the dimension of a screen can be calculated, considering different assumptions:

1. Provide two identical bar racks, each capable of handling maximum flow conditions and an inclination of the bar rack of $\theta = 75°$.
2. One screen chamber could be taken out of service for routine maintenance without interrupting the normal plant operation.
3. Bar spacing (clear) = 2.5 cm
4. Peak design wet weather flow = 1.321 m^3/s
   Maximum design dry weather flow = 0.916 m^3/s
   Average design dry weather flow = 0.441 m^3/s
5. Provide approximately following velocities through the rack at different flows:
   - Velocity through rack at peak design wet weather flow = 0.9 m/s
   - Velocity through rack at maximum design dry weather flow = 0.6 m/s
   - Velocity through rack at average design dry weather flow = 0.4 m/s
6. Diameter of the conduit = 1.53 m
7. Slope of the conduit = 0.00047
8. Velocity at peak design flow, v = 0.88 m/s
9. Depth of flow in the conduit at peak design flow, d = 1.18 m

The first step is to calculate the dimensions of the bar rack chamber. The rack chamber is designed for peak wet weather flow. The velocities through the rack and channel, and depth of flow in the channel, are also checked for average and minimum design flows.

Clear area through the rack openings

$$= \frac{\text{peak design flow}}{\text{velocity through rack}} = \frac{1.321\ m^3/s}{0.9\ m/s} = 1.47\ m^2 \qquad (1)$$

Clear width of the opening at the rack

$$= \frac{\text{area}}{\text{depth of flow}} = \frac{1.47\ m^2}{1.18\ m} = 1.25\ m \qquad (2)$$

Adding the total number of bars = 49 and the bar width = 0.1 m to the clear width (b), the width of the chamber is calculated as follows:

$$= 1.25\ m + 0.1\ m \times 49 = 1.74\ m \qquad (3)$$

The necessary length of the bar rack at peak design wet weather flow for the clean rack and with 50% clogging (figure 2c) is calculated by the following equations which relate to the longitudinal section through the rack chamber (figure 1b):

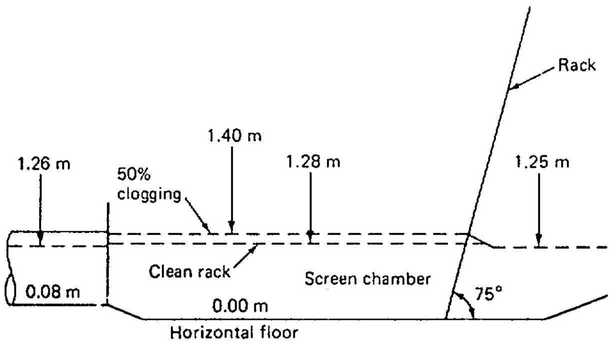
$$h_l = \frac{V^2 - (v_v)^2}{2g} \times \left(\frac{1}{0.7}\right) \quad \text{Head loss } h_l \quad (4)$$

Equation 4 is used to calculate head losses through clean or partly clogged bars, while equation 5 is used to calculate the depth of flow by using the energy equation with respect to the different sections (1-3, figure 2b) in order to obtain the length of the bar rack:

$$Z_1 + d_1 + \frac{(V_1)^2}{2g} = Z_2 + d_2 + \frac{(V_2)^2}{2g} + h_l \qquad \text{Energy equation (5)}$$

The results of the calculation are listed in the table below and are shown in the hydraulic profile in figure 5.

Figure 5. Hydraulic profile through the bar rack at peak design flow when rack is clean and at 50% clogging. All elevations are with respect to the datum at the floor of the rack chamber.



	upstream channel		*velocity through rack*	*downstream channel*		
conditions	*depth of flow (m)*	*velocity (m/s)*	*(m/s)*	*depth of flow (m)*	*velocity (m/s)*	*head loss (m)*
Clean rack	1.28	0.59	0.83	1.25	0.61	0.03
50 % clogging	1.40	0.54	1.51	1.25	0.61	0.15

The capacity of the design example for an average quantity of screenings is about 0.76 m^3/d and for a maximum quantity of screenings about 1.37 m^3/d at an average flow of 0.441 m^3/s. Observations over long periods show that an average amount of about 5 l screening oversize per capita and year can be expected for screens as in the above mentioned design example. Taking this into account, the capacity of such a calculated screening device can serve a population of around 55,000.

Description of production process

Dimensions of the example:

Length 2 m, width 1.74 m, angle of inclination in the rack chamber 75°

Screenbars: flat 50 × 10 mm, rectangular profile, openings between bars 25 mm

General arrangement of assembly and construction

a	width of channel	mm	1740
b	width of groove	mm	160
c	depth of groove	mm	100
rb	width of screen	mm	1740
r	width of frame	mm	1860
l	length of screen	mm	2000
s	width of openings	mm	25
p	partition	mm	35

Production process

The production process described hereafter is applied to a manually cleaned screen, which is built-in in a way that it can be pulled out of and pushed into the channel. For reasons of transportation and production, the screen can be mounted to the ground frame, whereby the screen is composed of three beams onto which the screen bars are welded. Galvanizing or a thick coat of coal tar pitch with epoxy provides protection against corrosion.

Process

Building and production

Beside the production process for the screen, a synchronized construction and space assignment are necessary in order to install the screen directly after its construction. The production process is structurized into *8 steps.* After every step a check is to be done by the worker or by the manager (figure 7). Firstly a drawing of the screen with a list of parts is to be prepared, corresponding to given dimension standards. Material is supplied according to the list of parts. In this case, rolled material from simple constructional steel is used. The raw rolled material is then cut to size corresponding to the given standards. For this construction, the cuttings, which will only be straight cuts, can be done with a saw machine. The parts cut are the parts for the frame, the screen bars and the beams for the bars. Completion, cleanness and requested dimensions are checked according to the plans.

If necessary, burr is removed from the cutting edges with a right-angle grinder. The ends of the section steel parts are chamfered for the preparation of the edge.

Figure 6. Detail drawing

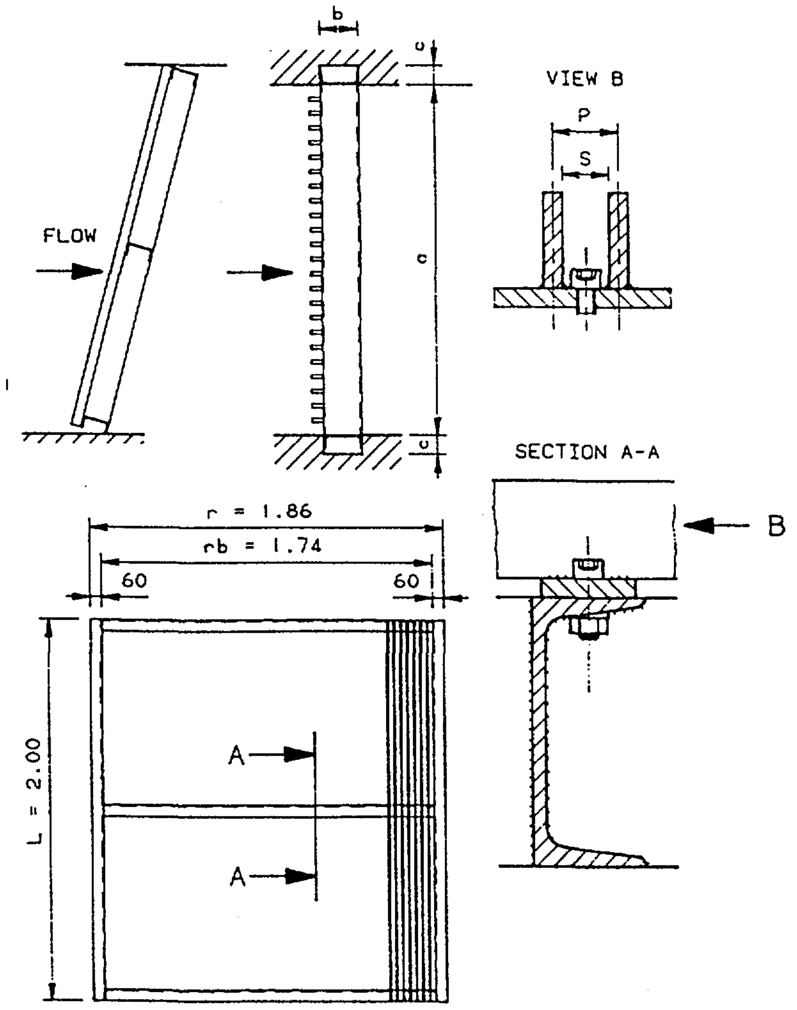
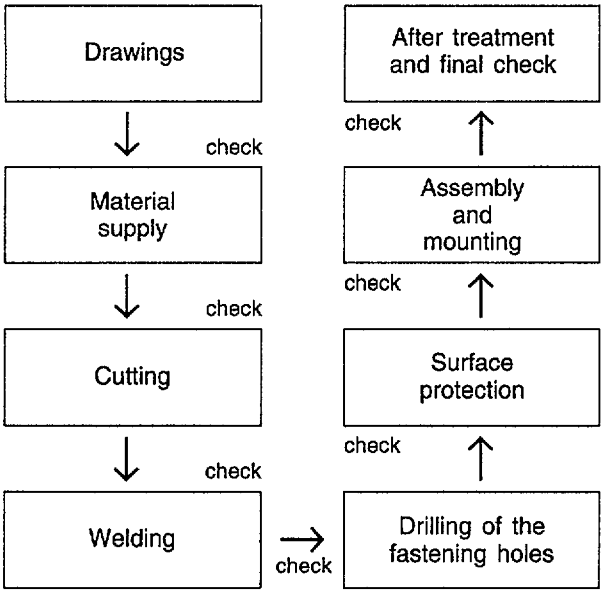


Figure 7. Production flow chart



The fastening holes are delineated, centred and drilled into the screen bars beams. Then all partitions of the holes are carefully controlled in order to guarantee exact fitting for the assembling. The bars are fixed to the three beams corresponding to the plan, whereby the partitions between the bars and in relation to the fastening holes have to comply with the drawings. All joints are fixed by electric welding. The welding seams have to be welded with sufficient root penetration and impermeability. The regulation of the welder depends on the material, the thickness of the electrodes and on the regulation possibilities of the welder. Slag and spatter formations have to be removed from the welding seams.

Before tacking the frame by welding corresponding to the plan, holes for the screen beams have to be delineated onto and drilled into the frame beams. The partitions and positions of the holes have to be checked very carefully for an exact fit. After tacking, the requested dimensions, angles, surface evenness and the diagonals have to be checked and realigned if necessary.

Surface protection

The durability of the screen depends on its protection against corrosion. Therefore, all steel parts have to be cleaned from rust and welding scales in order to guarantee a good bonding of the corrosion protection.

Zinc Coating: This is done in a zinc coat shop after chemical derusting of the steel parts.

Coal tar coating: For coal tar coating, a simple derusting with a file brush is necessary. The coating is applied with a paintbrush.

Coal tar/epoxy coating: Using a two component coal tar/epoxy coating, all steel parts have to be made blank by sand blasting.

Assembly and mounting

After surface treatment, the parts are assembled. The frame is layed down on two squared timber for protection. Then the screen is screwed to the frame using through bolts, washers and nuts (size of bolt head < 20 mm). After assembling, all coating damages have to be repaired and screws and bolts also have to be coated.

Example of production facilities

The production of a coarse screen requires only a minimum expenditure for machinery, equipment, personnel, space and materials. The time expenditure is about 20 hours excluding surface protection.

Required machinery and equipment

	Pieces
Marking table	1
Workbench with simple tools such as hammer, spanner, marking tools, centre punches, scales, file brushes etc.	1
Electric saw	1
Electric drill (min. hand drill or drill table and drills with the diameters 10 and 12 mm)	1
Electric welder with necessary accessories (electrodes ≤ 4 mm)	1
Facility for surface protection (by contract with a zinc coat shop)	1
Lifting gear (ca. 600 kg)	1

Necessary tools, equipment and machinery are available in the simplest version for approximately US$ 7.500-10.000 (1992 prices).

Required personnel

Manager	1
Skilled locksmith	1
Unskilled worker	1

Required area

	Square metres
Production area	25
Storage capacity	40
Recreation area, WC, washing facilities	30
Office space	30

Required power and utilities

Electric power	min. 1 kW

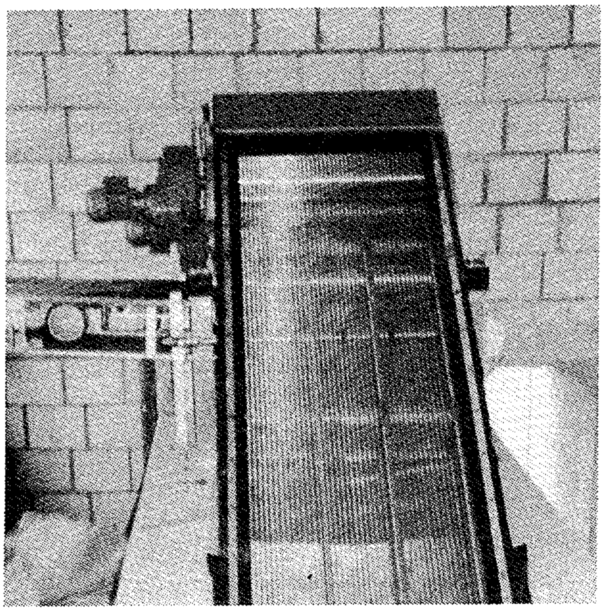
Required material

U-profiled steel U-140, flat steel 50 × 10 mm, hexagon socket screw M10, nuts, washers, coal tar coating or coal tar/epoxy coating.

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

How to Start Manufacturing Industries

Coarse sieves



Introduction

The treatment of domestic and industrial waste water is usually carried out using three different possible methods. These are:

Mechanical treatment (undissolved materials are mechanically separated from the waste);

Biological treatment (also referred to as clarification; waste water contains many substances in undissolved or dissolved form, which are used by micro-organisms for growth and metabolism and are thereby removed from the waste water);

Chemical treatment (supplementary method using chemical processes).

Whichever one of these methods is used depends on the prevailing causes, level and composition of contamination.

While all domestic waste water basically has the same features of contamination, industrial waste water has a non-uniform composition. Industrial operations in the various production sectors produce waste water in different specific quantities containing different materials; the types of content material are first and foremost determined by those raw materials and accessory agents used in the production process.

With practically all waste water treatment measures, rakes and sieves—as part of the mechanical process—form the first stage of treatment. Their task is to remove solid materials in the water and thereby ensure smooth progression to subsequent stages of clarification, especially safeguarding against clogging in canals and pipes.

The sieving process

The removal of coarse waste materials in waste water, such as fibrous and bulky materials, is done mechanically by rakes, though increasingly by sieves. Sieves are used above all because the pitch width between the rods of a rake cannot be reduced as desired. In addition to this, due to the rake's slit opening, long thin materials as well as fibres can also be washed through. Even a fine rake with a 10-15 mm pitch between rods cannot entirely prevent clogging in subsequent treatment stages.

Different sieving systems are used, such as:

Static sieves (e.g. flat sieves),

Rotational sieves (e.g. drum sieves),

Vibrating sieves (e.g. oscillating sieves).

Flat sieve

Flat sieves are, from the point of view of machine technology, the simplest sieves, as they themselves possess no mechanically operated parts. A flat sieve consists of a square or rectangular steel frame strung with wire, or of a perforated or slit plate fixed in the water inflow canal. Waste water flows through the sieve and bulky materials are caught and held. In smaller treatment plants the removal of accumulated screenings is done manually; larger plants use for this purpose a movable arm, fixed laterally to the water inflow canal and powered by means of an electric motor. Static sieves, or flat sieves, are used above all in the domestic sector.

Drum sieve

Drum sieves have a slow turning drum strung with a split or perforated cover, through which waste water can flow either from the outside to the inside, or *vice versa,* in order to get rid of its solid materials. Screenings are removed by a screw conveyer, when waste water is fed into the drum, or by a skimming device (e.g. brushes, water jets) when waste water is passed over the outside of the drum. Drum sieves are used for the pre-treatment of domestic and industrial waste water (e.g. in industries such as iron processing, sugar refining, dairies, textiles etc.).

Vibrating sieve

Vibrating sieves are mainly used for pre-treating waste water from the tinning, starch processing and paper industries, as well as from the chemical and ceramic industries.

With a vibrating sieve, waste water flows onto a flat conveyor sieve, made up of single sieving elements of fabric (or slit or perforated plates) set in an iron frame, which effectively sieves out material when immersed in water. When the sieve re-emerges, the separated solids are removed by shaking. This constant cleaning is necessary to prevent any loss in performance due to clogging.

Screenings collected from the different sieving processes comprise, depending on the width of the sieve pores:

> Food remains, hairs, excrement, fabrics, synthetic materials, street rubbish, tins, toilet paper, cigarette filters, as well as fibrous and woven materials, in the domestic sector;
>
> Synthetic materials, fabrics, ashes, wood and rubber pieces, broken glass and ceramics, stones, as well as fibrous and woven materials, in the industrial sector.

The proportion of fibrous or woven materials in waste water has recently risen due to the increasing use of fibre fleece in households, hospitals and industry. They are simply thrown away after use, sometimes ending up in the waste water.

In the following only one flat sieve from the group of static sieves—the coarse sieve—is considered. The effective part of this type of sieve consists of square or rectangular steel frames strung with wire, or of perforated or slit plates. These are either fixed in the waste water inflow canal, or mounted on a steel frame and rotated through the water and then raised again for the removal of the sieved materials.

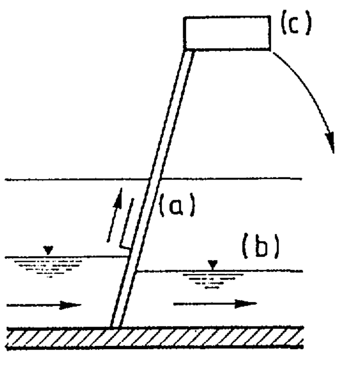
Sieve types are given below based on the width of their sieve pores and their general applications:

Normal width of sieve pores (In millimetres)	*Aggregate*	*Area of application*
5-15	Coarse sieves	Untreated waste water
1-6	Mesh sieves	Untreated waste water
0.5-5	Fine sieves	Untreated water, sludge
0.01-0.07	Micro-sieves	Biologically purified waste water, rain-water

Coarse sieves—function and structure

The flat coarse sieve described in figure 1, is used in domestic and industrial treatment plants to remove coarse or bulky materials in the mechanical cleaning of waste water. For this, the coarse sieve (a) is fixed at an incline of 45°-60° over the entire width of the water canal (b).

Figure 1. Function of a coarse sieve



The waste water flows through the sieve which screens out bulky and coarse materials. Such screenings are cast into a receptacle (c) either manually, as in the case of smaller plants, or mechanically, as in the case of larger plants. (The mechanical removal of screenings is done by a swinging arm mounted on the rim of the water inflow canal and powered by an electric motor; the interval between cleanings is regulated by the difference in water level and/or by a set time.) These screenings fall over the side of the receptacle and into a container (in smaller plants), or onto a conveyor belt (in larger plants). From there they are transported away for further processing or for disposal.

The yield of screenings fluctuates according to time as well as to the local conditions of the drainage system; heavy rains after long dry periods in particular, as is common in developing countries, will often result in extraordinarily high peak values.

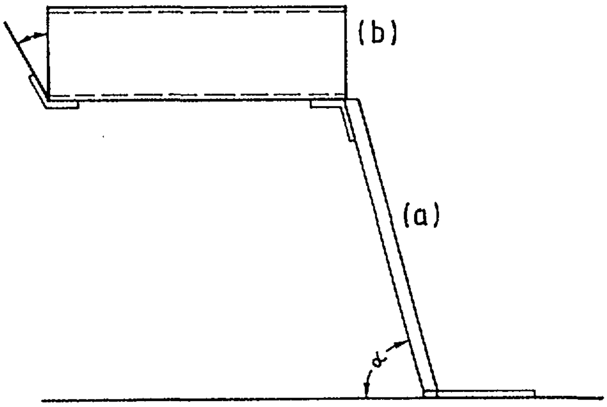
The stationary container for the screenings should be covered atmospheric influences (high temperatures in developing countries create, for example, unpleasant odours), and also for reasons of hygiene, aesthetics and emissions control.

Coarse sieves, which belong to the simplest group of sieve types, are generally plates of a different size, thickness and quality of material, with variously shaped sieve openings. A coarse sieve consists of:

The sieve surface, or sieve floor (a)

The receptable (b).

Figure 2. Structure of a coarse sieve



A galvanized stainless steel plate or, to a lesser degree, plastic is used to form the sieve surface and receptacle.

The sieve surface

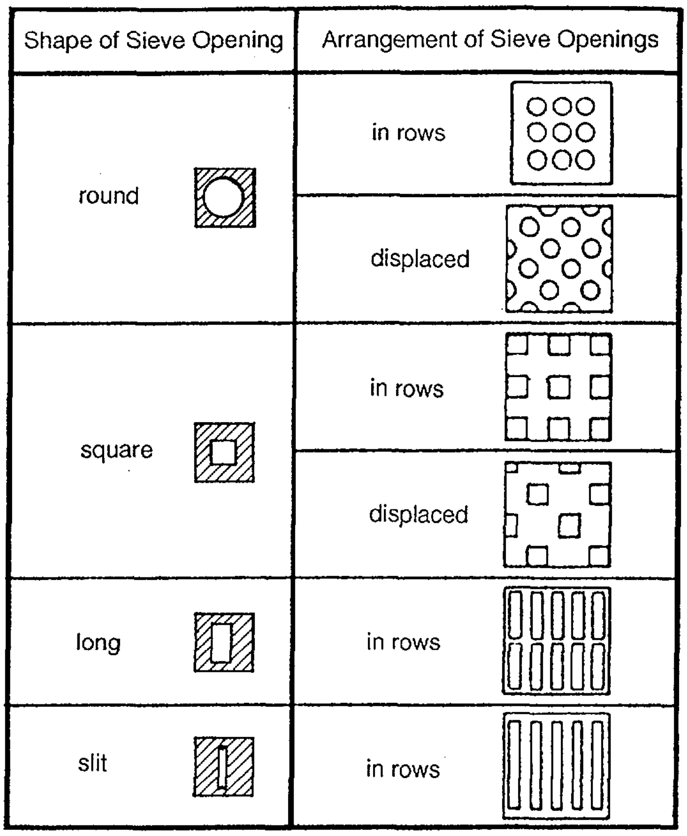
The shapes of the sieve openings for a coarse sieve and the arrangement of the sieve openings, common to sieve technology, are presented in figure 3.

Important for the sieving process is the open sieve surface, which is defined as the ratio of the sieve opening to the total area of the sieve floor. The formula below is used to calculate the open sieve area:

$$A_0 = \frac{A}{A_1} \times 100\%$$

A_0 = open sieve area,
A_1 = sum of the areas of all sieve openings
A = total area of the screen floor

Figure 3. Shape and arrangement of sieve openings



Shape of Sieve Opening	Arrangement of Sieve Openings
round	in rows
	displaced
square	in rows
	displaced
long	in rows
slit	in rows

The open sieve area in the case of different shapes of sieve openings becomes according to the sequence round, square, long. The rigidity of the sieve openings and the smooth sieve surface are advantageous for sieving in that they facilitate the transport of collected screenings and limit surface wear of the sieve floor. No generally applicable sizes can be given for coarse sieves. The dimensions of a coarse sieve (height, width, thickness, type of sieve opening, size of the open sieve area) must be individually established and depend above all on:

The dimensions of the waste water canal;

The type and amount of expected screenings;

The volume of water inflow.

The receptacle

The receptacle is comprised of: the receptacle floor; and the two sides of the receptacle. Smaller receptacles are formed from plates by bending the sides upwards. With larger receptacles the floor and both sides are first produced separately, and then the sides are welded to the receptacle floor. Several drainage holes are made in the receptacle floor, as water also filters into the receptacle along with screenings.

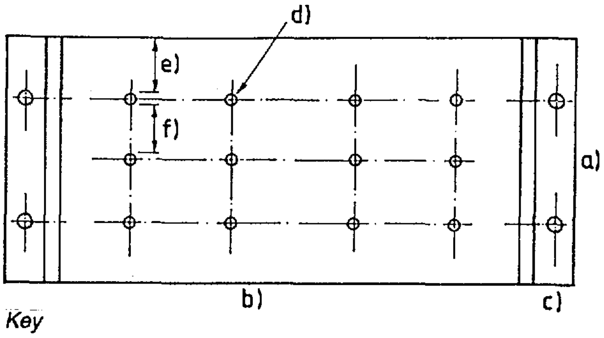
The receptacle is fixed on one side to the coarse sieve, level with the upper edge. The opposite side, from which the screenings, removed from the coarse sieve, drop into containers below the receptacle, is usually open; it can, however, also be fitted with a movable, self-closing flap.

As with the coarse sieve, the dimensions of the receptacle are calculated individually and partly predetermined by the measurements of the coarse sieve.

Description of the production process

The production process described here concerns a coarse sieve made from a 5 mm thick galvanized stainless steel plate and a receptacle made of the same material to be used in a 1000 mm wide waste water inflow canal.

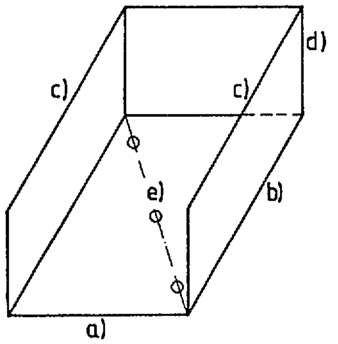
Figure 4. Dimensions of a sieve



Key

Height	500 mm
Width	1000 mm
Width of welding strips attached to the edges of the back, each with 2 holes for screws (diameter 14 mm)	20 mm
Four rows of sieve openings with a diameter of	10 mm
Distance from the top rim to the first row (and from bottom rim to last row)	100 mm
Distance between subsequent rows	150 mm

Figure 5. Dimensions of the receptacle



Key

Width of basin	1000 mm
Depth of basin	2000 mm
Length of sides	2000 mm
Height of sides	800 mm
Three diagonally placed drainage holes each with a diameter of	5-7 mm

The production of the coarse sieve and receptacle described here takes place in five stages (see figure 6).

Two supplied galvanized stainless steel plates of the appropriate size form the basis of the production process. The measurements of the coarse sieve and the welding strips to be produced are noted clearly on the one plate, and on the other those of the receptacle floor and both its side walls.

From the drafting table the plates are transported to the cutting or sawing area, where sieve floor, welding strips, receptacle floor and both side walls are made from the plates according to the specified measurements. Before proceeding on the next production phase measurements of the individual parts are checked, and burrs on the edges resulting from cutting and welding are removed.

In the subsequent phase the individual pieces are assembled. Both welding strips are welded level and at right angles to the right and left edges of the back of the coarse sieve. Similarly, the left and right side walls are welded to the long side of the receptacle floor at a 90° angle.

The last production phase entails post-production processing and a final check of the product: welded seams are checked and uneven surfaces are filed down. It is best to file corners and edges of the receptacle walls before being transported for a final check.

The assembly of the coarse sieve together with receptacle is best undertaken at the actual waste water treatment plant.

Example of production facilities

It can be seen from the preceding sketch (see figure 6) of the production process that the production of a coarse sieve and receptacle requires only a minimum expenditure for machinery, equipment, personnel and materials etc. The following list of figures are based on the production of the type of coarse sieves described in the previous section. It is assumed that the equipment listed here would also be capable of producing other sieve types.

The production of coarse sieves and receptacles requires an approximate total of 5-6 hours, which includes both pre- and post-production processing phases.

Required machinery and equipment

Description	*Pieces*
Drafting table	1
Workbench with simple tools	1
Sawing or cutting machine	1
Drill (with drills of various diameter)	1
Welding unit (with necessary accessories)	1
Buffing machine	1
FOB-price for machinery and equipment (1991)	Approx. US$ 30,000

Required personnel

Manager	1
Skilled locksmith or mechanic	1
Unskilled worker	1
Secretary	1

Required area

		Square metres
Production hall:	open space	200
including:		
Production area		80
Storage capacity		40
Recreation area, WC, washing facilities		30
Office space		30

Required power and utilities

Electric power	5 kW
Water	
Oxygen, acetylene	

Required raw materials

Galvanized stainless steel plates
Welding electrodes
Incidentals

Figure 6. Production stage for a sieve and receptacle

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Filter cloth for diffuser plates

Introduction

Waste water disposal rates as one of the most current environmental problems not only in industrial but also in developing countries. The heaviest pollution of surface water occurs through the discharge of waste water from cities, communities, as well as from agriculture and industry. In this way, surface water is heavily contaminated partly through a reduction of its oxygen content, through sludge deposition and algae formation. These qualitative changes in the surface water can, however, be avoided by treating waste water beforehand in such a way that it becomes free of pollutants and toxicants.

Waste water treatment generally covers, for both industry and the community:

The retention of pollutants, toxicants or recyclable materials contained in the waste water;

The specific treatment of waste water; and

The separate treatment of sludge in which filter cloths, among other devices, are used.

Methods of sludge treatment

During the cleaning process solid organic and anorganic pollutants are extracted from the waste water, and dissolved organic materials are transformed into CO_2 and biomass. The residue resulting from this clarification accumulate as water-rich sludge amounting to 1-2% of the entire volume of the treated waste water.

In sludge treatment the volume of the residue is reduced by lowering its water content, facilitating also storage at dump-sites or recycling. Both natural and artificial methods of dehydration exist which are used not only in communities but also in the chemical, textile and food industries, as well as in mining.

Natural methods of dehydration

Natural dehydration refers to those methods by which water extraction occurs under the influence of natural forces, for example, the earth's own gravitational field or thermal forces in the atmosphere. These methods include:

Sludge drying beds;

Sludge lagoons.

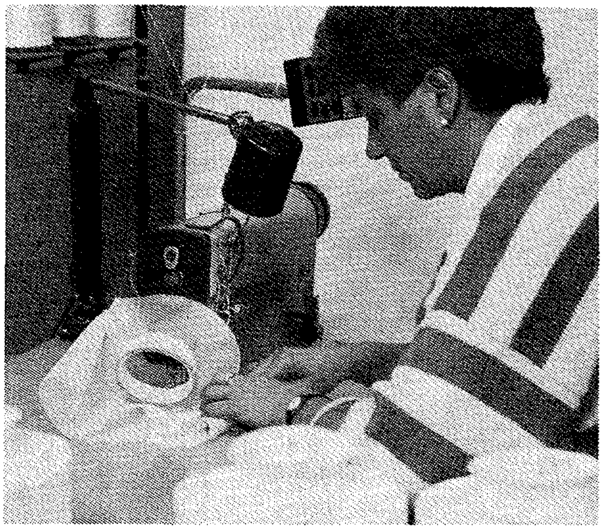
Sludge drying beds

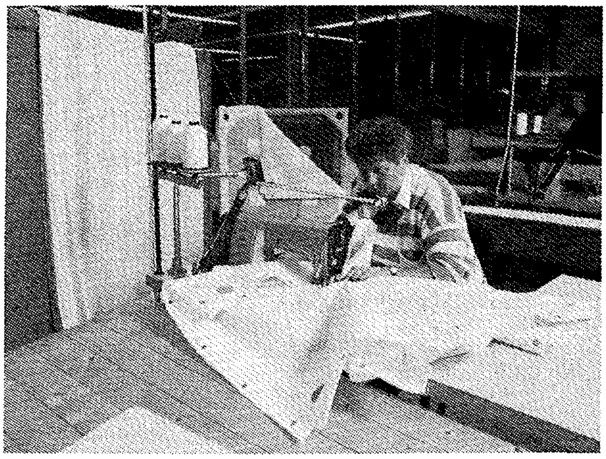
Sludge dehydration in sludge drying beds is regarded as the oldest method of its kind. The bottom of the sludge bed consists of drain pipes, above which gravel and sand layers (20-40 cm) of different grain sizes and thicknesses are arranged as filter media; the side walls are generally made from precast concrete parts. Sludge is distributed over the filter media in layers of approx. 20 cm in thickness and dehydration occurs partly with water running off downwards into the drainage system and partly through evaporation. With regard to the normally predominant atmospheric conditions in central Europe (temperature, humidity, precipitation), a yearly surface load of around 2 m^3/m^2 for drying beds can be expected.

From time to time the dried sludge must be removed for further treatment, recycling or storage either by hand in smaller installations, or by specially constructed machines in the case of larger beds.

Sludge lagoons

In contrast to sludge drying beds, sludge lagoons serve, in addition to dehydration, the final disposal of sludge. For this reason, the lagoons are used for 20 to 30 years, keeping in mind that volume reduction occurs during dehydration. Generally waste land, old





quarries and the like are especially suited for laying out sludge lagoons. It can, however, also be practical to seal off small valleys with dams in order to create large storage spaces. Care must be taken that surface water, spring water and other forms of imported water are kept clear of such lagoons so that dehydration through drainage and evaporation is not jeopardized in any way.

Artificial methods of dehydration

Artificial, that is to say, mechanical methods are used to facilitate dehydration, using less space and time. The obtainable performance in this respect depends on the energy input.

The traditional methods of artificial sludge dehydration can be divided into two groups:

Those which extract water by increasing gravitational force (centrifuges, separators);

Those which extract sludge liquid by exerting external pressure on a permeable separating membrane (e.g. belt filters, vacuum filters, filter presses).

Of these methods the following have found widespread use:

Centrifuges;

Belt filter presses;

Chamber filter presses.

Centrifuges

In centrifugation the separation of solid matter and water occurs in a drum rotating at high speed, as a result of their different individual settling velocities. Water thus extracted is discharged and solid matter, because of its higher settling velocity, is deposited on the drum wall, from where it is discharged through a screw conveyor rotating at a speed lower than the drum.

Investment costs for centrifuges are relatively low, though the installations are liable to relatively high wear. The advantages of using centrifuges are to be found—apart from their continuous and operation-free functioning—in their high volume flow rate with only a small space required. The sludge volume flow rate of a centrifuge for example with a 630 mm drum diameter and 1.7 m drum length amounts to 25 m^3/h. The disadvantage of such a system is that it attains a low dehydration rate, resulting in a dry matter content of only 15-20%.

Belt filter presses

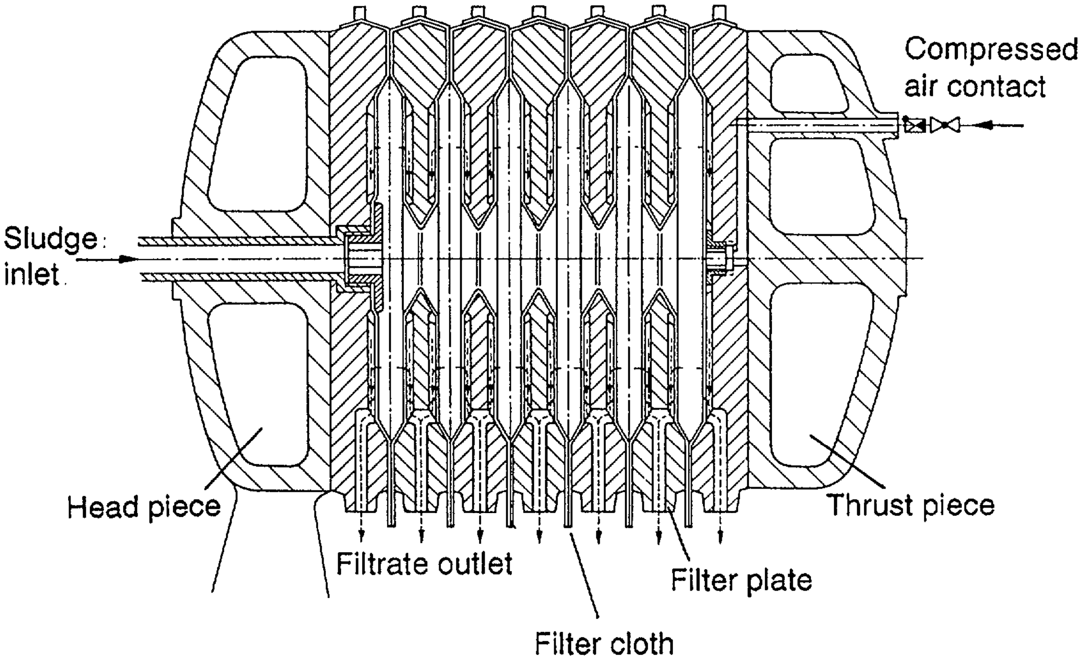
Installation sludge, which is to be dehydrated, is put in a thin layer in between two circulating belts and rolled dry between two cylinders under pressure. At any point along the belts' travelling route the belts can be diverted several times by means of a special installation of movable support and press rollers to exert—in addition to the forces of pressure—tangential stress on the sludge for better dehydration. After the sludge has run through the belt filter press, it can be removed at the end of the system.

Investment costs for belt filter presses are in the same range as those for centrifuges, though operational costs are somewhat higher. Belt filter presses with widths between 0.5 m and 3 m are used and have a volume flow rate in the range of 3-5 m^3/h and per metre belt width, resulting in a solid matter content of 25-30%.

Chamber filter presses

Chamber filter presses can be distinguished from the two above-mentioned dehydration methods by their filtrate quality, their attainable concentration of filter cake and their method of operation (see figure 1).

Figure 1. Chamber filter press



Chamber filter presses consist of a number of filter plates or plate packets (see figure 2) covered on both sides with a filter cloth that acts like a separating membrane. These plates hang parallel to each other in a supporting and guiding structure and are enclosed at the ends with a head and thrust piece. Upon decompression cavities form between the individual filter plates, which are filled with sludge to be dehydrated. Then when compressed sludge liquid is pressed through the filter cloth, leaving a filter cake of solid matter in the chamber. Sludge liquid (filtrate) is discharged through flutes in the filter plates. When the filtrate volume reaches its minimum after the filling and compression stages, dehydration is interrupted and the filter press emptied.

To empty the filter the plates move apart automatically, at which point the filter cake (dehydrated sludge) falls out. After it has been emptied the chamber filter press is closed and a new dehydration run can begin.

Investment costs for chamber filter presses are much higher than for centrifuges and belt filter presses. In contrast to these, however, a solid matter content of 50-70% in the dehydrated sludge, as well as a 100% screening effect can be obtained in chamber filter presses. That is to say, the filtrate contains no solids so long as contents in the single chambers do not leak into the filtrate through cracks in the plates or rips in the filter cloths.

Filter cloths

Wherever filter presses are employed, filter cloths are used to separate solid matter from liquids. The raw materials most frequently used today for filter fabric are polypropylene, polyamide and polyester. The fabric and filter characteristics of the filter cloths used are very diverse and are therefore especially selected for each individual case. The type of fabric for the filter cloths depends on how the cloths will be used, especially on the following:

Size of the particles which are to be separated;

Amount of solid matter and liquid;

Degree of compression;

Thermal, chemical or mechanical stress;

Condition of the liquid to be dehydrated.

Filter cloths are made according to the size of the plates (they can be anywhere between 100 × 100 mm to 2000 × 2000 mm). There are basically two types, overhang cloths and double cloths.

Overhang cloths consist of two identical halves which hang together, the eyelets of which are placed over fastening pins on the top edge of the filter plates (see figure 3). The halves are hung over both sides of the filter plate and are fastened at the sides and bottom edge with quick-stick bands or velcro seals.

Double cloths also consist of two identically shaped cloths of the same size sewn together at the circular opening in the middle of the filter cloths by using a tubular neck (see figure 4). To fix the filter cloth to the filter plate one filter half is first rolled together and inserted through the circular opening in the filter plate so that the neck sits in this opening. The inserted half of the filter cloth is then rolled out again and attached

Figure 2. Filter plate

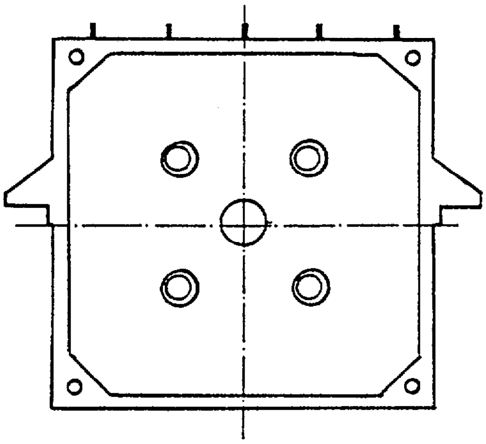


Figure 3. Overhang cloth

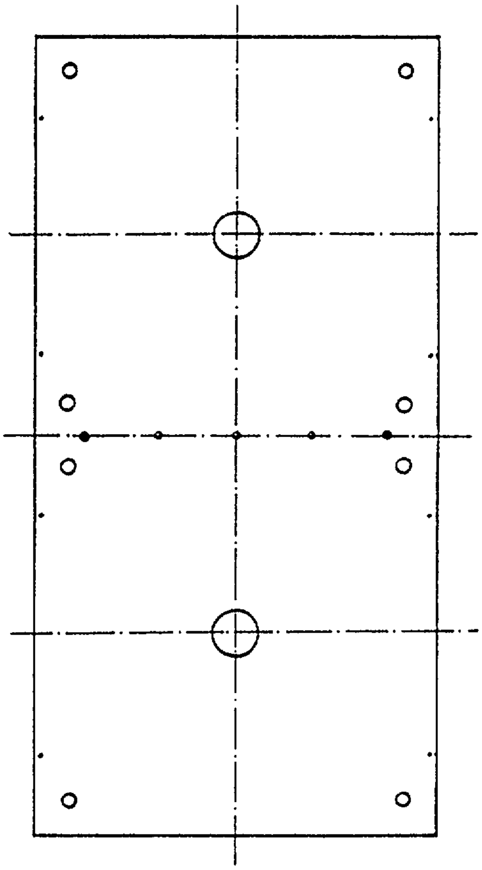
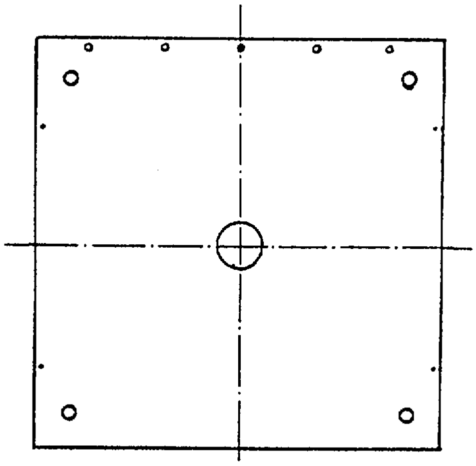


Figure 4. Double cloth



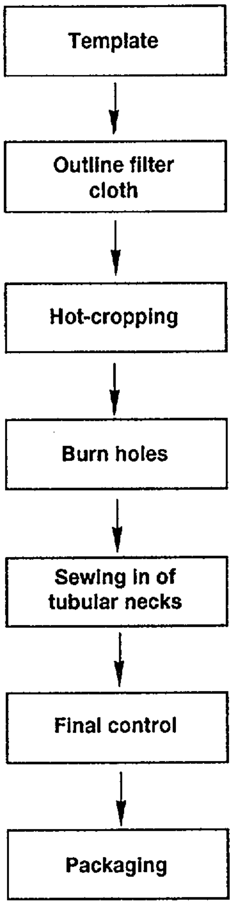
together with the other cloth half at the top edge of the filter plate by placing the eyelet over the fastening pins. Fastening at the sides and lower edge of the filter plate is also done with quick-stick bands and velcro seals.

Description of production process

The production process described below refers to the manufacture of a double cloth from polyester. Specific measurements are not required as the production process for filter cloths of all sizes is the same.

First, a template is prepared from cardboard or paper, according to the required measurements of the filter cloth (see figure 5). The template is layed onto the polyester fabric and the outline of the filter cloth and all openings and auxiliary markings are drawn onto it. The filter cloth is then cut out using hot-cropping shears, care should be taken not to fray the cutting edges. Once the outer shape of the filter has been cut, the openings, as well as notches, can be burned out. Finally, the two halves of the filter cloth are sewn together with a tubular neck made from polyester. Care should be taken that the cloth halves lie exactly on top of one another and that they cannot be twisted in the neck area.

Figure 5. Flow chart



Double filters thus produced are checked individually for possible faults in the fabric and for missing or inexact openings. Following this they can then be packed and transported in to storage.

Description of a production installation

It has already been mentioned that filter cloths of different sizes can be manufactured. Normally they are made by special order based on very specific measurements and integrated into regular production so that the production programme of one workday comprises different sized filter cloths.

Filter cloths of all types and sizes can be manufactured with the following machines and equipment, as well as personnel and area specifications. The figures for energy and materials, on the other hand, relate to the manufacture of 300 × 300 mm sized double filters of which 8 units—a total of 16 single cloths—can be produced in the course of an 8-hour workday.

Required machinery and equipment

Description	*Pieces*
Cutting board	1
Soldering iron	1
Hot-cropping shears with different blades	1
Sewing-machine	1
FOB-price for machinery and equipment (1991) Approx. US$	40,000

Required personnel

Manager	1
Administration, sales	2
Cutter	1
Sewer	1

Required area

	Square metres
Management, administration	60
Production	80
Social area	40
Storage	50

Required energy

Electricity	50 kW

Required materials

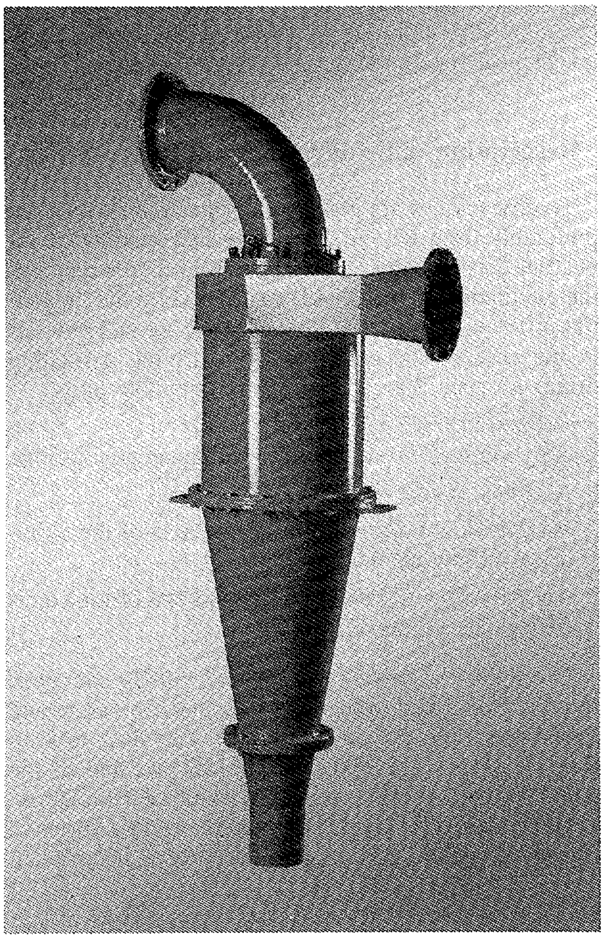
Polyester	4 m^2
Sewing thread	60 m

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

File: Z 15
ISIC CODE 9000
October 1992

How to Start Manufacturing Industries

Hydrocyclone



Introduction

For the separation of solid contents from waste water gravity on its own can be used if a sufficiently fast settling speed is given, enabling, even under the influence of turbulences, a sedimentation of non-coagulating solid particles in reasonably sized sedimentation tanks.

Mineral solids contained in household and industrial waste water should be separated from the waste water flow at the earliest possible stage, in order to:

Reduce breakdowns and deterioration of mechanical installations and pipe-systems;

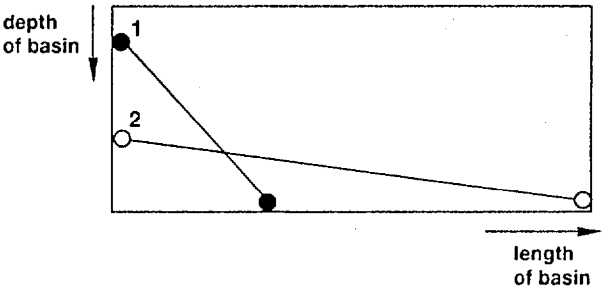
Prevent sedimentation in the installations;

Regain mineral deposits.

Mineral solids are isolated particles, which during sedimentation neither alter size, shape or weight (in contrast to flocculating particles). Each particle settles independently, the settling path remains uninfluenced and the settling speed stays constant. In an ideal, horizontally passed rectangular basin, the horizontal speed v_h remains constant; if the settling speed v_s is constant as well, the settling particle follows a straight line.

In figure 1 the sedimentation process of two particles with different settling speeds (different size/weight) in horizontally flowing liquid is shown:

Figure 1. Sedimentation process



If such a separation is not possible under reasonable conditions, then centrifugal force can be used in addition to gravity. In this case, use is made of radial acceleration for the grading effect, i.e. for an improvement in the separation of the organic and mineral contents of the waste water.

This process is used in centrifuges as well as in hydrocyclones. Hydrocyclones function as completely encased overflow centrifuges with an automatic sludge drain, but without rotating casings.

In contrast to centrifuges, hydrocyclones have the following advantages:

Simple operation;

Simple maintenance;

Simple construction;

Possibility of using various materials for a favourable constructional design in order to solve abrasion and corrosion problems;

High through-flow capacities;

Relatively low running costs;

Only a small area required for installation;

Low foundation costs.

The disadvantages are:

Difficult pre-calculation of separating results;

The necessity of laboratory tests using the original size, in order to determine the separating results as exactly as possible.

In comparison with traditional separation techniques (e.g. sedimentation tanks), hydroclones have the following advantages:

Higher separation forces;

Higher separation speeds;

A shortening of the separation time;

A reduction in the area required;

Lower investment costs.

However, the following disadvantages then arise:

A greater dependency on flow volumes;

An incomplete separation in the case of a partial load;

Relatively high energy costs.

Hydrocyclones are technically simpler and more economical than centrifuges, and also have advantages over traditional techniques. However, the higher working pressure needed requires an additional input of energy, which results in higher running costs. Because of these characteristics, and for economic reasons, their use is limited to industries, where valuable materials in solution are to be reclaimed.

Hydrocyclones are used, for example, in the following industries and for various tasks:

In the paper and pulp industry for the regaining of cellulose from waste water;

In dressing and processing techniques for dense-media separation, i.e. for the separation of mineral and other raw material mixtures where the components have different densities of floating and settling parts.

The hydrocyclone is especially appropriate for:

Stream separation for grain sizes between 5 and 100 microns, especially for:

De-sludging (separation of undesired fine grain from coarse grain = underflow regaining);

De-gritting (separation of undesired coarse grain from fine grain = overflow regaining);

Sludging (in principle the same procedure as for de-gritting, also multi-stage);

Thickening the separated coarse grain material (underflow).

The hydrocyclone is less suitable for clarification.

In both applications—thickening and clarification—the hydrocyclone is mostly only used for the first phase, as it can fulfil this task both effectively and economically. For the following phases other wet-mechanical separation appliances are used.

Description and functioning of hydroclones

Hydrocyclones are centrifugal separators, which are preferably used for the thickening and grading of industrial dense-media and sludges. With hydrocyclones the circulation of the liquid is achieved by the tangential inflow of dense-media under pressure and not—as in the case of the centrifuge—by driving a rotating drum. As such the cyclone has no movable parts.

A hydrocyclone consists of:

A cylindrical inflow chamber with tangential inflow;

A conus casing;

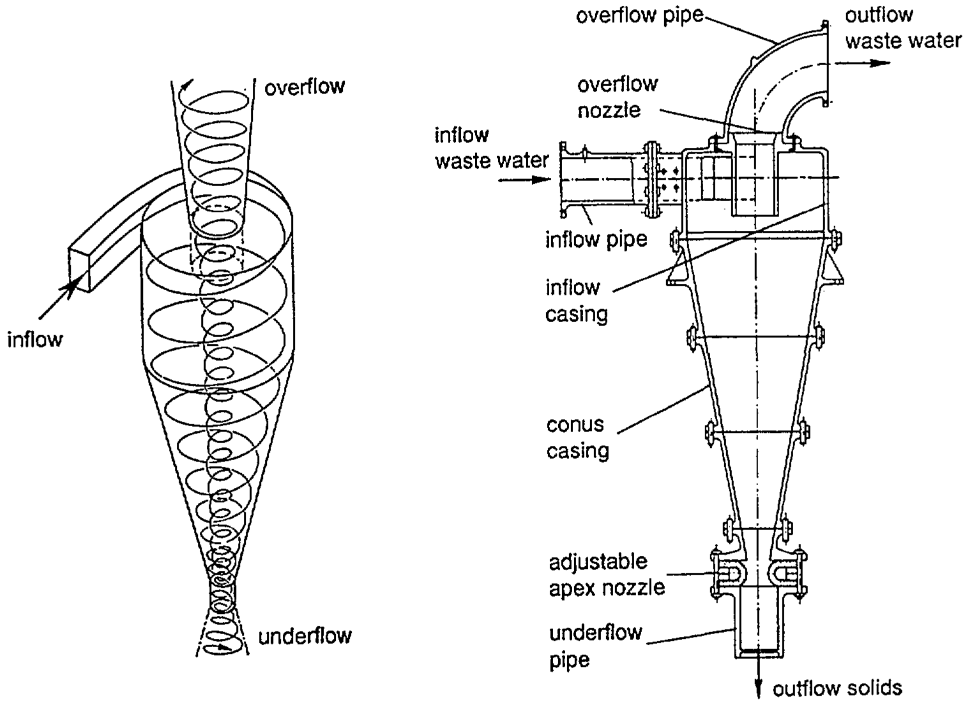
An overflow nozzle in the central axis of the cylindrical inflow chamber;

An underflow nozzle at the bottom end of the conus casing (see figure 2).

The industrial dense-media is tangentially conveyed into the cylindrical inflow chamber under pressure and then forced into a rotatory motion. The flow follows first the inner wall of the cylindrical part and of the conus until it reaches stagnation point near the apex.

Once there the downward directed primary vortex is forced to change its direction because of insufficient

Figure 2. Hydrocyclone



outflow possibilities. An upward directed secondary vortex is formed which circles around the air core near the central axis, finally leaving the cyclone through the upper axial nozzle, the immersion tube. Both vortexes turn in the same direction.

Under the influence of the rotatory motion heavier solids are pressed against the walls and from there, because of the gravity and the primary vortex, they move downwards along the walls. This sludge stream leaves the cyclone through the apex opening as an underflow stream (underflow nozzle). It thereby seals the underflow nozzle hydraulically, preventing the outflow of the main part of the meanwhile diluted and clarified suspension. This suspension thus moves upwards via the inner vortex and leaves the cyclone through the overflow pipe (overflow nozzle).

If specifically lighter material is contained in the water, then this gets into the centre of the rotatory motion and is carried off together with the liquid.

As the underflow of the hydrocyclone is of a solids-water-mixture, water may have to be extracted at a later stage.

The necessary inflow pressure is created by means of a pump. In order not to disturb the dynamic equilibrium inside the cyclone, only pumps with a constant delivery may be used. Therefore, for the direct charging of a cyclone, piston or surge pumps are not suitable.

Dimensioning

A cyclone has to be dimensioned according to the grain sizes to be separated, and not according to the volume of through-flow, because for large volumes cyclones with large cross-sections, i.e. big nozzle openings, would be necessary; in this case, however, only large grain sizes could be separated. Small grain sizes on the other hand need small cross-sections and the longest possible length of cyclone. To reach great capacities in this case, many smaller cyclones have to be connected in parallel. They can be positioned in a row or in a ring. To improve the separating capacity, cyclones can also be connected in series, whereby multi-stage blocks, so-called multi-cyclones, are created.

The grading effect to be achieved by a cyclone is determined by various factors, which can be combined to form the following approximate formula:

$$d \sim \sqrt{\frac{\eta \cdot D}{(\rho_p - \rho_l) \cdot n \cdot v_t}} \qquad [\mathrm{cm}]$$

Key:

d = diameter of a solid particle [cm]
D = nominal diameter of the cyclone [cm]
ρ_p = density of the solid [g/cm^3]
ρ_l = density of the flow medium [g/cm^3]
n = number of circulations by the liquid during passing time
η = dynamic viscosity [g/cm·s]
v_t = inflow velocity [cm/s]

The formula indicates, that where the range of grain sizes gets smaller:

The diameter of the cyclone has to be reduced;

The inflow velocity has to be increased and/or;

The number of circulations has to be increased (which means an enlargement in the over-all length of the cyclone).

Nevertheless, because of the danger of clogging, hydrocyclones should not fall below certain diameter sizes.

The share of solids in dense-media should not exceed a certain percentage; for example, in the case of dense-media to be desilted 3-6% are allowed.

Description of the production process

The stainless steel plates, ordered from outside firms, are cut into the necessary shape and size by a cutting machine. The mantle piece is brought into a cylindrical shape to form the inflow cabin and is welded together. Into this an opening is cut, where the waste water influx pipe is welded on.

Into the circular lid piece a round opening is cut to take up the dip pipe with overflow jet and overflow pipe, which are welded together and then welded into the lid piece.

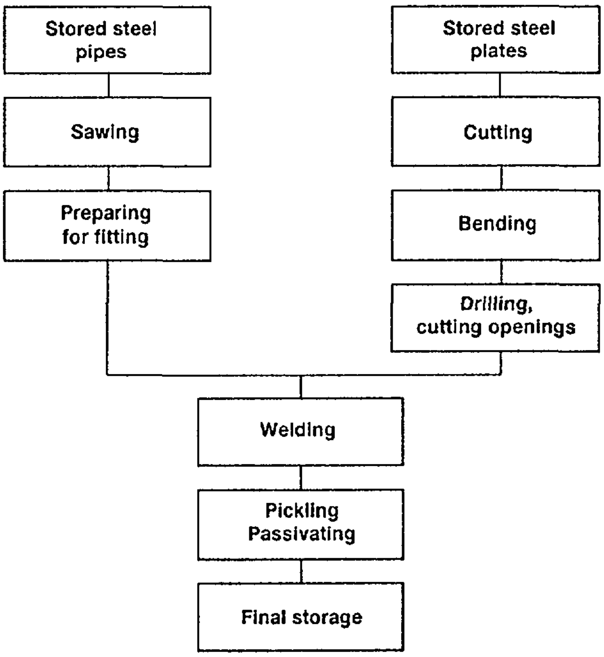
The conus is either produced within the firm (the conus must have a smooth inner surface to avoid turbulences) or it is ordered from an outside firm. To the conus the apex-valve with the underflow pipe is fitted.

Conus, cylindrical inflow cabin and lid are welded together. Parallel to the production of the cyclone casing, the pipes are cut to length and prepared for fitting. Finally the finished hydrocyclone is pickled and passivated and brought into final storage.

Example of a production plant

A small production plant with three production workers can produce a middle-sized hydrocyclone within four days.

Figure 3. Flow chart



It has to be stated, however, that not all the required machinery and equipment, or all the required manpower and area, as mentioned in the following tables, will be fully used. For the full use of these capacities a higher production is necessary.

Required machinery and equipment

Description		*Pieces*
Cutting machine		1
Folding machine		1
Welding apparatus		1
Drilling machine		1
Work-bench for assembly (incl. tools)		1
Forklift 1½ t		1
FOB-price for machinery and equipment (1991)	Approx. US$	125,000

Required manpower

Metal worker	1
Welder	1
Electrician	1
Production engineer	1
Administrator	1
Manager	1

Required area

	Square metres
Production	200
Storage	
Raw materials (covered)	50
Finished parts (outside)	100
Facilities	50
Open area	500

Required power and utilities

Electric Power	100 kW
Water	

Required raw materials

Stainless steel plates (2 mm)
Stainless steel conus (different sizes)
Pumps
Stainless steel pipes (different diameters)
Elbow-shaped pipes
Sealings and flanges
Switch box

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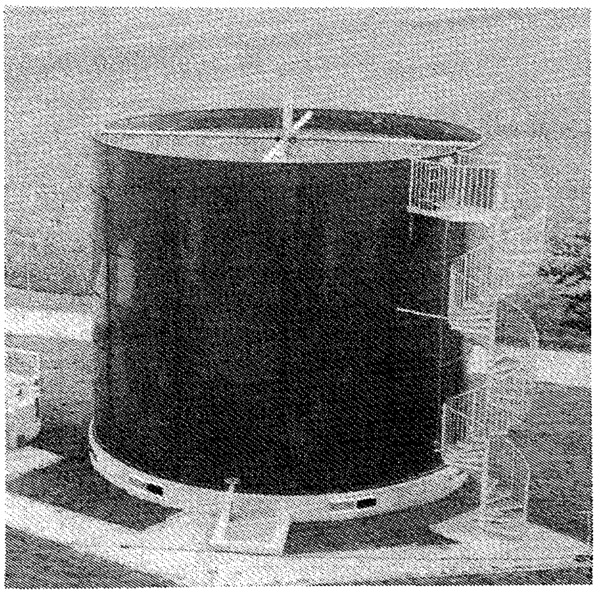
How to Start Manufacturing Industries

Trickling filter



Introduction

In its narrowest sense waste water can be defined as water polluted through domestic, agricultural, commercial and industrial use. In a wider sense it also comprises of rain-water running off from streams, farms, streets or public places, as well as seepage from underground drains.

The volume and composition of waste water results from human activities which change the physical, chemical and/or biological properties of water. Before the water can be used again its original properties must be restored through treatment.

Waste water treatment is carried out using three basic methods:

Mechanical treatment (screens, sand traps, settling basins);

Mechanical-chemical treatment (possibly including the chlorination of water that has been mechanically cleaned beforehand);

Biological treatment using either, natural methods (waste water oxidation ponds, polishing ponds), which require large areas; or, technical-biological methods (trickling filters, activated sludge processes, or combined processes), which require small areas.

Trickling filters are used for the treatment of municipal and industrial waste water. They are essential to the cleaning process, as seen in figure 1 below of a traditional combination of elements used in cleaning municipal waste water.

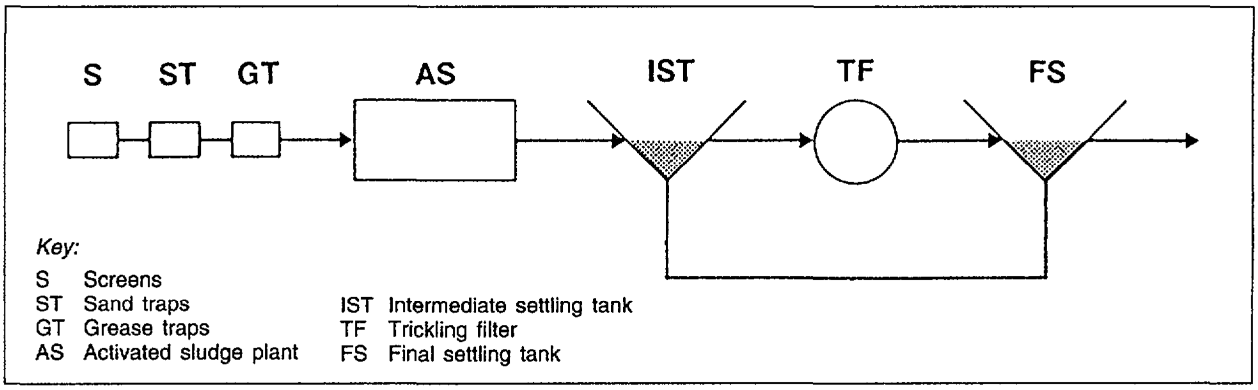
Trickling filters are well suited for the treatment of municipal waste water and waste water from the following industries:

Textile mills
Tanneries
Flaying houses
Leather factories
Slaughter-houses
Meat-packing factories
Tinning factories
Sugar refineries
Breweries and distilleries
Soap factories
Cellulose mills
Paper and pulp mills

Method

The biological treatment of waste water uses the metabolism of bacteria, fungi and protozoa (these include all animal unicellular organisms) in the waste water to convert organic compounds of a higher valency into a lower one. In this way, the self-cleaning potential of the water is intensified with the aim of

Figure 1. Waste water treatment



attaining as complete a decomposition as possible of putrescible matter in the waste water.

By using the trickling filter, the waste water is treated with the aid of the aerobic, waste-decomposing micro-organisms, which live on the solid matter (filter or contact material) in the trickling filter. The dirty water constantly flows past, feeding these micro-organisms, whereby its organic contents are decomposed.

The waste water, that has to be cleaned must first be treated to remove those materials which may cause clogging in the trickling filter. It is distributed over the filter material using various devices and then, because of gravity, trickles through the porous filling.

In this way, a slime layer, formed by the mineralizing micro-organisms from matter found in the waste water, builds up on the filter (or contact material). This layer, or those micro-organisms living in it, also known as the "biological filter film", absorbs and mineralizes the organic matter contained in the waste water. The basic substance of the biological filter film consists of bacteria which, by means of a self-produced slime mass, stick to each other and to the filter material. Through the metabolism of these bacteria putrescible organic matter is partly oxidized and partly converted into a substance which can be used in the bacteria's own metabolism. Furthermore, the biological filter film is populated with organisms which, through their feeding and aerobic sludge decomposition, constitutes the actual function of the trickling filter.

At the bottom of the trickling filter water that has passed the contact material and been cleaned drains through the filter floor. It is collected in flumes and runs into a final settling basin. This additional cleaning process is necessary because the bacterial growth on the filter material ages, thereby losing its adhesiveness and, over longer periods, is drained from the system along with the treated water.

The formation of the biological film required for waste water treatment takes approx. six weeks. Trickling filter facilities are therefore not suited for short seasonal operations.

The trickling filter

Type

Trickling filters belong to the group of fixed bed reactors. Their structural form determines how, and for which type of waste water, they are most suitable e.g. shallow flat trickling filters or high, tower-type, trickling filters. Depending on the waste load they can be either low-rate or high-rate trickling filters.

Shallow trickling filters have a working height of around 2-4 m and are used, above all, for cleaning household waste water. High trickling filters have a height of 5-20 m, or a ratio of diameter to height of 1 : 6 to 1 : 8 and are predominately suited for treating commercial waste water of heavier organic contamination. Furthermore, their small base is well suited for industrial areas.

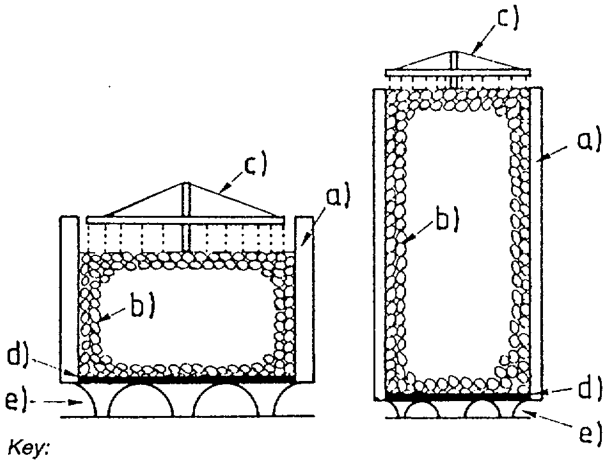
The waste load of a trickling filter (shallow and high) is defined as the volume of waste water distributed over 1 m^3 of filter material in one time unit, usually 1 day (expressed as m^3 waste water/1 m^3 filter material × days = m^3/m^3 d). Correspondingly for:

Low-rate trickling filters: 1-3 m^3 waste water per 1m^3 filter material daily;

High-rate trickling filters: more than 3 m^3 waste water per 1 m^3 filter material daily.

Components of the trickling filter

Figure 2. Trickling filter



Key:

a) Casing
b) Contact or filter material
c) Waste water distribution device
d) Trickling filter floor
e) Drain floor

Casing

The casing is constructed from reinforced concrete or brickwork. It is usually circular in shape and open at the top and bottom, forming a chimney which creates a draft to supply the oxygen necessary for cultivating bacterial flora.

Trickling filters, however, can also be built with square or rectangular layouts. Round trickling filters are suited for irrigation using rotary sprinklers which can distribute waste water evenly. On the other hand, square and rectangular-shaped filters require other types of equipment to adequately distribute the water, such as nozzles, flumes and moving steel pipes on motorized carts.

The filter floor is built from concrete or reinforced concrete and contains flumes to collect treated waste water; the gradient of the flumes should be at least 0.3-1%.

The drain base is a hollow construction attached to the filter floor that fulfils the following tasks:

Forms the support for the contact material;

Is necessary for collecting and discharging treated waste water;

Serves to supply the trickling filter with sufficient quantities of air.

The drain base should have sufficient height so as to guarantee a constant air supply.

Contact or filter material

The contact material serves two tasks. It acts as a support material for the biological filter film and forms cavities for aeration. It consists of coarse gravel, cinder, pumice, plastic, etc. which are arranged in three layers:

The support layer above the drain base, usually with a grain diameter of 60-100 mm;

The working layer which, with low-rate trickling filters, consists of grains of 30-50 mm diameter and with high-rate filters of grains of 40-80 mm diameter;

The distribution layer, at the filter surface, with grain diameters of 20-30 mm.

The danger of clogging imposes limits on gravel-filled filters in terms of feed concentration and volume load. Larger grain diameters or substantially increased scavenging power, for example, will lower cleaning capacity.

Waste water distribution facilities

Waste water distribution devices must guarantee uniform distribution of the waste water to be treated over the entire surface of the contact material in order to utilize the filter's full cleaning capacity.

Waste water can be distributed by two different methods:

Using fixed nozzles with high pressure (> 1.5 m) or flumes, which require a feed tank (feeding chamber) that regulates the interruptions in waste water feed;

Using movable devices such as rotary sprinklers, tipping ducts or troughs.

Size of trickling filter

The most important determinants for the dimensioning of a trickling filter are:

Waste water quality;

Waste water temperature;

Composition of the contact material;

Surface feed;

Aeration.

Waste water quality has a significant influence on the cleaning effect of the trickling filter. Should commercial waste water, be treated together with municipal (household) waste water, or should commercial waste water be treated alone, then the necessary cleaning capacity must be determined by experimentation.

Waste water temperature influences the heat balance in the trickling filter (reaction space); on the other hand, outdoor air temperature has, however less of an influence. The effects on the cleaning process are not uniform: between 4° C and 30° C biological activity increases to varying degrees with rising temperature.

At a waste water temperature of 10° C the capacity for decomposition reaches only 62% of the value at 20° C. More highly-developed organisms cease to be active below 10° C, at which point the danger of clogging increases.

The choice of *contact material* depends on the composition of the waste water and the degree of purification desired. Investment costs, however, are also a significant criterion and therefore economic, as well as technical, factors should also be considered.

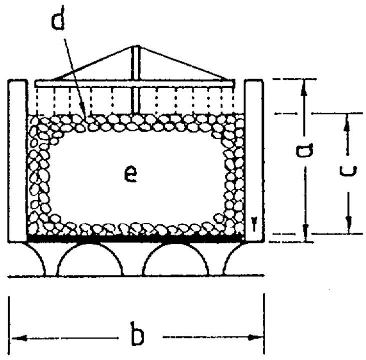
Surface feed depends not only on the shape and surface of the contact material, but also on the thickness and type of biological filter film, and on the feed concentration and quality of the waste water. The most favourable surface feed also has to be determined by experimentation.

Aeration of the trickling filter occurs through natural ventilation. Air movement results from the difference in temperature waste water and air. In the event that the temperature inside the trickling filter is higher than that outside, then this causes a flow of air from bottom to top. On the other hand, lower temperatures inside the filter result in a falling air movement. As practice has shown, a temperature difference of only 4° C guarantees this natural movement of air. Should however the temperature of the waste water correspond to that of the air, then an artificial means of aeration must be used.

Description of the production process

For the purpose of outlining the production process a flat trickling filter with a circular base and the following dimensions has been chosen (see figure 3).

Figure 3. Dimensions of a flat trickling filter



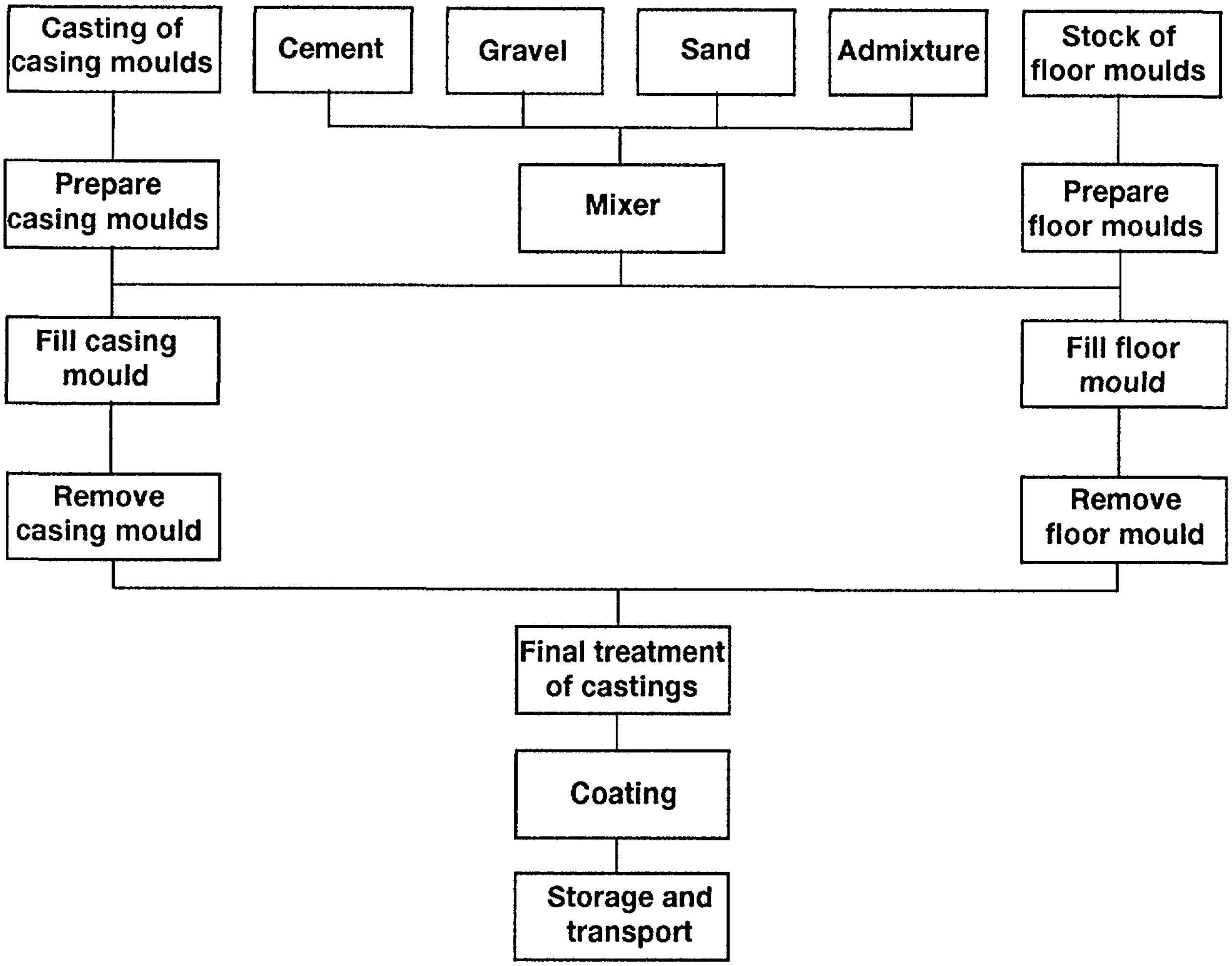
a	Height:	1.80 m
b	Diameter:	2.00 m
c	Filling height:	1.50 m
d	Surface:	1.49 m²
e	Volume of filling:	2.24 m³

The trickling filter is equipped with a rotary sprinkler. The appropriate rotary sprinkler with accessories, as well as the contact material, are supplied.

The production process described below refers to the manufacture of the filter casing and floor from reinforced concrete in a concrete factory. It should be noted, however, that a concrete factory is generally over-equipped for the production of only filter components and that these articles represent only a part of its production range.

The production process begins by determining the amount of cement, gravel, sand and admixtures are necessary for the required concrete volume for the mixer at the desired quality. Using the admixtures impermeates the concrete.

Figure 4. Flow chart



While the concrete is being produced (or even beforehand), moulds of the filter casing and floor are prepared, that is to say, sheathing may be done and various elements may be attached to form recesses (e.g the recesses in the filter floor for securing the rotary sprinkler mast).

If a sample taken from the mixer indicates that the concrete is of the required quality, it is then poured by a casting ladle on a crane into the prepared moulds and compressed by jolting. After the concrete has set the casting moulds are removed and final treatment follows. This includes removing any casting seams, as well as coating the inside and outside of the trickling filter casing and the floor, using a roller or spray gun, to increase its impermeability. After the protective coating has dried both filter casing and floor can be prepared for storage or for transport to the place of use.

The filter casing is assembled to the filter floor on top of the drain base, which has been set up beforehand. The rotary sprinkler is then mounted, the electric motor and feed-pipes installed and the contact material poured in.

Example of a production plant

It has already been noted that the trickling filter casing and floor are only two products among many others (e.g. pipes, shafts, covering plates) manufactured in concrete factories. Because these filter parts are normally only produced and integrated into the regular production programme when needed, it is not possible to give exact figures for the required equipment, personnel and power/ utilities etc. for a single production operation. However, in order to give some idea of what may be required, the following listed figures are estimates based on the manufacturing of only five units per day, assuming that the concrete factory is equipped to produce only those trickling filter components described here. Measurements are for:

Filter casing: height 1.80 m, diameter 2 m, casing thickness 0.24 cm;

Filter bottom: diameter 2 m, height 0.35 cm.

Required machinery and equipment

Description	*Pieces*
Gravel/sand silo	1
Cement silo	1
Mixer	1
Casting moulds incl. jolt ramming	2 (per unit)
Crane	1
Fork-lift	1
FOB-price for machinery and equipment (1991) Approx. US$	1.8 million

Required personnel

Business supervisor	1
Technical supervisor	1
Administration, purchasing, sales	3
Skilled workers	5
Unskilled workers	10

Required power and utilities

Electricity	200 kW
Water	

Required area

	Square metres
Silos and mixer (outside)	330
Production	300
Management and administration facilities	80
Social rooms	100
Storage	200

Required materials

Concrete		20 t/day
Concrete constituents:	53% gravel 28% sand 19% cement	
Steel		1.5 t/day
Special purpose paint (for coating)		1.4 m^3

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How to Start Manufacturing Industries

Activated sludge process

Introduction

The activated sludge process is today very common in biological waste water treatment. It imitates, in artificially built basins, the natural self-cleaning processes of water courses. Suspended particles, colloidal and completely dissolved organic or inorganic substances are eliminated from the waste water by mainly microbal metabolic processes, or they are turned into harmless compositions. The resulting waste water sludge normally has a high water content and a greater rotting capability, so that a re-treatment is necessary (thickening, digesting, conditioning, de-watering, agricultural use, sludge dumping area or incineration).

There are three commonly used process alternatives in biological waste water treatment: two aerobic, the activated sludge and the biological filter processes; and the anaerobic, waste water treatment.

In contrast to the biological filter process the activated sludge process has a higher degree of efficiency, which is only slightly reduced at lower temperatures. A further advantage is its adaptability to different loads, of quantity as well as composition. However, the operational process involves a higher expenditure both in general as well as in energy consumption.

When waste water has a highly concentrated organic load, it is often not possible to use the activated sludge process because of its potential to form bulking sludge. In this case the anaerobic process is more often used, especially when greater quantities have to be handled, resulting in lower costs and a higher reliability in operation than the aerobic treatment. The anaerobic treatment is also used for the treatment of sludge.

The activated sludge process is nowadays used for:

Communal waste water treatment;

Industrial waste water treatment, especially in food industries, such as slaughter-houses, dairies, breweries, sugar refineries, canning factories.

The activated sludge process can also be used in other industries, but then in most cases it needs a physico-chemical pre-treatment (e.g. neutralization, oxidation). This occurs in such industries as:

Leather and textiles;

Pulp and paper;

Petrochemical and organic chemical industries;

Oil refineries.

There are some important preconditions for the use of the activated sludge process.

The share of those compounds, which are not decomposable or which can only be decomposed with difficulty, or any influence hindering the biological processes should not exceed a certain value (BOD_5: $COD < 0.4$).

For the aerobic treatment of waste water the most favourable pH range is between 6.5 and 8.

The usual and most satisfactory temperature range lies between +10°C and +25°C.

Micro-organisms need for their conservation and multiplication a number of minerals, such as nitrogen and phoshorus, however they also need sulphur, potassium, sodium, calcium, magnesium, iron and some trace elements.

Process description

In water there are many different organisms (bacteria, protozoa), which decompose dissolved and colloidal particles of a mostly organic nature. In waste water treatment, the decomposing processes have to be very intensive, that means the organisms have to be stimulated to be more active; this is achieved by giving them a continuous supply of air.

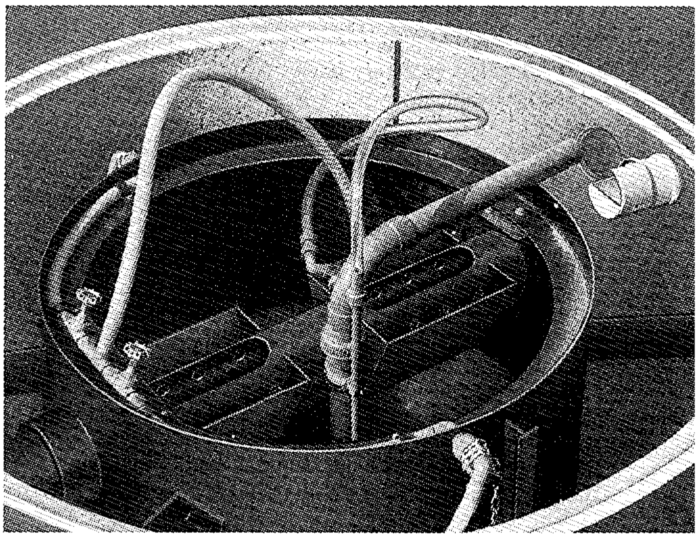
Organisms need body building material as well as energy, both of which have to come from outside. However, not all organisms need the same building materials or the same sources of energy, which is an advantage for the decomposition of harmful substances in the water. In waste water treatment organisms of a chemo-organotrophical nature play the most important role, because they eliminate organic substances from the waste water.

Because of the many types of organisms very different substances in the waste water can be decomposed:

Dissolved or colloidal organic substances;

Mineral particles;

Substances with a good absorbent capability for biomass (e.g. detergents);



Substances with a good chemical reaction to proteins (e.g. heavy metals).

Furthermore, these organisms are capable of adapting to changes in their food supply (= change in composition of the waste water). This happens either by enzymatic adaptation or by natural selection, whereby species, which are better able to digest the new substrate, multiply quicker (ecological adaptation).

The processes described mostly need oxygen, which has to be supplied from outside. The oxygen demand corresponds to the load of the biological waste water treatment, thus the term "Bio-chemical Oxygen Demand" (BOD) is used.

In the case of strongly polluted waste water (high values of BOD_5; see section "Dimensioning"), the purification of the waste water will be concentrated on the transformation of dissolved substances into bacterial mass ("high load process" with a decomposition time of 6 to 12 hours). In the case of mildly polluted waste water, according to required task, the "low load activated sludge process" can be employed, especially if the discharge can be used for agricultural purposes or fed into fish ponds. To the latter process a second phase has to be added, whereby the biomass is almost completely oxidized via the feeding chain of the heterotrophic organisms. For this, however, a period of several days is required in the case of the waste water and a period of several weeks in the case of sludge.

High load process	*Low load process*
Advantages:	*Advantages:*
• small sizes of aeration basin and of clarifier • lower investment costs • lower energy consumption for aeration	• effective removal of BOD_5 • good nitrification qualities • mineralization and through this stabilization of surplus sludge (no further treatment necessary) • less affected by changes in the composition of waste water because of larger basin sizes
Disadvantages:	*Disadvantages:*
• lower elimination of BOD_5 • incomplete or impossible nitrification • increased amounts of sludge (larger sludge treatment units) • sludge not stabilized; stabilization necessary in sludge treatment	• higher retention time, therefore larger basin sizes • more highly concentrated sludge, poorer sedimentation qualities; therefore larger surfaces of clarifier necessary • higher oxygen demand, therefore higher energy consumption

The low load process has a special advantage for developing countries in tropical and arid zones; the discharged water can be dispersed in a thin layer on slowly sloping ground, covered with foliage.

Functioning of an activated sludge plant and technical variants

An activated sludge plant usually consists of three units: pre-treatment basin; aeration basin; and secondary settling tank (clarifier).

Aeration basin

Aeration basins are in the main simple concrete basins, built into the ground, with artificial aeration. Form and shape of the basin are mostly determined by the aeration system. This aeration system also stirs and mixes the contents of the basin. The bacteria form flakes, which float freely in the turbulent current of the basin.

Besides bacteria, protozoa are also to be found in the aeration basin; it is their task to eat the free bacteria, which are not embedded in flakes, thus improving the running of the plant. Because this mixture of micro-organisms and waste water looks like sludge, it is called activated sludge.

The micro-organisms needed for waste water treatment usually enter the plant in the waste water and multiply there. If there is an insufficient number or variety of micro-organisms, then they can be added from other sources.

The running-in period of activated sludge plants lies between two and six weeks.

Normally there are no reagents needed. In exceptional cases, however, it may be necessary to add certain reagents, as for example, if bulking sludge develops, greatly hindering sedimentation:

Toxic agents (chlorine, hydrogen peroxide);

Flocculating agents (ferric chloro-sulphate, lime);

Adding deficient nutrients (nitrogen and phosphorus).

Alternatively, if chemical phosphate has to be eliminated then iron or aluminium compounds are added.

In order to keep the activated sludge basin as small as possible, the waste water should stay there only for a very short time. This can only be achieved, if the number of working bacteria is high. The concentrations lie between 2 and 6 kg biological solids per m^3 (normal concentration lying between 3 and 3.5 kg/m^3).

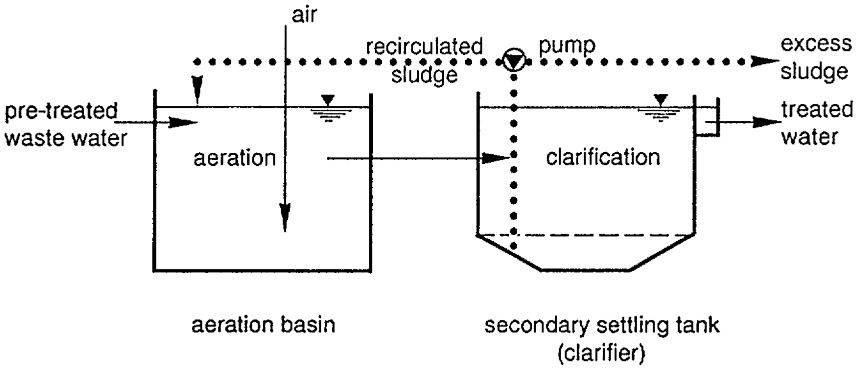
Under optimal conditions the organic matter is decomposed within 6-12 hours, having an air demand of 30-40 m^3/kg BOD_5. Only 5-15% of the oxygen, brought in by the air, can be used for biological activities.

Construction designs

According to the area of employment of the activated sludge process, different designs can be found.

Separate tank system: two separate tanks or basins are used for aeration and clarification (see figure 1); sludge from the clarifier is recirculated to the aeration basin (in order to maintain an equilibrium between the activated sludge and the substances brought into the basin by the waste water; any excess amount of bacterial sludge will be removed from the system).

Figure 1. Separate tank system



The basins can be:

Rectangular or circular;

Built on the site or assembled from prefabricated units;

Have the inflow and outflow at opposite sides or—in the case of long basins—subdivided inflows in the first section of the basin give a more even distribution of the nutritive contents.

Joint tank system: aeration and clarification take place in the same basin, which is subdivided by partitions (see figure 2). The activated sludge enters into the clarifier section of the basin via an overflow, while the settling sludge either moves automatically by gravitation back into the aeration basin or is returned there by means of a pump.

Figure 2. Joint tank system

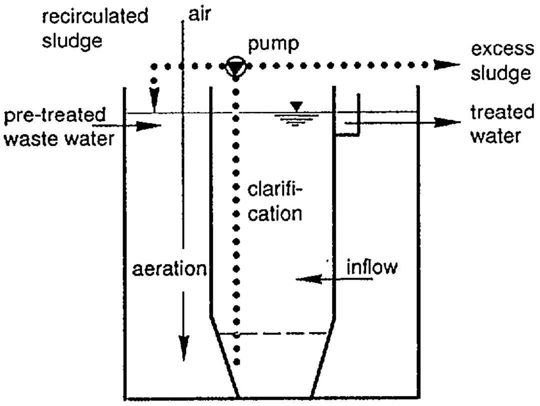
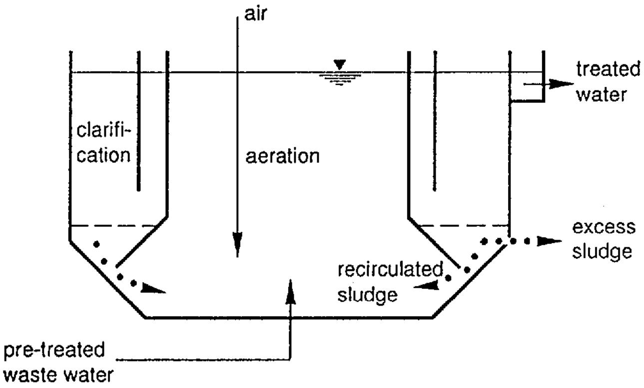


Figure 3. Aeration system



Aeration system: two different processes can be used (see figure 3):

Surface aeration (turbine, brush-bridge);

High pressure air injection (diffusers at the bottom of the basin);

Fine bubbles through porous material (polyester mass),

Middle-sized bubbles through perforated tubes,

Big bubbles through open pipes (support by mixer necessary).

Dimensioning

For *aeration basins* two parameters have to be established:

The volume of the basin;

The necessary oxygen supply.

Both parameters depend on the:

Amount of waste water;

Composition of the waste water;

Degree of purification.

A measure for the composition of the waste water is expressed by the term BOD_5, which defines the amount of oxygen used within five days at a temperature of 20 °C for the biological cleaning process (measured in mg/l or g/m^3).

There is no formula to calculate the necessary parameters or rather the dimensions of an activated sludge basin. In practice empirical values are used; they are either compiled in tables or in so-called nomographs.

The *clarifier* has three separate tasks to fulfil:

To separate the activated sludge from the waste water (separation zone);

To condense the activated sludge (sedimentation zone);

To store the activated sludge (storage zone).

Above these three zones there should be a clear water zone of at least 0.5 m. The then following separation zone should be between 0.8 and 1.0 m.

The surface area of the basin, the sedimentation and storage zones can be calculated on the basis of certain formulae.

Construction and functioning of a compact activated sludge plant

In practice different activated sludge plants can be found:

Large, small, compact plants;

Plants for domestic, industrial or communal waste water;

Plants of concrete or steel;

Plants built on the site (concrete) or assembled on the basis of prefabricated parts;

Separate or joint tank systems.

In the following, a compact activated sludge plant for communal use will be described, using standardized concrete elements, in this case concrete rings. Such compact plants can be used up to a certain capacity (e.g. 75m^3 waste water per day with a load of 30kg BOD$_5$ per day), whereby the higher capacities can be reached by connecting several units in series, the smaller capacities by integrating aeration basin and clarifier in one unit.

The basic model consists of three concrete rings, each of them having a separate function (see figure 4): pre-treatment basin, aeration basin, clarifier. According to its function different installations are necessary. Each ring is fitted with a shaft piece and a manhole cover.

The pre-treatment basin is subdivided by partitions into two or three separate chambers, through which the waste water flows successively using openings beneath the water level. In these chambers sand and other heavy particles settle on the bottom, floating materials (grease, oil) are retained by a dip pipe.

The pre-treated waste water flows into the aeration basin; here it is aerated, stirred and rotated by air blown in from the bottom of the basin. Aerobic micro-organisms (bacteria), floating freely in the waste water, live and multiply under the influence of oxygen (blown-in air) and from the nutrients in the waste water. They agglomerate and form flakes, thus creating activated sludge.

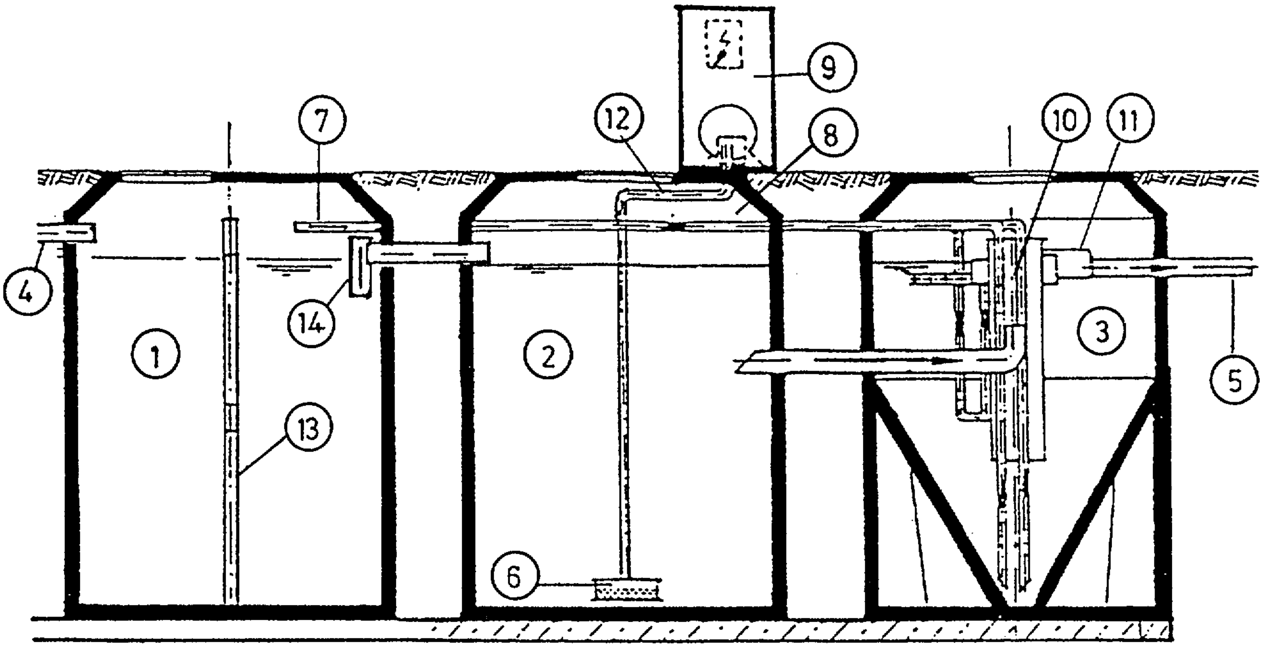
From here the water/activated sludge mixture flows into the clarifier, where the heavier activated sludge separates from the water and sinks into the funnel end of the clarifier. The settled activated sludge is recirculated into the aeration basin by an air lift pump to enable further purification of the waste water. If too much activated sludge has accumulated, during the maintenance of the plant the sludge—now called excess sludge—is taken out of the system or is pumped into the pre-treatment basin, from where it is removed by suction with the sediments.

The water, now separated from the activated sludge, flows over a spillway into a discharge channel, from where it leaves the system as purified water.

By means of a time switching device the blower is switched on and off to achieve an intermittent aeration. In this way the aeration time and also the oxygen supply can be adjusted to the waste water load.

A further adjustment is possible by using different sized bubbles. Medium-sized interval aeration is sufficient for waste water with a low to average pollution. Highly polluted waste water has to be aerated by fine bubbles.

Figure 4. Sludge plant



Key:

1 Pre-treatment
2 Aeration
3 Clarifier
4 Inflow
5 Discharge

6 Aerator
7 Excess sludge
8 Recirculated sludge
9 Blower and switch cabinet
10 Air lift pump

11 Discharge funnel
12 Aeration pipe
13 Partition
14 Dip pipe

Each activated sludge plant needs a certain running-in time before an optimal purification can be reached; this is four to six weeks in the case described.

Description of the production process

The complete plant consists of three concrete rings, which can be ordered from a cement works, already prepared for their specific use (bottom, ducts etc.).

The partitions of the pre-treatment unit are preferably cast from concrete on the site though it is also possible to use PE-plates (polyethylene), ordered from outside, but prepared at the works: they are cut to size, holes are drilled and plates welded together.

The pipes needed for the transportation of waste water, sludge and air are cut to size and as far as possible welded together at the works. They are cemented in on the site.

Also the aeration installation required for the aeration basin is produced at the works. It is either a shallow cylindrical PE-element with a perforated side wall or a cross of two perforated PE-pipes welded together and to a feed pipe. This system also is installed on the site.

The secondary settling tank receives its final shape on the site. The lower part is formed into a funnel with the help of cement. Then into this the sludge recirculation pipe with the air lift pump is fitted, as well as the waste water inflow and outflow pipes including the spillway and discharge channel.

Finally all pipe ducts are sealed with cement and the shaft pieces and covers put on.

Example of a production plant

Production of five compact activated sludge installations (up to $45 m^3/d$ and/or 18 kg BOD_5/d) per week; delivery of concrete elements from the cement works directly to the site; positioning of the concrete units with a specially ordered mobile crane; preparation of the components in the firm's own workshop; final assembly of the total installation with assembly teams at the site.

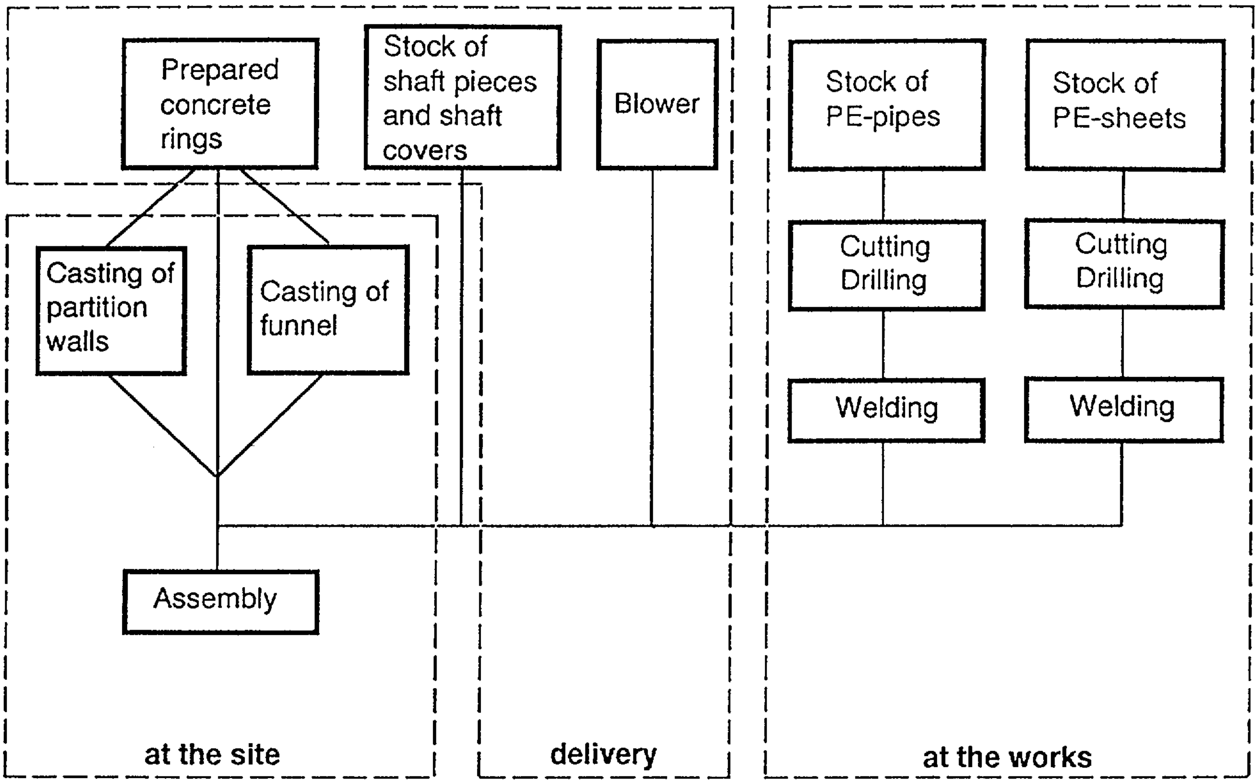
Required machinery and equipment

Description	*Pieces*
Assembly truck with trailer	2
Shaft claw set (triple lifter) to place the concrete rings	2
Hammer drill (to perforate and to cut openings)	2
Concrete mixer (mobile)	2
Power supply unit (mobile, 4 kW)	2
PE-welding equipment	1
Workplace	3
FOB-price for machinery and equipment (1991) Approx. US$	130,000

Required manpower

Sales and administration	3
Engineer	1
Unskilled workers	
assembly teams	6
workshop	2

Figure 5. Flow chart



Required area

	Square metres
Production hall	200
storage	100
workplaces	30
Administration and social facilities	100
Outside storage	100
Open area	600

Required power and utilities

Electric power	4 kW
Water	

Required inputs

Concrete rings
Shaft pieces
Shaft covers
Sand, cement
Sealing material
PE-pipes
  (50 mm to 200 mm)
PE-plates
PE-welding wire
Diaphragm aerator
Blower
  (lateral channel compressor)

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How to Start Manufacturing Industries

Anaerobic waste water treatment

Introduction

Anaerobic waste water treatment is employed in those cases where waste water is concentrated, highly organic, ($BOD_5 > 1000\text{-}1500\ g/m^3$) and has a low content of solids. The alternative case of an aerobic biological treatment would require high energy costs.

Waste water from the following sectors comes into this category:

Agricultural industries;
  sugar refineries
  starch plants
  food canning plants (fruit, vegetables)
  fruit juice and drinks factories
  breweries
  dairies
  yeast factories
  molasses distilleries
  slaughter-houses

Pulp and paper industries;

Chemical and pharmaceutical industries.

Compared with the aerobic process, the anaerobic process has the following advantages:

Small amount of surplus sludge which is odourless and capable of storage;

Production of biogas/methane;

Possibility of using residual materials;

Relatively low energy consumption;

Low operation costs.

However, it has the following disadvantages:

Lower process stability, i.e. more difficult process operation;

Corrosion by microbial H_2S-oxidation.

The anaerobic process is also used in the treatment of sludge with a high water content (> 95%), which has come from mechanical pre-treatment or other biological treatment processes.

The aim of further treatment of sludge is to:

Reduce the sludge volume by de-watering;

Diminish the capability of rotting;

Improve the hygienic condition of the sludge, i.e. to kill any pathogenic bacteria or maggots' eggs.

Anaerobic processing is especially suitable for developing countries because the methane produced can be used for energy purposes and the residual material as fodder or as feed in fish ponds.

Description of the process

The decomposition of organic substances in the waste water takes place under anaerobic (without air) conditions in two parallel stages. First, the organic substances of the waste water are decomposed by acid bacteria to organic acids, alcohols and carbon dioxide. Second, the methane bacteria, living in symbiosis with the acid bacteria, decompose the products of the acid bacteria to methane, carbon dioxide and water.

During this process biogas (methane) of a high caloric value is produced consisting of 70% methane and 30% carbon dioxide. A number of organic substances, such as greases, proteins, carbohydrates, amino acids and organic acids can be decomposed on an anaerobic basis. Greases yield a high amount of gas per unit of quantity with a high percentage of CH_4, proteins yield a smaller amount, while carbohydrates produce just a small quantity of gas.

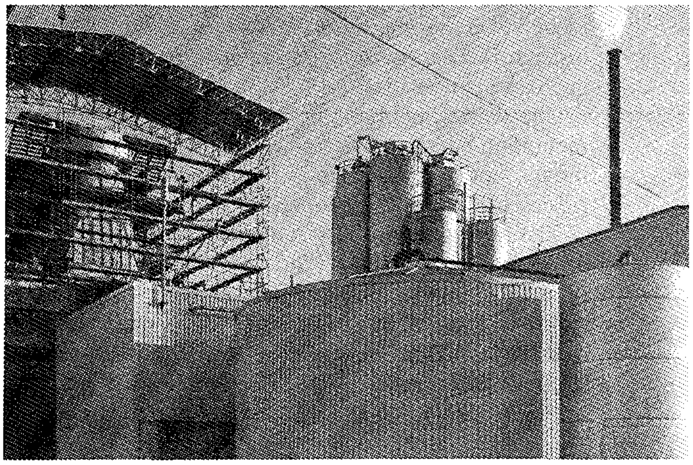
Sludge has a technical rotting limit; only approximately a third of the organic substances is utilized. The remaining mixture has to be retreated on an aerobic basis before it can be fed into the main canal.

There is another disadvantage of the anaerobic process: methane bacteria are very sensitive to changes in pH, to decreases in temperature and to toxic substances. This causes disturbances in the equilibrium between acid forming and methane forming bacteria. Disturbances in the rotting process can be detected through:

A decline in the pH-value;

Strong smells;

An increase in carbon dioxide.



Countermeasures that can be taken are:

A reduction of the load;

An increase, or rather stabilization of the pH value by adding lime milk.

Rotting processes normally need temperatures of 30°-37 °C.

For the reasons mentioned above it is more difficult to operate an anaerobic rather than an aerobic plant as more experience and surveillance work is required from personnel.

Technical variants and functioning

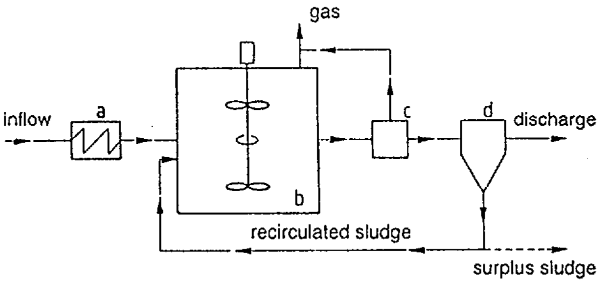
The anaerobic process can be divided into two variants:

Rotting without sludge recirculation where bacteria created during the process reaction leave the system with the discharge;

Rotting with sludge recirculation where microorganisms are retained in a sedimentation tank and recirculated to the digester.

In the second variant the decomposition time of the waste water can be drastically reduced from a few weeks to a few days. The amount of surplus sludge created is much smaller than that in the aerobic process.

Figure 1. Digesting process with bacteria recirculation



a Heat exchange
b Digester with stirring device
c Degasifier
d Sedimentation tank

Digesters are closed tanks or constructions. The contents of the tank can be mixed by feeding the waste water into the bottom section, by injecting biogas or by mechanical means. The digester is mostly heated in order to accelerate the decomposition processes; biogas can also be used.

The degasifier, built in between digester and sedimentation tank, has the task of removing the remaining biogas from the water so as to prevent flotation occurrences hindering sedimentation.

The anaerobic process is already relatively old. The development began with the "septic tank" and continued through different intermediate stages, as for example the CSTR (completely stirred tank reactor), nowadays still in use, right up to the modern reactors to these belong:

The UASB (upflow anaerobic sludge blanket) reactor;

Fixed bed reactors such as the AF (anaerobic filter) reactor and the DSFF (downflow stationary fixed film) reactor;

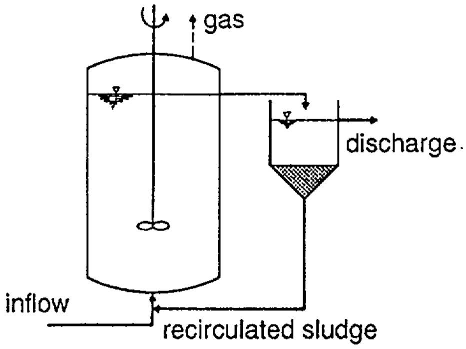
Floating bed reactors as, for example, the AAFEB (anaerobic attached-film expanded bed) reactor;

Fluidized bed reactor.

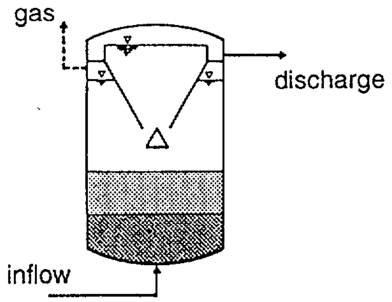
In figure 2 four frequently used process alternatives are shown. Only the *anaerobic activated sludge process* has an external sludge recirculation to inoculate the inflowing water.

Figure 2. Process alternatives for waste water treatment

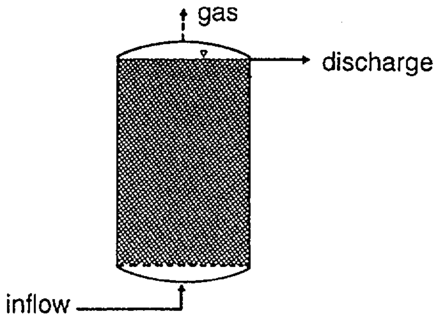
I. Anareobic activated sludge process



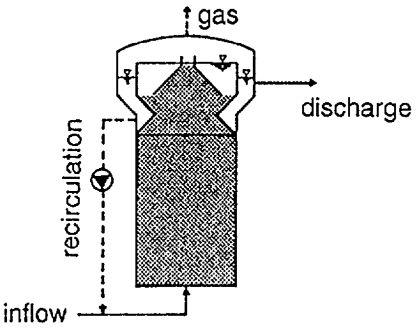
II. UASB (upflow anaerobic sludge blanket)



III. Anaerobic fixed bed reactor



IV. Fluidized bed reactor



In the *UASB reactor* the mixing is caused by injecting the water into the bottom section. The upstreaming waste water at the same time keeps the biomass afloat and delivers, while passing through the sludge blanket, its nutrients to the bacteria. Bacterial flakes, accidentally carried along, settle in the sedimentation channels at the upper end and fall back into the reactor.

Anaerobic *fixed bed reactors* are anaerobic trickling filters, whereby the areas covered with foliage, similar to the aerobic trickling filters, consist of solid filling material of sand, gravel or plastic. In fixed bed reactors the waste water also flows through from bottom to top. In some cases a water recirculation is found.

In *fluidized bed reactors* activated coal, sand, fine-grained synthetic substances or little clay balls are used as carrier material for the biological carpet. As in fixed bed reactors, a flushing out of the biomass is prevented and a relatively large surface created.

In practice, the two first mentioned processes are used the most. In the following sections only the UASB reactor is dealt with.

The UASB reactor: product description and functioning

The UASB reactor is a sludge bed reactor through which the waste water flows in an upward stream; it has a special sludge structure and an integrated gas-solid-separator (GSS). The sludge bed, which shows a high solid content, is covered by a thick sludge blanket, consisting of sludge flakes with a lower specific weight. This sludge blanket reaches up to the GSS.

The waste water passes upwards through the UASB reactor, where the intermixture with the biomass only takes place by the turbulence, created by rising biogas bubbles. In order to guarantee a good intermixture even with a small load, it is important to have a good distribution of the inflowing water.

The most important element of the reactor is the GSS, which has to fulfil several functions:

To separate the biogas from the intermixed liquid phase and from floating sludge flakes;

To separate dispersed sludge particles from the liquid by sedimentation, flocculation and incorporation into the sludge blanket within the sedimentation zone;

To enable the separated sludge to sink back into the rotting zone;

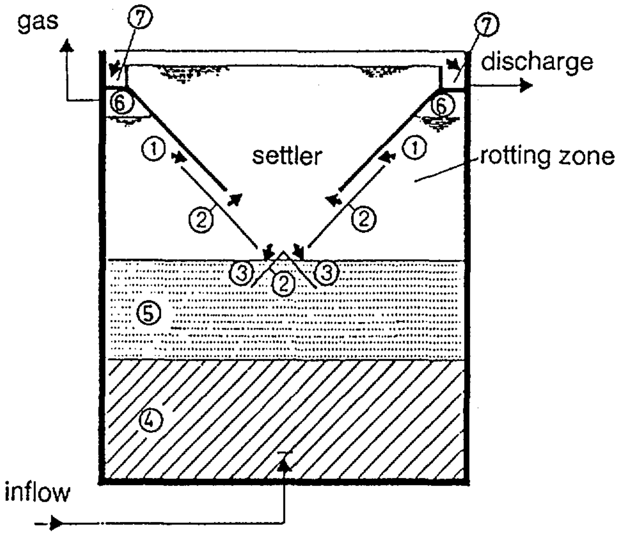
To prevent a too great extension of the sludge blanket.

Besides the GSS the formation of the sludge blanket is decisive for the functioning of the UASB reactor; this formation depends on the nature of the waste water and the initial putting into operation of the reactor.

The starting operation of the reactor has to be carried out very carefully: duration and execution of the starting process are dependent on the nature of the waste water and the nature of the inoculum.

The best inoculum is pellet sludge from another UASB reactor, which has already been in operation for a longer time. As this sludge, however, is difficult to obtain and very expensive, in most cases sludge from communal septic tanks is used.

Figure 3. The UASB reactor



Key:

1 Inflow openings for waste water
2 Baffels
3 Sludge outlets
4 Sludge bed (pellets)
5 Sludge blanket (flakes)
6 Gas collecting zone
7 Discharge channel

Pellet sludge is formed in different stages; the initial putting into operation of the reactor requires a total time of 100 days or more (depending on the quality of the inoculum). A re-start after a shut-down period, as is necessary, for example, in seasonal firms of the agro-industry, needs only two to three weeks.

Dimensioning

For the anaerobic waste water treatment no general information concerning dimensioning can be given as it would depend on the process alternative chosen.

For the UASB reactor the following typical information on dimensioning can be given.

Inflow distribution:

One supply inlet per 1 to 2 m^2 (in the case of a high load one supply inlet per 5 to 10 m^2 is sufficient)

Sludge bed thickness:

Between 2 to 3.5 m

Gas-solid-separator:

Inclination of the plates 45° to 50°
Sedimentation zone > 2 m.

Size of the reactor:

Height of the reactor 4 to 6 m
Relation of height to surface area dependent on the surface charge (surface charge $g_A = 1$ to 2 m/h)

Horizontal enlargement of the reactor is possible if there is a good inflow distribution; for larger reactors several separators (GSS) are necessary (maximal surface charge $g_A = 0.7$ m/h).

For the anaerobic treatment of 100 m^3/d waste water from a sugar refinery, for example, a reactor volume of approx. 150 m^3 is necessary. (The figures are based on an average retention time of 0.8 to 1.5 days.)

Description of the production process for UASB reactors

It should be noted that the UASB process is still protected by national and international patents which are to be observed when taking up production.

For the construction of UASB reactors it is possible to use different materials. Large plants are generally built using concrete mixed locally with installations from stainless steel or plastic coated steel. Smaller units are produced totally from stainless steel or coated steel.

The following description concentrates on the manufacturing of anaerobic units from stainless steel.

The stainless steel plates, the thickness of which is determined by the size of the reactor, are cut to size with a cutting torch. Into the side walls—very near to the bottom—the holes for the pipe ducts, the hole for the gas discharge as well as the opening for the water discharge are cut. For technical reasons concerning installation the bottom usually stays untouched. The stainless steel plates are now welded together to form a rectangular tank.

The gas-solid-separation unit (GSS) is similarly manufactured from stainless steel plates. The thickness is determined by the size of the reactor and it is cut to size with a cutting torch. The plates, which later form the discharge channels and the lower baffle plate unit respectively, are brought into shape by a bending press. With the help of stainless steel bars, cut beforehand to size, the lower baffle plate unit, the middle baffle plate unit and the settler walls are welded together. The last step is the welding of the unit to the discharge channel.

Before the whole unit is fitted into the tank, the inflow pipes and the gas discharge pipe are welded into the side walls. The inflow pipes are mostly connected to a ring conduit.

After pickling and passivating the GSS unit is fitted and the discharge nozzle welded on. The reactor is then covered by a stainless steel lid.

In the case of very large reactors it may be necessary to fortify the side walls by welding on a supporting frame.

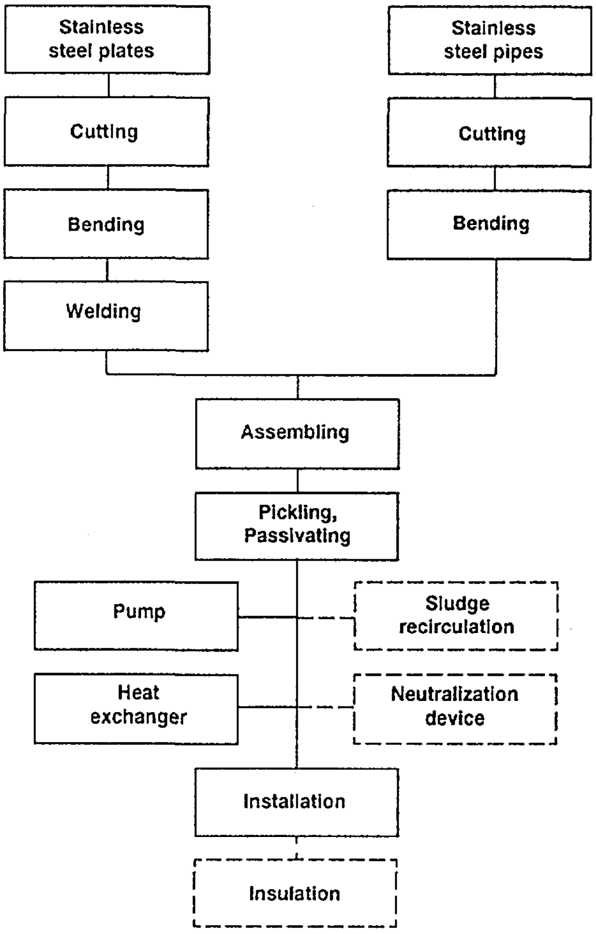
Into the feeding pipe of the reactor a pump and then a heat exchanger have to be fitted. The latter is necessary to heat the inflowing waste water to 35°-37 °C. The heat exchanger (plates or double casing), like the centrifugal pump, is ordered from an outside firm and built on the site between the already existing collecting basin of the industry concerned and the reactor. The heat exchanger—according to place of application—is operated by already existing waste heat or by its own boiler, probably run on methane.

According to the composition of the waste water, the developing sludge bed can hinder the waste water inflow, so that an occasional pumping out and recirculation of the sludge into the waste water inflow might be necessary. In this case a corresponding pipe system with pump has to be installed.

According to the composition of the waste water a neutralization agent may have to be added. For this purpose a special device consisting of dosing container, dosing pump and throttle valve has to be installed. Such containers, fittings and pumps are parts which are mostly supplied from outside.

Depending on the location of the plant an insulation of the reactor against over-heating might be necessary; as could be the case in developing countries. For this purpose it would be reasonable to use mineral wool, covered by plastic foil, zinc plates or aluminium sheets.

Figure 4. Flow chart



Example of a production plant for UASB reactors

The example applies to a firm that manufactures UASB reactors from stainless steel. One unit is produced within 14 days.

Required machinery and equipment

Description	*Pieces*
Cutting torch	1
Welding machine	1
Drilling machine	1
Angle sander	2
Workbench including tools	2
Monorail crab with electrical lifting appliance	1
Van (for assembly)	1
FOB-price for machinery and equipment (1991)	Approx. US$ 30,000

Required manpower

Manager/Engineer	1
Welder	1
Locksmith	1
Unskilled Workers	2
Electrician	1
Administration	1

Required area and buildings

	Square metres
Production hall	250
Work-places	90
Storage	50
Social facilities	30
Administration	40
Outside storage	50
Free area	150

Required power and utilities

Electric power	10 kW
Water	

Required inputs

Stainless steel plates (2-4 mm)
Stainless steel pipes (50-150 mm)
Fittings (elbows, T-shaped pieces)
Armature controls (slide valves, nonreturn valves)
Centrifugal pumps
Insulating material
Heat exchanger
Heating for heat exchanger (if no waste heat available)
Burner control
Switch board
Measuring instruments (pressure gauge, thermo-electric switching elements)
Electric cable
Small parts (welding electrodes etc.)

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How to Start Manufacturing Industries

Oxidation/reduction neutralizing precipitation

Waste water treatment in the metal-processing industry

Introduction

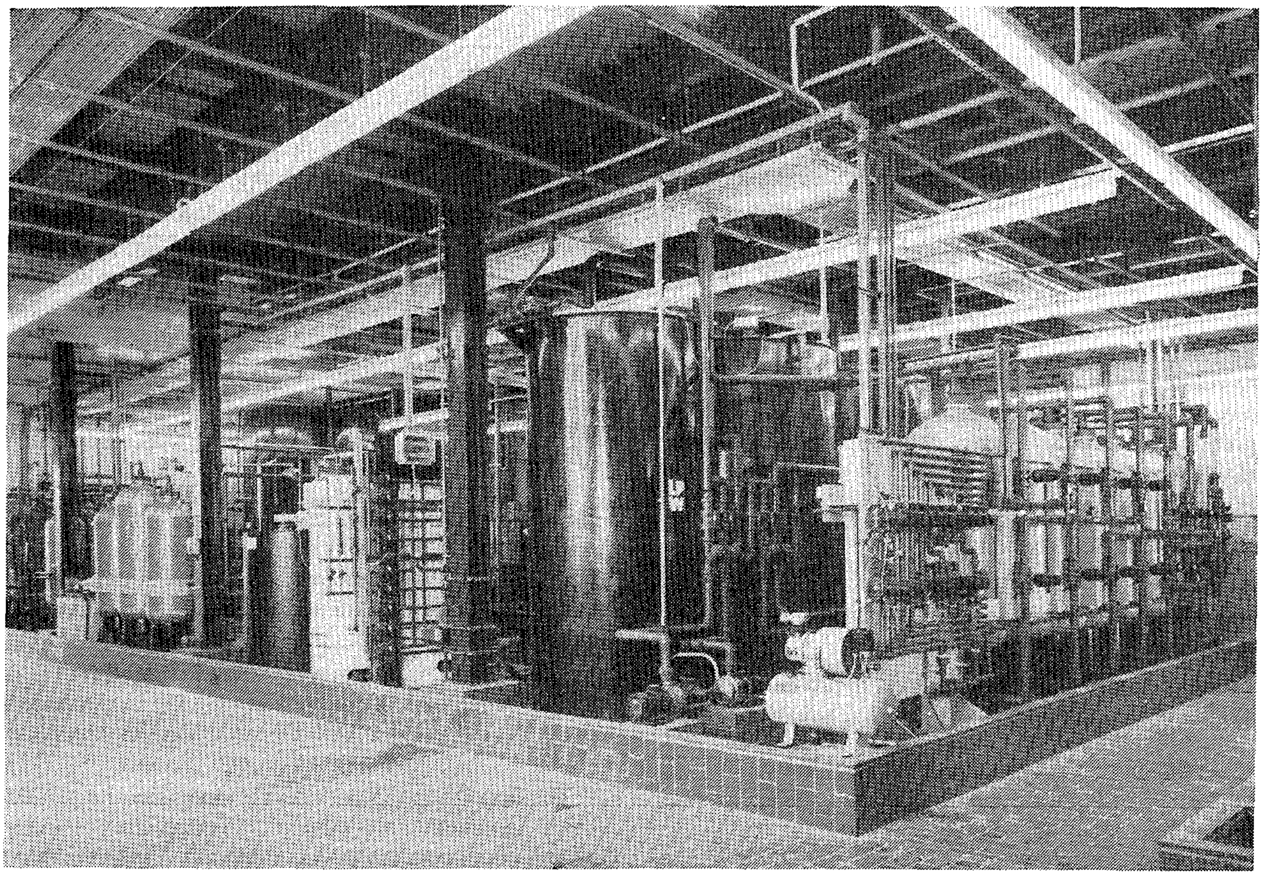
Waste water results from industrial manufacturing processes and from households during washing and cleaning. Household and sanitary waste water, as well as waste water from different industries spheres, e.g. sugar factories and breweries, contain organic material that has to be treated in biological clarification plants.

Furthermore, there are industrial areas producing waste water with inorganic material that usually cannot be removed from the waste water by biological processing. In most cases the material has a toxic effect on the bacteria working in the clarification plant, therefore waste water of this type has to be chemically/physically pre-treated. This type of waste water occurs in some chemical industries, mainly in the metal-processing industry.

As industrial areas not only exist in highly industrialized countries but also in developing countries occurrence and treatment of these different types of waste water are an international problem.

The metal-processing industry is represented by various manufacturing programmes in different branches of the industry:

Steel and light metal construction;
Rail and road vehicles;
Ship-building industry;
Aircraft industry;
Precision mechanics, optics, watch manufacturing;
Iron, sheet and metal products manufacturing;
Musical instrument and toy manufacturing;
Manufacturing of household appliances;



- Manufacturing of writing materials;
- Manufacturing of jewellery and sports apparatus and equipment;
- Manufacturing of sanitary fittings.

Most of the industrial waste water from the metal-processing industry develops in aqueous solutions from the chemical and electrolytical treatment of metal surfaces.

A number of chemical treatment processes are conducted on metal surfaces, for example:

- Metal depositing by reduction, e.g. chemical copper plating in the PCB (printed circuit board) industry and chemical nickel plating;
- Surface removing processes, e.g. pickling, etching, chemical deburring, polishing and metal stripping;
- Surface converting processes, e.g. chromating, phosphating, black oxidizing.

Similarly, the following occur in electrolytical treatment processes:

- Electrolytical, metal depositing in the electroplating industry, e.g. zinc plating, copper plating, nickel plating, chromium plating;
- Metal removing processes by anodic treatment, e.g. electrolytical deburring, pickling, grinding, electrolytical metal stripping (e.g. dechroming);
- Surface converting processes, e.g. anodizing of aluminium.

Common to all these processes is that the workpieces to be treated are immersed into an aqueous process solution or sprayed with an aqueous solution. Prior to each process step, workpieces are rinsed with water in order to avoid any contamination in the subsequent process solution and, thus, avoiding a deterioration or "drag-in" from the preceding solution.

Furthermore, workpieces have to show a certain degree of cleanliness in order to achieve a satisfactory product quality.

These rinse waters and exhausted process solutions, e.g. degreasing and pickling baths, are the waste water of the metal-processing industry. Additional types of waste water come from pre-treatment and coating processes of metals with non-metallic materials, e.g. when lacquering plastic materials, enamelling and hot galvanizing.

Waste water also occurs in metal-processing from mechanical manufacturing i.e. cleaning, cooling, greasing, and heat-treatment. This type of waste water mainly contains:

- Acids and lyes;
- Heavy metal compounds;
- Cyanides and nitrites;
- Hexavalent chromium compounds;
- Fluorides, phosphates, sulphates;
- Hydro-carbons and halogenated hydro-carbons;
- Complex formers.

As the afore-mentioned types of compounds have to be treated differently, the waste water has to be collected separately and delivered to the specific waste water treatment plants.

Process specification

General view

The aim of treating waste water containing inorganic substances is to convert—by a chemical reaction—toxic substances into non-toxic or less toxic compounds. The chemical reaction can be achieved through an oxidation, reduction or neutralization process.

Certain conditions apply when processing. The following sequence is important for their application:

- The process has to proceed quickly;
- The equilibrium of the chemical reaction has to be, as far as possible, on the side of the reaction's final product;
- No new toxic substances should result from the process;
- The chemical reaction process must be controlled and measured.

Maintaining the above conditions is also dependent on the pH ranges required for oxidation and reduction. These pH ranges differ widely from the neutral range found in waste water. In the neutral range, however, a large quantity of noxious substances can still be eliminated from the waste water. A neutralizing precipitation should therefore follow the oxidation and/or the reduction process.

Oxidation

Waste water containing noxious substances, e.g. cyanide, nitrite and bivalent iron compounds, can be detoxicated by oxidation.

In general, the oxidation process means a transition of a compound from a low valence to that of a higher one. As the compound cannot achieve the transition by itself, for thermo-dynamical and/or kinetical reasons, an oxidation agent must force this valence change. By this the oxidation agent itself is reduced.

For the oxidation of compounds, sodium hypochlorite has been used nearly exclusively up to now. The cyanide oxidation can only be carried out in the alkaline pH range. Although the reaction velocity reaches its optimum in the range of pH 10-11.5, 20 minutes are at least necessary for a complete oxidation. From this reaction cynant is produced, which is less toxic than cyanide by a factor of 10^{-3}.

Frequently, electroplating deposition of certain metals is done by means of metal cyano complexes. The waste water arising from this process is treated in the same way as the simple cyanidic waste water. Heavy metal hydroxides will in addition result from this process.

The nitrite oxidation with sodium hypochlorite in the pH range of 3-4 proceeds so quickly that reaction times of 10 minutes will be sufficient for complete oxidation. Nitrate results as an end product.

The iron oxidation with sodium hypochlorite should be carried out at a pH-value of 9. The reaction is spontaneous and trivalent iron compounds result.

Reduction

The hexavalent chromium compounds in the waste water are detoxicated by reduction. In general, the reduction process means a transition of a compound from a higher valence to a lower one. As the compound cannot achieve the transition by itself, for thermo-dynamical and/or kinetical reasons, a reduction agent must cause the valence to change. In this process the reduction agent itself is oxidized.

The reducing agent used in most cases is sodium bisulphite. As this reducing agent only reaches its full reduction force at a pH-value of 2.5 or less, the chromate reduction is effected at a pH-value of 2.5.

Trivalent chromium compounds result through this reduction process, while sodium bisulphite is converted into sodium hydrogen sulphate. In another process step, neutralizing precipitation, the trivalent chromium compounds have to be converted into chromium hydroxide.

Large quantities of acid are sometimes necessary for the adjustment of the reaction pH-value; it seems recommendable to use a reducing agent being effective in the alkaline range. In these cases, sodium dithionite is used.

Neutralizing precipitation

Acids and lyes contained in the waste water and compounds formed during the oxidation and reduction processes have to be detoxicated by the neutralizing precipitation process.

During neutralizing precipitation, precipitable compounds still contained in the waste water (heavy metal compounds, sulphates, fluorides, phosphates) are simultaneously converted into insoluble compounds. As the heavy metal compounds have a considerable toxicity, the heavy metal ions have to be removed. Some small residual concentrations still, however, remain after the neutralizing precipitation process.

As waste water from metal-processing factories may contain different types of heavy metals, (copper, chromium, nickel, zinc, iron, tin and lead) and the respective heavy metal hydroxides do not have their solubility minimum at the neutrality point of the waste water, neutralizing precipitation is carried out at a pH-value ranging between 9 and 9.5. In this range, it is possible to precipitate heavy metals except for a residual content of some milligrams.

For a neutralizing agent, in general, caustic soda solution or lime milk are used. In cases where the pH-value exceeds 9.5 prior to the neutralization, hydrochloric acid or sulphuric acid has to be added. Preference is given to lime milk as a neutralizing agent as heavy metal hydroxides arise which are easier to be settled out and dewatered. Furthermore, other substances are precipitated as insoluble compounds, such as calcium sulphate, calcium fluoride and calcium phosphate.

Normally, the chemical treatment of the waste water ends with the neutralizing precipitation process. The subsequent process steps serve for the removal of the precipitated substances from the waste water by sedimentation or filtration. The waste water free of solids flows to a biological clarification plant or to a receiving ditch. The separated solids are brought to a dumping site.

Operational mode of the waste water treatment plants

Waste water may contain noxious substances with different concentrations indicating whether it is diluted waste water (50-500 ppm) or concentrated (1000-12,000 ppm).

Depending upon the share of these partial flows related to the total waste water flow, treatment will be effected in continuous treatment plants or batch-type plants.

Separation of waste water

As chemical reactions between noxious substances in waste water and the oxidation/reducing agents proceed under different reaction conditions and with different reaction chemicals, untreated waste water has to be collected and treated in separate processing tanks, for example:

Cyanide waste water in the cyanide oxidation;

Nitrite waste water in the nitrite oxidation;

Chromate waste water in the chromate reduction;

Heavy metal, acid and alkaline waste water as well as waste water pre-treated in the above detoxification processes in the neutralization.

Where concentrates and semi-concentrates have to be treated, they are also led to separate collecting tanks. If their share of the total waste water flow is less than 10% they can be mixed in a small volume flow with the diluted and untreated waste water and treated in the specific reaction step.

If the share of the concentrated waste water is more than 10% of the total waste water flow, a pre-treatment in a batch-type plant is absolutely necessary.

When the waste water is treated in a batch-type plant, a separation—in contrast to continuous treatment plants—can often be neglected.

In general, acid and chromate waste water, alkaline and cyanide waste water and nitrite waste water are collected in separate storage tanks.

It is often unavoidable to lead chromate and cyanide waste water into a common storage reservoir in which case only the acid waste water is collected separately in order to avoid formation of the highly toxic hydrocyanic acid. Nitrite waste water can also be collected together with cyanide waste water.

Waste water treatment in a continuous treatment plant

Continuous treatment plants are used when diluted waste water arising in continuous quantities has to be treated. Semi-concentrates and concentrates can be uniformly mixed with the diluted waste water; they do not have a negative influence on the operation of the plant when the share of the semi-concentrates is distinctly less than 10% of the total waste water volume.

The feature of the continuous treatment plant is that the untreated waste water enters and flows continuously through the plant finally leaving the plant in a treated state. The treatment tanks are flown through by free passage. As the detoxification reactions, described above, need relatively short reaction times, small reactors can be used. When selecting a small reactor, it is a prerequisite, however, that the substances have sufficient contact with each other in order to react. Therefore, the contents of the reactor have to be thoroughly mixed. As a basis of evaluation it can be said that the volume in the reactor has to be circulated 90-120 times per hour.

Every treatment station in a continuous treatment plant is designed in the same way (see figure 2) and consists of:

The reactor, a rectangular tank divided into two equal compartments by an immersing wall and a separating wall;

The mixer, a stirring device with required circulation capacity mixing the contents of the first compartment of the reaction tank;

The measuring and control technique, consisting of the measuring electrodes (glass electrode for pH-measuring), Redox [= *red*uction/*ox*idation] electrodes for measuring the potential drop), the measuring amplifier and the regulator;

Chemicals in the dosing tanks necessary for the reactions;

Solenoid valves or dosing pumps allowing a regulated addition of the reaction chemicals.

For the *cyanide oxidation* process, the cyanide-containing waste water is mixed with the oxidation agent in the first compartment. At a pH-value of 10.5 and higher, sodium hypochlorite is added until a sudden drop in the Redox potential is effected. The Redox potential is measured by means of a gold electrode compared with a reference electrode. The pH-value is measured by means of a glass electrode.

The second compartment of the reaction tank serves as a post-reaction compartment. From the cyanide oxidation, the detoxicated waste water flows to the neutralization.

The treatment step for *nitrite oxidation* is similar. For measuring the potential drop, a gold or platinum electrode with reference electrode is used, for measuring the pH-value a glass electrode is used. As an oxidation agent, sodium hypochlorite is added till the potential drop is reached; as neutralizing agent, to keep the pH-value constant at 3-4, caustic soda solution or lime milk is used.

The waste water from the nitrite oxidation flows subsequently to the neutralization.

The treatment step for *chromate reduction* is similar. For measuring the potential drop a combined gold/platinum electrode is used and for measuring the pH-value a glass electrode is used. As reducing agent, mainly a sodium bisulphite solution is used and for keeping the pH-value constant at 2.5 hydrochloric acid or sulphuric acid is used. The waste water from the chromate reduction flows subsequently to the neutralization.

A glass electrode is used for the measurement of the pH-value in *neutralization.* As a neutralizing agent, a caustic soda solution/lime milk or hydrochloric acid/sulphuric acid is used. The pH-value has to be kept constant at approximately 9.

For separation of the precipitated substances, the waste water flows, either by gravity or by means of pumps, to the appropriate sedimentation equipment. The waste water free of solids flows to a biological clarification plant or to a receiving ditch. The separated solids are brought to a dumping site. The chemicals necessary for oxidation, reduction, and neutralizing precipitation are taken from storage tanks.

Waste water treatment in batch-type plants

Waste water is treated in batch-type plants (schematically shown in figure 3) when concentrated waste water is prevalent. Diluted waste water arising erratically and in small quantities should be treated in batch-type plants as well.

The characteristic feature of batch-type plants is that the necessary detoxification reactions are sequentially carried out in a reactor. The waste water collected in a storage tank is pumped into the reactor, is treated there and the reactor is emptied afterwards. The sequence of the detoxification reactions is determined and cannot be varied.

The individual steps are:

Cyanide oxidation at	pH = 10.5-11.5
Nitrite oxidation at	pH = 3-4
Chromate reduction at	pH = 2.5
Neutralization at	pH = 9

If one or several types of waste water are non-existent, the relevant reaction steps can be neglected. Only the neutralization has to be effected in any case.

In contrast to the continuous treatment plants, when considering the quantity of waste water, the batch-type plants require larger reactors, as a fast mixing of waste water and detoxification chemicals is necessary in these reactors. However, a thorough mixing is not always ensured in larger reactors; thus the upper limit for a reactor volume should be 20 m^3.

Batch-type plants are designed in a similar way and consist of:

Storage tanks;

Reactor, a vertical round or rectangular tank;

Mixer having the required circulation capacity;

Measuring and regulating equipment;

Chemicals necessary for the reactions (these chemicals are in storage or dosing tanks);

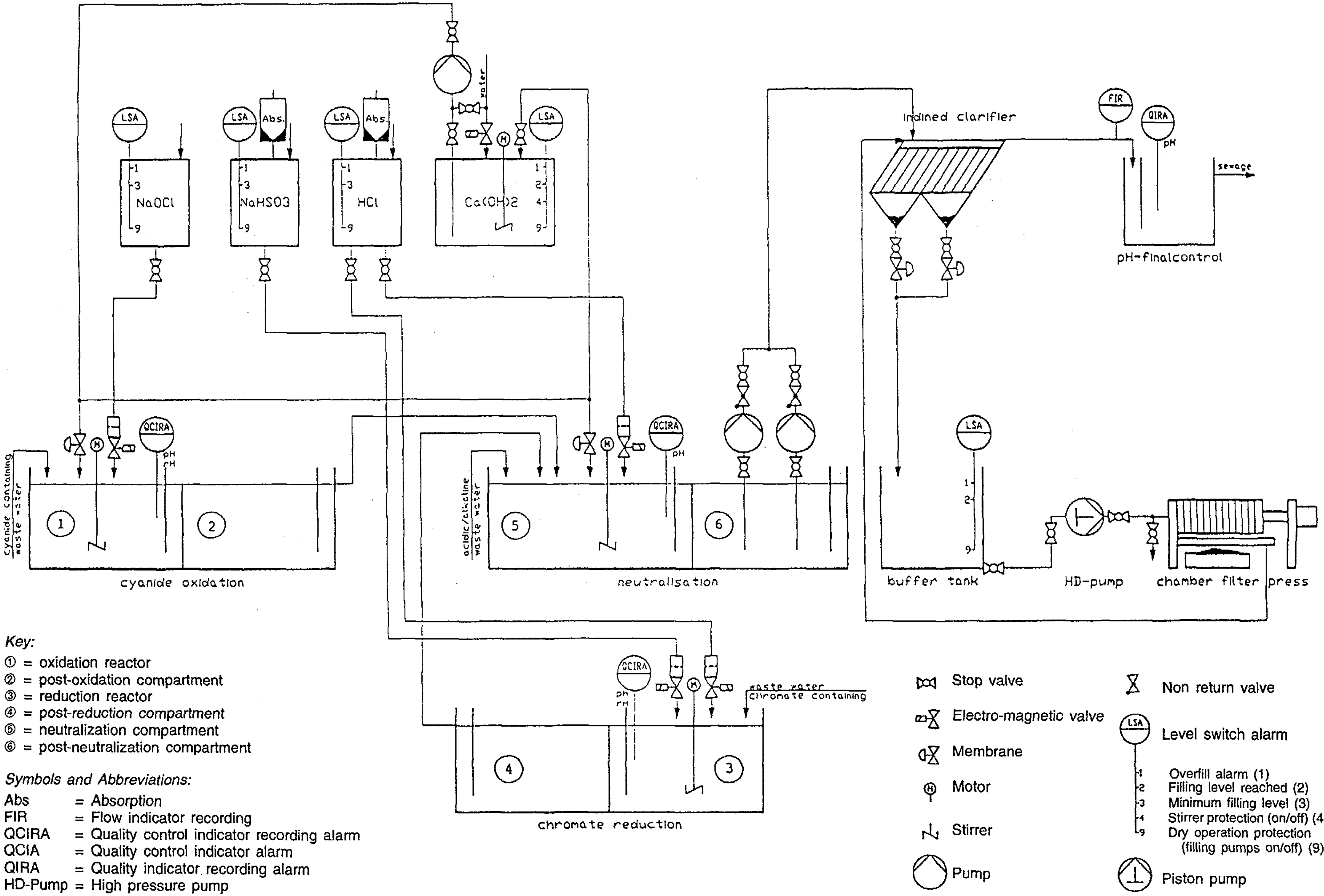
Solenoid valves or dosing pumps for a controlled addition of the reaction chemicals.

Control of the waste water treatment is kept by starting manually the reaction steps which correspond to the programme steps; these programme steps then automatically proceed, i.e. the filling of the reaction tank with the corresponding waste water, the addition of the required chemicals via solenoid valve or dosing pumps and the observance of possible post-reaction times are effected without manual intervention.

After completion of each reaction step an analytical test, with regard to the total conversion, should be carried out and only then should the next reaction step be initiated.

The same reaction chemicals are used as described for continuous treatment plants.

Figure 2. Flow diagram of a continuous plant



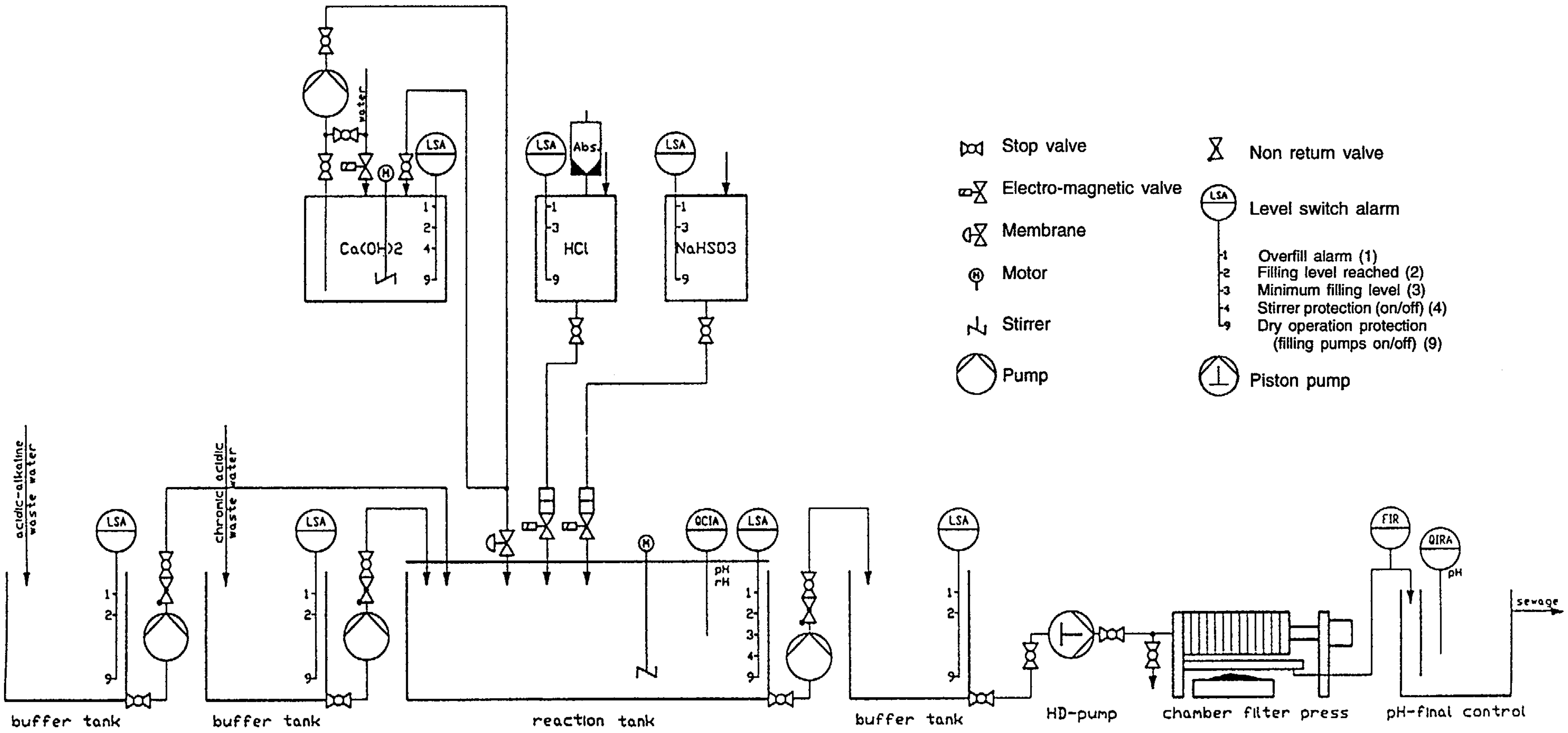
Key:

① = oxidation reactor
② = post-oxidation compartment
③ = reduction reactor
④ = *post-reduction compartment*
⑤ = neutralization compartment
⑥ = post-neutralization compartment

Symbols and Abbreviations:

Abs	= Absorption
FIR	= Flow indicator recording
QCIRA	= Quality control indicator recording alarm
QCIA	= Quality control indicator alarm
QIRA	= Quality indicator recording alarm
HD-Pump	= High pressure pump

Figure 3. Flow diagram of a batch-type plant



After completion of the neutralization process, the whole volume of the reaction tank is pumped into a collecting tank, so that the waste water can be treated in the reaction tank again. The pump is operated manually.

The solids occurring during the various treatment steps are eliminated from the waste water in the subsequent process steps. Filtration units are used for this purpose, for example chamber filter presses.

Due to the limited quantity of waste water, the entire waste water is filtrated. The filtrate flows to a biological clarification plant or a receiving ditch, while the solids are brought to a dumping site.

Dimensioning

Continuous treatment plants

Decisive for the size of the individual treatment steps are the various waste water volume flows and the retention times necessary for a complete detoxification. The cyanide oxidation stage is dimensioned for a mean retention time of at least 20 minutes in each compartment; the nitrite oxidation stage, the chromate reduction stage and the neutralization stage are dimensioned for a retention time of at least 10 minutes in each compartment. The stirrer necessary for a thorough mixing should have a circulation capacity of 1.5 times/min. of the volume of the reaction compartment.

Batch-type plants

For the determination of the volume of the reaction tank, the mean retention time is of secondary importance. There are no hard rules for the dimensioning. Experiences in practice have shown, however, that it should be possible to oxidize, to reduce and to neutralize waste water accumulated in eight operating hours.

Specification of production plants

Specification of continuous treatment plants

The plants described in the following are shown as a process flow diagram (figure 2); figures 4 and 5 show a continuous treatment plant and a barrel plant.

Example 1: Carburettor plant

In a factory for the production of automobile carburettors, 180 kg/h of individual parts are zinc plated and chromated in a 3-shift-operation, with the following process steps:

Degreasing
Pickling
Electrolytical degreasing
Zinc plating
Chromating.

After every active bath, a rinse tank is arranged in which the parts are immersed and which is continuously washed through with water.

Figure 4. View of a continuous plant

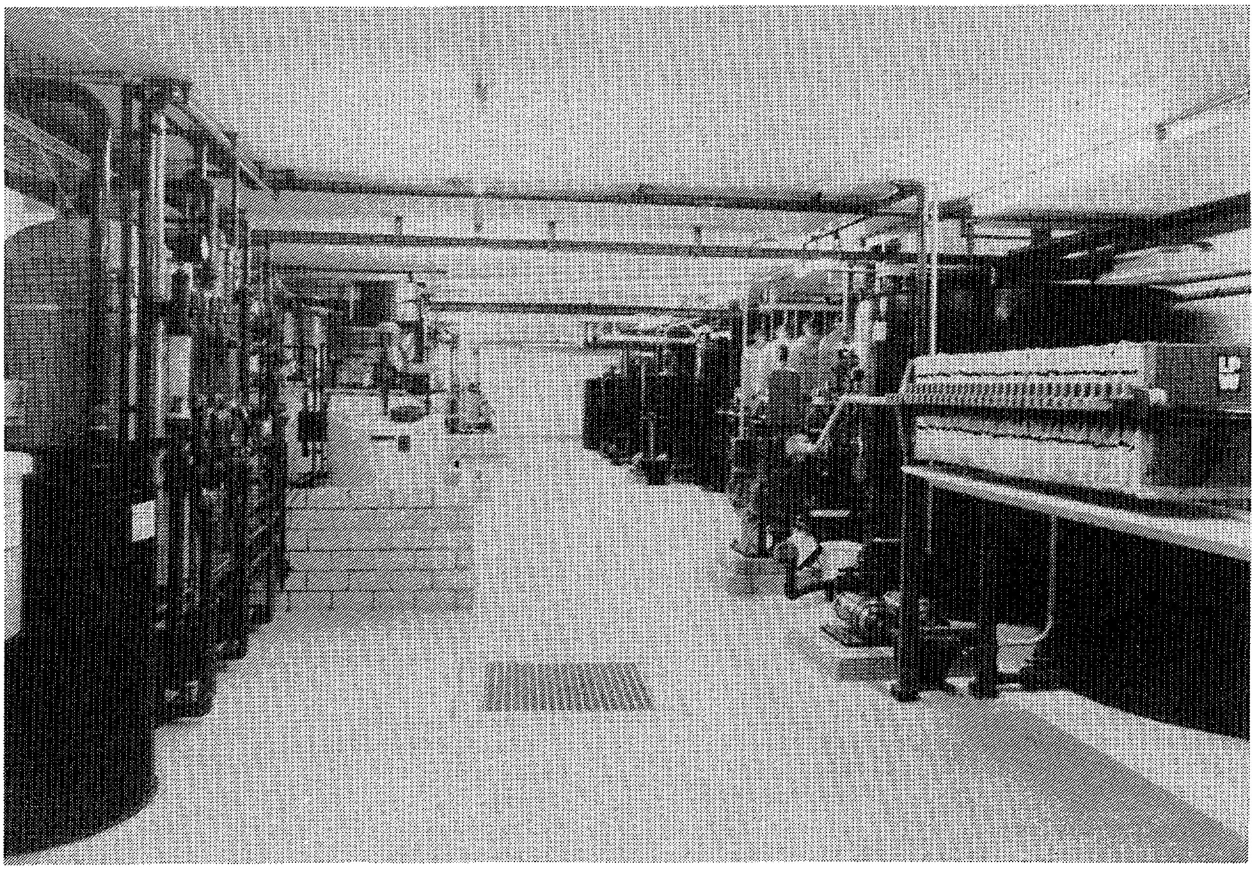
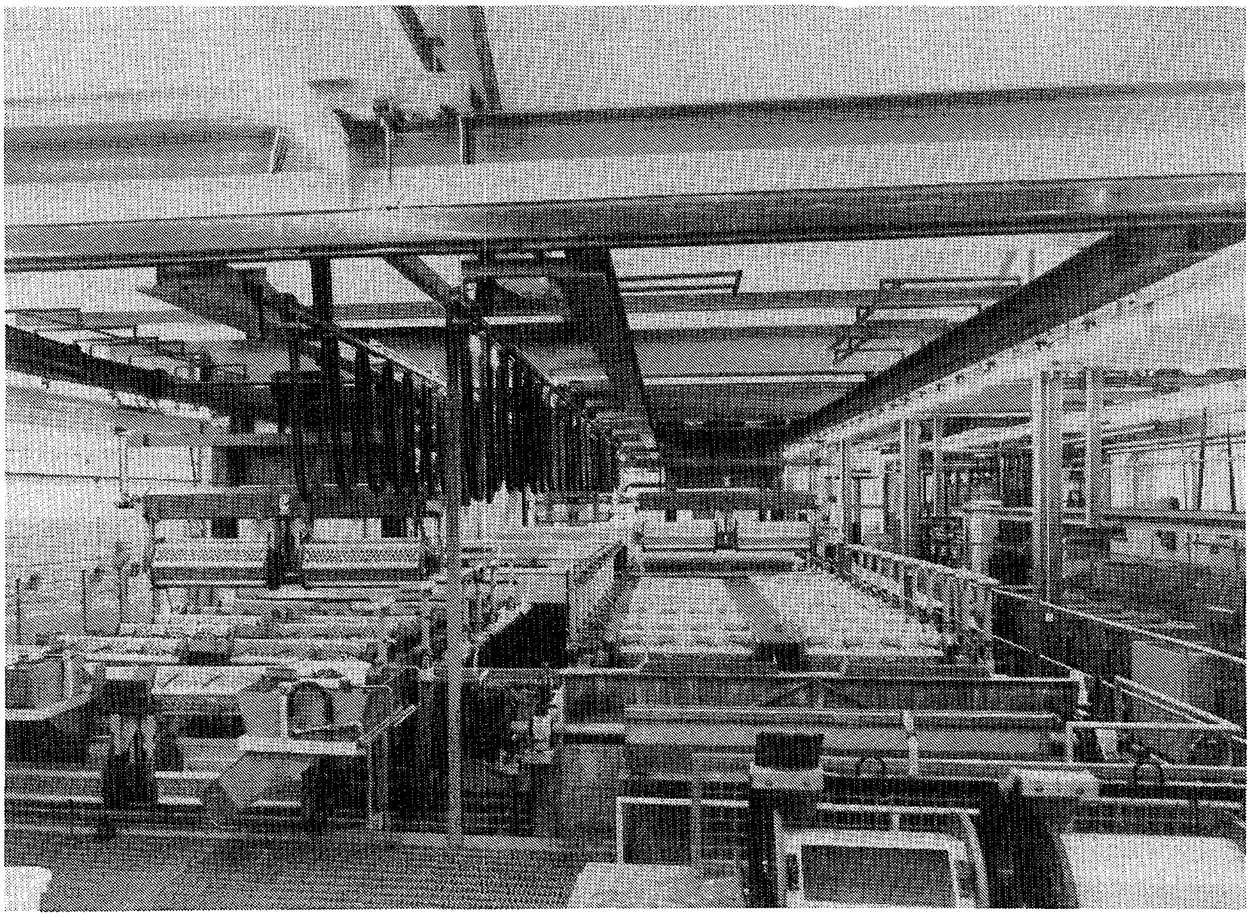


Figure 5. View of a barrel plant



The rinse water after degreasing and pickling process contain only acids and lyes and flow directly to the neutralization process; the rinse water after electrolytical degreasing and zinc plating contains cyanides and flows to the cyanide oxidation process; the rinse water after chromating process contains hexavalent chromium compounds and flows to the chromate reduction process.

The following quantities of waste water have to be treated:

Cyanide waste water	4 m^3/h
Chromate waste water	2 m^3/h
Acid and alkaline waste water	2 m^3/h

The different types of waste water are treated in a continuous treatment plant. The individual reaction steps have the following volumes:

Cyanide oxidation:	
Reaction compartment	1.5 m^3
Post-reaction compartment	1.5 m^3
Mean retention time	45 min.
Capacity of stirrer	2.5 m^3/min
Chromate reduction:	
Reaction compartment	0.5 m^3
Post-reaction compartment	0.5 m^3
Mean retention time	30 min.
Capacity of stirrer	1.0 m^3/min.
Neutralization:	
Reaction compartment	1.5 m^3
Post-reaction compartment	1.5 m^3
Mean retention time approx.	25 min.
Capacity of stirrer	2.5 m^3/min.

FOB-price for plant parts
and control device Approx. US$ 45.000

Required space (incl. sedimentation basin)	50 m^2
Required staff	1
Required operating agents and energy:	
Water	200 m^3/year
Sodium hypochlorite	200 m^3/year
Sodium bisulphite	80 m^3/year
Hydrochloric acid	120 m^3/year
Lime milk	150 m^3/year
Electrical energy	Approx. 24,000 kWh/year

	Expenditure in US dollars min.	max.
Plant	45,000	45,000
Building (depending upon climatic conditions)	10,000	40,000
Preparation of the secured foundation soil (depending upon the environmental conditions)	2,000	12,000
Lighting, ventilation, air-conditioning	5,000	10,000
Total	62,000	107,000

Example 2: Plant for sanitary fittings and accessories

In this factory, sanitary fittings and accessories are nickel plated and chromium plated in a rack plant. In a 3-shift-operation 160 pcs./h are manufactured, by the following process steps:

Ultrasonic degreasing
Electrolytical degreasing
Copper plating
Dipping
Nickel plating
Chromium plating

After every active bath a rinse tank is arranged and continuously washed through with water. The rinse water after the ultrasonic degreasing, electrolytical degreasing, dipping, and nickel plating flows directly to the neutralization; the rinse water after copper plating contains cyanides and flows to the cyanide oxidation; the rinse water after chromium plating contains hexavalent chromium compounds and flows to the chromate reduction.

The following quantities of waste water have to be treated:

Cyanide waste water	1 m^3/h
Chromate waste water	3 m^3/h
Acid and alkaline waste water	8 m^3/h.

The different types of waste water are treated in a continuous treatment plant. The individual reaction steps have the following volumes:

Cyanide oxidation:	
Reaction compartment	0.75 m^3
Post-reaction compartment	0.75 m^3
Mean retention time	1.5 hours
Capacity of stirrer	1.2 m^3/min.
Chromate reduction:	
Reaction compartment	0.5 m^3
Post-reaction compartment	0.5 m^3
Mean retention time	20 min.
Capacity of stirrer	1.5 m^3/min.
Neutralization:	
Reaction compartment	2.0 m^3
Post-reaction compartment	2.0 m^3
Mean retention time approx.	20 min.
Capacity of stirrer	6.0 m^3/min.

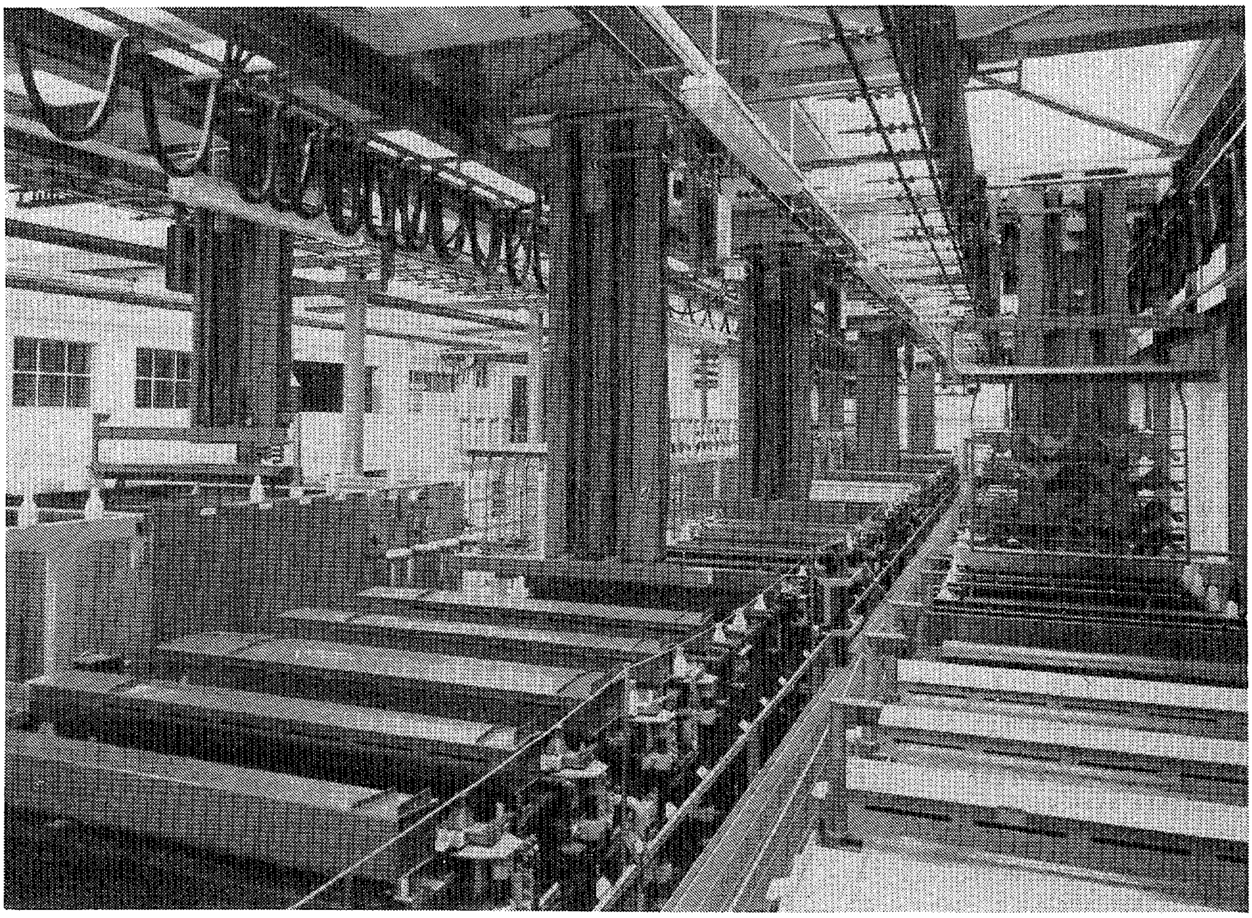
FOB-price for plant parts and control device	Approx.	US$ 70,000
Required space (incl. sedimentation basin)		90 m^2
Required staff:		1
Required operating agents and energy:		
water		250 m^3/year
sodium hypochlorite		90 m^3/year
sodium bisulphite		260 m^3/year
hydrochloric acid		70 m^3/year
lime milk		260 m^3/year
electrical energy	Approx.	6,000 kWh/year

	Expenditure in US dollars *min.*	 *max.*
Plant	70,000	70,000
Building (depending upon climatic conditions)	20,000	80,000
Preparation of the secured foundation soil (depending upon the environmental conditions)	2,500	15,000
Lighting, ventilation, air-conditioning	7,000	15,000
Total	99,500	180,000

Specification of a batch-type plant

The plants described in the following are shown as a process flow diagram in figure 3; figures 1 and 6 show a batch-type plant and a rack plating plant.

Figure 6. View of a rack plant



Example 1: Plant for parts of office chairs

In a factory producing the lower parts of office chairs, a surface treatment is carried out as a final step. This is done as follows:

Degreasing
Pickling
Electrolytical degreasing
Dipping
Nickel plating
Chromium plating

After every active bath, several rinse tanks are arranged in which the parts are immersed one after the other. As several rinse tanks are arranged after every active bath, the quantity of rinse water is small and the waste water can be treated in a batch-type plant.

The following quantities of waste water have to be treated:

Acid/alkaline waste water	19.5 m^3/week
Chromate waste water	14.0 m^3/week

The two types of waste water are collected in collecting tanks with the following volumes:

Acid/alkaline waste water	8.0 m^3
chromate waste water	6.0 m^3
The reaction tank has a volume of	6.0 m^3
FOB-price for plant parts and control device Approx.	US$ 70,000
Required space (incl. filter aggregate)	70 m^2
Required staff	1
Required operating agents and energy:	
Caustic soda solution	65 m^3
Hydrochloric acid	80 m^3
Sodium bisulphite	35 m^3
Electrical energy approx.	40,000 kWh/year

	Expenditure in US dollars	
	min.	*max.*
Plant	70,000	70,000
Building (depending upon climatic conditions)	15,000	60,000
Preparation of the secured foundation soil (depending upon the environmental conditions)	2,000	12,000
Lighting, ventilation, air-conditioning	5,000	10,000
Total	92,000	152,000

Example 2: Plant for screw spanners

Here is another example of a factory where screw spanners are nickel plated and chromium plated in a rack plating and barrel plating plant. In a two-shift operation, 800 parts/h are surface treated. The process sequence is the same as for chromium plating of lower parts of office chairs. After every active bath, several rinse baths are arranged in which the parts are immersed one after the other. The quantity of the waste water is so small that it can be treated in a batch-type plant.

The following quantities of waste water have to be treated:

Acid/alkaline waste water	9 m^3/week
Chromate waste water	2 m^3/week
The two types of waste water are collected in a collecting tank with a volume of	3 m^3
The reaction tank has a volume of	4 m^3
FOB-price for plant parts and control device Approx.	US$ 55,000
Required space (incl. sedimentation basin)	90 m^2
Required staff	1
Required operating agents and energy:	
Lime milk	30 m^3
Hydrochloric acid	10 m^3
Sodium bisulphite	15 m^3
Electrical energy Approx.	16,000 kWh/year

	Expenditure in US dollars	
	min.	*max.*
Plant	55,000	55,000
Building (depending upon climatic conditions)	10,000	40,000
Preparation of the secured foundation soil (depending upon the environmental conditions)	1,500	9,000
Lighting, ventilation, air-conditioning	3,000	6,000
Total	69,000	110,000

Manufacture of the plant

Experience has shown that the design of the basic engineering done by the company producing the plant and the order-specific production of the individual components carried out by companies specializing in this field are the most economical method for the production of the afore-mentioned waste water treatment plants (see flow chart).

The most important components are:

Collecting and reaction tanks which are made of polyethylene or polypropylene and manufactured by plastic-processing companies. The plastic plates are chamberferred or bent after heat treatment and are subsequently butt-welded with a special machine;

Electrical equipment e.g. individual contactors, relays, motor protection switches, fuses and clamps are installed in the switch cabinet and are interconnected;

Pumps, stirrers, and solenoid valves;

Piping material of PVC or PP.

All parts are brought to the erection site. The tanks are mounted on a plane surface, stirrers are installed on the tanks, pumps are mounted on pump supports and the electrical aggregates are connected with the switch unit. The tanks are interconnected by plastic piping.

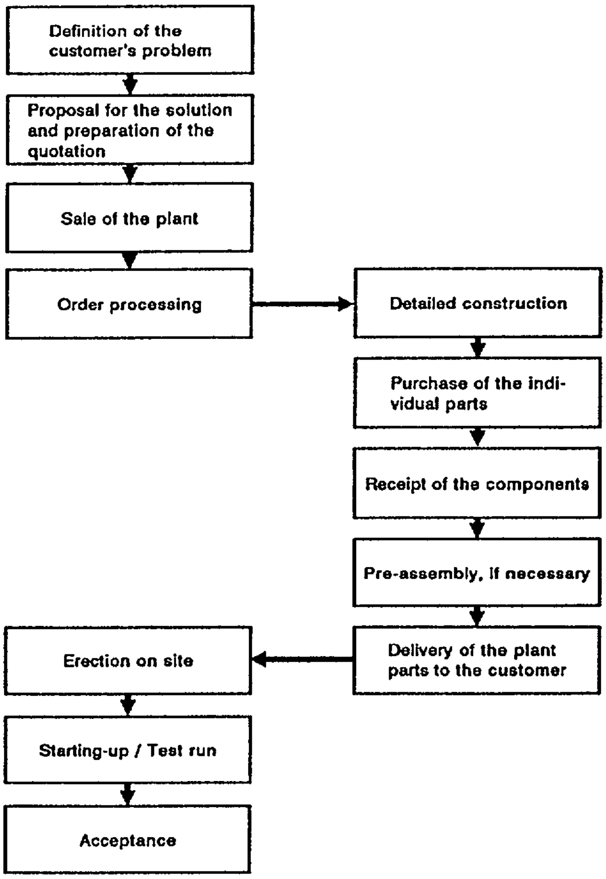
Piping and electric cables are installed over pipe bridges. The starting-up of the plant can then be carried out.

If a pre-erection of the plant becomes necessary, the electric equipment can be manufactured by the company building the plant after having bought the individual components.

For the manufacture of 10 continuous treatment plants and 10 batch-type plants per year as described above, the following overheads are necessary:

Flow chart

The individual steps for setting up of continuous treatment plants and batch-type plants



Required personnel

Personnel	*Qty.*	*Qualification*
Management	1	
Administration	1	Industrial clerk
Sales Department	2	Processing Engineer
Projecting Department	1	Processing Engineer
Order processing	1	Mechanical engineering technician
Erection	3	Plastic mechanics, electricians
Total	9	

Required area

Management, administration and sales department	60 m^2

In case partial erection is necessary, the following costs and requirements would occur in addition to the already stated personnel and space requirements.

Area for erecting shop including storage area	20 m^2

Required energy

Energy requirements for lighting, air conditioning and appliance tests

Required machinery and appliances

Hydraulic lifting device	1
Voltmeter	2
Ammeter	2
Drilling machine	3
Screwdriver, electrical set of tools	2
FOB-price for machinery and appliances	Approx. US$ 10,000

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How to Start Manufacturing Industries

Coagulation/flocculation

Introduction

A large number of waste water systems have heavy organic loads and dispersed solids which require a physico-chemical treatment. Coagulation/flocculation is a widespread process especially used in those cases where very fine dispersed solids, of colloidal size, are to be agglomerated in water in order to allow for sedimentation or filtration. Sedimentation is only possible if a particle size of at least 1 micron is reached. Dispersed colloids, however, only have sizes of $^{1}/_{1000}$ micron to 1 micron, that is to say, they are still in the macromolecular area.

In the case of organic colloids, coagulation/flocculation very often allows a mechanical separation from the waste water, thus avoiding biological treatment. Accordingly a biological waste water treatment plant can often be relieved by adding a coagulation/flocculation installation. By using coagulants/flocculants the settling speed of a biological floc can be increased and the filterability of the excess sludge improved.

The terms coagulation/flocculation are used to describe the process whereby colloids are converted into removable small particles. This first stage has to be followed by a second stage in which the small particles are separated from the water. This is done by means of sedimentation, flotation or filtration.

In contrast to this induced flocculation process, coagulation/flocculation also automatically takes place to a certain degree during some chemical precipitation processes, as for example in waste water treatment plants, especially those in the industrial field, which have a neutralization phase. However, the process is often not strong enough to induce separation so it has to be supported by coagulation agents/flocculants.

Coagulation/flocculation offers the following possibilities for waste water treatment in general:

Shortening of sedimentation time in secondary sedimentation tanks;

Improvement of sludge filtration in vacuum filtration or belt type sludge presses;

Quicker sludge dewatering in sludge drying beds or centrifuges;

For industrial waste water treatment it allows for quick removal of floating substances, including dye stuffs.

Process description

Coagulation/flocculation are processes where suspended material existing in water in a colloidal form is converted into greater agglomerates. The flocs attain a condition and a size whereby they can be separated from water by sedimentation, flotation or filtration.

Two separate process phases can be distinguished:

Coagulation;

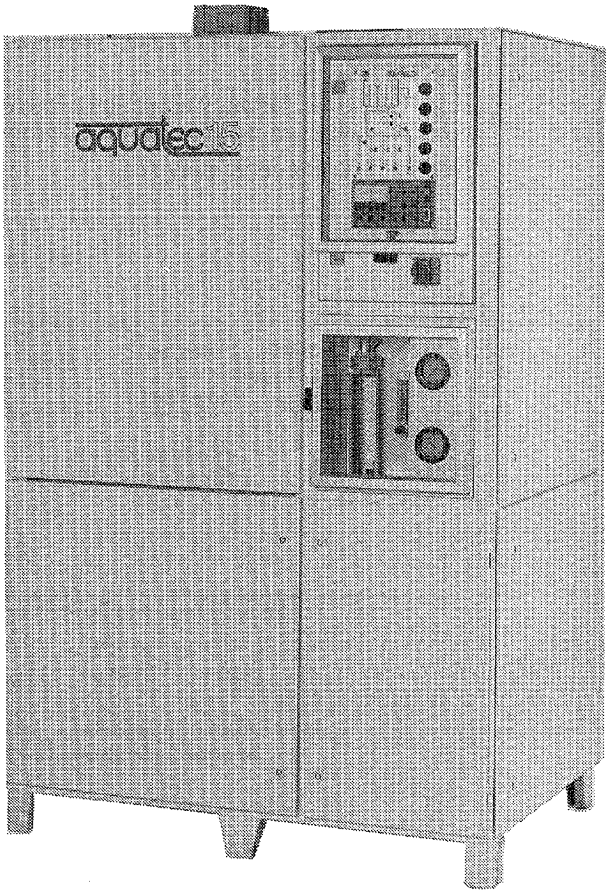
Flocculation.

Coagulation

Coagulation is that part of the process where those forces which hinder an approach or an amalgamation of the colloidal particles, evenly distributed in the water, are compensated for, thus enabling their agglomeration. For this a certain coagulant has to be added in order to destabilize the dispersed system.

An amalgamation of the particles is made impossible by the electrostatic surface forces: the colloids, dispersed in the water, are covered with a double layer of equally loaded ions. By adding ions with an opposite charge the electrostatic surface load of the solid particles is reduced, so that an approach followed by an agglomeration can take place.

In practice coagulation by adsorption is mainly used. Iron and aluminium salts are added to the waste water, whereby their positive load compensates the load of the colloids/flakes.



At the same time, if necessary, the pH index can be corrected by adding caustic soda or lime, which also has a positive influence on floc formation.

Flocculation

Flocculation means the binding and reticulation of very small particles by bridges, formed by linear chains of molecules. This agglomeration can be induced to a certain extent just by stirring. In practice, however, flocculation agents are mostly used.

Flocculation agents can be of an organic or anorganic, natural or synthetic, anionic, cationic or non-ionic nature.

Today synthetic organic polymers are mainly used, which by means of their spacious construction are able to facilitate the uniting of finely dispersed particles into greater agglomerates. In addition to these, activated silica and alginate are also used as flocculation agents.

The most commonly used coagulation/ flocculation agents

Coagulants

Iron sulphate, iron chloride	$Fe_2(SO_4)_3$; $FeCl_3$
Aluminium sulphate	$Al_2(SO_4)_3$
Cation polyelectrolytes	
for pH correction	
Lime:	$Ca(OH)_2$
Activated clay	
Caustic soda	$NaOH$
Sodium carbonate	Na_2CO_3
Sulphuric acid	H_2SO_4
Carbon dioxide	CO_2

Flocculants

Low-molecular substances (mostly with an opposite charge);

High-molecular, strongly adsorbant, negatively or positively charged polymers (polyelectrolytes);

Non-loaded, non-ionic polymers.

Functioning of flocculation devices

For effective coagulation, quick and even distribution of the adjuvants added in small quantities is decisive; followed by vigorous stirring with propeller mixers or rotary pumps. Coagulation takes only a few seconds.

The flocculation process which follows is intended to join the neutralized particles into even larger flocs. For this "growing" process a moderate turbulence is favourable in order to form flakes as compact as possible by increasing the contact frequency between the particles (too great a turbulence destroys the floc). This process often runs without a flocculant, however sometimes it is necessary to add one in order to increase the efficiency of the floc formation.

The flocculation reactors have to be dimensioned in such a way that a retention time of 15 to 30 minutes is possible. The moderate turbulences can be achieved either by baffle-plates in the water stream, pipe rerouting, or by slow running stirring processes (paddle, turbine, cylinder stirring devices).

Coagulation and flocculation are closely connected and represent a relatively complex and delicate process. It is not only difficult to determine the type and quantity of the adjuvants added, but also the optimal adaptation of the device (stirring device, stirring speed etc.) to the running processes.

A further important factor is the pH index. There is an optimal pH for every type of waste water and every agent so that in some cases a correction of the pH may be necessary.

For optimal waste water treatment the following variables can be influenced:

Nature of the coagulant and the flocculant;

Dose of added reagents;

pH;

Type and duration of stirring.

A rather reliable method for determining the type and quantity of the reagents is the "jar-test", which reflects the running processes on a small scale. In six

Figure 1. Process treatment

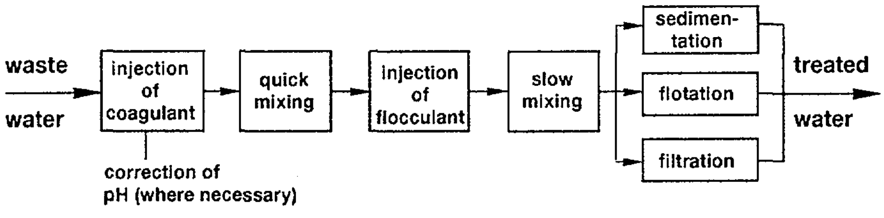
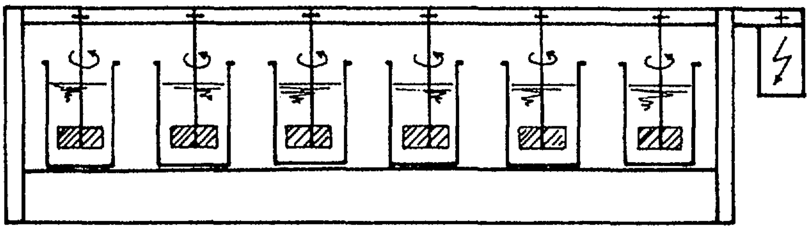


Figure 2. The jar-test



jars with a common stirring device the flocculation process, including sedimentation, is simulated and controlled by the regular taking of samples.

The following factors are decisive for the choice of reagents:

Type and composition of the waste water;
Fluctuations in the quality of the waste water;
Target criteria for the treated waste water;
Technical processes used.

A classical flocculation plant consists of three separate units:

Mixing device
Via dosing pumps the suitable chemicals (coagulants, substances for pH correction and/or flocculants) are added to the waste water, which is stirred and intensively mixed at high speeds;

Flocculation reactor
The waste water is only moderately stirred in order to attain flakes which are easily sedimented or filtered;

Separating device
Here the flakes, formed in the process, are separated from the waste water.

For *mixing and flocculation* different devices are commonly used, as already mentioned above.

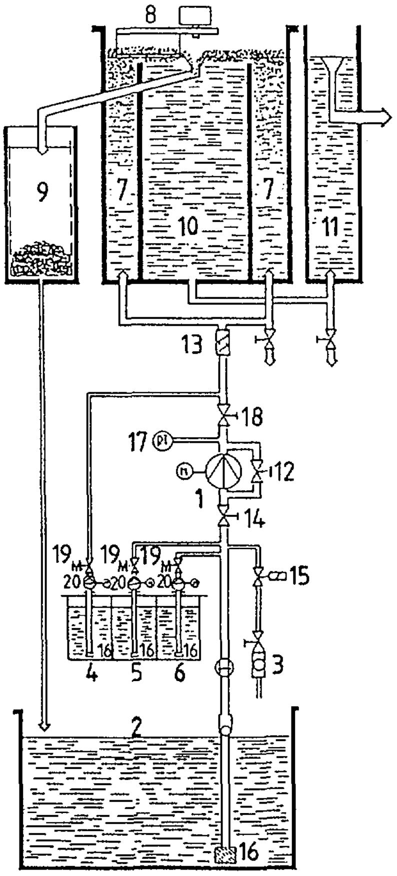
For *separation* different processes can be used. Which of these will be the best is basically determined by factors such as size, form, specific density, porosity, or number of substances contained in the water to be separated. The size distribution of the particles is therefore of utmost importance.

Sedimentation: theoretically all particles can be separated by sedimentation, provided that their density is higher than that of water. In practice, however, the sedimentation processes are limited by the sedimentation speed. If this is too low, other processes have to be used. In the treatment of waste water sedimentation is generally only used if the diameter of the particles is greater than 10 microns. Problems arise in the case of extremely flocculent structures, as, for example, with activated sludge.

Flotation: flotation is used if the particles are smaller and sedimentation speed is reduced. For the technical operation not only are the size of the particles important, but also the concentration of the solids in the water, as well as their form and surface structure.

Filtration: the retaining of particles is achieved by contact and subsequent adhesion to the filter material. Filtration is appropriate for particle sizes between 1 mm and $^{1}/_{10}$ micron. According to the specific composition and concentration of the suspended solids, different types of filtration can be used.

Figure 3. Emulsion separating unit



Key:

1	Operation pump
2	Collecting and buffer basin
3	Air intake / air volume meter
4	Dosing chamber for flocculant
5	(emulsion separating agent)
6	Dosing chamber for neutralizing agent
7	Reacting chamber
8	Reamer with motor
9	Filter container with flotate dewatering
10	Separaing chamber
11	Levelling chamber with clearwater discharge
12	Pump by-pass with throttle valve
13	Static mixer
14	Nonreturn valve
15	Magnet valve
16	Filter basket
17	Pressure gauge
18	Expansion valve
19	Pressure retaining valve
20	Dosing pump

Construction and function of a coagulation/ flocculation plant

Coagulation/flocculation units are used in waste water treatment to fulfil different tasks. The following example describes an emulsion separating unit.

Emulsion separating units are used in industry to treat stable emulsions, which, if at all, can be partly separated by mechanical separators. One possibility is chemical demulsification followed by flotation.

Construction: the unit consists of a dosing device, an operating pump, a reacting and separating chamber including reamer, a levelling chamber and a filter container to take up the flotate.

Function: the operating pump sucks in the emulsion out of a collecting and buffer basin outside the unit and, at the same time, air from the surroundings. Pressure and rate of flow are regulated by a pump by-pass. The coagulant is added in precise quantities with the help of a dosing pump (diaphragm pump) and mixed with the emulsion and air by the operating pump. If necessary, a pH neutralizing agent and a flocculant to stabilize the flocs can be added. The coagulant forms flocs adsorbing the harmful substances. A hydraulic static mixer provides the appropriate slow stirring.

From here the liquid reaches the reacting chamber, i.e. the outer ring chamber of the cylindrical flotation tank, which is made of polypropylen (PP) or other emulsion-resistant materials and here the water relaxes. By this process the enclosed air forms fine bubbles which settle on the already formed flocs and transports them to the surface where a foamy floc layer, containing the harmful substances, is formed. This flotate is collected by a reamer and brought into a dewatering unit where it condenses to a solid filter cake that has to be disposed of.

The purified water flows from the reacting chamber into the separating chamber, from where the last flocs, taken along with the water, can separate, and it leaves the unit via the levelling chamber.

Adjustment: the adjustment of the unit depends on the waste water load. First the coagulant is adjusted to the condition of the waste water, i.e. if the waste water is only lightly fouled, different coagulants are employed than for heavily fouled waste water. Second the dosing pump used for adding the coagulant is adjusted according to the measurements taken from the outflowing treated water (oil content, pH value). In the case of an insufficient treatment or a too high pH value, neutralization agents and flocculants have to be added, whereby the pump adjustments are made on the same basis as mentioned above. By measuring the outflowing water it is also possible to measure the acidity, caused by the coagulant. All adjustments are carried out manually (automatic adjustment is also possible).

Description of the production process

The unit consists mainly of parts ordered from outside firms, which are assembled at the work site.

The basis for the assembly of the unit is a painted iron frame, manufactured according to given plans by an outside firm, into which the individual PP-containers—flotation tank and the three chamber dosing devices—are mounted. These containers are produced, according to given specifications, by specialized firms. The feedpipe with filter basket, dosing pump, pressure retaining valve and pressure tube, also delivered from outside, are fitted into the dosing chambers.

The waste water is fed into the flotation tank through a PVC-pipe. At the works the lower part is fitted with a non return valve and connection nozzles for the pressure tubes from the dosing device, for the air intake pipe and the pump by-pass; the upper part is fitted with an expansion valve, the hydraulic static mixer and connection nozzles for the pump by-pass, the pressure gauge and for the pressure pipe connection for the flocculents.

Both parts of the feedpipe are connected to the operating pump and the complete emulsion feedpipe is built onto the reacting chamber. The lower end of the feedpipe at first stays open; this end is connected to the collecting basin after the unit has been installed for the customer.

The following steps are necessary for installation:

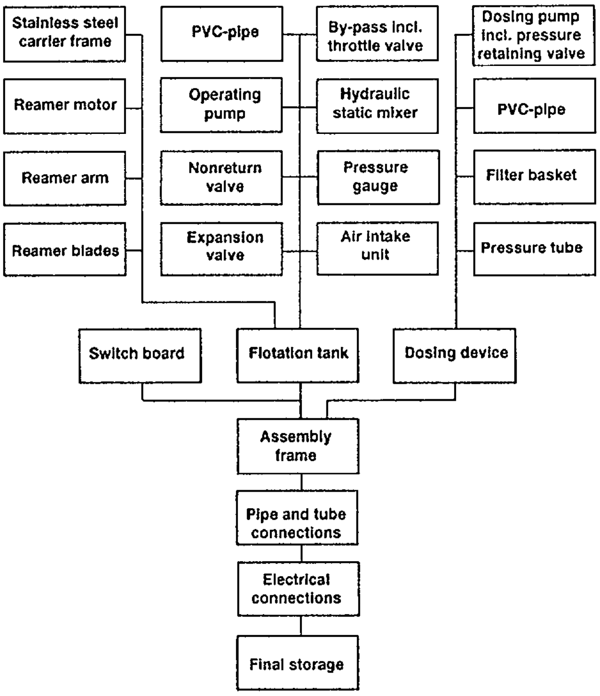
Making the connections to the above mentioned dosing device, air intake etc.;

Fitting the pump by-pass including throttle valve and the pressure gauge;

Fitting the reamer unit into the flotation tank. The reamer unit is assembled at the works, i.e. the reamer motor is fitted into the stainless steel carrier frame, the reamer arm (stainless steel pipe) onto the main shaft and the reamer blades (PP plates) onto the reamer arm via adjusting rings;

Finalizing the electrical installation e.g. switch board, connections to electrical users etc.

Figure 4. Flow chart



Example of a production plant (emulsion separating unit)

Production of 1 emulsion separating unit in 2 days; the production section is a pure assembly line, with all important parts being delivered from specialized firms. The assembled units are transported to the customer, installed there, put into operation and optimally adjusted.

It has to be pointed out, that the following details do not mean full capacity at all points. To achieve that situation, also the production of other devices or installations would be necessary.

Required machinery and equipment

Description	*Pieces*
Reflex welding machine	1
Drilling machine	1
Work place with bench	1
Hand-operated fork lift	1
Delivery van	1
FOB-price for machinery and equipment (1991)	Approx. US$ 25,000

Required manpower

Manager/engineer	1
Electrician	1
Chemist	1
Unskilled worker	1
Administration	1

Required buldings and areas

	Square metres
Production hall	100
Work places	20
Storage (delivered parts and final products)	25
Social rooms	20
Administration	30
Open area	100

Required power and utilities

Electric power	5 kW
Water	

Required inputs

PVC pipes ($^3/_4$', 1', 1 $^1/_4$')
Flotation tank (PP = polypropylene)
Dosing device (PP)
PP-plates
Stainless steel pipes
Pressure tubes
Reamer motor
Rotatory pumps
Dosing pumps
Valves (nonreturn, expansion, pressure retaining, throttle, magnet)
Small parts (clamps, adjusting rings, filter baskets etc.)
Switch board
pH measuring instrument
Pressure gauge
Water meter
Air flow meter

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How to Start Manufacturing Industries

Ion exchanger process

Introduction

In nearly all industrial spheres water plays a central role in the production factor. In the chemical industry it is required as a reaction partner when producing substances of different kinds such as for the production of sulphuric acid; in the textile industry it is needed for dyeing purposes as a solvent for colouring substances; and in electric power stations it is used as a cooling agent and, in the form of steam, for the generation of electricity. The quality demands set for water vary in all fields of application. Filtrated river water can be used for cooling purposes, whereas boiler feed water for the generation of electricity has to be demineralized in order to avoid any deposits on the turbine blades.

Demineralization means the removal of dissolved substances contained in natural water.

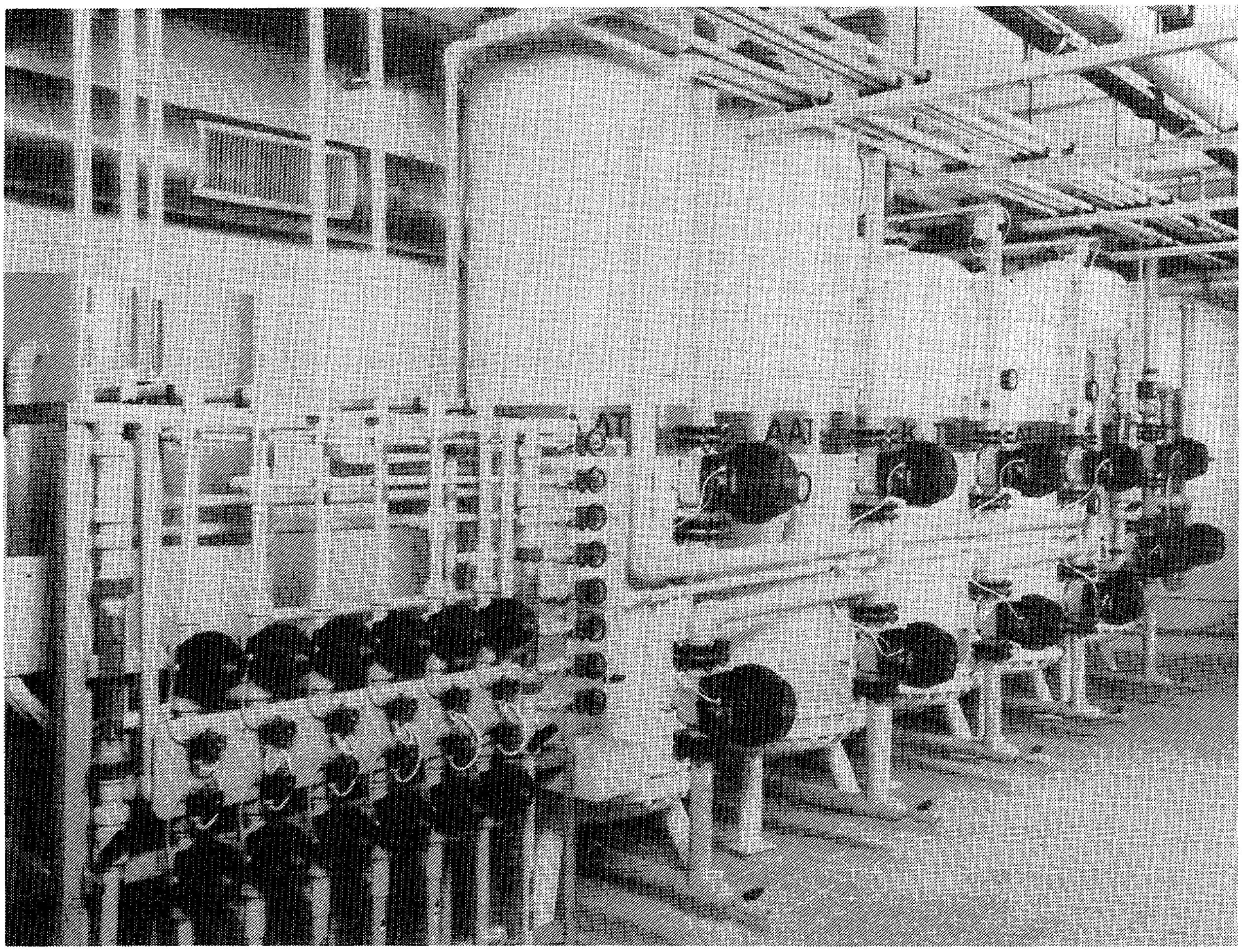
The demineralization process can be done at an ion exchanger plant provided that the salt content of the water is not too high. This condition is normally given in the case of sweet water.

The usage of ion exchanger plants is not restricted to the demineralization of water; these plants can also be used in the sugar industry for decalcimation of the molasses, and in the metal-working industry for the recovery of metal salts from the waste water. The main field of application of the ion exchanger plant, however, is the demineralization of water.

Principle of the ion exchanger

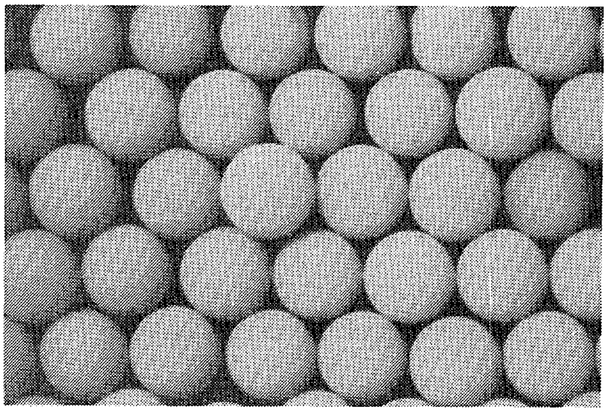
Ion exchanger resins

Nowadays, ion exchangers are normally synthetic resins which are insoluble in water and which contain ion-active groups. The synthetic resin, which makes the ion exchanger insoluble, is a copolymeride of organic compounds, such as styrene, acrylate, acrylamide and its derivatives with divinyl benzene acting as a lattice-like polymerization agent. The ion-active groups are already contained in the monomeres or will be substituted after polymerization.



The manufacturing is effected by pearl-polymerization where the ion exchangers are produced into ball-shape and are sold in grain sizes ranging between 0.3 and 1.4 mm (see figure 1).

Figure 1. Ion exchanger resin



Exchange procedures

The ion exchange procedures take place at the ion-active groups of the exchanger resins. If an ion exchanger loaded with ions of the type A is brought in contact with an aqueous solution containing ions of the type B of the same charge, an exchange of the ions A and B takes place until an equilibrium is reached which corresponds to the chemical law of mass action, i.e. ions of the type A separate from the resin and shift into the solution, whereas simultaneously ions of the type B shift from the aqueous solution to the ion-active group of the resin. In the state of equilibrium, exchanger resin, loaded with ions A and B, is present as well as the solution with the ions A and B.

The decisive fact for the functioning of the ion exchanger is that the exchanger reactions taking place at the ion-active groups are completely reversible. If an ion exchanger resin which was originally loaded with ions of the type A, is partially loaded with ions of the type B, the ions of type B can be removed from the resin by bringing the resin into contact with an aqueous solution showing a higher concentration of the ions type A. By this method it will be possible to load an exchanger resin—by selecting the ion concentration in the aqueous solution—with one or more types of ions of the same charge.

This is particularly important for the regeneration of the ion exchangers.

Aqueous solutions very seldom contain ions of only one single valency. Due to the different densities of charge of monovalent and multivalent ions, they also have a different tendency to shift to the ion-active group and to the ion exchanger. In general the ion with the higher valency is preferred and is more strongly bound to the resin.

Exchanger resins

In the same way as salts dissociate in water into cations and anions, it is possible to produce ion exchangers with cation-exchanging and anion-exchanging active groups—the cation exchanger and the anion exchanger.

These groups can be subdivided into strongly and weakly acid cation exchangers and into strongly and weakly basic anion exchangers. During the exchange reactions they behave either as strong and weak acids, or as strong and weak bases.

Strongly acid cation exchangers

These have a high affinity to trivalent and tetravalent ions, a medium affinity to bivalent ions and a weak affinity to monovalent ions. Within the monovalent ions the affinity to the hydrogen ions is the lowest. All ions having a higher affinity to the resin than the hydrogen ion are able to keep the hydrogen ions away from the resin.

Weakly acid cation exchangers

These have the highest affinity to hydrogen ions whereas other monovalent and multivalent cations are less absorbed.

The ions bound to the cation exchanger can be removed by a regeneration with hydrochloric acid or sulphuric acid and can be replaced by hydrogen ions.

Strongly basic anion exchangers

These are able to bind likewise anions of strong and weak acids and to release them by regeneration with caustic soda solution. But anions of strong acids are more strongly bound.

Weakly basic anion exchangers

These bind anions of weak acids only in a minor way, whereas anions of strong acids are very well absorbed. Regeneration is effected with caustic soda solution as well. The different absorption capacity for anions of strong and weak acids by the two types of resin is important for the demineralization of the water.

Fundamental design and method of operation of an ion exchanger plant

The basic equipment of an ion exchanger plant consists of:

Waste water collecting station and pumps;

Filters;

At least two cation exchangers;

Measuring and control devices.

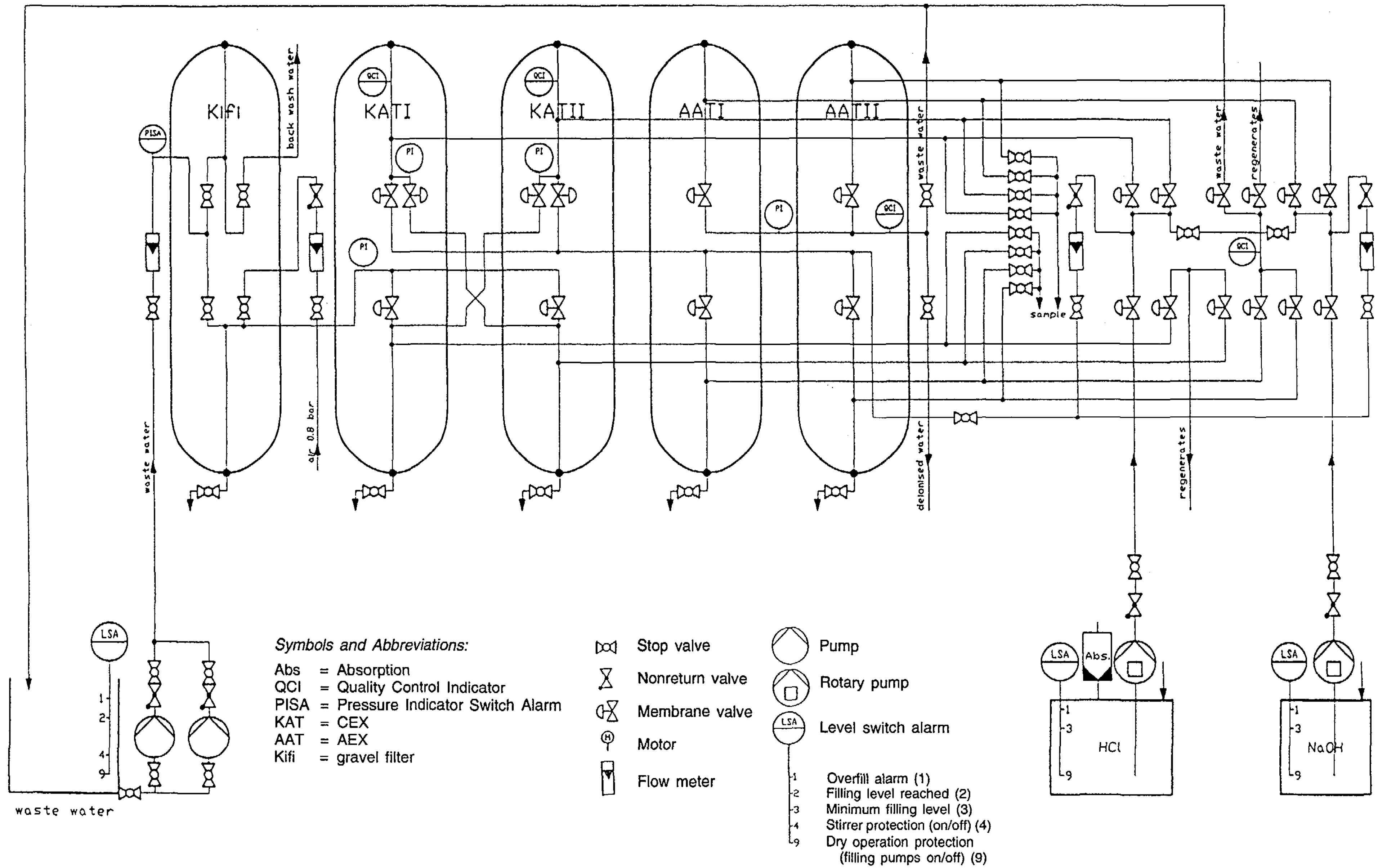
In figure 2 an ion exchanger plant is shown in the form of a diagram.

The waste water collecting station serves as an intermediate buffer in order to constantly bring the quantity of liquid to the exchangers.

The collecting station can be made of concrete with a chemical resistant inner lining or of steel tanks, hard rubber lined, or of plastic material.

The pumps convey the water which has to be demineralized to the exchangers. One pump is on stand-by

Figure 2. Ion exchanger plant—liftbed



Symbols and Abbreviations:

Abs = Absorption
QCI = Quality Control Indicator
PISA = Pressure Indicator Switch Alarm
KAT = CEX
AAT = AEX
Kifi = gravel filter

1 Overfill alarm (1)
2 Filling level reached (2)
3 Minimum filling level (3)
4 Stirrer protection (on/off) (4)
9 Dry operation protection (filling pumps on/off) (9)

in order to ensure a continuous operation in case the other pump fails to work. The capacity of both pumps must be sufficiently dimensioned in order to pump the water through the filter, the exchanger, and through the piping to the consumption points. In general, single-stage centrifugal pumps of stainless steel are used. The adjustment of the flow rate is effected at the pressure side of the pumps before the filter.

To protect the exchanger against mechanical impurities the water flows through a filter. Because of the large throughputs, at times gravel filters, which are flown through from the top to the bottom, are used almost without exception. The solids are collected in the gravel bed and the filter is regularly cleaned. The water flows at a high velocity through the bed from the bottom upwards and all solids are carried away.

The filter is made of sheet steel with an inner rubber lining or, in the case of lower capacities, of plastic material. Filtering material consists of quartz gravel with a grain size of 0.8-1.5 mm.

The water leaving the filter flows to the cation exchanger columns which are filled with strongly acid cation resins. The exchangers can be flown through either from the top to the bottom or vice versa. Depending upon the flow direction, the reaction zone shifts toward the bottom or the top.

The exchanger resin is in the cylindrical part of the round column which is made of steel with an inner rubber lining or of plastic material. To keep the resin in the column, strainer plates or nozzle crosses provided with slots of 0.2 mm are arranged inside the column at the upper and lower side allowing a uniform flow through the resin bed due to their geometrical arrangement.

Together with the shifting of the reaction zone, loading of the resin with cations takes place. After the reaction zone has reached the upper or lower end of the resin bed, the exchanger is no longer in a position to exchange cations against hydrogen ions; the exchanger is loaded.

In order to refurbish the absorption capacity for cations, the exchanger has to be regenerated with hydrochloric acid. It is used as a 6% solution and flows through the resin bed from the top to the bottom. As more acid equivalents have to be used for the regeneration than the exchanger can absorb, the excess of acid has to be washed away with water. The washing water occurring in this process are called regenerates, and they have to be neutralized in a waste water treatment plant.

When the regeneration of the exchanger is started, the second exchanger starts operation to ensure the production of debased water. The newly regenerated exchanger is available as a stand-by. The debased water coming from the cation exchanger flows to the anion exchanger columns which are filled with a strong or weak based anion exchanger resin. The decision as to whether to use weak or strong based anion exchangers, or both types in separate columns, depends upon the chemical compound of the usable water.

If both exchanger types are used, first the weak basic and then the strong basic anion exchanger has to be flown through. The flow direction and the equipment of the anion exchanger are the same as for the cation exchanger.

After the anion exchanger is loaded, it is regenerated with a 4% caustic soda solution. These regenerates also have to be neutralized in a waste water treatment plant. After initiating the regeneration, the stand-by exchanger starts operation; after the regeneration has been finished the regenerated exchanger acts as a stand-by.

Ion exchanger plants are fully automatic. They are equipped with automatic opening and closing valves which operate according to a control programme. As a control element, indicating the end of the loading of the exchanger and the start of the regeneration, the electrical conductivity of the debased and demineralized water is used.

Ion exchanger plants can operate in series or in the so-called "street-connection". In a series arrangement the usable water flows through:

gravel filter – cation exchanger I (= CEX I) – cation exchanger II – anion exchanger I (= AEX I); or
gravel filter – CEX II – CEX I – AEX I; or
gravel filter – CEX I – CEX II – AEX II; or
gravel filter – CEX II – CEX I – AEX II.

During the regeneration of a cation exchanger the following operating situations result:

gravel filter – CEX II – AEX I; or
gravel filter - CEX I - AEX I; or
gravel filter - CEX II - AEX II; or
gravel filter - CEX I - AEX II.

In the so-called "street-connection" the water flows through

gravel filter – CEX I – AEX I; or
gravel filter – CEX II – AEX II.

At this time the other "street" is being regenerated or is in a stand-by position.

When the series arrangement is used, a better utilization of the resin capacity is obtained, whereas when using the "street- connection", the control programme is simpler.

Dimensioning

For the design of an ion exchanger, the following data are required:

Quantity of water in m^3/h;

Salt content of the water to be demineralized in mol/m^3;

Desired period between two regenerations in hours, minimum 16 hours;

Quality of the demineralized water in mS/m.

Further data have to be considered when designing the exchanger.

Velocity of flow through the empty exchanger column	max. 40 $m^3/m^2 \times h$
Useful resin capacities	
Cation exchanger	max. 1.2 mol/l resin
Anion exchanger	
Weakly basic	0.8-1.0 mol/l resin
Strongly basic	0.6-0.8 mol/l resin
Regenerant	
Cation exchanger	250 g HCl 32% /l resin

Anion exchanger	
Weakly basic	140 g NaOH 45%/l resin
Strongly basic	180 g NaOH 45%/l resin
Quantity of wash water cation exchanger	5 l/l resin with max. 10 $m^3/m^2 \times h$
Anion exchanger Weakly basic approx.	8 l/l resin with max. 10 $m^3/m^2 \times h$
Strongly basic approx.	10 l/l resin with max. 10 $m^3/m^2 \times h$
Minimum layer of resin	1000 mm

An example for the design of an ion exchanger

Quantity of water	100 m^3/h
Salt content	
Cations	2.4 mol/m^3
Anions	2.5 mol/m^3
thereof	1.8 mol/m^3 anions of strong acid 0.8 mol/m^3 anions of weak acid
Time of use	20 hours
Quality of demineralized water	0.1 mS/m
Selected type of plant	series arrangement gravel filter – cation exchanger – anion exchanger weakly basic – anion exchanger strongly basic

Cation exchanger

$$\text{Quantity of resin: } \frac{100 \times 2.4 \times 20}{1200}\left[\frac{m^3 \times mol \times h \times m^3}{h \times m^3 \times mol}\right]$$

$$= 4\ m^3\ /\ \text{column}$$

Diameter of column	at 40 $m^3/m^2 \times h \rightarrow D = 1.8$ m
Solution	4 000 m^3/column
Thickness of resin layer	1.6 m
Quantity of regenerant	1000 kg HCl 32%/regeneration
Quantity of dilution water	4300 kg water/regeneration
Quantity of wash water	20000 l/regeneration
Quantity of waste water	Approx. 25000 l/regeneration

Anion exchanger

$$\text{Weakly basic quantity of resin } \frac{100 \times 1.8 \times 20}{900} = 4\ m^3/\text{column}$$

Diameter of column	at 40 $m^3/m^2 \times h\ D \rightarrow 1.8$ m
Thickness of resin layer	1.6 m
Quantity of regenerant	480 kg NaOH 50%/regeneration
Quantity of dilution water	5500 kg water/regeneration
Quantity of wash water	32000 l water/regeneration
Quantity of waste water	Approx. 38000 l/regeneration

Anion exchanger

$$\text{Weakly basic quantity of resin } \frac{100 \times 1.8 \times 20}{600} = 2.7\ m^3/\text{column}$$

Diameter of column	40 $m^3/m^2 \times h \rightarrow D$ 1.8 m
Thickness of resin	1.1 m
Quantity of regenerant	480 kg NaOH 50%/regeneration
Quantity of dilution water	5500 kg water/regeneration
Quantity of wash water	32000 l water/regeneration
Quantity of waste water	Approx. 36000 l/regeneration

Example of a delivered plant

In a glass-making factory, hot water and steam are required for the production process. To meet the requirements, 30 m^3/h of demineralized water are necessary for a 24-hours-operation. The demineralized water is gained from well water having a cation concentration of 0.9 mol/m^3 and an anion concentration of 0.8 mol/m^3.

The ion exchanger is designed as a double-line plant with an irrigator between the cation and the anion exchanger.

Cation exchanger	1000 l
Anion exchanger strongly basic	1000 l
Diameter of column	1 m
Thickness of resin layer	1.25 m
Period between two regenerations	Approx. 45 hours
Required regenerant	
Hydrochloric acid	250 kg HCl 32%/regeneration
Caustic soda solution	160 kg NaOH 50%/regeneration
Required wash water	
Cation exchanger	5000 l/regeneration
Anion exchanger	Approx. 10000 l/regeneration
Quantity of wash water	Approx. 15500 l/regeneration
FOB-price for plant parts and control device	Approx. US$ 240,000
Required space	30 m^2
Required operating agents and energy	
Water	2,800 m^3/year
Caustic soda solution	29,000 kg/year
Hydrochloric acid	45,000 m^3/year
Electric energy	Approx. 60,000 kWh/year

	Expenditure in US dollars *minimum*	 *maximum*
Plant	240,000	240,000
Building (depending upon climatic conditions)	6,000	24,000
Preparation of the secured foundation soil (depending upon the environmental conditions)	1,500	9,000
Lighting, ventilation, air-conditioning	5,000	10,000
Total	252,000	283,000

Manufacture of the plant

Experience has shown that the design of the basic engineering done by the company producing the plant and the order-specific production of the individual components carried out by companies specializing in this field are the most economical method for the production of the afore-mentioned ion exchanger plant.

The most important components are:

- Exchanger columns (see figure 3)

  These are made of glass-fibre reinforced polyester, manufactured by plastic-processing companies. Subsequently, the exchanger columns are provided with an inner lining of PVC or polyvinylester.

- Exchanger resins

  Resins are bought in the required quality from resin manufacturers.

- Collecting and reaction tanks

  Tanks are made of polyethylene or polypropylene plate material manufactured by plastic-processing companies. The plastic plates are chamberferred or bent in warm condition and are subsequently butt-welded with a special machine.

- Electrical equipment

  The individual contactors, relays, motor protection switches, fuses, and clamps are installed in the switch cabinet and are interconnected.

- Pumps and solenoid valves
- Piping material made from PVC or PP

The manufacture of the connecting pipings between the exchanger columns, and installation of valves, can only be carried out economically when certain conditions are met. A sufficient assembly height for a suitable subconstruction of T-iron girders, and a small hoist for erection and adjustment of the columns as well as the small parts for the pipings (fittings, T-pieces, bends) are available in the required nominal widths. Therefore, the factory producing the plant should have a small erecting room equipped with the afore-mentioned parts. In this shop a pre-erection can be carried out by fixing the pipings on a steel frame mounted to the columns; after completion the pipings are demounted as a unit.

All parts are brought to the erection site. The columns are mounted on a flat rigid surface, the pipe system is again fastened to the columns, the pumps are mounted on pump supports and the electrical aggregates and valves are connected with the switch unit. The required connecting pipings and electric cables are installed over pipe bridges. Subsequently, the starting-up of the plant is carried out (see flow chart).

Figure 3. Ion exchanger colums

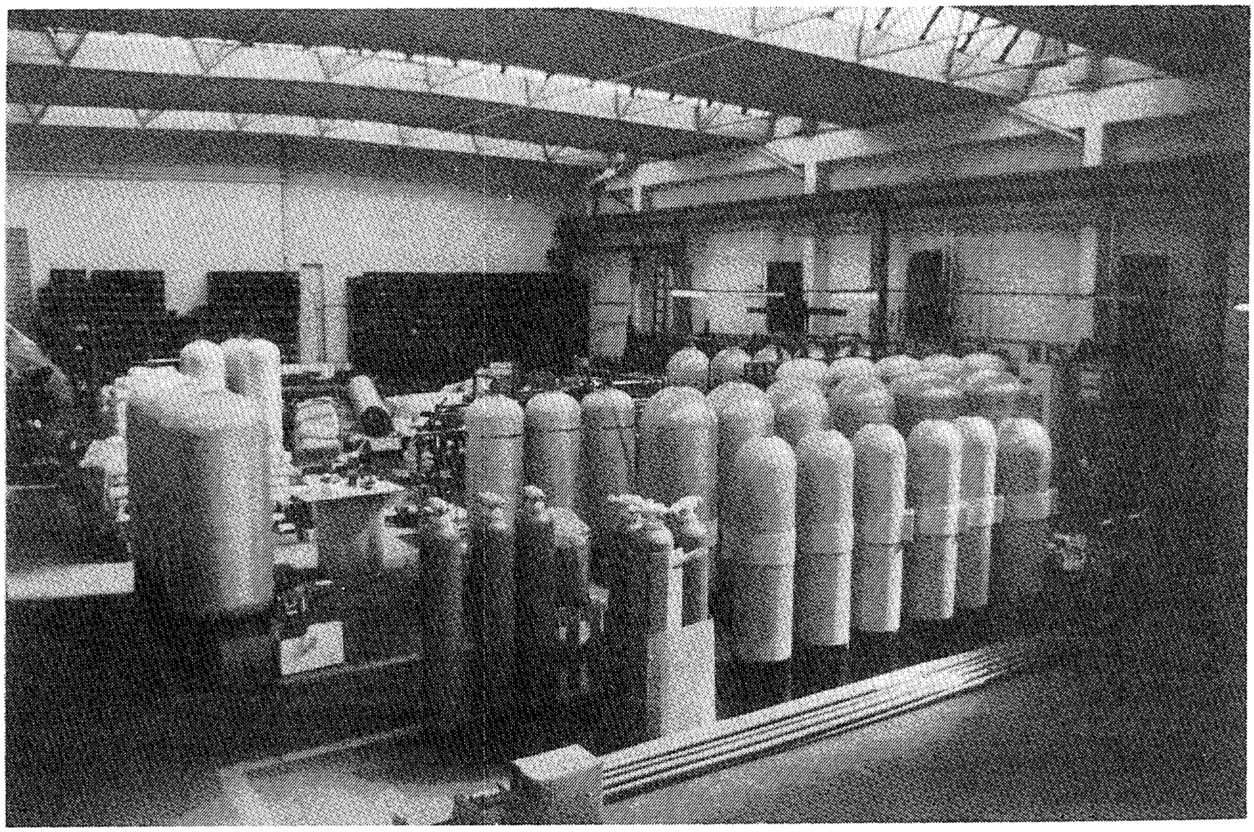
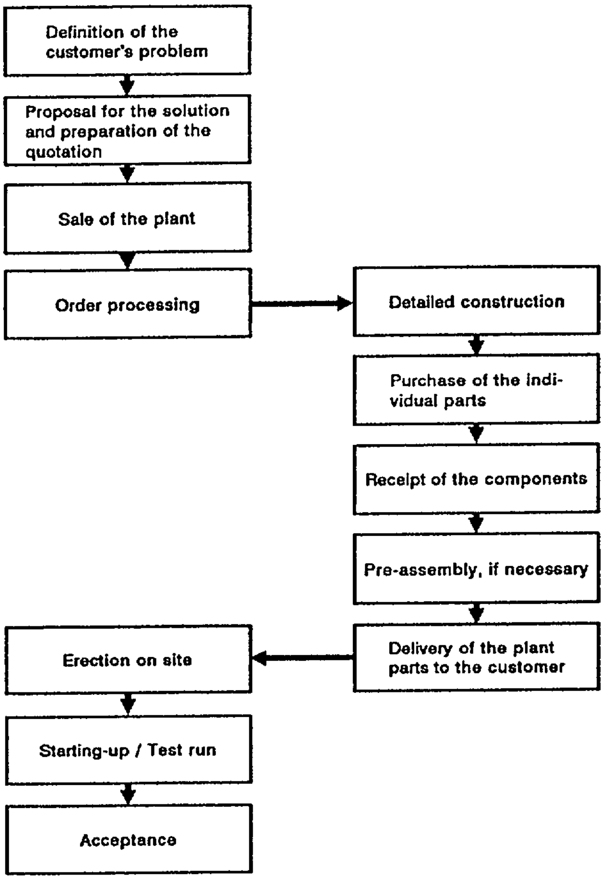


Figure 4. Flow chart



Required machinery and equipment

Description	*Pieces*
Hoist unit	1
Work bench (including necessary tools)	1
Truck	1
Maintenance truck	1
FOB-price for machinery and equipment (1991)	US$ 40,000

For the manufacture of 20 ion exchanger plants p.a.—as described above—the following overheads are necessary:

Required personnel

Management	1
Administration	1
Sales department	2
Projecting department	1
Order processing	1
Erection	4

Required area

	Square metres
Management, administration and sales department	60
Pre-assembly shop including small hoist	50

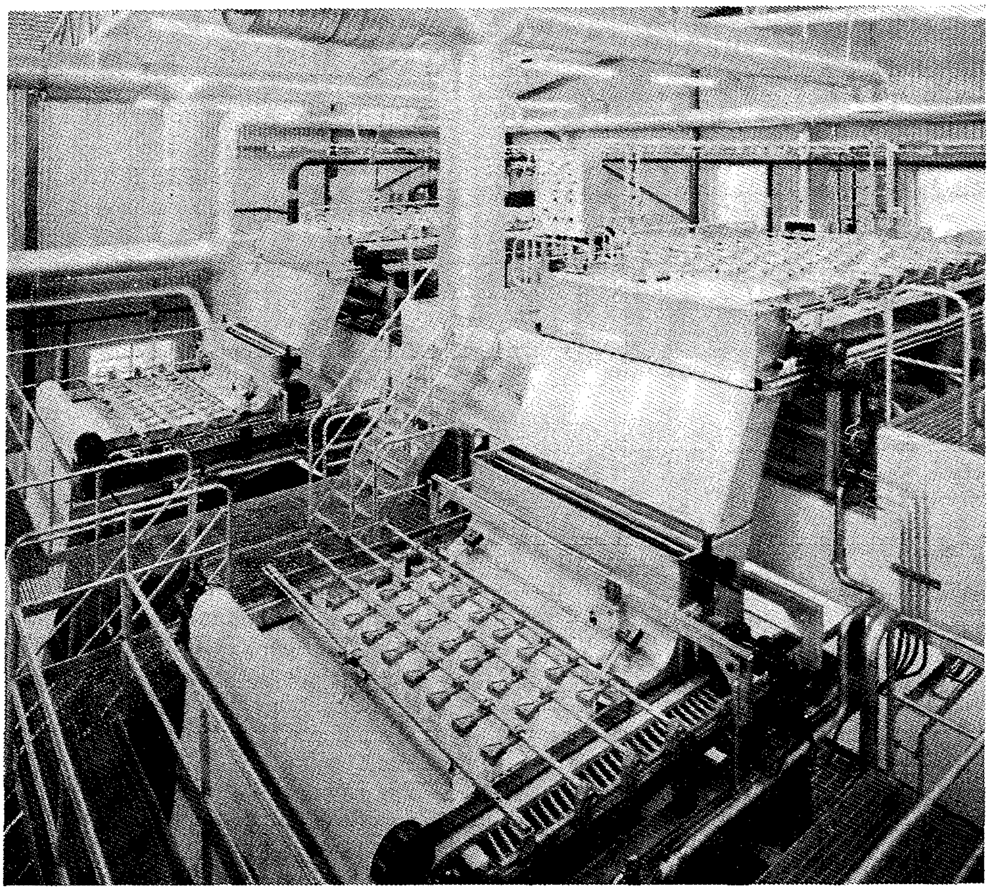
Required energy

Electric power	2 kW

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

File: Z 22
ISIC CODE 9000
October 1992

Belt filter press for draining domestic and industrial sludge from sewage treatment plants



Introduction

Sewage treatment generally means separating those harmful substances from the sewage which poison, damage or pollute natural waters. This procedure inevitably produces large amounts of sludge with a high water content, which in this form cannot be utilized or deposited economically. The general aim of sludge treatment is to process the residues from sewage treatment for their final disposal/use.

Different methods and phases of sludge treatment are applied. The material to be deposited has to meet several physico-chemical and hygienic requirements.

The sludge undergoes the following main combination of processes:

Thickening

Reducing the volume by force of gravity

Stabilization

Aerobic, anaerobic, thermal composting, combustion

Conditioning

Adding metallic salts, lime, polyelectrolytes, fine-grained substances as filter aids and supporting structure

Drainage

Natural processes: sludge drying beds and lagoons, drainage through percolation and evaporation

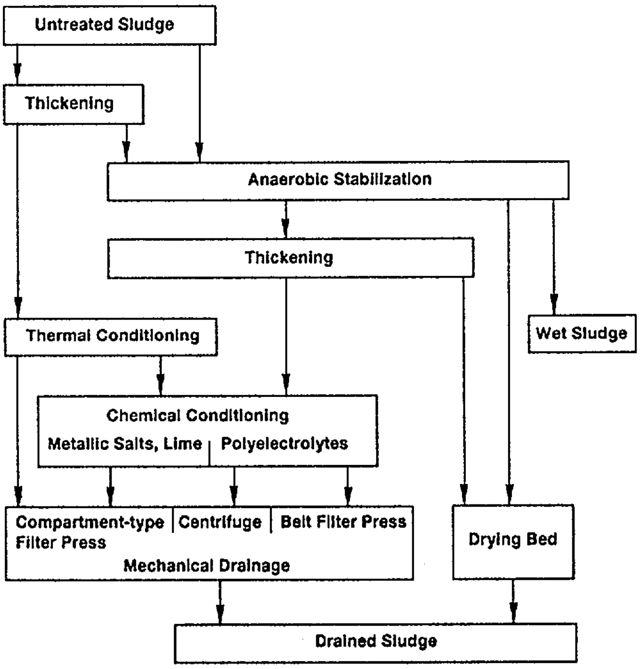
Mechanical processes: centrifuges, compartment-type filter presses, belt filter presses etc.

Decontamination, thermal treatment. These are additional stages of treatment for agricultural sewage use.

As it becomes increasingly difficult to deposit wet sludges in industrial centres, incineration, burning and drying will gain in importance. Due to the large surface area needed and for hygienic reasons natural draining methods will play a negligible role in the future.

The following flow chart shows tried and tested combinations of methods for draining domestic sludges.

Figure 1. Reliable combinations of methods for wet and drained sludges



Possible application of belt filter presses

The selection of the drainage method usually depends on the characteristics of the sludge to be treated. For sludge drainage, however, the belt filter press is superior to centrifuges or compartment-type filter presses for the following reasons:

Very good drainage performance with low energy consumption;

Continuous, fully automatic operation over 24 hours;

Only small amounts of conditioning aids are needed;

No inert materials, such as lime or stone dust;

Low initial outlay;

Very low staffing requirements;

High operational safety.

The belt filter press is primarily used for draining domestic and industrial sludges. Belt filter presses can also be used in the separation/suspension method. The applications are listed here for the sake of completeness, but will not be dealt with in further detail:

Primary sector

Dehydration of herbs for the pharmaceutical industry;

Paper industry

Material processing;

Food industry

Juice extraction in viticulture or for the production of apple-juice, or for pressing tropical fruits etc.;

Mining industry

Very fine coal sludges;

Other areas

Processing of residues, treatment of waters, desludging lakes and rivers, soil treatment.

Description of the product

Belt filter presses are automatic sludge draining machines. They effect a preliminary drainage of the conditioned sludge input by force of gravity and then its maximal mechanical drainage via a gradual pressure build-up.

A refined version of the belt filter press is the wedge filter press. Especially adapted to the requirements of sewage treatment, it has a high shearing resistance of the filter cake for deposition. A distinctive feature of wedge filter presses is that the sludge is not only horizontally drained between two revolving sieve belts but that, prior to rolling, it is also drained considerably in a vertical wedge arrangement, which almost fully excludes the formation of water bubbles.

The sieve belts, generally made of a high quality monofilament synthetic fabric, are conveyed between the press-rolls at a width of up to 2700 mm.

Special attention must be paid to the support structure and the alignment of the rolls in order to guarantee a smooth running of the sieve belt and thus a long lifespan. The bearings should have only a slight friction so that even under high pressure their energy requirement is low. The frame should be constructed in line with the latest findings in heavy engineering, so that forces generated during the pressing cycle can be absorbed without any problems.

The entire press can be hygienically capped and the outgoing air purified by means of a biofilter, so that no unpleasant smells enter the surrounding atmosphere.

The wedge filter press is available in six different sizes.

Figure 2. Specifications of wedge filter press, V-version

Size of Wedge Filter Press	Width of Sieve Belts (mm)	Through-put* (m^3/h)	Dimensions (mm approx.) Length	Width	Height	Weight (kg)
05	500	5	5000	1300	2700	2900
08	800	5-10	5000	1600	2700	3600
1	1200	10-15	5000	2000	2700	4300
2	1700	15-25	5100	2800	3000	7000
3	2200	20-35	5500	3400	3300	9000
4	2700	30-50	5700	4000	3300	14000

* Typical sludge treatment data.

The larger machine has a sludge throughput of about 30-50m²/h. By connecting several machines in parallel the performance can be increased accordingly. The throughput or the outcome of the pressing process depends mainly on the organic or anorganic components of the treated sludge.

With automatic control, the consumption of polyelectrolytes amounts to approx 1.8-2.5 g/kg of dry substance (in the case of sludge treatment).

Mode of operation

In wedge filter presses the draining process is conducted in four consecutive areas.

- In the supply line of the wedge filter press the sludge to be drained undergoes maximum coagulation by means of polyelectrolytes (organic coagulants) and subsequently reaches the horizontal initial drainage line. The filtrate which has not been separated during the conditioning process is then discharged.

  Measurements show that domestic sludge doubles its concentration at the end of this line. In other words, the original volume has been halved.

Figure 3. Sludge drainage with belt filter presses

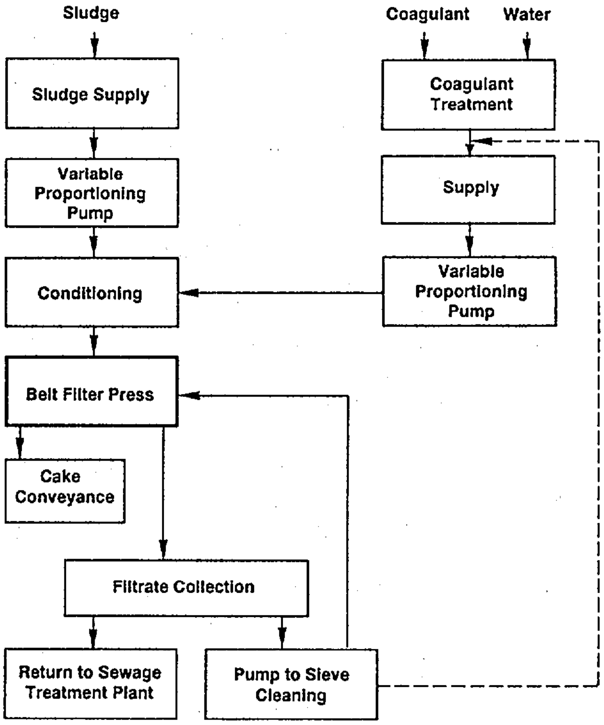
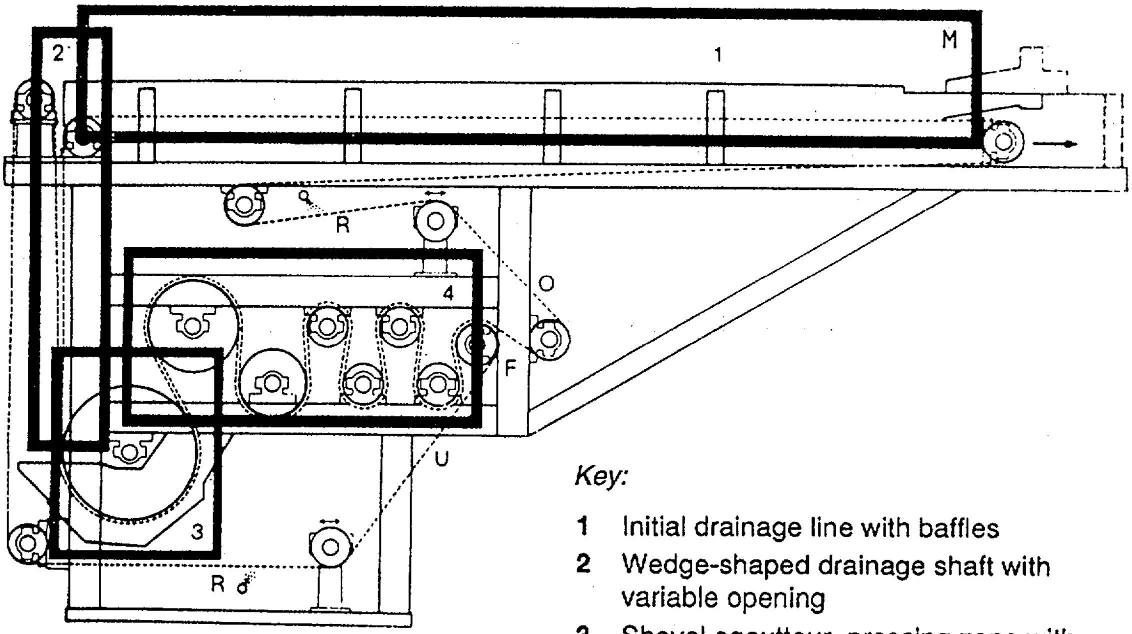


Figure 4. Press with four drainage areas



Extended version with
even better performance

Key:

1	Initial drainage line with baffles
2	Wedge-shaped drainage shaft with variable opening
3	Shovel egoutteur, pressing zone with drainage to the inside and to the outside
4	Press rolls with churning effect
M	Sludge intake
O	Upper sieve
U	Lower sieve
R	Sieve cleaning station
F	Filter cake discharge
↑	Sieve tension
↔	Sieve control

- After preliminary drainage the sludge, now located between two sieve belts, reaches a vertical, wedge-shaped shaft with an adjustable opening. (The wedge filter press is the only belt filter press equipped with this useful device.) The drainage is carried out in exactly the same way as for the preliminary drainage, i.e. by force of gravity combined with a slight pressure.
- The sludge now passes around the patented shovel egoutteur. In this first pressing, drainage fluid flows directly to the outside and also to the inside through the perforated roller casing of the egoutteur. When the shovel egoutteur rotates the inner bailers take in the water and discharge it from the centre of the egoutteur to both sides of the drainage zone.
- Press-rolls with decreasing diameters then convey the sludge cake in S-shaped curves in between the sieve belts, where it is further drained. The resulting shearing effect releases the entrapped liquid, so that the final dry content of the sludge is gradually increased. After discharging the filter cake, both sieve belts pass through a cleaning station, where they are automatically and continuously spray-cleaned with water from flat jet nozzles. No fresh water is required. The filter cake can then be removed by any conveying system.

Preconditions for use

As a general rule the sludge should be free of coarse impurities, which could clog or damage the pumps.

When feeding the press with the sludge the variations of volume and concentration should be kept low, as they influence the outcome of the pressing process.

Suitable polyelectrolytes should be chosen and employed.

The concentration of the sludge should range between 4-8% of dry substance.

Low concentrations of under 0.5% of dry substance require additional initial draining.

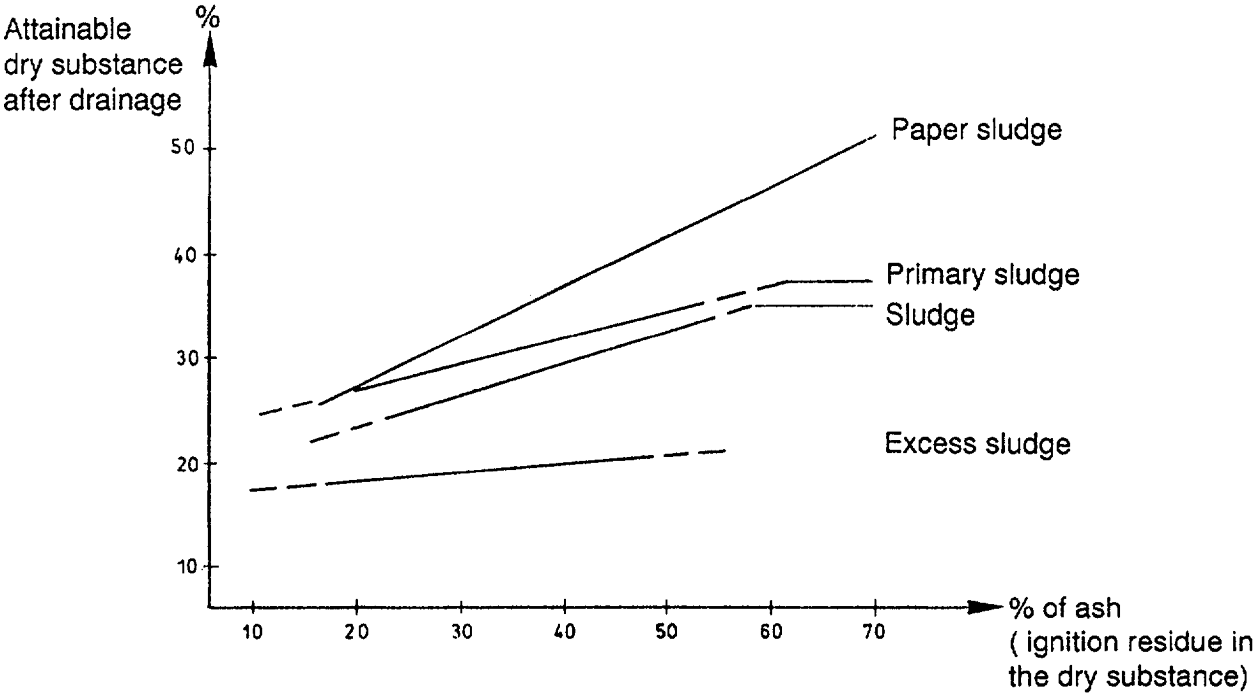
The polyelectrolytes solution should have a concentration of 0.1%.

Manufacture

Material requirements for the production of a wedge filter press (standard for pH-values between 6.5 and 8)

Rollers	Plastic-coated steel (Rilsan)
Drive and sieve control rolls	Rubberized steel
Shovel egoutteur	Hot-dip galvanized steel
Collecting tanks	Fibreglass-reinforced plastic
Inner tubing	PVC
Sieve belts	Polyester fabric
Sieve benches	High-quality steel with synthetic strips
Mixing device	Cast aluminium
Sludge feed jet	Coated aluminium
Baffles	Grey cast iron basic body, galvanized and with plastic wedge, galvanized cross shaft
Screws and nuts	Galvanized
Piston rods	High-quality stainless steel
Control piston rods	Chromium-plated steel
Bearings	Roller bearings with labyrinth grease packing
Gangway	Aluminium
Cast and prefabricated parts, such as electromotors etc.	Painted
Hydraulics	Tubes: rubber fittings: chromium-plated steel

Figure 5. Final dry content as a function of the ignition residue



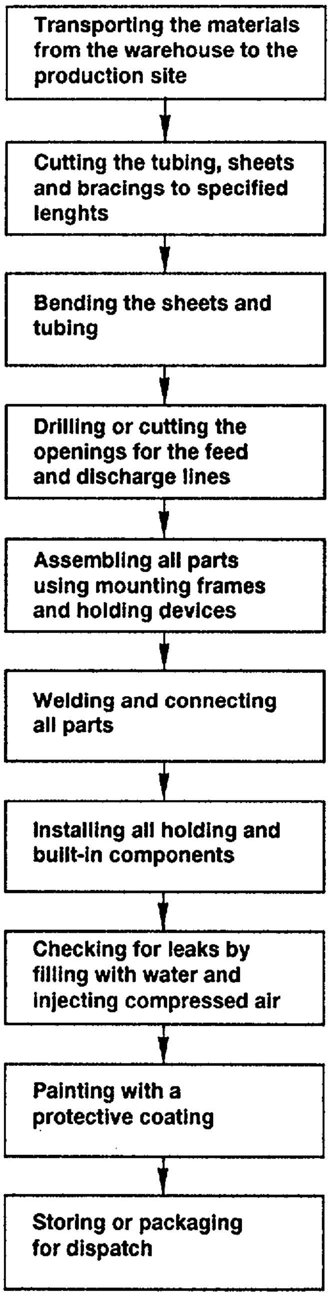
The above listed parts are either self-produced or purchased from parts suppliers. The supplier should be an engineering firm with theoretical and practical know-how in the field of mechanical engineering.

For the manufacture of the above-listed parts the following machinery and equipment is needed:

Lathes, milling machines, steel planing benches, cutting tools, automatic hacksaws, cut-off saws, box column drilling machines, cutting and folding benches, plate bending machines, welding machines, standard production engineering tools.

The following chart shows the main stages of production. The technical qualification required of a production plant is equivalent to that of a plant construction engineer. This includes knowledge in the fields of process and analytical engineering, metal working and welding engineering.

Figure 6. Flow chart



Examples of production plants of different scales

The following plants and equipment are needed for the respective output per year.

Required machinery and equipment

Description	*Number of Belt Filter Presses* 10	25	50
Cutting and folding bench	1	1	2
Lathe	1	2	3
Guillotine shears	1	1	2
Milling machine	1	1	2
Folding press	1	1	1
Saw, cutting-off saw	1	2	3
Plate bending machine	1	1	1
Form bending machine	1	1	2
Hoisting unit	1	1	3
Welding unit	2	3	3
Cutting torch	2	3	3
Drilling machine	2	4	4
Grinding tools	2	4	4
Spray gun	2	4	6
Extraction and cleaning plants	–	–	1
Mounting frames for painting	1	3	5
Standard tools	1	2	4
FOB-prices for machinery and equipment in 1000 US$	208	210	250

Required manpower

Number of Belt Filter Presses	*10*	*25*	*50*
Managerial and administrative staff	3	4	5
Technical manager	1	1	2
Engineers	1	2	5
Skilled workers	3	5	9
Semi-skilled workers	3	6	9
Personnel for quality control and maintenance	–	–	1
Chemicals expert	–	–	1
	11	18	32

Required area

	Number of Belt Filter Presses 10	25	50
Administration (m²)	50	50	100
Production (m²)	450	650	800
Paint shop (m²)	200	200	200
Storage (m²)	400	600	800
	1 100	1 500	1 900

Required energy

	Number of Belt Filter Presses 10	25	50
Electric power (kW)	100	150	220

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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October 1992

How to Start Manufacturing Industries

Measurement of flow volume of waste water

Introduction

For an effective waste water treatment it is necessary to measure flow volumes. This is especially important for the dimensioning, operation and control of public or industrial waste water installations.

The measurement of flow volumes may be necessary at different points:

At communal or industrial waste water installations;

At discharge points into the public sewage system or rivers.

Measuring at the latter discharge points is mainly of importance for fixing waste water charges, whilst measuring at installations serves to control the following:

Retaining basins;

Oxygen supply;

Recirculation sludge;

Dosing of chemicals.

The measurement of flow volumes requires strictly maintained, unchanging measuring conditions, which, in the form of specially designed measuring sections or constructional parts, are the main element of the measuring process.

The measuring of waste water volumes takes place under aggravated conditions due to:

Backwash effects;

Large fluctuations in flow volumes, from small discharges at night and during dry weather, to large discharges by day during rainy weather in a mixed system;

Interference effects as a consequence of the often changing contents of the waste water, which can lead to fouling, sedimentation and clogging;

Large fluctuations in temperature, especially in the case of industrial waste water.

Measuring methods

The determination of flow volumes takes place by indirect processes, where one or several measurements are used, which are directly connected to the flow volume.

Several measuring methods can be distinguished:

- Measurement of flow volume of waste water in open channels and gravity conduits with contracted cross-sections;
  Venturi flumes
  Measuring weirs
  Without contracted cross-sections;
- Measurement of the water level in one or two cross-sections
  Measurement of the discharge speed (different measuring methods)
  Volumetrical measuring methods
  Dilution method
- Measurement of flow volume of waste water in pressure pipes.

In addition there are continuous or intermittent measurements.

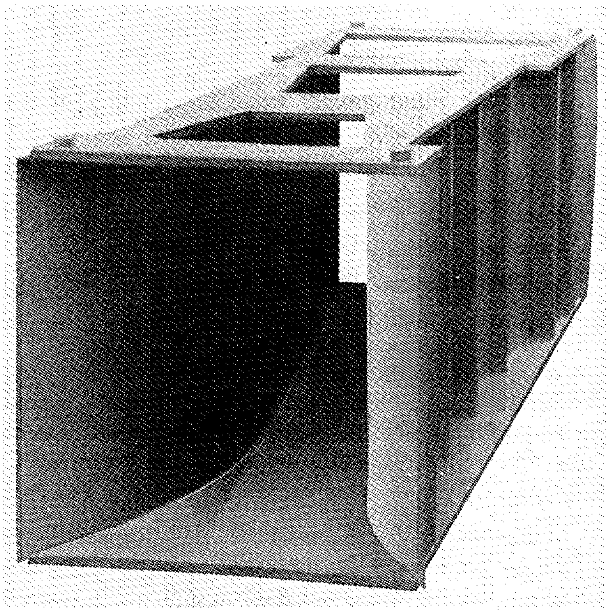
Continuous measurement of flow volumes in open channels is very widespread in waste water treatment. In the case of open channels with contracted cross-sections there is a direct relationship between the flow-through and the water level as a measuring factor because of standardized measuring conditions.

In the case of open channels, without contracted cross-sections, different physical factors are used to determine indirectly the flow-through, as, for example, water level, average velocity, cross-section of flow and time. Because of the more complex measuring process, it is preferred to use, as far as possible, the relatively simple method of measuring the water level.

Basically, two different measuring devices can be distinguished:

Measuring weirs

Venturi flumes.



Measuring weirs are thin-walled plates which are built across the open channels in a vertical position in relation to the flow direction, and which have—according to task—differently shaped openings (triangular weirs, rectangular weirs, trapezoidal weirs).

Venturi flumes are channel sections with constrictions placed symmetrically on both sides of the cross-section and with streamlined warpages on the afflux side.

Both processes have characteristic features, which are compared in the following table:

Characteristic features	
Venturi flumes	*Measuring weirs*
Slight loss in energy height Continuous channel floor Suitable for the continuous measuring of waste water with solid content (little maintenance) Designs for large flow-throughs also possible Limited accuracy in the lower section of the measuring range Relatively large floor space required	Small amount of constructional requirements and little floor space required Attainable accuracy very high, if properly constructed, installed and maintained Higher backwash compared to Venturi flumes Solids can sediment in front of the weir and on the overflow edges (increased maintenance)

To measure the water level different devices can be used. The devices most commonly used are the following.

Float gauge: mechanical transmission (lever, tackle) to indicator gauge or measurement transmitter.

Features:

Parts, which move mechanically, can become stiff through environmental influences;

Measuring faults through material deposits (e.g. grease, foliage);

Possible disturbance of the flow profile by the float gauge;

Simple examination.

Automatic point gauge: periodic scanning of the water-level; discontinuous signal.

Features:

Mechanically moved parts;

Very high measuring accuracy attainable;

No disturbance of the flow profile;

Sensitive to material deposits.

Air immersion tube: air is introduced into the water by means of an immersion tube. Assuming a constant density of the water, the pressure created in the immersion tube is a direct measurement of the water level.

Features:

Maintenance of the immersion tube, especially of the air outlet opening, necessary;

Little disturbance of the flow profile;

Measuring accuracy dependent on the quality of the pressure meter.

Pressure meter: hydrostatic pressure measurement, whereby meter can be built in flush with the channel floor or the channel wall.

Features:

No disturbance of the flow profile;

Relatively susceptible to mechanical damage;

High sensitivity;

Temperature dependent.

Capacity water-level gauge: two condenser areas, one with a plastic coating acting as dielectric, the other acting as earth electrode connected with the waste water as conductive fluid. The capacity of the condenser changes as the water level changes.

Features:

No movable parts;

Little or no disturbance of the flow profile;

Possible measuring faults through material deposits or clinging humidity;

Not linear in the lower section of the measuring range.

Echo sounder: a sound emitter, installed above the water-level, emits a short impulse, which is reflected by the surface of the water and received by a receiver. The time between emission and reception is a measure of the distance between emitter and receiver and thus also of the water level.

Features:

Dependency of sound velocity on temperature and humidity;

Measuring faults through foam possible, if ultrasound is used;

No disturbance of the flow profile;

Minimum distance between sensor head and highest water-level necessary.

The Venturi flume: product description and functioning

The Venturi flume is a defined flow section with constrictions placed symmetrically on both sides of the cross-section of the channel, thus achieving by force special rheological properties (flow transition). The constrictions should be situated in such a way, that over the whole measuring range a backwash-free flow-through is possible. This is then the situation, when the upstream water level is not influenced by the downstream water.

By calibrating the measuring section, the cross-section geometry and the parameters specific to the channel are determined. If these values are known, then the flow volume can be ascertained only by measuring the upstream water level.

According to the measuring range desired, the design of the Venturi flume can be varied by altering the constriction ratio and the form of the constriction. The measurement of the upstream water level can be adjusted to any single case by selecting the appropriate measuring unit.

Venturi flumes need a considerable constructional effort as well as a sufficient length of afflux before the contracted cross-section is reached.

The Venturi flume cannot be used:

Where there is insufficient space;

Where backwash effects from downstream water are to be expected;

Where variations in flow-through are too large (ratio of smallest to largest flow-through ≥ 0.1);

Where the volume of flow is too small (minimum water depth ≥ 3cm);

Where there is a danger of sedimentation in the afflux area (rate of flow too low);

Where a streaming afflux cannot be achieved in the upstream water;

Where there is a danger of clogging in the constriction area (bulky material).

Dimensioning

The cross-section of the constriction determines the important hydraulic characteristics of the measuring arrangement. Therefore the effect of the constriction upstream of the measuring arrangement has to be considered. This effect means the development of a backwash area with reduced flow velocity and, at the same time, the elevation of the water level. The length of the elevation increases with the size of the backwash.

To determine the volume of flow the depth of the upstream water has to be measured. The accuracy in determining the volume of flow is influenced by the form of the cross-section.

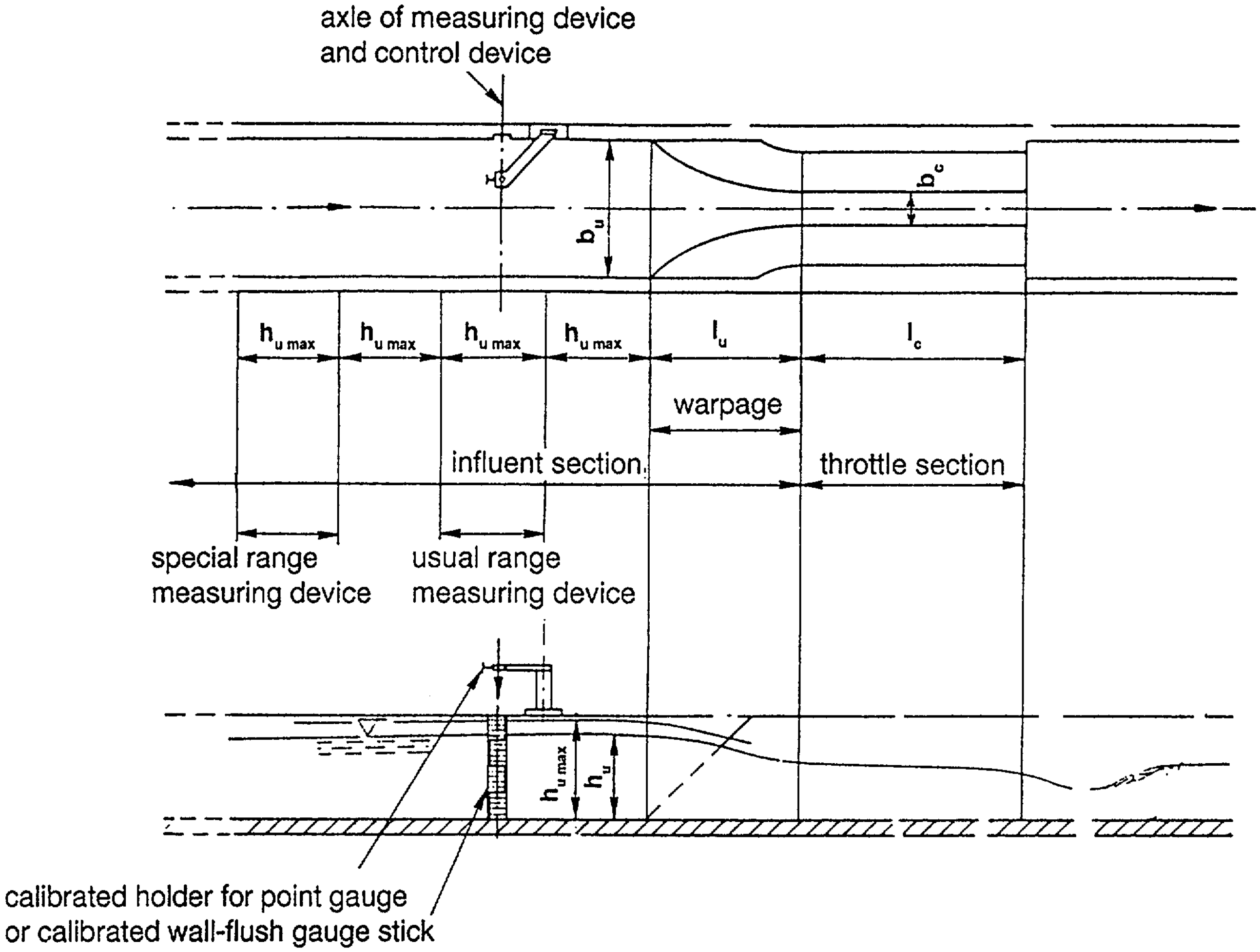
When choosing the *form of the cross-section* the accuracy requirements within the measuring range have to be considered. For example, strongly changing effluents with dominant small values may require a higher accuracy for effluents in the lower measuring range than for maximum efflux. A trapezoidal cross-section with increasing width to the top will fulfil this requirement better than a rectangular form.

The *constriction ratio,* i.e. the ratio of the cross-section area in the constriction to the cross-section area outside the constriction, is the next important factor.

The maximum upstream water height h_{umax} will be used to determine the maximum height over the channel floor. In the case of a rectangular cross-section the constriction ratio is given by the width ratio b_c/b_u and often lies between 0.3 and 0.6.

A reduction in the constriction ratio leads to a diminished afflux velocity, thereby increasing the danger of sedimentation, which in turn can only be prevented by increased maintenance. The constriction

Figure 1. Principal outline of a venturi flume



ratio has to be chosen in such a way, that the maximum efflux can be discharged in the open channel.

The incline of the *influent section* has to guarantee streaming afflux also in the case of the maximum possible flow-through. The necessary flow transition (turbulent/laminar) has to occur at a distance of $\geq 20\ b_u$ before the start of the warpage. At the point $10\ b_u$ before the warpage the following conditions must be maintained:

Constant incline;

Straight course of the axle of the open channel and measuring section;

Constant cross-section of the channel;

No inflows or outflows;

No protrusions or dents in the channel floor or channel walls.

The *warpage* has to be streamlined and should pass over tangentially into the throttle section. A favourable measurement for the length of the warpage is $1.5 \cdot (b_u\text{-}b_c)$.

The length of the *throttle section* should be at least twice the maximum upstream water depth. The incline of the channel floor in the warpage and throttle sections should be zero (or at least not greater than that in the influent section).

For the *transition into the downstream water,* i.e. for the widening of the narrowest part of the constriction to the width of the downstream water channel, a special warpage is not necessary.

The water level is measured by a *measuring device* at a distance of 1 to 2 h_{umax} before the start of the warpage. If flow-throughs near to the maximum flow-through are to be determined as precisely as possible, then this distance can be enlarged to 3-4 h_{umax}.

The relationship between flow volume Q and height of the upstream water level h_u is in the case of rectangular cross-sections in the influent and warpage sections given by the formula:

$$Q = \mu \cdot c \cdot b_c \cdot \sqrt{g} \cdot h_u^{3/2}\ [\mathrm{m^3/s}]$$

μ = flow parameter (dependent on width ratio b_c/b_u; in the range 0.96-0.99
c = factor to consider the width ratio b_c/b_u; in the range 0.55 to 0.6
b_c/b_u = 0.4 to 0.7
b_u = width of upstream water channel
b_c = width of the constriction
h_u = height of the upstream water level.

For further details see DIN 19 559 part 1 and 2 of July 1983 (German standard).

Description of the production process

Venturi flumes can be produced from materials such as concrete, stainless steel, or plastics.

Concrete is less suitable, as it is very difficult to achieve the required measurements. Furthermore it has to be coated to protect it against abrasion and chemicals.

Stainless steel and special plastics do not have these disadvantages. Nowadays, for various reasons (simple handling, light weight, high power of resistance) plastics are the most used material, especially glass-fibre reinforced plastics. Their advantages as against other plastics (e.g. PVC) are:

High elasticity;

High resistance to almost all chemicals (expect caustic soda at a higher temperature and hydrofluoric acid);

Large temperature range (–80 °C to +145 °C);

Simple handling.

Glass-fibre reinforced plastics can be easily manufactured in different forms without the help of machinery. In the following a simple manual process is described.

The first step is to manufacture the form needed, for which glass-fibre reinforced plastics can also be used. After hardening this form is mounted on a frame, which can also be self-produced, so that the following parts can be manufactured under easy working conditions.

During the second step the form is coated with a separating layer consisting of two coats: a coat of silicon or wax and a coat of water soluble polyvinyl alcohol.

The next step is the application of a primar layer, which can be done by brush or roller. This layer consists of a coloured, unsaturated polyester resin, whereby the colouring can be adjusted according to the customer's wishes.

On top of the primary layer the first glass-fibre mat is laid and the resin mixture applied with brush or lambskin-roller. This process, mat laying and application of resin mixture, is repeated over and over again, until the desired thickness of the product is reached.

The applied resin mixture consists of polyester resin and chemical additives according to requirements. Such additives are hardeners and catalyzers, or liquid paraffin, which is used for the last coat, in order to seal the product against air and to remove the stickiness from the product. As for the resins different types are used depending on the chemical requirements or the construction of the layers and the desired stability. Thus, a chemical-resistant type of resin is used for the first layers, another type, selected according to stability considerations, is used for the following layers.

After hardening the new part is separated from the form by injecting water into the separating layer. The product is then brought into its final shape by use of a disc grinder, angle grinder or similar tools.

As far as is necessary the product can be worked on with metalloid cutting tools.

A manual production, as described, is only sensible in the case of a limited output and favourable wage relations. The next stage, leading to a considerable simplification and acceleration of the work, is the use of a high-pressure airless machine. Instead of glass-fibre mats glass-fibre threads are used, which are cut into small pieces and thrown onto the part by a rotating chopping head combined with a spray-pistol. Then the respective resin mixture is sprayed on and worked to an impregnated layer by a disc-roller. After hardening, whereby the hardening time is determined by the added hardener, the procedure is repeated, until the necessary thickness of the wall is reached. The high-pressure airless machine runs with approx. 10 bar and a throughput of 1200 l/min.

Example of a production plant

The production of glass-fibre parts can be started on a very small scale with no machinery and little manpower. The few tools needed can be bought locally.

Increasing production numbers or taking up additional production lines can easily be met by increasing the work-force and the number of tools, on condition that the area was large enough at the beginning to allow for future production increases.

A further step would be the introduction of a high-pressure airless machine in order to simplify and speed up the production process. For quicker handling and heavier lifting a small forklift truck would be helpful.

The following example given comprises this latter type of production with a daily output of 4 to 5 medium-sized parts.

Required machinery and equipment

Description	*Pieces*
Different moulds	
High-pressure airless machine	1
Work-bench including tools (hand drill, disc grinder, angle grinder, fret-saws, chisels, hammer, lambskin-roller, disc-roller, brush etc.)	2
Forklift truck 1½ t	1
FOB-price for machinery and equipment (1991) Approx. US$	100,000

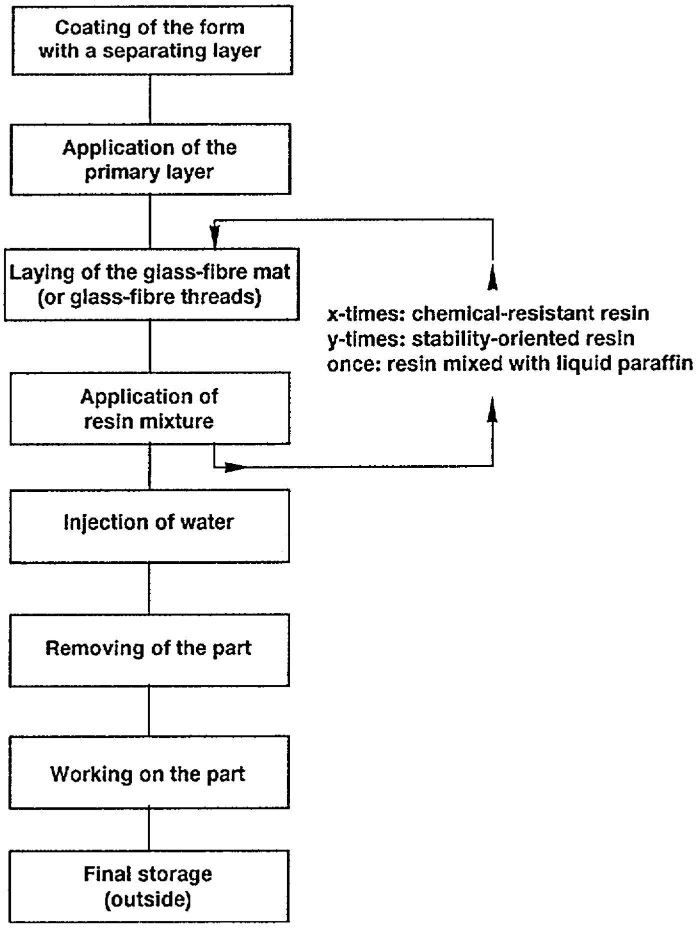
Required manpower

Workers (semi-skilled)	3
Manager	1

Required area

	Square metres
Production	100
Storage (covered)	50
Storage (outdoor, finished parts and moulds)	300
Facilities and administration	50
Open area	500

Figure 2. Flow chart



Required power and utilities

Electric Power	20 kW
Water	
Compressed air	10 atm.

Required inputs

Glass-fibre mats
Unsaturated polyester resins
Silicon or wax mixtures
Water-soluble polyvinyl alcohol
Colouring material
Chemicals (solvents, hardeners, catalyzers, liquid paraffin)

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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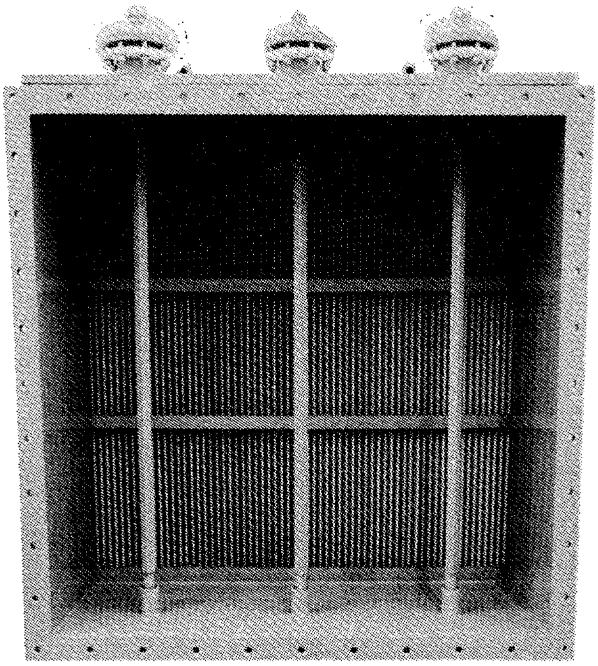
May 1993

How to Start Manufacturing Industries

Droplet separators



Introduction

Droplet separators are widely used in dust collection as well as in exhaust air, off-gas and flue gas cleaning. Their main task is to prevent droplets, laden with dust or harmful substances, getting into the atmosphere via exhaust air outlets, chimneys or stacks. They are especially to be found behind scrubbers for dust collection, behind absorbers for the removal of harmful gaseous components and in different industrial processes. Droplet separators are either integrated into the scrubber or absorber or are connected downstream.

Because droplet sizes generally range from one to several hundred micrometers, commercial separators utilize inertial forces to separate droplets from the gas stream. Several principles are employed, such as: stacks of plates; centrifugal devices; and layers of wire mesh or fabric.

Droplet separators have attained even greater importance since environmental regulations have required a drastic reduction in the final content of harmful substances behind gas scrubbers. This fact has made it necessary to use efficient devices which separate even the smallest droplets of < 10 m with possibly only minimal pressure loss. For this, separation systems are needed which can handle high afflux velocities at minimal constructional depth.

Droplet separators are used mainly in the following industrial areas:

Scrubbing;
Flue gas desulphurization;
Air-conditioning and exhaust air installations;
Off-shore installations;
Cooling towers and evaporative condensers;
Mass transfer processes;
As a part of other environmental technologies;
Chemical industry;
Pulp industry;
Nuclear power plants.

Description of the separation principle

Lamellar separators are especially suitable to meet the demands for high afflux velocities at little constructional depth. In addition to this they are of simple construction and have a low pressure drop, which explains the common use of this device. Three factors determine the degree of separation:

The primary separation;
The secondary separation;
The positioning of the separator in the air or gas stream (horizontal, vertical or inclined afflux).

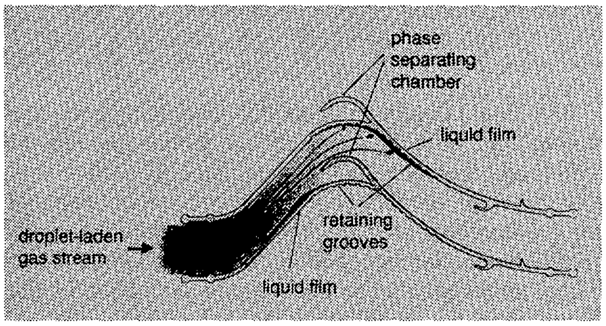
The separator consists of bent and profiled lamellas forming parallel channels with multiple deflections and liquid retaining grooves.

Primary separation

The droplet-laden gas stream undergoes many changes of direction in the channel (see figure 1). By virtue of their inertia, the flight path of the droplets differs from that of the gas stream, thus causing the droplets to collide with the wall to create a film which is removed in the retaining grooves. The geometry of the direction changes so that the gas and liquid parameters, as well as the size and position of the droplets, decide if a droplet passes by deflection or collides with the wall.

Those droplets touching the walls under given conditions and forming there a liquid film are called cri-

Figure 1. Droplet separation process



tical droplets. Droplets with a diameter greater than that of the critical droplets are completely separated. Droplets with a smaller diameter are separated to a lesser degree. This part can be considered for the evaluation of the separating capacity of the system.

Secondary separation

The form and profiling of the separating lamellas are responsible for the liquid film, forming on the walls because of primary separation, being totally removed from the gas stream. For this purpose specially formed phase separating chambers are built onto the lamellas.

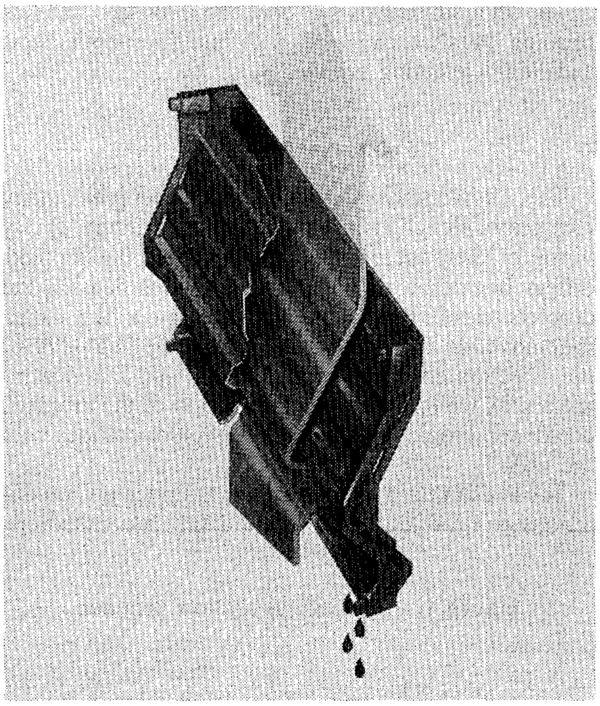
If separating systems are optimized for minimal pressure loss, retaining grooves are used instead of phase separating chambers.

Horizontal, vertical or inclined afflux

The choice of afflux direction is given by the technical process and the type of construction. Separators with vertical afflux have different constructional characteristics for the secondary separation than those with horizontal afflux.

In the case of a vertical afflux (see figure 2) the separating lamella and especially the phase separating chambers or retaining grooves lie horizontally or have a slight incline to the horizontal axle.

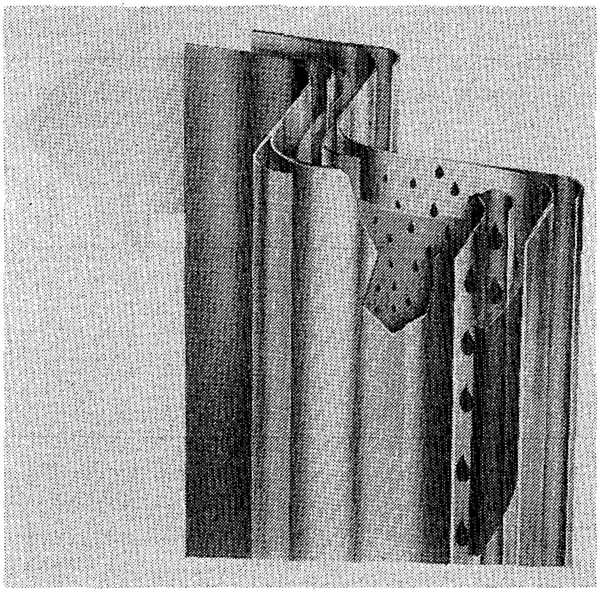
Figure 2. Vertical afflux separation



The liquid has to drip off downwards against the upward gas stream. A separation profile for vertical afflux has therefore to be constructed in such a way that zones of slower air or gas flows are to be found on the lamellas, whereby more or less no mutual effects between the film and the air or gas stream arise. These zones also serve for the safe derivation of the liquid from the lamella surface.

In the case of a horizontal afflux (see figure 3) the separating lamellas and the phase separating chambers or retaining grooves are built in vertically and lie also vertical to the gas stream. The liquid runs down the profile because of its inertia; this happens in front of, in or behind the phase separating chambers or retaining grooves without making new contact with the air or gas stream.

Figure 3. Horizontal afflux separation



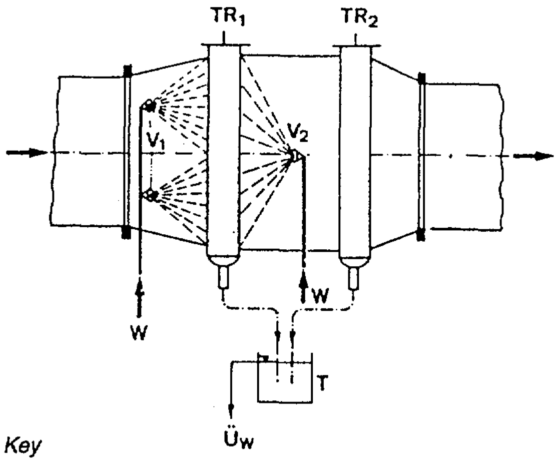
The fact that inertia assists the derivation of the liquid, leads to very effective separating systems, where—according to construction—afflux velocities of up to 10 m/s are possible.

Lamella plates can have various profiles. Typical channel widths are 20-30 mm and gas velocities can lie between 5-10 m/s.

For separators with vertical afflux the gas velocities are only 2-3 m/s.

Lamellar separators become—like all inertial collectors—more efficient as flow velocity increases. How-

Figure 4. Components of a droplet separator



Key

TR_1	Droplet separator	V_2	Full cone jet
TR_2	Secondary separator	W	Water
T	Tank	$Ü_w$	Overflow to scrubber
V_1	4 full cone jets		

ever, an upper velocity limit should not be exceeded, because otherwise the formation of secondary droplets due to impact on the liquid film becomes significant.

To prevent caking, the plates can also be irrigated; a second downstream stage is then installed to trap the droplets collected at the leading edges of the plates in the first stage. A cyclical spraying of the droplet separator is also highly effective.

Lamellar separators are limited in their separation regarding the size of the droplets. Droplets < 5 m cannot be separated in most cases. Here special aerosol separators are necessary, consisting of knitted wire packets of 50 to 100 layers of wire mesh with wire diameters of approx. 250 m. With this type of separator droplets down to 0.6 m can be separated.

If the separation of such small droplets is necessary, the lamellar separators can be combined with aerosol separators (the knitted wire packet being situated behind the lamellar separator) or, more often, aerosol agglomerators (the knitted wire packet being put in front of the lamellar separator). The latter combination has particular advantages.

The high afflux velocities of the lamellar separators allow small afflux areas, which could not be realized by an aerosol separator alone. The aerosol agglomerator picks up very small droplets at high afflux velocities and passes them on to the lamellar separator as agglomerated bigger droplets.

The agglomeration effect can be increased in special cases by the additional spraying of liquid onto the wire net packet.

Dimensioning

The dimensioning of droplet separators needs precise knowledge of the function and efficiency data of the separating systems as well as a good understanding of the individual case for use. Knowledge on droplet creation and movement in a gas stream is an additional important factor for a satisfactory functioning of a droplet separator.

The basis for dimensioning and for the design of a particular droplet separator are measured data in each individual case, concerning sizes and velocity of the droplets, sort and consistency of the liquid to be separated and the transformation of these data into design specifications.

Description of the production process

As different wash suspensions are used with different acid or leach concentrations, special materials are necessary, adapted to the individual installation. Mostly used are the following materials:

Synthetics like PP, PE, PVDF, PVC, glass fibre reinforced synthetics;

Different qualities of stainless steel;

Aluminium.

Which material is actually used, depends on different factors, such as:

Field of implementation;

Resistance to chemicals;

Temperature;

Pressure;

Weight;

Price.

The cheapest materials are plastics, starting with PP and followed by PE, PVC and PVDF (twice as expensive as PP).

Glass fibre reinforced synthetics are mainly used for frames, casings etc., stainless steel for higher temperatures (> 150° C), mostly in the chemical industry.

In the following process polypropylene (PP) is used for the lamellas as well as for the frame elements. This material is heat resistant up to 80° C. PP-granulates, ordered from a chemical firm, form the basis for the production process. These granulates are fed into a mixer, in some cases together with special additives (e.g. colouring), from where the extruder sucks out the necessary amount to produce the profiles needed. In the extruder, the granulates are heated, melted into a paste of a certain consistency, which is then continuously pressed through a shaped aperture, thereby producing the necessary profiles in an endless manner. Profile widths of up to 400 mm are generally possible without greater constructional investments. Immediately after having passed this aperture the endless profile is cooled down in a water bath and afterwards cut to length by a circular saw.

Exactly the same process applies to the production of the frame profiles, the only difference being that a heavier machine is needed. In some cases the frame profiles can be ordered from outside firms.

In the assembly department several preparatory steps are carried out:

The sawing of ordered pipe profiles (approx. 30 mm diameter) to the necessary length and the sawing of slots into these pipes at given intervals for the fixing of the lamellas;

The drilling of the necessary holes into the edges of the lamellas, which are needed in order to fix these into the pipes;

The cutting of the solid plastic rods (8 mm diameter) to length, which are needed to fix the lamellas;

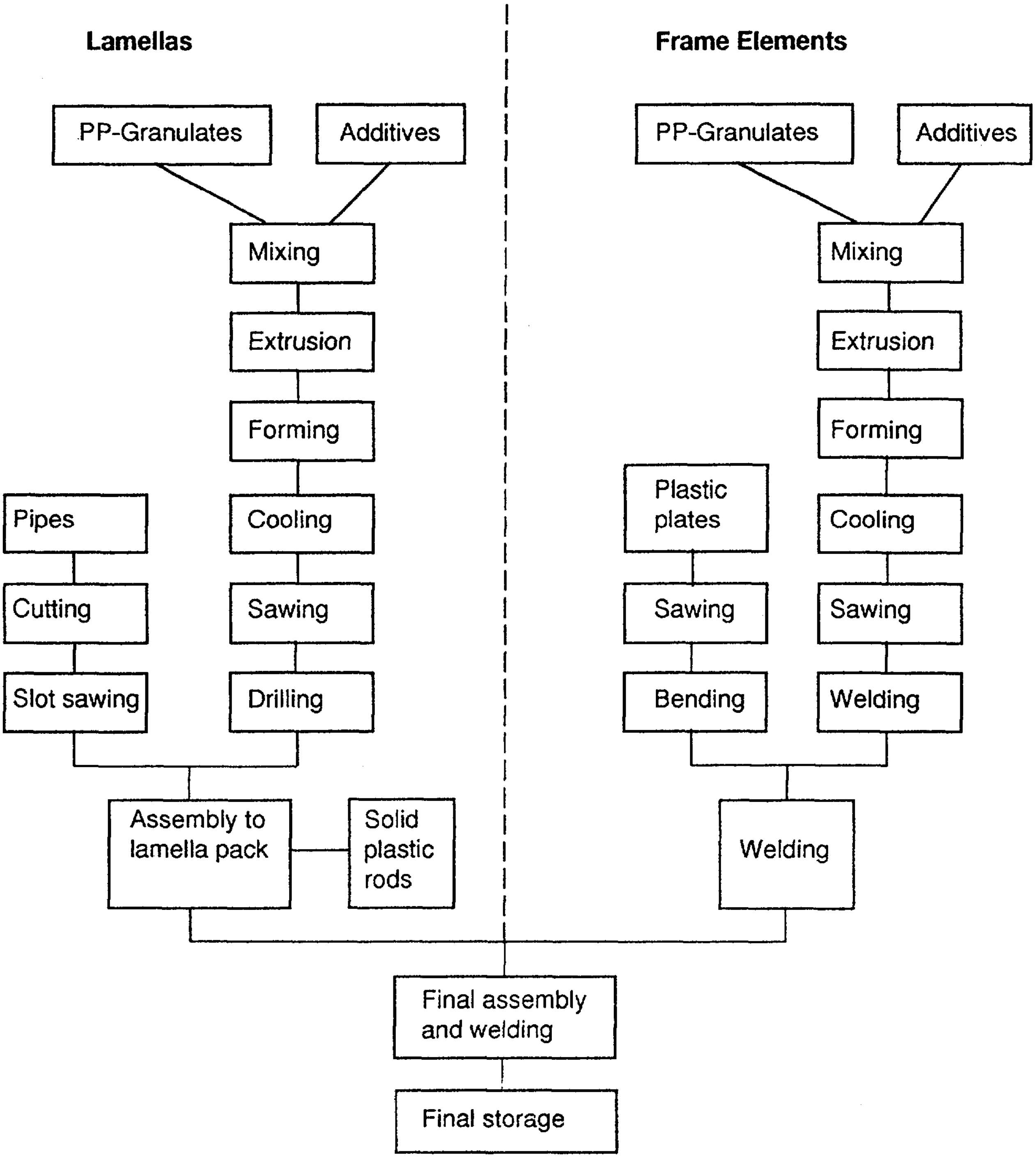
The sawing to size of the plastic plate material and the bending of this material to a given shape to form guards for the frame bottom.

In the final assembly the frame profiles are cut on a circular mitre-box saw at 45° and three sides are welded together. In this U-shaped frame two guards are welded in on either side of the frame bottom. The task of these guards is the creation of a quiet zone with little air or gas flow to allow the liquid to collect and to be drawn off into a collecting tank.

The next step is the assembly of the lamella pack by fitting the lamellas into the prepared slotted pipes. When all are in position, the prepared plastic rod is pushed through the pipe and through the prepared holes in the lamellas and fixed either end by welding.

The pack is then fed into the frame and fixed there by welding the pipes to the frame.

Figure 5. Flow chart



Example of a production plant

The firm, considered here, produces droplet separators of different sizes and different lamella profiles by using different extruder forms. Several standard profiles are in use, but the firm can also design new profiles or adapt existing profiles to special needs.

The following example is based on the assumption that 100 standard droplet separators in a standard-sized frame of 2 × 3 m are produced in one month.

Required machinery and equipment

Description	*Pieces*
Extruder (different forms)	2
Circular saw	2
Mitre-box circular saw	1
Plastic welding machine	2
Series drilling machine	1
Folding machine	1
Breaking knife	1
Workplaces (hand drilling machine, plastic welding machine)	10
Trolley crane (1 tonne)	1
Fork lift truck (2 tonne)	1
FOB-price for machinery and equipment (1992)	Approx. US$ 700,000

Required manpower

Manager	1
Engineers	3
Foremen	2
Extruder technician	1
Plastic workers	15
Semi-skilled workers	2
Purchase/sale/dispatch staff	3
Managerial and administrative staff	4

Required area

	Square metres
Production hall	2000
inside storage (semi and finished products)	700
facilities	100
Administration	150

Required energy

Electric power	150 kW

Required inputs

PP-granulates (polypropylene)
PP-semiproducts (plates, pipes, rods, angle section)
Welding wire
Flanges
Rubber profiles

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

SOLID WASTE TREATMENT

File: Z 24
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December 1993

How to Start Manufacturing Industries

Industry briefing paper:
Solid waste treatment

Introduction

Solid waste treatment and disposal is an important part of the material cycle. A long-term solid waste management has four main components: materials recovery; organic stabilization; energy recovery; and storage (land-filling) of residuals.

Solid waste can be catagorized into two main types: industrial waste—as discharge from the manufacturing industry; household waste—as refuse from households, public offices and small businesses.

In addition, some special types of solid waste are known and require special treatment: agricultural waste; hospital waste; and sewage treatment waste.

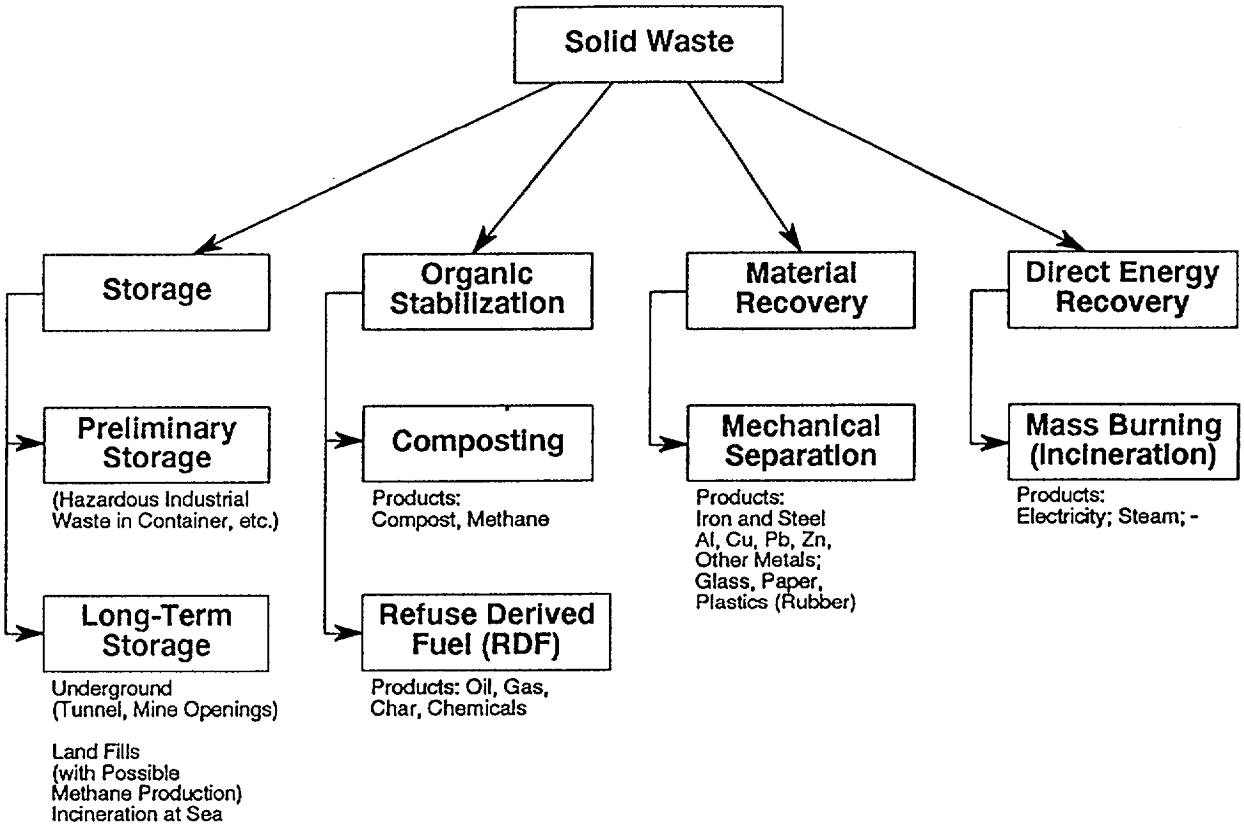
This paper focuses on technologies for the treatment of industrial waste. The treatment aims to recover materials or to stabilize organic components. Materials recovery is generally practiced in two ways: source separation which requires the manufacturer to separate certain materials for recycling (or down-cycling); or processing plant separation where the waste is processed in various stages to recover materials of value for recycling.

The *stabilization of organic waste material,* such as food processing residuals, food scraps, garden debris or some sewage sludge is usually a composting process. In such composting systems, the organic material is stabilized aerobically and under pasteurization temperatures.

Energy recovery became very popular in the 1980s, especially with regard to the disposal of solid household waste. In Japan, 65% of all solid wastes are burned in incineration plants (stoker-type and, more recently, fluidized bed-type) in order to produce electricity and, in some systems, steam also. In the USA, only 20% of the solid waste is used for energy recovery, and in Germany even less (17%), because environmental legislation requires sophisticated air pollution control.

A long-term solid waste management has the following four main components (see figure 1): material recovery (for recycling or down-cycling); energy re-

Figure 1. Options of solid waste treatment and disposal



covery (in incineration plants or gas producing processes); organic stabilization and fuel production (see figure 2); and long-term storage.

Many developing countries face special problems in the field of solid waste treatment and solid waste storage such as:

Hygienically proper waste management in fast-growing metropolitan areas; regular collection and disposal of solid waste as well as the uncontrolled material recovery by individuals or small-scale enterprises;

Import of solid wastes containing sometimes hazardous compounds from industrialized countries for energy recovery in incineration plants;

Hygienically proper treatment of animal waste in rural areas;

Application of modern landfill technologies for the storage of industrial and household solid wastes.

Composition of solid waste

The solid waste of cities and other municipalities contains food (vegetables, fruits, etc.) and garden (leaves, twigs, etc.) wastes; paper, cardboard and similar packaging; glass; plastics; and metals/minerals (see table 1). In many countries, source separation of paper, glass, plastics, metals and, sometimes, textiles, became popular in industry and households. Solid wastes from industries differ widely in composition and quantities. The main categories of industrial solid waste can be classified according to their origin from the following sectors:

Power plants, gas plants, cokeries, such as ashes and slags;

Mining industry, such as excavated material (overburden, rocks) and benefication discharges (tailings);

Metallurgical industry, such as moulding sand, core sand, slags, sweepings or rubble;

Manufacturing industry, such as plastics, rubber, metals, paper, textiles, oils, lubricants or sludges;

Food processing industry, such as vegetable and fruit residuals;

Construction industry, such as excavated material and building rubble;

Chemical (petrochemical) and pharmaceutical industry, such as sludges, residuals, detergents.

Table 1. Composition of municipal solid waste (industrial and household waste), 1991
(Percentage)

Content	*Germany*	*USA*
Food and garden residuals	30	29
Paper, cardboard	17	38
Glass and ceramics	10	9
Plastics	5	5
Textiles, rubber, disposable nappies	5	5
Metals, minerals, ashes	5	8
Medium-grained refuse	16	–
Fine-grained refuse	12	6

Source: Umweltbundesamt Berlin 1992

In industrialized countries, the volume of solid wastes from the manufacturing industry, the construction industry and the chemical industry is considerably high, and in developing countries, larger tonnages of solid wastes from the mining industry, the construction industry and the food processing industry are discharged.

Industrial solid waste might contain the following hazardous compounds:

Inorganic acids and caustic agents (often more than 50% of all hazardous wastes)

Salt slags

Paint sludge

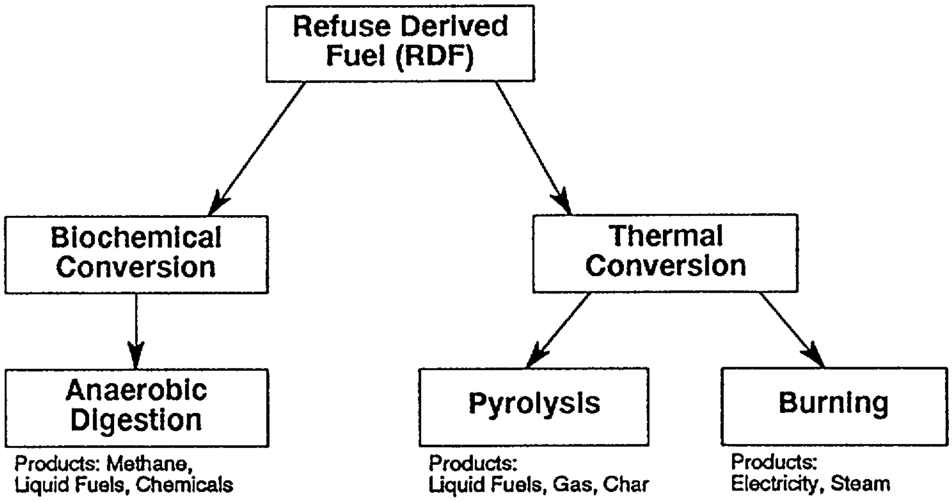
Oil and lubricant emulsions

Organic solvents

Alkalis

Metals such as lead (Pb), cadmium (Cd), mercury (Mg), arsenic (As), or beryllium (Be).

Figure 2. Options of fuel production from solid waste



Major sources for industrial solid waste

The review of the present material/affluent production system in industry and the necessary change to a recycling-oriented production, distribution and consumption system requires resources management, from primary industry (mining, agriculture) through to end-users.

Industries with high potential of material recycling

Mining industry: many of the solid waste statistics do not include the high volumes of mining excavations (overburden, rocks, etc.). Large open-pit operations, like lignite mines, tin mines, bauxite mines, etc. remove millions of tonnes of material every year. Since this kind of waste material is not contaminated, it should be used for the refilling of old pits or it might even be used as construction material (roads, buildings). The disposal of wastes from mineral processing plants is more difficult. Coal washing plants produce tailings containing rocks, inter-growth and fine-grained coal. Ore dressing plants may produce tailings containing various metal compounds (sulphides, oxides, sulphates, etc.) which have not been recovered, and chemicals from flotation or swim-sink processes. Old tailings can be redressed in order to recover the remaining metal contents, provided this procedure is economically viable.

Metallurgical industry: iron and steel plants as well as non-ferrous metal smelters produce slags, dusts, new scraps and electrolytic sludges (in metal refineries). The recycling rate of slags is considerably high (60-70%), since the material is used in the construction industry. The recycling rate of metal scraps is even higher (80-95%) but at present sludges are recycled in very limited amounts only.

Food processing industry: solid wastes are mainly produced by the processing of vegetables, potatoes, fruits and meat. Vegetable and fruit residuals of the food processing industry show a very high recycling rate in industrialized countries (70-80%), but slaughter residuals do not (15-20%). In developing countries, the recycling rates for residuals of food processing vary, and potential for increase is evident.

Construction industry: the quantity of waste occurring from construction work is very high and can amount to 50% of all solid wastes in some countries. Earth, sand, gravel, concrete blocks, bricks, asphalt/bitumen blocks, rocks and timber in various combinations and quantities are discharged by excavations, reconstructions and construction works. The recycling rate is highest in the case of timber (50-80%) and sand/gravel, and lowest in the case of concrete, bricks and asphalt (15-20%). Potential for increase is considerably high.

Chemical and pharmaceutical industry: the composition of solid wastes from petrochemical plants, fertilizer plants, paint shops etc. is complex and requires special treatment. Sludges, detergents, waste plastics, chemical compounds are at present recycled in limited amounts only. Most of these wastes are classified as hazardous wastes and have to be processed or stored under special safety regulations.

Table 2. Recycling rate of industrial waste in Japan

Category	*Rate (%)*
Sludges	9
Cattle Manures	90
Construction Debris	22
Slags	63
Waste Acids	42
Waste Oils	37
Dusts	49
Waste Plastics	27
Glass and Ceramic	22
Woods	51
Cinders	7
Scrap Paper	61
Waste Alkalis	77
Organic Residuals	82
Slaughter Residuals	16
Scrap Rubbers	14
Scrap Textiles	49
Scrap Metals	93
Others	2
Average recycling rate	*41*

Source: K. J. Thomé-Kozmiensky (Ed.): *Waste Management International,* vol. 1, Berlin 1992.

Solid waste treatment and disposal systems

Municipal solid waste is generated by industry, (public) institutions and households. It is very heterogeneous and requires special processing systems. In principle, there are the following three options:

(a) Landfill: with the possibility of producing methane;

(b) Mass burning in incineration systems: producing electricity (or steam);

(c) Mechanical separation system (products: iron and steel, non-ferrous metals, aluminium, glass, plastics, rubber and "refuse derived fuel", RDF) followed by biochemical conversion (anaerobic digestion, producing mainly methane or ethanol) or by thermal conversion (pyrolysis, producing oil, gas, charcoal).

Mechanical systems

These systems have three essential parts: size reduction; separation; and refuse optimization. The size reduction equipment installed depends on the waste content. Hammer mills or shear shredders are commonly in use. Before separation, the size-reduced material is screened and three types of screen are currently used: flat, rotary and disk. The separation methods take into account the physical and chemical properties of the components to be recovered. All magnetic material such as iron, steel and other ferro-magnetic metals are separated by magnetic separators; the other materials (paper, plastics, glass) are separated by a classifier which drops materials from an air current according to their size, density and aerodynamic properties. Also, wet processes have been operated successfully in special cases: froth flotation for the separation of glass, heavy-media separation for aluminium, etc. An important product of the mechanical separation process is refuse derived fuel (RDF). It is often a papier-machélike mass and requires improvement before burning. To improve the RDF characteristic, pelletizing or briquetting is common, or treatment with acid, which results in powdered RDF.

Thermochemical systems

Thermochemical systems are based on pyrolysis and can process RDF into hot water, steam or even oil and gas. If the available oxygen is limited as RDF is heated, the combustion process is incomplete and hydrocarbons are produced as gas and liquid (oil) and solids (carbon char). The pyrolysis systems for RDF are still at the research and development stage. Slow and fast pyrolysis methods produce varying amounts of gases and liquids, and appropriate catalysts can improve the system's efficiency.

Biochemical systems

Biochemical systems use microorganisms to convert solid waste into fuel. Two main biochemical systems now available are: the anaerobic digestion of solid waste (preferably a mixture of RDF from municipal waste and sewage sludge) to produce methane-rich biogas; and the fermentation of cellulose to glucose for further conversion to ethanol.

In the case of anaerobic digestion, a process under controlled conditions takes place in a reactor, breaking down the complex organic material with the help of anerobic bacteria to methane and carbon oxide. A variety of reactor vessels are known; the most common one being the continuously-stirred tank reactor (CSTR).

The second biochemical conversion system has five steps: *(a)* concentrating the lignocellulosic part (wood, foodstuff waste, leaves, etc.) of the solid waste; *(b)* pretreating the cellulosic and carbohydrate components by acid or enzymatic hydrolysis; *(c)* converting the pretreated components to sugars; *(d)* fermenting the sugars (glucose and other six-carbon sugars) to ethanol; *(e)* distilling the ethanol/water mixture by steam distillation. The ethanol can be used as an automotive fuel.

Table 3. Selected emission standards for municipal waste incinerators

Emission	*USA (California)*	*Japan*	*Germany*	*Sweden*
Solid particulates (mg/m^3)	25	150	30	20
CO (ppm)	–	–	80	–
HCl (ppm)	30	430	31	63
SO_2 (ppm)	30	60-100	35	0
Dioxins (ng/m^3)	0	0	0	0.5
Hg + Cd + Tl (mg/m^3)	–	–	0.2	0.08

Source: American Institute of Chemical Engineers

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Incineration plant for domestic waste

Introduction

Growing material affluence and an increasing degree of industrialization in the manufacturing and distribution of goods which are in daily use, serve to increase the amount of waste from private households. Waste is disposed of by the following methods: land-filling; composting; incineration.

However, not all components of domestic waste are suitable for composting, and land-filling requires large areas of land, which causes great location problems in conurbations. For these reasons, the incineration of waste is becoming increasingly the most suitable option. Furthermore, hot water, steam and electricity are "produced", depending on the type of incineration plant.

Great efforts were necessary in order to overcome the mechanical, ecological and chemical problems associated with the incineration process. This has obviously resulted in incineration being one of the most expensive methods of waste utilization. Incineration has proved to be an effective method of waste utilization in the disposal of domestic waste. However, due to the heterogeneous composition of this type of waste, incineration is no simple technical procedure.

Domestic waste as fuel

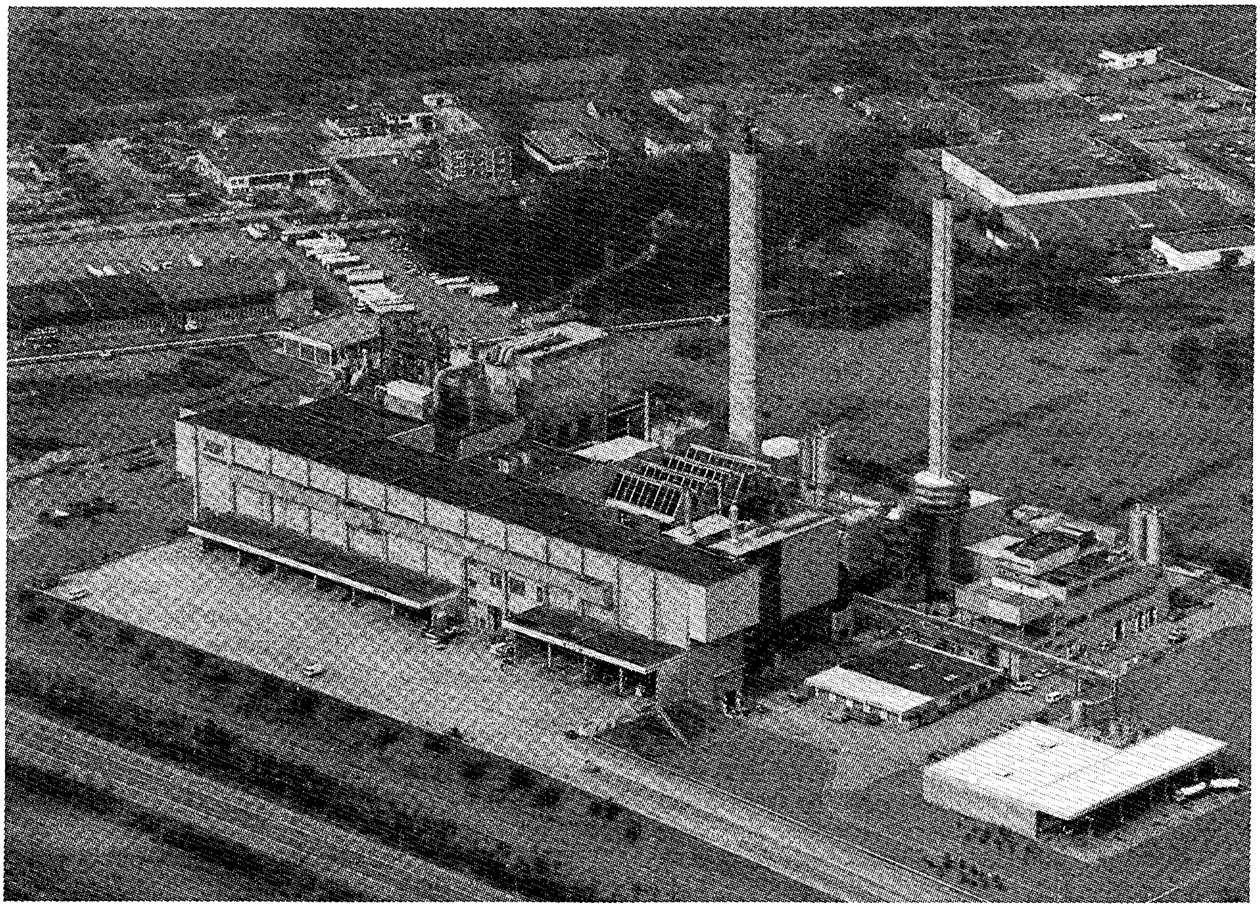
Fuels which are fed into incineration plants are mainly:

Hazardous waste (e.g. hospital waste) which is incinerated in a plant for that type of waste.

Sewage sludge, which is either mixed into the domestic waste or, as is now often the case, incinerated in plants designed solely for that purpose.

Domestic waste and industrial waste of a similar composition which is incinerated in plants for domestic waste.

Owing to the inhomogeneous composition of domestic waste fuel, it is not feasible to comment on the



quality of the fuel mixture. The waste composition has to be known in order to determine the design and operation of a plant as well as which steps to be taken to lower emissions.

Domestic waste can, by and large, be subdivided into different groups of material which can be disposed of by the following methods:

Incinerated or composted (vegetative waste, textiles, paper, straw etc.);

Incinerated only (thick cardboard, plastics, rubber, leather, bones etc.);

Neither incinerated nor composted (metals, glass, stones, ceramics etc.).

Over a period of five years, the average composition of waste from private households in a city of approx. 200,000 in an industrialized country proved to be the following:

Household waste	*Percentage*
Paper, printing material	35
Vegetable matter	30
Plastic, wood, textiles, leather, rubber	25
Ferrous metals, non-ferrous metals, glass, ceramics	10

The diversity of this waste composition is greatly increased by regional, temporal and seasonal factors as well as by changing life styles. As compared to conventional fuels, it is the most obvious characteristic of domestic waste fuel. It is essentially this unstable composition which hinders the process of thermal waste treatment. The thermal efficiency is determined by the calorific value of domestic waste. This can be roughly calculated from the calorific value of the combustible fraction and from the waste's weight composition of ash, combustible matter and water. Compared to other solid fuels, the calorific value of non-pretreated domestic waste is approx. 8,200 kJ/kg and is thus below the otherwise lowest value of soft coal (8,370 kJ/kg) and is approx. a quarter of the calorific value of high quality pit coal (32,000 kJ/kg).

Secondary raw materials are obtained through the process of preparing domestic waste for incineration. Additionally, an improved raw product is obtained for incineration. In principle, two methods are feasible for improving the fueling qualities of domestic waste: either preparation (comminution, screening, drying, briquetting etc.); or separate collection of different waste material groups.

The sorting of domestic waste into homogeneous material groups allows the calorific value, and consequently the degree of efficiency, to be increased and the pollutants to be decreased.

Methods of incineration

The main objective of the incineration of waste, including domestic waste, is to reduce the waste volume. The reduction in volume achieved in today's plants is, without utilization of slags, 85-90%, and approx. 97% when the resulting slags are dressed and utilized. Furthermore, the energy contained in domestic waste can be utilized as district heating, process steam and electricity.

The centre-piece of any incineration plant, the combustion unit, can consist of one of the following furnace types:

Rotary kiln
Multiple hearth furnace
Fluidized bed incinerator
Grate furnace.

Rotary kiln

This type is especially suited to the incineration of hazardous wastes which, compared to domestic waste, contain more pollutants and can also be liquid or pasty. A rotary kiln is principally made up of a cylinder which is tilted in the direction of the flow. The cylinder revolves around its longitudinal axis. It is brick-lined which fireproof material and often has a cooled steel jacket (in the kiln, temperatures of up to 1,400 °C are reached). The cavity inside the cylinder can be filled up to 30% with fuel. The waste is rolled around when the cylinder turns on its longitudinal axis and thus becomes more easily accessible to the burners.

Usually, a rotary kiln is 8-12 m long, with a diameter of 1-5 m. The average combustion temperature lies between 800 °C and 1,400 °C for a duration of approx. 60 minutes. Post-combustion chambers ensure the destruction of combustion gases.

Multiple hearth furnace

This type is especially suitable for: incineration of sewage sludge of all kinds; combined incineration of sewage sludge/domestic waste; incineration of oily and greasy wastes; or incineration of grit and sand from sewage plants.

A multiple hearth furnace consists of a standing, cylindrical steel form in which there are a number of circular hearths at different levels. These are brick-lined with fireproof materials or made of heat-resistant steel and are pierced through the centre by a hollow shaft which is fitted with rabble arms.

The waste is charged onto the top hearth. During the whole incineration process, the material is continuously turned over by the rabble arms and transported downwards from hearth to hearth, where it falls alternately into inner and outer shafts. This continuous movement ensures that the necessary contact surface between the material and air-gas current, necessary for combustion, is produced by the spreading out of the waste on the hearths.

The height of the individual hearths is limited in order to ensure sufficient turbulence on the surface of the waste and flue gas currents for material and heat transport. The height is from 60-80 cm. Therefore, there is a danger of clogging taking place if the waste is not comminuted. In multiple hearth furnaces, temperatures of up to 500 °C are reached. Post-combustion chambers for destroying the waste gases are also employed.

Fluidized bed incinerator

This type is especially suitable for the incineration of the following waste materials: liquid or pasty sludge, oily wastes (e.g. waste oil, sludge, sediments from oil tanks, oil separators, oil emulsions); or grit and sand.

A fluidized bed incinerator principally consists of a vertical, cylindrical, brick-lined combustion chamber. In its lower section, a bed of sand whirls, aided by compressed air, over a grate which is fired from below. The material to be incinerated is introduced into the combustion chamber from the side. It falls into the fluidized bed and is incinerated there. The fluidized bed provides a quick, continuous interchanging of solid particles. This allows close contact between gas and solid matter. A fluidized bed incinerator means quick, intensive and efficient incineration at relatively low temperatures between 800-950 °C.

Grate furnace

Refuse incineration on the basis of different grate systems represents a thermal treatment process that has proven satisfactory for the incineration of domestic waste. The reason being that it is not necessary to sort or comminute the waste beforehand as has to be done, for example, when using a multiple hearth furnace. Despite the heterogeneous composition of domestic waste there is a furnace availability of more than 90%.

Incineration takes place in a combustion chamber, which is formed at the bottom by the grate, at the sides by cooled or not cooled steel plates and at the top by a steel ceiling.

The main functions of the grate are: to transport the waste (the grate is driven by various aggregates depending on the different systems) from the charging to the discharging installation; to provide an even supply of air into the fuel layer; and to stoke the fire in this layer.

Depending on the transport and the stoking of the combustion material grates can be distinguished as one of the following:

Forward feeding grates
Reciprocating grates
Travelling grates
Roller grates.

Of these systems, the roller grate represents an optimal process in the incineration of domestic waste, guaranteeing the complete and nearly residue-free thermal decomposition of the waste.

Example of a waste incineration plant with roller grate

Functioning of a waste incineration plant

In a waste incineration plant, domestic waste basically passes through seven stages as can be seen from figure 1.

Delivery of the domestic waste

The dust vans tip the collected domestic waste into a bunker, from where it is taken by a grab and disposed into the charging funnel of the incineration system.

Incineration

The waste is then conveyed onto the rolling grate of the furnace, where the actual thermal treatment takes place at temperatures of over 1000 °C. Blowers deliver the air needed for combustion. The burnt-out and mineralized residues of combustion fall at the end of the combustion grate into the water-filled slag remover, where they are slaked and then conveyed into a bunker for further treatment.

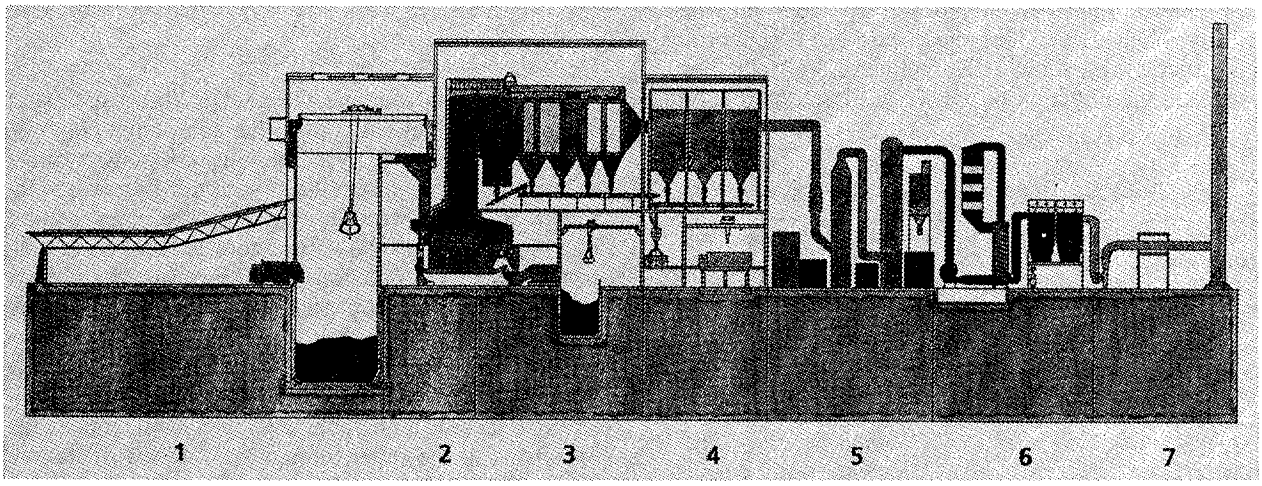
Heat utilization

The temperature of the burnt-out flue gases is reduced to approx. 200 °C in a steam generator, thereby producing overheated steam for further use.

Dust precipitation and electricity generation

The flue gases coming from the boiler have the flue dust removed and are then fed into a washer. The separated dust is collected in a silo for use or for further treatment.

Figure 1. Stages of waste incineration



Key:
1 Delivery of domestic waste
2 Incineration
3 Heat utilization
4 Dust precipitation and electricity generation
5 Two-stage gas scrubber
6 Destruction of dioxine and nitric oxides
7 Emission control

The steam produced earlier drives a turbo-generator for the production of electricity and can also be used for long-distance heat supply by means of a heat exchanger. The exhaust steam of the turbine is condensed in the condensers and re-fed into the boiler.

Two-stage gas scrubber

The waste gas is cleaned of the main acid components and heavy metals.

Destruction of dioxin and nitric oxides

After passing through the scrubber and a blower the waste gas is re-heated. The nitric oxides are destroyed in a catalyzer; the dioxin contained in the flue gas can be destroyed in a further catalyst layer. The last stage for the flue gas is an activated coke filter, where still remaining noxious matter is absorbed.

Emission control

This takes place at the end of the flue gas treatment and both monitors and safeguards the keeping of the emission regulations.

Incineration of domestic waste on a rolling grate

Rolling grate

As has been indicated before, domestic waste is, because of its continuously changing composition, a fuel difficult to control. It is therefore necessary to use special design and operational measures in order to safeguard a good combustion of the domestic waste despite these difficulties, while keeping a high availability of the total plant. This is why the combustion grate is an important process-technological element of a waste incineration plant. The dimensions as well as the functioning of the total plant is mainly dependent on the design of the furnace.

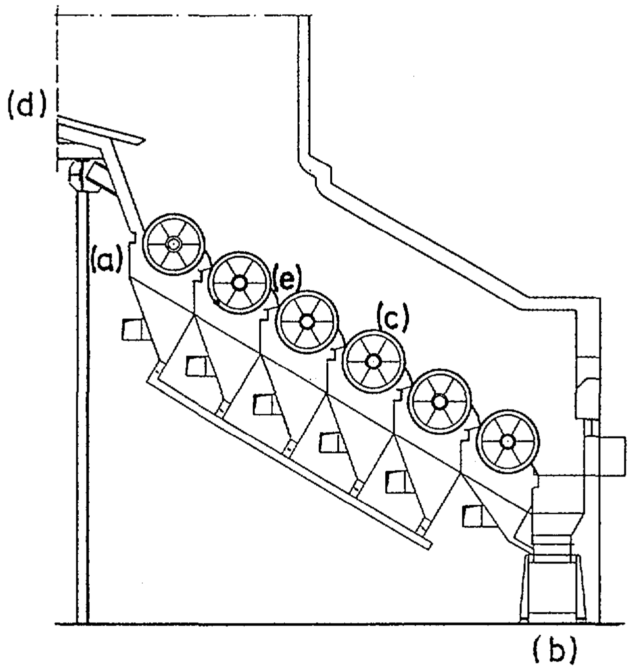
The rolling grate has proven successful for the incineration of domestic waste; the optimal dimensioning of the combustion chamber is given by the factors and figures shown in table 1.

Figure 2 shows a combustion chamber provided with a roller grate. The grate consists of a supporting construction (a), showing an incline of 30° to the horizontal in the direction of the waste discharge (b). Into this supporting construction six grate rollers (c) are hung one behind the other stepwise, thus forming the grate area. Each grate roller is electrically driven. The rotation speed of each individual roller can be continuously adjusted to the necessary forward feed, i.e. to the burning out or burning-off of the domestic waste, which is distributed on the roller grate by a charging device (d). By means of the force created from the weight and friction factor of the burning material in connection with the rotating grate rollers, the domestic waste is well mixed, distributed and turned during incineration.

Table 1. Dimensions of a rolling grate

waste throughput (kg/h)	*rollers (number)*	*diameters of rollers (mm)*	*length of rollers (mm)*
4 000	6	1 500	1 600
6 000	6	1 500	2 100
8 000	6	1 500	2 600
10 000	6	1 500	3 100
12 000	6	1 500	3 600
18 000	6	1 500	4 600
26 000	6	1 500	5 600
30 000	6	1 500	6 100
40 000	6	1 500	8 100

Figure 2. Combustion chamber



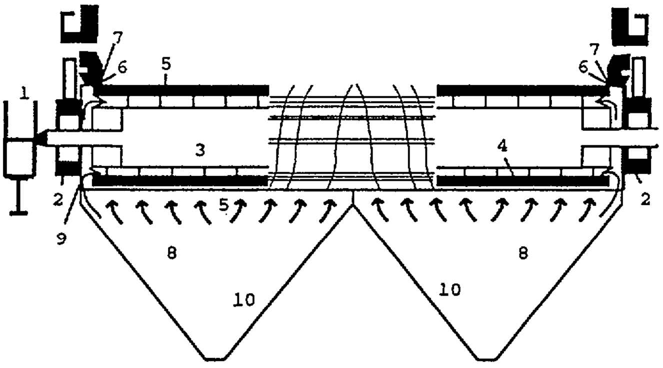
Behind every roller there are strippers (e), stripping the unburnt waste from the roller and transferring it to the next roller. Underneath each roller there are collecting funnels for the material falling through the grate; through these funnels also combustion air is fed into each individual roller separately, by means of a compressed air system.

Grate roller

As mentioned earlier, the use of roller grates in waste incineration has shown that an optimal combustion can be reached by employing six single rollers with equal diameters but each with a different length, according to the waste throughput. The cross section of a grate roller, as shown in figure 3, gives its important components. The grate roller consists of a hollow shaft, resting in roller bearings at both ends outside the furnace.

On the driving side of the grate roller the hollow shaft is fixed in the roller bearing, while on the opposite side there is a movable bearing. This facilitates the expansion of the roller through heat during operation. The roller bearings and the electric driving unit, including all parts and greasing points, are outside the furnace and therefore easily inspected and maintained during operation.

Figure 3. Grate roller



Key:

1	Drive	6	End grate bar
2	Roller bearing	7	Lateral air seal
3	Hollow shaft	8	Air intake
4	Grate-bar bearer	9	Sheet metal casing
5	Middle grate bar	10	Funnel

The hollow shaft is fitted, in a longitudinal direction, with distance pieces for the mounting of the grate-bar bearers, onto which the grate bars are fitted. At the lateral air seal the grate roller is hermetically sealed from the furnace by a side construction, in order to avoid any unwanted penetration of combustion air between grate roller and sheet metal casing. The combustion air enters the funnel through the air intake openings.

As can be seen from the description of the design of a roller grate, this consists of a number of individual components, which are mostly not manufactured by one but by several firms.

Description of the product

From the numerous components of a roller grate the production of a grate roller is chosen, comprising of the following parts (see figure 4):

One cylindrical hollow shaft made from a fire-resistant stainless steel sheet (10 mm thick) (a);

Two round cover plates, also made from a fire-resistant stainless steel sheet (5 mm thick) (b);

Two supporting shafts from fire-resisting stainless steel (c);

Six grate-bar bearers (d) from fire-resistant stainless steel with five distance pieces (e) per steel bearer, in total 30 pieces from the same material.

This roller is installed in a roller grate of an incineration plant for domestic waste with a throughput of 6000 kg/h; this leads to the following measurements for the roller:

Length of the grate roller	2 100 mm
Diameter of the grate roller	1 500 mm

On account of these above-mentioned values, the following measurements result for the hollow shaft to be produced and its parts:

Length of the hollow shaft	2 100 mm
Diameter of the hollow shaft	1 100 mm
Diameter of the cover plates	1 100 mm
Length of the supporting shafts	200 mm
Diameter of the supporting shafts	20 mm
Length of the grate-bar bearers	2 100 mm
Width of the grate-bar bearers	100 mm
Height of the distance pieces	100 mm
Width of the distance pieces	50 mm

Description of the production process

The description of the production process entails the production of one hollow shaft, two cover plates, two supporting shafts, six grate-bar bearers and 30 distance pieces. In practice these parts are produced by a firm in the metal-processing industry only according to demand or order, and are thus integrated into the daily production process of the works.

First, after receiving the order the measurement calculations of the simple components of the roller are done before they are transferred to the materials to be used.

The next step is the torch-cutting of the stainless steel plates for the hollow shaft and the cover plates, and parallel to the cutting of the supporting shafts, the distance pieces and the grate-bar bearers. Distance pieces and grate-bar bearers pass a quality inspection and are after-treated if necessary. Cover plates and supporting shafts are welded together and checked for their quality.

The cut-out stainless steel plate is—after successful inspection—admitted to an electric heating furnace in order to increase its elasticity. It is bent or pressed into its cylindrical form and welded along the join. After the weld seam has cooled off, it is tested for solidity and then the hollow shaft is transported to the next processing stage, where in the meantime the two other

Figure 4. Components of a grate roller

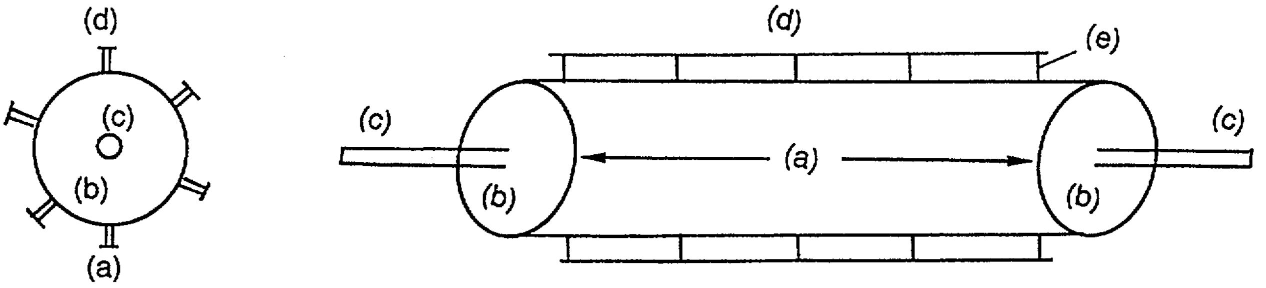
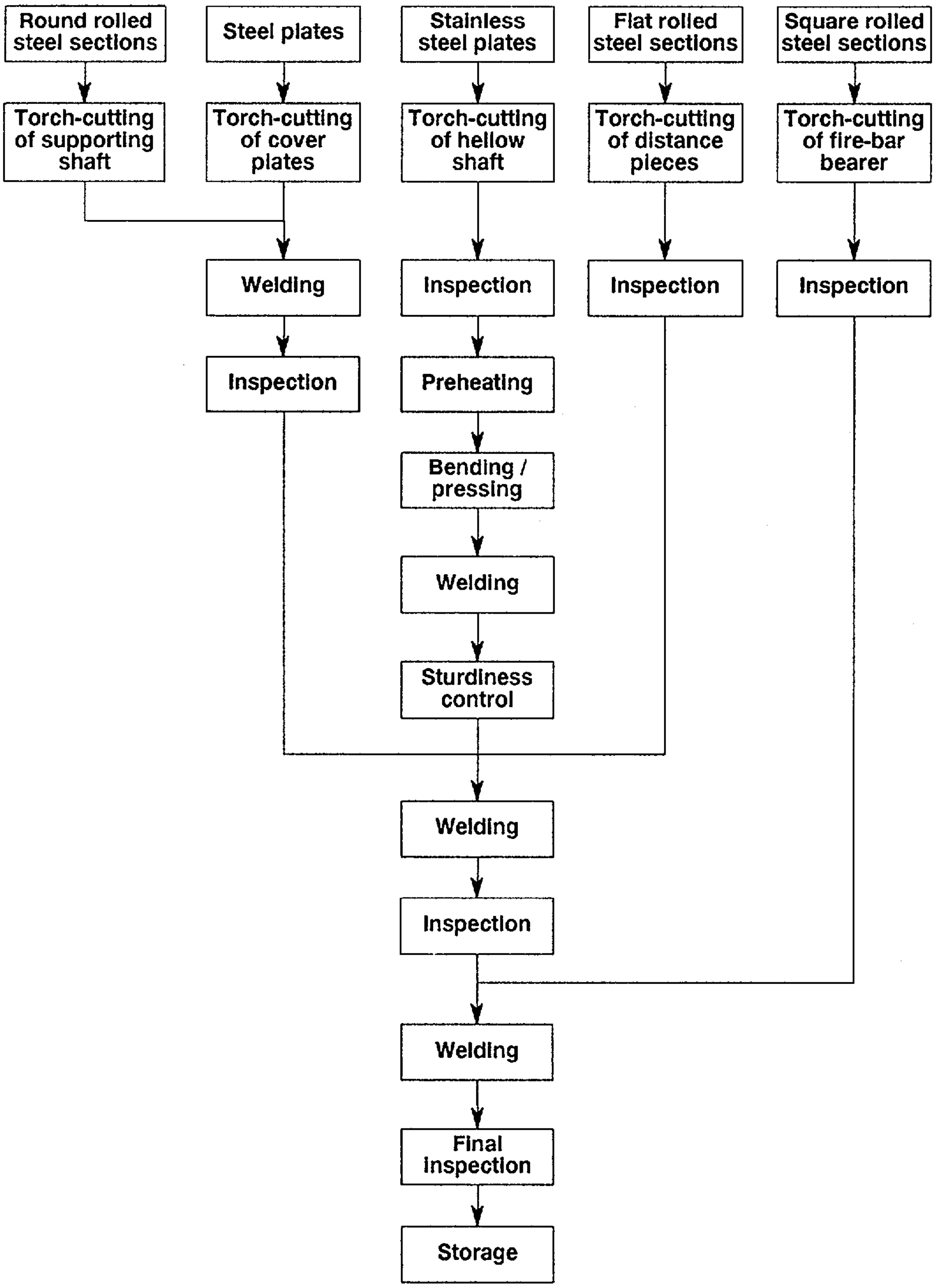


Figure 5. Flow chart



components have arrived. The two cover plates are welded onto the hollow shaft; after marking the points on the surface of the hollow shaft, the 30 distance pieces are welded on. When these seams have cooled off and their precision has been checked, the six grate-bar bearers are welded onto the distance pieces. The final inspection is the last step.

If no retouching is necessary the grate roller can be put into store or prepared for transport to the site of installation.

Example of a production plant

It has already been mentioned, that a metal-processing firm not only produces grate rollers during a working day, but also other products. It is therefore not possible to give exact data, e.g. demand in energy or personnel, for their sole production. However, to obtain a reasonable idea, it is assumed, that the firm only produces grate rollers, namely two units in the course of an eight hour working day.

Required machinery and equipment

Description	Pieces
Flame cutting machine	2
Welding apparatus	2
Heating furnace	1
Bending/pressing machine with integrated welding device	1
Crane	1
Workbench	3
FOB-price for machinery and equipment	Approx. US$ 4.2 million

Required manpower

Manager	1
Technical manager	1
Administrative manager (administration, accountancy, marketing etc.)	1
Administrative staff	2
Foreman	1
Metalworkers	4
Semi-skilled workers	4

Required area

	Square metres
Production hall	600
Administration	120
Facilities	140
Storage	300

Required energy

Electric power	40 kW
Water	5 m^3/d
Acetylene, oxygen	

Required inputs

Steel plates (10 mm)	approx. 20 m^2/d
Steel sheets (5 mm)	approx. 8 m^2/d
Square rolled steel sections	approx. 32 m/d
Round rolled steel sections	approx. 1 m/d

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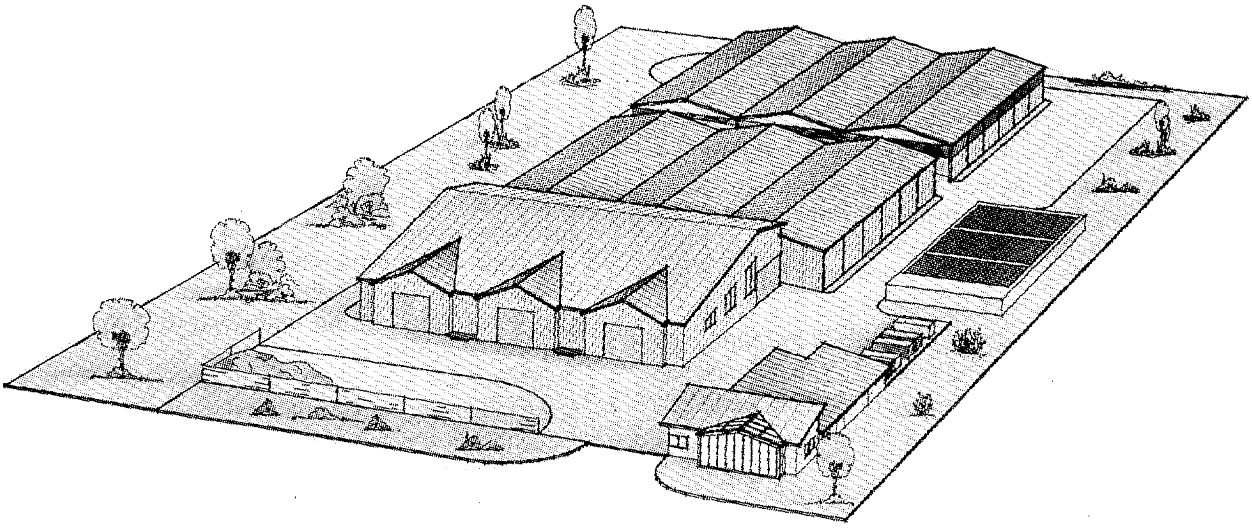
December 1993

How to Start Manufacturing Industries

Composting plant



Introduction

Every day from nature's circulation system vast amounts of organic materials are being removed, used and finally discarded in the form of burdensome and even harmful waste. Composting can help by working against this careless removal and its disastrous consequences.

Composting is an ancient agricultural process for the reutilization of organic waste as a carrier of nutrients for plants and for the improvement of the earth's fertility. The decomposition of organic substances through vegetable or animal micro-organisms which takes place in a damp medium under the admission of air and which leads to a humus-type product, is known as composting or rotting.

Composting is technically a more simple process than waste incineration, it reduces the ever increasing use of land for rubbish dumps and it can use the large amounts of organic waste materials, which arise, to produce an organic fertilizer and a texture improver.

The following waste materials are used today for composting:

Organic parts of household waste;

Sludge;

Leaves and other waste from parks;

Garden and kitchen waste;

Organic residues from the food industry as well as from winemaking;

Bark peelings;

Waste of abattoirs (contents of entrails);

Dung, remains of harvesting and other agricultural waste (including those from factory farming).

Basically all waste with a high degree of materials, which can be easily broken down biologically, are suitable for composting. The potential of waste capable of being composted (household waste, waste of agricultural concerns or of factories in the food industry) is very different, depending on the country and the type of waste.

The problems of composting lie above all in a continual collection of as pure organic waste as possible; in the varying composition (quality) of the product; and thus in the sales of the ready compost, which have a decisive influence on the economy of the plant.

Composting and influential factors

Composting

Composting is an aerobic process in which organic materials are broken down by means of micro-organisms into substances which create humus. Anaerobic conditions are usually not desirable, because among other things they create problems of smell and can restrict the actual process of composting.

After processing the raw material (crushing, sieving, mixing, separation of ferromagnetic particles) composting basically follows the following chemical-biological phases, whereby there are no strict boundaries between the phases.

The first phase is called the intensive rotting or the prerotting phase. Its characteristics are:

Bacterial activity with a relatively high mebabolic performance and as a consequence a high material conversion;

High rate of utility of the offered oxygen (approx. 20%);

Time required approx. 2-4 weeks.

Through the intensive bacterial activity many exotherm reactions take place, which lead to a maximum temperature of approx. 70-80 °C. This is accompanied by a desired pasteurizing effect. The result is fresh compost, which cannot yet be used for most areas of application, as the biological conversions are still not complete and the fresh compost is putrefactive.

The pre-rotting phase is followed by the conversion phase (main rotting) and then the post-rotting phase, which is necessary to obtain nature, i.e. ready, compost. These phases are characterized as follows:

A considerably slower material conversion, as the composition of the microbial community shifts away from bacteria to mycetes and fungi, whose metabolism is considerably smaller than that of bacteria;

The available oxygen is only utilized to approx. 5%;

The temperature drops again gradually and approaches towards the end of the rotting period the temperature of the surroundings;

The result is ready compost.

For the technical realization of the composting processes it is important to note that only the first phase of bacterial activity can be influenced, i.e. accelerated, by optimizing the parameters. In contrast the metabolic performance of the following mycetes and fungi cannot be influenced, so consequently it is also not possible to accelerate time-wise the post-rotting phase.

The aim of composting (rotting) is to gain a humus like decomposed product, compost. This compost can be used for garden vegetable growing, in agriculture for the production of field crops and fodder, for fruit and wine growing, in orchards, for the development of barren land and in private gardens. It is rich in organic substances and the nutrients, nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) as well as magnesium (Mg). The use of compost leads to an increase in the amount of humus and to erosion stability, it activates life in the soil, improves the structure of the soil, its warmth and water households as well as its store of nutrients. In the case of sandy ground compost raises the capacity of water retention and reduces desiccation, in the case of heavy clay soil it improves air and water permeability and reduces thereby surface erosion.

Influential factors

Nutrients

For the bacterial activity there must be a balanced supply of main nutrients and trace elements. Of particular interest is the supply of the main nutrients, carbon (C), phosphorous (P) and nitrogen (N). As a lack of phosphorous is normally not to be expected, the observations can be limited to the carbon/nitrogen ratio, as this alone can be subjected to larger fluctuations.

The carbon/nitrogen ratio influences the speed of decomposition and thereby the composting process both qualitively and quantitatively. A carbon/nitrogen ratio of 30-35:1 is considered to be optimal.

If the ratio is too small (a relative nitrogen surplus), then the result can be the formation of NH_3 with a consequential displacement of the pH value. This situation can be remedied by specifically adding carbon sources (e.g. straw, sawdust).

Should the ratio be too large (a relative carbon surplus), then the lack of nitrogen will lead to a slower and incomplete decomposition. The remedy for this is the addition of materials with a close carbon/nitrogen relationship (e.g. sewage sludge: C/N approx. 10:1; green silage).

Water content

The water content is also an important parameter, because the bacteria can absorb the substrates only out of a watery solution; the optimum amount is approximately between 40-55%.

A water content of less than 30% slows down the transportation of the nutrients and finally prevents their intake, so that the rotting process comes to an end.

In the case of a water content of over 70%, too many pores are filled with water, so that there is a reduction in oxygen intake and anaerobic conditions arise. Depending on the water content of any sewage sludge, possibly to be treated, then this will influence the water content of the compost itself.

Oxygen supply

As the composting process should take place aerobically and anaerobic processes are undesired then the main parameter is a sufficient supply of oxygen. The need for oxygen is at its greatest during the pre-rotting phase on account of the intensive bacterial activity, thus making it essential, particularly in this phase, to take corresponding measures; this can be by changing silos or by turning the compost over in the rotting reactors or channels.

Temperature

The aerobic composting process is exothermal with the result that the generation of heat in the pre-rotting phase leads to an increase in temperature in the rotting reactor. There, peak temperatures of 70-80 °C can be reached. If this temperature level is maintained over several days, then the compost is hygienized.

The temperature of the outgoing air is subject to considerable fluctuations during the first phase and falls strongly during the last third of the intensive rotting. It is therefore better to define the intensity of the rotting processes in terms of the specific heat loss (in W/m^2), because the temperature of the outgoing air depends too strongly on the distribution of temperature and dampness in the bulk of the compost.

The specific heat loss reaches its maximum after almost 100 hours at approx. 1,800 W/m^2 and then steadily drops to about 200-300 W/m^2 after 500 hours.

The highest decomposition speeds for compost gained from waste materials in the intensive rotting phase are achieved with effective process temperatures of 40-45 °C (determined from the amounts of water and heat carried out with the outgoing air, based on the saturation level of the air with water vapour).

In order to maintain the optimal temperature the process must—after the hygienisation effect at higher temperatures has been reached or through renunciation of this effect—be cooled by continual watering and optimal ventilation cycles.

pH value

The pH value is normally within the area of the chemical neutral point. It can however, influenced by intermediate products of the decomposition process (e.g. organic acids), be shifted at intervals. The entire community of the various bacteria is however not sensitive to these limited fluctuations in the pH value, thus the pH value must not be considered as a limiting factor of the rotting process.

Automatic composting plant

Because of the necessity to ease the burden of the rubbish dumps and the controversial discussions on refuse incineration, composting should be given more importance in waste disposal. Decentralized smaller plants, which among other things considerably reduce transportation distances and costs, should in the main be preferred as against technically more complicated plants. In smaller plants, with a flow rate of for example 20,000-25,000 m³/a, an efficient load (decisive for their economy) is more likely to be achieved than in large centralized works. Moreover several composting plants offer altogether greater safety in waste disposal than one central plant.

Design

The plant described here corresponds to the above-mentioned capacity. As can be seen from the schematic chart (see figure 1) of an automatic composting plant, it comprises of the following:

A delivery and processing area (1);
A rotting area (2);
A fine processing area (3).

All areas are built into a hall, in order to avoid material drifting on the plant. To prevent corrosion by rotting material or waste air on parts of the machinery, these are covered with a corrosion-resistant paint.

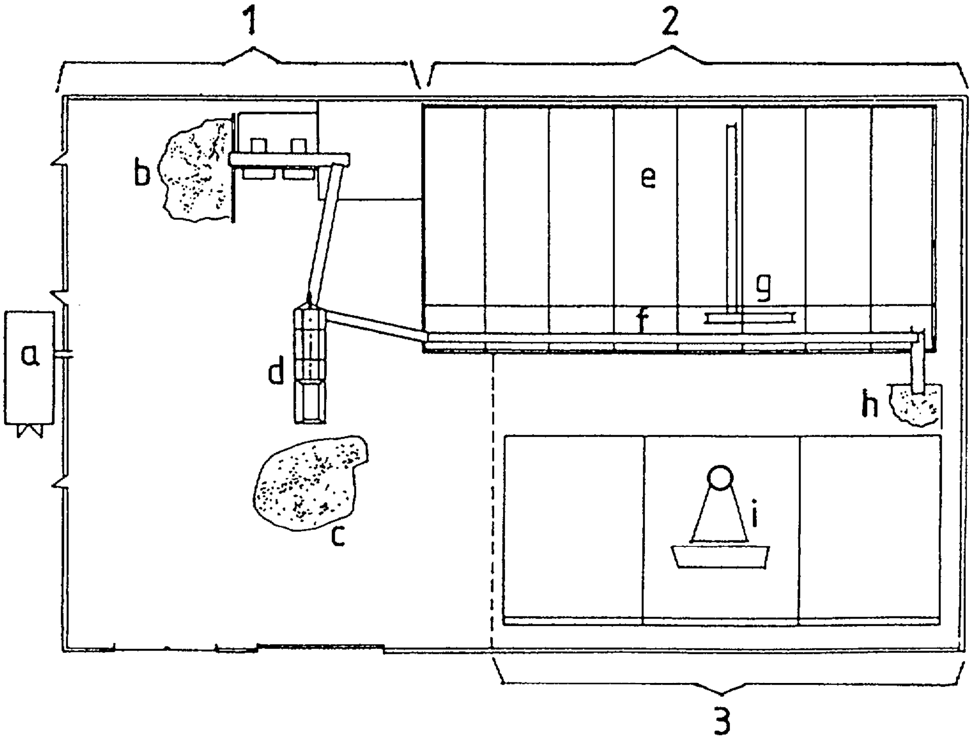
Delivery and processing area

This area serves the delivery, sorting and separation of impurities of the waste; it is divided into two separate treatment areas, namely one for biological waste (b) by means of a screening drum, a sorting belt and metal separation facility, as well as one for green waste, waste from industry or agriculture (c) with the additional use of a crushing machine. This division has the advantage that each of the two sorts of waste can be properly pre-treated, regarding their composition, before being put into the mixing and homogenizing drum (d) so that unnecessary work and costs are saved. Furthermore, correct pre-treatment is an important step in achieving a high composting quality.

Rotting area

This area is the heart of the plant in the case of the plant described here and on account of the required

Figure 1. Automatic composting plant



Key:

1 Delivery and processing area
2 Rotting area
3 Fine processing area

a Hall extraction fan
b Delivery area of biological waste
c Delivery area of green waste

d Homogenizing drum
e Rotting channel
f Feed-in area

g Rotating equipment
h Material discharge
i Sieve

capacity it consists of eight parallel rotting channels (e) with charging area, which are made of corrosion-free concrete and which are 12 m long, 5 m wide and 3 m high; this corresponds to an actual volume of 180 m³ per rotting channel or 1,400 m³ for the complete plant. The transformation of the collected waste materials into compost takes place in these channels. A shifting machine (g), which consists of: a horizontal spiral conveyor; an ascending spiral conveyor; a horizontal dividing spiral; a suspended frame as well as a watering device, provides for the rotation of the compost.

Fine processing area

To achieve a compost low in impurities and thus of a high quality, a technical fine processing line is used, which consists of a sieve device. The completely rotted material is after a short period of storage in the material discharge area (h), sieved using different sieve sizes (drum sieves with different hole sizes). Therefore several compost qualities can be produced for the individual areas of application.

Operation procedure

The operation procedure described here concerns an automatic composting plant with the following data:

Flow rate m³/a	24 000
of which:	
biological waste (m³/a)	13 600
green waste (m³/a)	10 400
Eight rotting channels with a total volume (m³)	1 440

To run the plant six persons with the following qualifications are required:

1 works manager
1 driver for the wheel loader
1 assistant
3 workers for the sorting section.

The process is divided into the following three stages: preparation; composting; and fine processing.

Delivery and preparation

The waste, separately delivered on vehicles according to whether it is biological or green waste, is registered and weighed and then deposited separately in the delivery area, generally in flat bunkers. For both types of waste there is a separate treatment.

The biological waste materials are taken by means of a conveyor belt to a screening drum; here they are loosened, homogenized and sorted. The sieve usually has a hole size of 60 mm in diameter. However, the screen lining is easily exchangeable, thus making it possible to react to the true structure of each individual waste material. The sieved part of the biological waste is taken via a conveyor belt to the mixing and homogenizing drum, before it proceeds to the next phase, the rotting area.

The sieve overflow, waste materials larger than 60 mm in diameter, are transported by conveyor belt to a sorting station; here recognizable impurities (non-compostable materials) are sorted out by hand and sent to a rubbish dump. After this the hand-sorted material passes under over-head magnets to separate the metal; the sorted metal objects are collected and proceed to further processing. After the removal of the metal the now "pure" biological waste is sent through a slow-running crushing aggregate, from where it is also taken, after an intermediate storage period, to the mixing and homogenizing drum. Parallel to the preparation of the biological waste materials there is the preparation of the green waste materials, which undergo only one stage of treatment, namely comminution in a shredder, before also being transported to the mixing and homogenizing drum. After remaining in the drum for approximately 30 minutes all the waste is transported by a conveyor belt to the next treatment phase, the rotting area; where the waste passes a metal separator, in order to eliminate the last pieces of metal, which were not sieved away at the beginning of the treatment.

Composting in the rotting area

In the rotting area, which consists of eight rotting channels, the transformation of the waste into compost takes place; this biological-chemical process lasts 8-10 weeks. It is therefore important, to prepare a time and feeding plan for charging the individual channels.

The rotting material, i.e. the pre-treated biological and green waste materials, is continually transported from the preparation area by conveyor belt to the charging area of the channel. It is dumped there and then taken up by an automatic shifting machine and distributed in the channel to be charged. This shifting machine, which is on rails and which can be moved to any position above each individual rotting channel, carries out not only the filling of the channel but also its mixing and discharging.

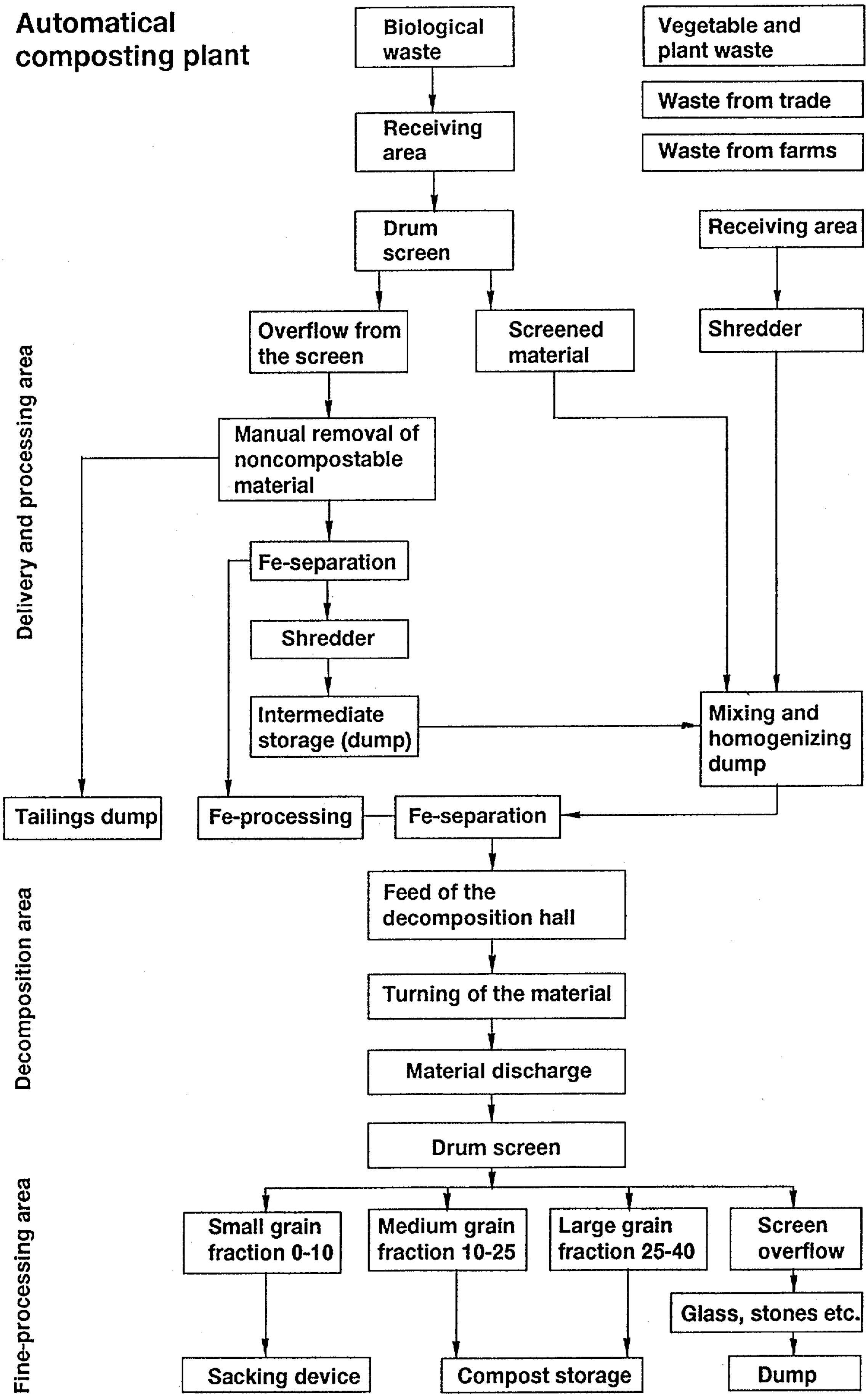
The composting process requires a regular mixing of the rotting material and, as it should take place aerobically, also requires a sufficient supply of oxygen and a sufficient dampness of the rotting material. The oxygen is supplied through a system which allows the individual ventilation of the rotting material in each separate channel depending on the temperature prevailing there. If the rotting material is too dry through ventilation, then watering is carried out by means of a watering device installed on the shifting machine. The temperature and the dampness of the rotting material are regularly controlled and registered.

After approximately 8-10 weeks storage of the waste in the rotting area, the composting process is ended and the fine processing phase can begin.

Fine processing phase

This processing phase serves to prepare the compost for use. The compost is removed from the rotting channel by the shifting machine, deposited in the material discharge area, and from there transported by means of a wheel loader to a screening drum with three fractions: a fine fraction (0-10 mm), a medium fraction (10-25 mm) and a rough fraction (25-40 mm). The fine fraction goes to a bagging installation, the other fractions, for reasons of quality and sale purposes, are transported to their own individual storage area for further use; this takes place either by means of a

Figure 2. Flow chart of an automatical composting plant

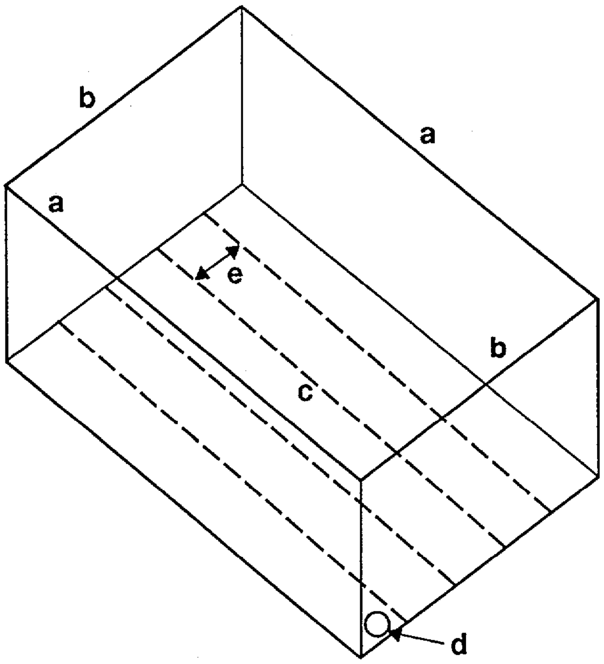


wheel loader or a conveyor belt. From the sieve overflow, stones, pieces of glass, etc., still contained in it, are separated; these materials are then deposited on a rubbish dump.

Description of the production of a rotting channel

An automatic composting plant comprises, as presented above, many aggregates, machines, etc. From these the production of a rotting channel with the following characteristics (see figure 3) has been chosen:

Figure 3. Rotting channel



Material: corrosion-free steel-reinforced

Method of building: for reasons of transport pre-fabricated concrete parts
2 side walls (a)
2 front walls (b)
1 floor (c)

Measurements:

Front wall: height 3 m
width 5 m

Side wall: height 3 m
length 12 m

Floor: length 12 m
width 5 m

The walls have a thickness of 10 cm; on one front wall at the bottom on the left there is a hole (diameter 25 cm (d)) for the in-take of the ventilation system.

The floor is 18 cm thick; in addition it has four longitudinal rows of slit-shaped openings (2.5 cm wide, 12 cm long (e)) to let the water out.

All other machines, systems and aggregates, belonging to a functionable automatic composting plant are delivered from outside and integrated into the plant on the site.

Description of the production process

The description of the production process concerns the manufacture of two front walls, two side walls and the floor for a rotting channel with the above-mentioned measurements in a concrete factory. In practice these parts are only produced according to demand or on order and their production has to be integrated into the daily production process of the factory.

The production process begins with the determination of the amounts of cement, gravel, sand and perhaps any necessary additional materials, which are required to produce in a mixer the necessary volume of concrete in the desired quality; also the amounts of steel armouring or necessary protective paint have to be calculated.

Parallel to concrete production—or even before—the preparation of the moulds for the individual channel walls and the channel floor can take place. This means that the steel armourings as well as the different recesses (on one front wall the circular opening for the ventilation connection, on the floor the longitudinal openings for the water flow) are prepared.

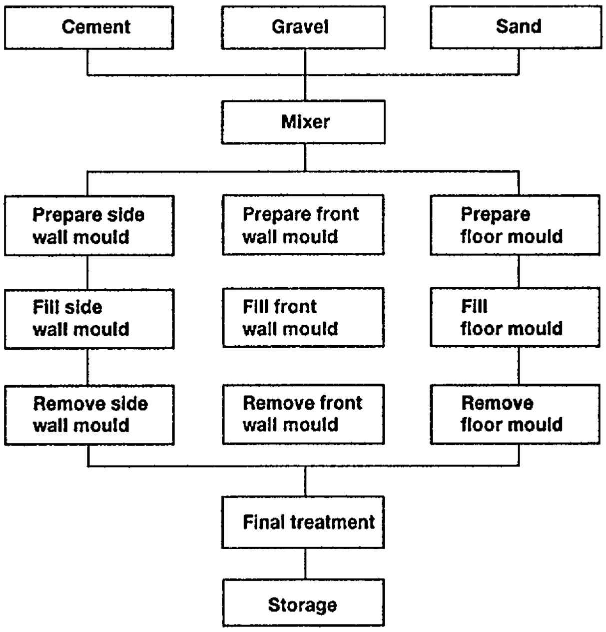
If, after taking a sample, the concrete is shown to have the required quality, then this is poured into the prepared moulds by means of a pouring bucket suspended from a crane and condensed through even vibration.

When the concrete has set, after approx. 48 hours, the moulds can be carefully removed; this is followed by the after-treatment. In this case any existing seams are removed. Special attention should be given to the circular recess on the one front wall and to the water exit slits in the channel floor.

Finally all produced parts are coated with a concrete-protecting paint; because of the relatively large surfaces it is advisable to use either a paint roller or a paint spray.

When the paint has dried all the prefabricated concrete parts can either be stored or prepared for transport to the site, where the rotting channel is assembled and fitted into the composting plant.

Figure 4. Flow chart



Example of a production plant

It has already been mentioned, that a concrete factory does not normally produce a rotting channel or rather the five prefabricated concrete parts each day, but instead integrates their manufacture according to demand into its production; for this reason it is not very easy to give exact details on the energy and personnel required for their specific manufacture. However, in order to obtain some basic values, it is presumed that the concrete factory only produces rotting channels and in this case three units per day.

Required machinery and equipment

Description	*Pieces*
Cement silo	1
Gravel/sand silo	1
Mixer	1
Casting moulds	15
Vibrators	5
Crane with pouring bucket	1
Fork-lift truck	1
Work-benches	3
FOB-price for machinery and equipment (1991)	Approx. US$ 2 million

Required manpower

Manager	1
Technical Manager	1
Economic Manager (also responsible for administration, accounting, advertising, etc.)	1
Administration personnel	2
Foreman	1
Skilled workers	2
Semi-skilled workers	4

Required buildings and areas

	Square metres
Production, total area	650
of which:	
Silos and mixer (outside, whereby the mixer should be covered by a roof)	330
After-treatment, assembly (in a hall)	320
Management and administration	110
Social facilities	140
Storage	250

Required energy

Electricity	230 kW
Water	60 m^3/day

Required area

Concrete		30 t/day
made up from:	40% gravel 25% sand 35% cement	
Steel		1.5 t/day
Paint		1.8 m^3/day

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Refuse sorting plant

Introduction

With progressing civilization the amount of refuse is also increasing drastically. It is collected by refuse trucks and transported to the rubbish dump. The volume of dumped material is constantly increasing. The refuse collected from households and general trade consists of many different materials, kitchen waste; paper; cardboard; textiles; leather; rubber; metal; glass; ceramics; plastics; etc. Of these materials, quite a number can be utilized or recycled; the precondition is, however, their separation from the other refuse and the existence of markets into which they can be absorbed.

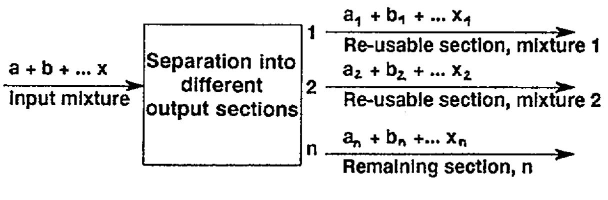
This separation can be carried out by conventional methods, i.e. in central or decentral sorting plants after collection and transport, or by new methods, i.e. the refuse is pre-sorted in the households or general trade into the desired groups of materials and then transported to special user or recycling firms.

In the latter case, a considerably smaller amount of refuse remains, which may be suitable for further separation, the type and extent of which, however, depending on the already separated usable materials.

The separation of the refuse can be carried out manually or mechanically, but an optimal separation is desirable. Against this, however, are economic as well as separation efficiency aspects. Separation efficiency not only depends on the separation aggregate but also on the characteristics of the materials.

Both from an ecological and an economic point of view, simple mechanical sorting plants seem to be the most sensible option, perhaps supplemented by manual sorting. Not only can the volume of refuse be diminished considerably, but a regaining of important valuable materials is also possible. This means schematically, that the input mixture can be separated into different output sections (see figure 1).

Figure 1. Scheme for separating waste



The output sections consist of product streams enriched with reusable materials and the remaining rubbish. Separation aims at diminishing as far as possible the number of remaining impurities in the reusable products. Possible reusable products for sorting are: paper and cardboard, tins, non-ferrous metals, glass, ceramics, paper and plastics usable for energy, composting materials.

It is very difficult to separate glass and plastics mechanically at a reasonable expense and with an acceptable quality of the product. The quality of the paper and cardboard is much lower in the case of collective refuse collection as against separate collection.

The use of mechanical sorting plants is, of course, only reasonable from a certain minimal collection amount onwards; below that level, pure manual sorting is the most sensible method.

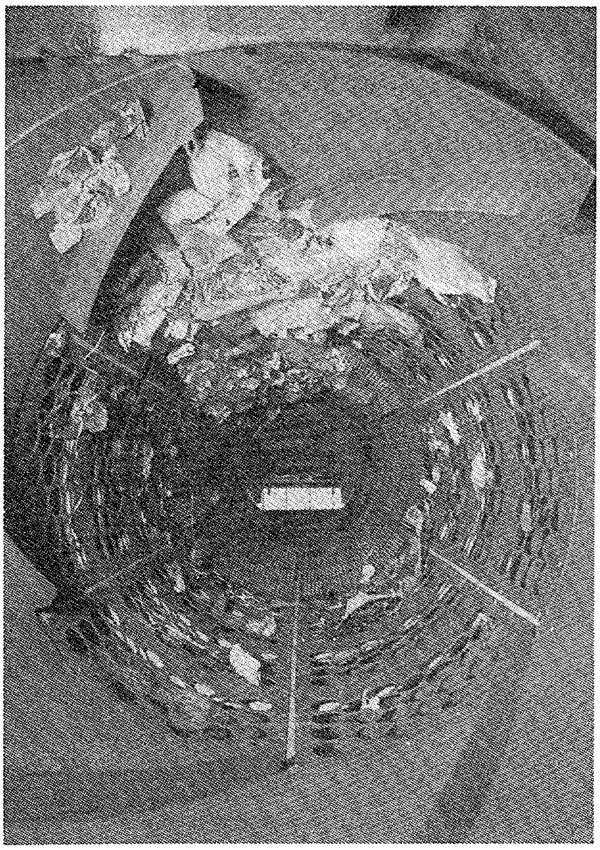
Basic process and machine arrangement

Strictly speaking for the sorting of reusable materials and reusable material mixtures, not only are sorting processes necessary, but also screening, comminuting, consolidating and even drying processes might be necessary. In addition to this, transportation, feeding and transfer equipment play an important role.

Comminuting steps are essential in the mechanical treatment of unsorted household refuse, whereas in the treatment of pre-sorted, reusable material mixtures they are only necessary under certain preconditions. As comminuting belongs to the cost, repair and maintenance-intensive process steps, this is avoided as far as possible. The following types of machines are basically used for comminuting:

Slow revolving cutting-shearing rollers;

Light hammer mills;



Specially prepared hammer mills (selective comminuting);

Cylinder mills.

Screening is an unavoidable part of sorting. Screening is necessary, for example for the separation of contaminating fine grain before sorting, or for the division of the reusable material streams into more easily sorted grain classes. Screening classification can be done by screening drums, grizzlies, and flat screens (vibration, swinging, cascade screens).

For the treatment of refuse, screening drums are mostly used as they can easily dissolve agglomerations, easily free single particles for screening, and are suitable for mixtures with round and plane parts.

Screening drums, however, require a lot of space and are relatively expensive. Furthermore, they create large amounts of broken glass, making it impossible for the glass to be sorted according to colour. Should the latter be required, flat screens have to be used.

A basic part of each refuse treatment plant is the *magnetic separation* of ferrous metals, mostly tins. For this separation magnetic rollers, and top belt magnets, crossways or parallel to the direction of flow are used.

For an efficient magnetic separation, it is important to lift out loose material, i.e. at the point of discharge from a device or at the point of transfer. Even then it cannot be avoided that some parts of rubbish are entrained with the removing of tins. This contamination can be diminished by a sensible arrangement of the single magnets within the top belt magnet separator as follows. The ferrous piece of metal to be removed is taken by the first magnet, but released again after a certain distance to a second magnet, which attracts the piece of metal immediately after its release. By this procedure, any loose contaminations can be removed to a certain degree from the piece of metal.

Depending on the field strength and the distance of the magnetic separator from the material to be sorted, different sorting aims can be achieved, as e.g. tins, crown caps, batteries or others.

Simple *blow-out processes* against or with the flow of material, e.g. at transfer points, at the screen discharge or at suction devices, are suitable to separate materials like plastic foils or sheets.

The separation of other sections, as for example, plastics and paper or glass and paper as well as the separation of paper/cardboard, plastic mixtures and non-ferrous metals can still best be done manually.

Example of a simple refuse sorting plant

An economical start in the mechanical sorting of refuse should comprise of screening, magnetic separation, and manual sorting.

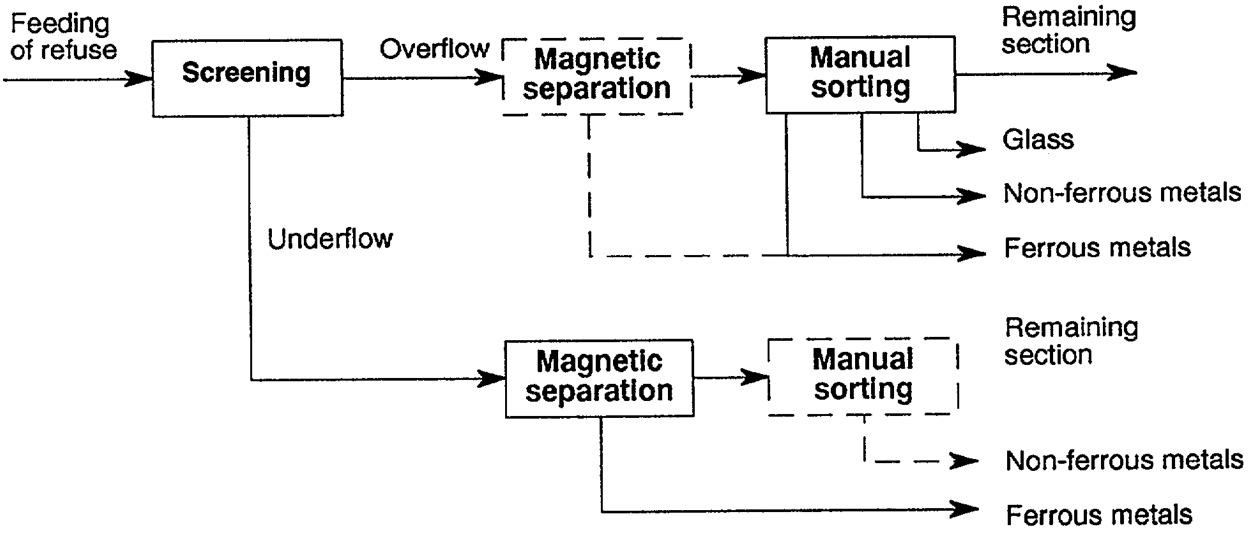
A hall with a width of about 40 metres and a length of about 70 metres is optimal for the arrangement of the machines and offers enough space for deliveries and products.

The separation process is shown in figure 2. The plant comprises of a refuse feeding installation which takes up the dumped refuse. This consists of a plane bunker with bunker plate from where a wheel loader pushes the refuse onto an underfloor conveyor belt. The driver of the wheel loader should also have the task of removing bulky parts before they enter the installation and of loading them into containers set out for this purpose.

The refuse is fed from the underfloor conveyor belt via a following ascending belt to the screening drum: the first separating stage of the plant. Sorting is done by means of the round holes in the drum, the optimal diameters being between 100 and 180 mm, depending on the refuse structure. Through baffles built into the drum, closed bags should be opened during the revolving movement, thus freeing their content. The screening drum has to be dimensioned according to the amount of refuse and the task of separation.

The further treatment of the overflow and underflow of the screen is carried out in two parallel processes. The *overflow section* is discharged into a sorting station: a large sorting belt from where glass, ferrous, non-ferrous metals and other inert materials are removed either for re-use or for the dump.

Figure 2. Refuse sorting plant



At the point of transfer to the sorting station, a top-belt magnetic separator may be installed for the mechanical separation of ferrous metals.

The remaining stream represents the fuel section, which can, after the necessary further treatment (comminution, packing press), be fed into an incineration plant.

By the installing of further equipment, the sorting plant offers the possibility of also separating paper and plastics for re-use.

The *underflow section,* mostly organic material, is taken by means of a conveyor belt to the top belt magnetic separator (possibly multipole), positioned at the end of the belt, which removes the ferrous metal parts crossways to the conveyor belt and deposits them into a container.

The remaining underflow stream is either transported directly to the dump via open containers or is brought there after passing along a small sorting belt to allow the extraction of the remaining non-ferrous metals.

By extending the plant it is possible to use the underflow of the screen for composting. In this case, a second screening drum is installed behind the magnetic separator. The overflow of this screening process is dumped, while the underflow, representing the compostable material, is transported into composting reactors. The compost produced can, in most cases however, only be used for subordinate purposes (e.g. covering the dump).

According to the structure of the remaining stream of refuse, a comminuting of the material might also be necessary. For this, an impact tearing machine can be used.

Dimensioning

The plant has to be dimensioned according to the amount of refuse to be treated. There is no calculation formula in existence, only figures gained from experience of the different producers. However, these are only guidelines, as not only the volume but also the composition of the refuse play an important role.

Concerning the screening drum, the following dimensions will be necessary for a throughflow of 5-10 t/h:

Length of the drum: 6 m
Diameter of the drum: 2 m
Diameter of the holes: 120 mm (1st half of the drum)
180 mm (2nd half of the drum)

However, it has to be taken into consideration that, besides the outside dimensions of the drum and the diameter of the holes, the throughflow and the separating efficiency are also determined by the rotating speed, the built-in baffles, the angle of inclination, humidity and the characteristics of the material to be screened. In order to prevent clogging it may be necessary to install certain screening aids, such as brushes or other gadgets.

In order to increase the effective screening area, suitable carrier plates are installed to take the material to be screened as far as possible to the top of the drum. These carrier plates can, with the corresponding construction, also be used for transporting the material through the drum, so that the angle of inclination of the screening drum can be reduced to 0^0.

There are some basic rules which can be given for the technical design of screening drums:

Drum load	$\leq 0{,}1$ Mg/m^2
Duration time	25-30 s in the case of un-comminuted refuse
Rotation speed	~ 45 % of critical speed
Hole diameter	> 10 mm

Magnetic separation involves top-belt magnets which extract ferrous metals from the refuse. A precondition for effectiveness is the ferrous metals having been comminuted and thus, to a large extent, separately fed to the magnets. There is no limit to the size of the ferrous metals, since magnets are available for extracting almost all weights. However, the most suitable particle size for magnetic separation of household refuse is 10-100 mm.

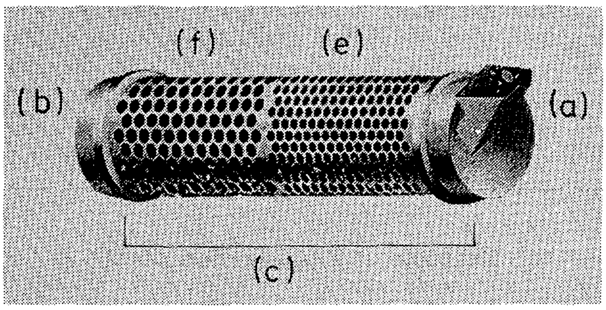
Manual separation takes place on a sorting belt. For the accepted refuse throughflow of 5-10 t/h, 4 to 6 workers are required to remove foreign bodies without hindering the separation process.

Description of the product to be manufactured

As previously mentioned, the classic separating aggregate in a modern sorting plant is the screening drum, the construction of which is outlined in figure 3. A stainless, high-quality steel drum serves as a screen. At one end of the drum is a joining ring (for the driving aggregate and feeding-in of material) (a) and at the other an end ring (for discharge of the screen overflow) (b). The drum is divided into two halves, each with equidistant holes; the holes of the first half being smaller than those of the second half. The screening drum to be constructed requires the following dimensions:

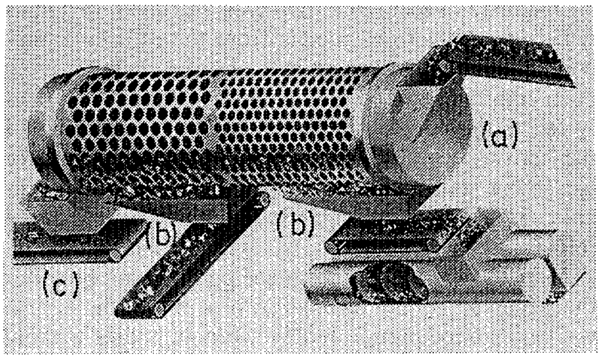
Length of drum: 6 m (c)
Diameter of drum: 2 m (d)
Diameter of holes (1st half): 120 mm (e)
Diameter of holes (2nd half): 180 mm (f)
Steel thickness: 5 mm

Figure 3. Screening drum



The necessary auxiliary equipment for making the drum operational is delivered separately and fitted to the drum at the place of operation. As can be seen from figure 4, this means the driving aggregate and the material feed-in are fitted to the joining ring (a). The refuse to be sorted enters the material feed-in via a conveyor belt. On the underside of the drum, two underflow containers are fitted, one for each of the two sections with different hole diameters. The screened material falls into these containers and is consequently transported by belt on for further processing. The material discharger, into which the overflow falls, is fitted to the underside of the end ring. The overflow is also transported by belt to the next processing stage.

Figure 4. Operation of screening drum



Description of the production process

The first production stage is the exact calculation of the dimensions of the stainless steel plate out of which the screening drum is to be formed. Equally important is the calculation of the number and position of the holes of different diameters which are to be cut out of the drum.

This having been done, the stainless steel plate is cut to the required size with a cutting torch. Subsequently the different sized holes are cut out in the same way. After the steel plate has cooled down it is given after-treatment (smoothing down of any possible burrs) and the holes are inspected to check the diameter and spacing.

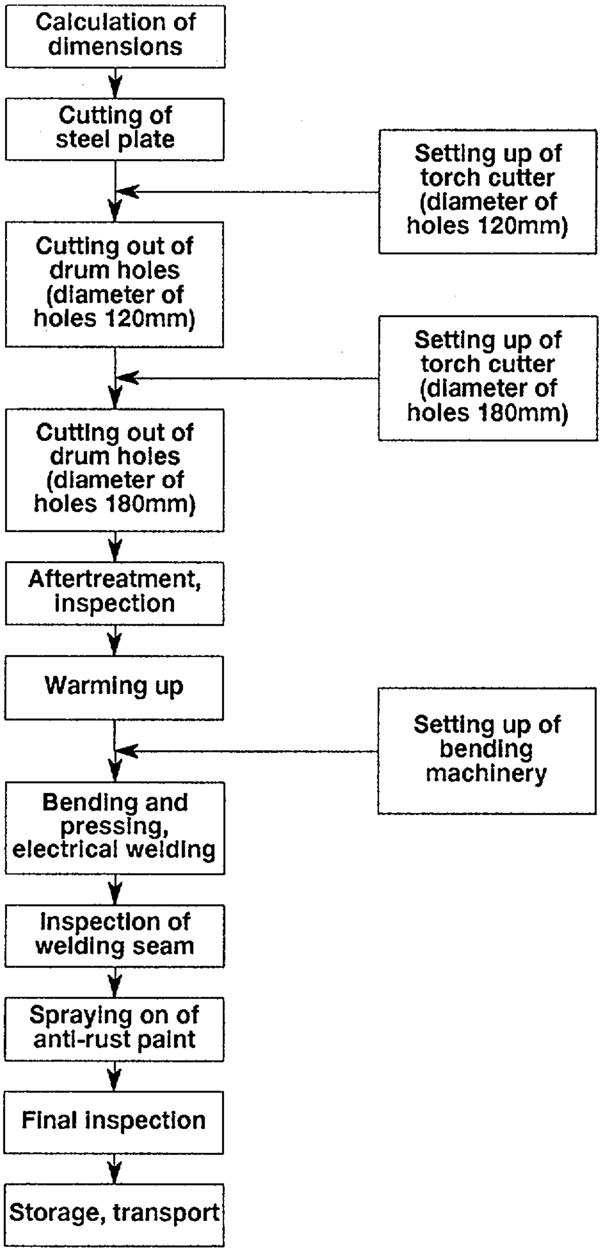
By crane, the steel plate is then lifted to the next processing stage: an electric heating apparatus for warming up the steel in order to increase its bending and tensile properties. This is necessary, since afterwards the steel plate is formed into its cylindrical shape by a bending machine which has been set up to correspond with the dimensions of the drum to be produced. Subsequently, the cylinder is electrically welded along the join of the two long sides.

Before the drum is removed, the welded seam is inspected to ensure perfect cohesion. This being so, the drum is removed by crane and taken to the last processing stage where it is sprayed with a rust-resisting paint. After drying and final inspection, the drum can go to the storage depot or be prepared for transport.

Example of a production plant

Screening drums are produced in the metalworking industry, whereby the relevant firms concentrate more heavily on products other than screening drums. The latter are only produced on special demand and have to be fitted into the regular, daily production programme. For this reason, it is not possible to give exact figures regarding, e.g. personnel and energy requirements for the production of a screening drum. However, in order to procure reliable data, it is assumed that a firm is producing screening drums only, i.e. 2 units in the course of an 8-hour working day.

Figure 5. Flow chart



Required machinery and equipment

Description	*Pieces*
Autogenous welding and cutting apparatus	1
Electric furnace	1
Bending machine with integrated electric welding apparatus	1
Crane	1
Work benches	3
Drawing table	1
Colour-mixing machine	1

FOB-Price for machinery and equipment: Approx. US$ 3.0 million

Required manpower

Technical manager	1
Administrative manager	1
Administrative staff	2
Foreman (metalworking)	1
Skilled workers	3
Unskilled workers	5

Required area

	Square metres
Production hall	200
Management and administration	100
Social rooms	120
Storage	300

Required energy

Electricity	60 kW
Water	
Oxygen, acetylene	

Required inputs

Stainless steel plates
Joining ring
End ring
Electric motor
Charging funnel
Discharging section
Underflow containers
Conveyor belts
Electrodes
Rust-resisting paint

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Hazardous waste incineration

Introduction

With increasing population, industrialization and production of goods, the amount of hazardous waste in the form of solid, liquid, pasty or gaseous material continues to rise, which adds to environmental pollution. More often than not this waste comprises organic materials which, for thermodynamic reasons, cannot be destroyed or eliminated directly. For this reason it is necessary to convert them into other materials which pollute to the least possible extent the water, soil and air.

The amount of hazardous waste, comprising some 1,000-2,000 different types, produced by large-scale chemical plants is mostly so great, that works-own incinerators are employed for disposing of and converting this waste. In practice, therefore, the question can be asked what is hazardous waste. Based on chemical criteria, hazardous waste constitutes:

Residual matter containing halogen, nitrogen, sulphur, phosphorus, chlorine, silicon, metals, etc.;

Mixtures of small amounts of different residues of largely unknown composition;

Toxic, self-igniting, spontaneously disintegrating or polymerizing wastes;

Highly reactive wastes which react spontaneously with other waste materials or which have a highly corrosive effect.

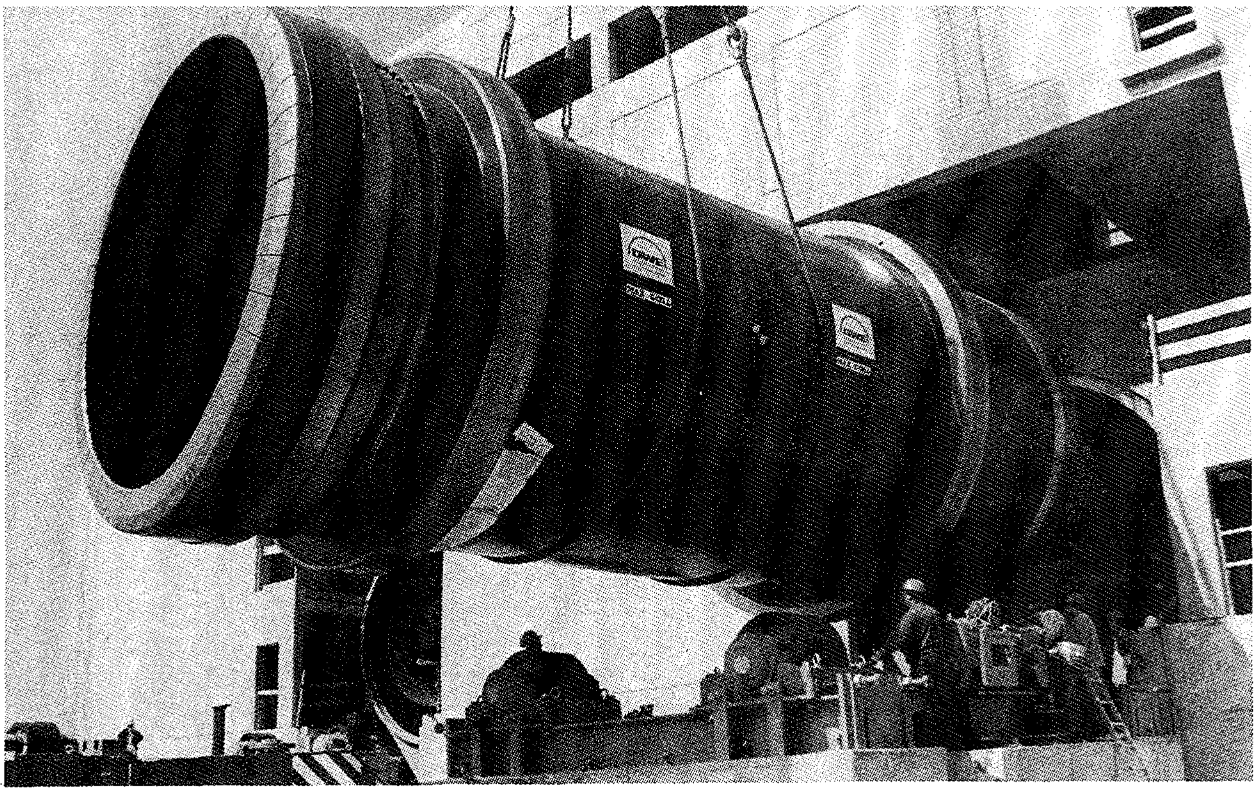
A classification based on physical criteria mainly deals with the following states: solid; pasty; liquid; gaseous. Prior to further handling, treatment, mixing and storage, all types of waste must be carefully examined, analyzed and classified, in order to determine the most suitable method of incineration and optimal conversion regarding the requirements of environmental protection.

By means of thermal conversion (incineration), the greater part of all dangerously toxic materials is converted into harmless products in such a way that the volume of the waste is reduced to about 5-10% of the original.

Description of the process

Experience gained from the thermal conversion of hazardous waste during recent decades enables us today to carry out incineration in such a way that the products of combustion meet the requirements of environmental protection. Various types of incinerators are employed for the disposal of waste depending on its physical condition.

Rotary kilns are an optimal solution to the problem of burning hazardous waste with a differing consistency. The kiln is most flexible in operation whatever the charging conditions. One or several additional burners may be required depending on the calorific value and



ignition properties of the hazardous waste to be handled. Nowadays, rotary kiln based incineration plants, with heating and auxiliary burners fitted in the kiln front face, are universally used for liquids having particularly high contents of ash and dust.

Incineration plants are designed to guarantee the fulfillment of all demands, such as high incineration temperatures in excess of 1,200 °C, high excess air, a minimum O_2 content of 6% in the flue gas, and a retention time of 4 seconds at these temperatures, without appreciable heat loss. As a result, chlorinated hydrocarbons, askarels and other substances containing a high proportion of polychlorinated biphenyls are fully converted without the formation of TCDD (tetrachloride benzodioxine) or other dioxin or furane derivatives.

The products remaining after combustion are in each case, and over the entire load range of the incineration plant, in line with the requirements of environmental protection, i.e. dust less than 30 mg/m^3, chlorine compounds less than 50 mg/m^3, fluorine compounds less than 2 mg/m^3, carbon monoxide less than 100 mg/m^3, carbon compounds (organic matter) less than 20 mg/m^3, and SO_2 and SO_3 less than 100 mg/m^3.

Hazardous waste high-temperature incineration pursues the main objective of converting the refuse material into flue gases and slag or ash as the final products, thus eliminating the previous pollution risk to the environment.

Rotary kilns have been used frequently for the incineration of industrial waste. Basically all organic residues from production can be incinerated in these kilns independent of the consistency and the condition of the aggregate. The combustion in the rotary kiln goes through the usual stages of draining, de-gassing, and combustion. According to the type of waste the incineration temperature is high enough to guarantee that all organic waste is completely burned after an appropriate time. All gaseous elements of the waste leave the rotary kiln and go to the post-combustion chamber, where they are optimally burned out with the help of additional gaseous or liquid fuels of high thermal power.

Product description

Hazardous waste incineration plants essentially comprise of the following:

Feeding and batching facilities;

Incinerator (kiln);

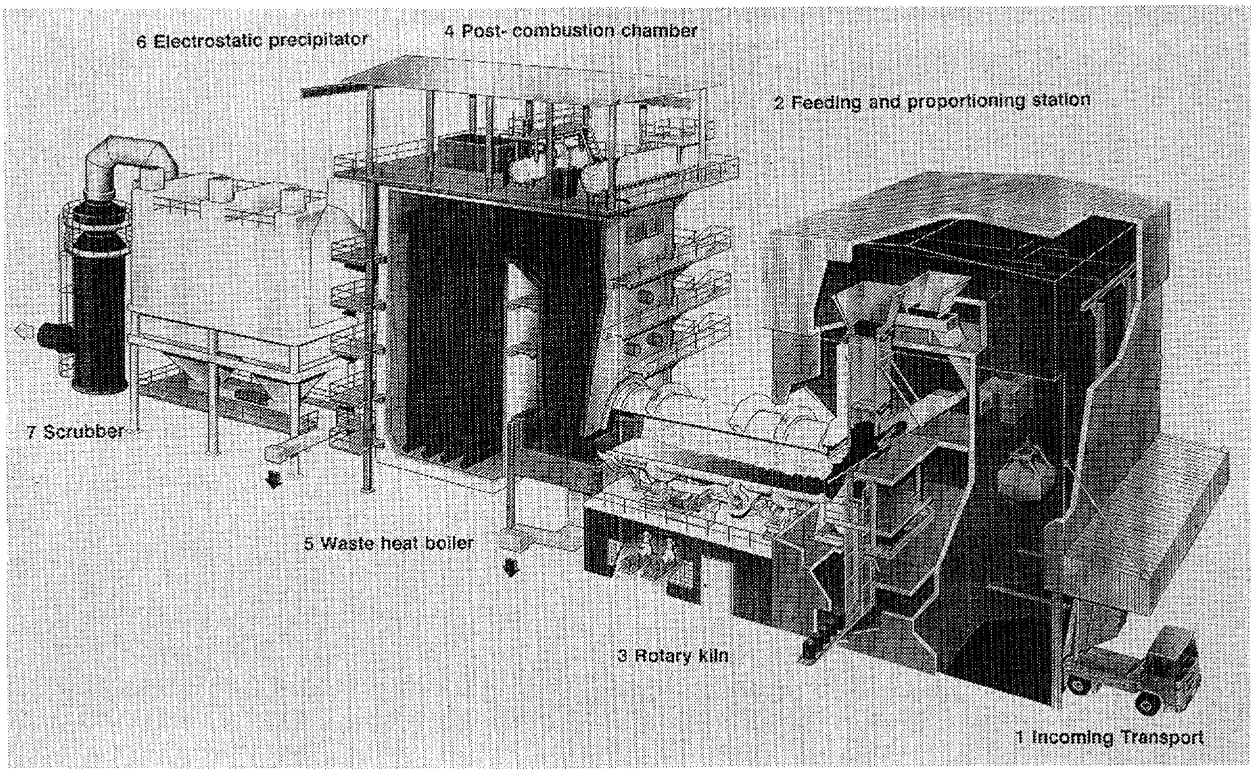
Post-combustion chamber;

Waste-heat boiler;

Flue gas cleaning system, and supply and disposal equipment.

Depending on the condition of the aggregate or the consistency of the waste to be incinerated—i.e. solid, liquid, pasty, or gaseous—the following furnaces can be employed for incineration: combustion chambers; fluidized bed kilns; rotary kilns; and burner systems in post-combustion chambers. In this paper we shall only deal with rotary kiln-based plants, as they are universally used for incinerating special waste of fluctuating chemical composition and consistency.

Figure 1. Incineration plant for hazardous waste



Hazardous waste storage, preparation and proportioning

The great variety of industrial waste materials to be destroyed in an incineration process, including tar and paint residues, refuse containing oil, acid tars, chemical sludge, solvents, or askarels, require extremely diversified material storage facilities with the appropriate handling and preparation equipment. Particular attention has to be paid to the chemico-physical properties of the refuse material. This aspect must also be considered regarding the charging and proportioning facilities, which are to permit the continuous and uniform charging of every kind of refuse material, in terms of quantity and calorific value, into the rotary kiln in order to ensure complete incineration.

Rotary kiln

Forming the key installation of the incineration plant, the rotary kiln is meant for the simultaneous combustion of solid, pasty, liquid and gaseous waste. It is amply dimensioned to ensure that even with peak loads—which may exceed the maximum—the specific kiln chamber load and flue gas velocity are relatively low and that a complete combustion of the waste can take place.

The kiln is slightly tilted in the longitudinal direction and lined with a refractory material which permits operation both with dry ash and fluid slag, thus affording a certain flexibility and ability to cope with varying temperatures. The highly heat-loaded discharge end of the kiln is designed as an air-cooled, heat-resistant shell section. This shell section is fitted with a machined buckstay on which the resilient and self-adjusting sealing segments move. The feed side of the kiln is likewise fitted with an identical sealing system which is maintenance-free and which keeps the ingress of secondary air down to a minimum.

The kiln rotates on two cast steel riding rings supported on rollers. A longitudinal shifting system makes for a uniform wear of the rollers. The kiln is driven via a gear rim (spring-mounted on kiln shell), a pinion, a reducer, and a (controlled) electric motor. For emergency operation of the kiln, it is customary to provide an auxiliary drive in the form of a second electric motor, diesel engine or on air-operated motor.

Longitudinal kiln shifting system. The position of the rotary kiln can be fixed in the longitudinal direction by means of a pressure roller station. The disadvantage of this method is that the riding rings are forced centrally on the running rollers and, as a result are exposed to uneven wear. In order to achieve an even loading of the running rollers, a longitudinal kiln shifting system is provided which absorbs the axial forces of the kiln and causes the kiln to undergo a reciprocating movement. This movement is brought about with the help of two hydraulically actuated special rollers acting on the faces of the front riding ring. Virtually maintenance-free, this system also prevents the riding rings from interfering with the running rollers.

Kiln design and lining life. Irrespective of the stresses to which the kiln lining is subjected during incineration of corrosive and abrasive waste, the life of the lining is not inconsiderably affected by the mechanical concept of the kiln, i.e. by the design, the strength values and the deformation undergone by the kiln during operation. In particular, the oval deformation must not exceed 0.3%, in relation to the kiln shell diameter, in the case of a properly dimensioned kiln. Another criterion for the life of the lining is the sag of the kiln in the longitudinal axis, which is of the order of 0.002 mm of the bearing spacing and which is taken into account in selecting the shell thickness.

In general, rotary kilns in hazardous waste incineration plants operate under the following conditions:

Incineration temperatures around 1,200 °C, in some cases even over 1,400 °C;

Gas velocity in kiln: about 5 m/s;

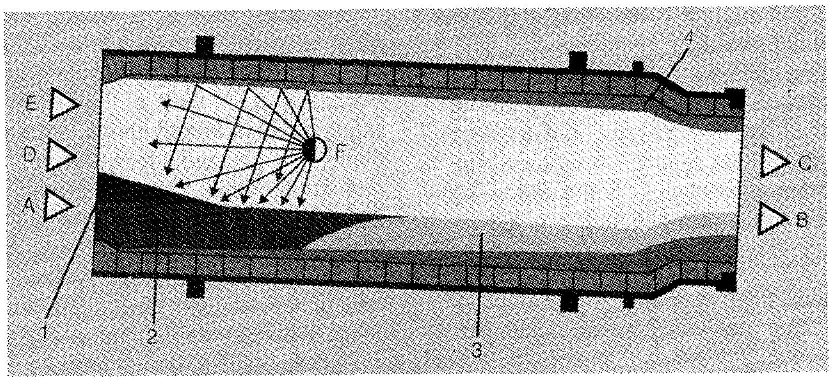
Thermal combustion chamber loading: 0.4-max. 0.6 GJ/m^{3}h;

Thermal cross-sectional loading: 6-max. 8 GJ/m^{2}h;

Dwell period of waste in kiln: 0.5-2 h;

Excess air: 1.6-2.5 m^3/s.

Figure 2. Rotary kiln



Key:

A Waste/feeding
B Ash/slag/discharge
C Flue gases
D Additional burners
E Combustion air
F Incineration temperature

1 Waste
2 Waste to be burned
3 Ash/slag
4 Slag coating

Kiln lining. The lining of the rotary kiln is exposed to chemical, mechanical and thermal stresses caused simultaneously by hazardous waste, slag, combustion gases and mechanical forces arising from the rotary movement of the kiln.

A very significant feature is the change in the composition of the slag over the length of the rotary kiln. Various components, such as for example, certain Na, K, Si, Mg compounds, get dissociated or evaporated, causing an increase in the slag melting point over the length of the kiln. All this results in a maximization of the load on the refractory lining in the last zone of the kiln.

In the case of an incineration with wet deslagging, it must be noted that for all slag components there is only a certain temperature range between liquefaction and sublimation with the result that, with an increasing combustion chamber temperature, higher slag melting temperatures are to be expected. It is also quite possible that a part of these compounds recondenses on cold parts of the kiln, again leading to lower slag melting points.

To build up and retain a slag coating, it is important that very high temperature peaks are avoided in as far as drums containing high-calorific waste should only be partly filled before being fed into the kiln, and that the desired viscosity of the slag coating at temperatures of around 1,200 °C and over can be achieved by the addition of sand and glass.

Post-combustion chamber

Some of the gas components produced during the incineration of organic compounds in the rotary kiln have such a high thermal stability that a complete combustion in the rotary kiln is not possible. For this reason, a post-combustion chamber must be provided downstream of the kiln for the incineration of hazardous waste, where a complete combustion of the flue gases is obtained at high temperatures, with long retention times and with a suitable supply of air. The design of the post-combustion chamber and the arrangement of the burners in it are such that a complete mixing of the flue gases from the rotary kiln with those generated in the post-combustion chamber is achieved and an almost homogeneous gas mixture is fed into the waste-heat boiler located downstream.

The post-combustion chamber is designed to first of all allow the flue gases coming from the rotary kiln to expand on entry before rising upwards, and to keep gas velocity very much lower than in the rotary kiln. In designing post-combustion chambers the following parameters have to be taken into account:

Combustion temperatures: from 1,200-1,400 °C;

Gas velocities (theoretical) referring to the over-all cross-section of the post-combustion chamber: 2-4 m/s;

Thermal combustion chamber load: 0.4-0.6 GJ/m^{3}h;

Thermal cross-sectional load: 5-12 GJ/m^{2}h;

Theoretical dwelling time of flue gases in the post-combustion chamber, measured from the last burner level up to boiler entry: 4-6 s.

Underneath the post-combustion chamber and in the area of the rotary kiln discharge, a wet de-slagger is usually provided to remove the ash/slag from the rotary kiln and the post-combustion chamber. Suitable air locks are provided to secure a tight seal against the atmosphere.

Waste-heat boiler

The waste-heat boiler is employed for cooling the flue gases, at the same time utilizing their heat for the generation and superheating of steam. The combined arrangement of hazardous-waste incineration and waste-heat recovery facilities makes special demands on the waste-heat boiler. Experiences from conventional boiler-making are only of limited use.

The boiler must be extremely flexible in its operating mode to cope with differences in heat input from the various furnaces and the inherent load changes. These load variations may well come up to more than 20%/min.

The post-combustion chamber merges with the waste-heat boiler, the design of which is such that the flue gases can enter it at a high temperature (1,200-1,400 °C) without the need of being cooled down by air or by water injection. This results in a high boiler efficiency and operational economy.

The flue gas produced through the incineration of hazardous waste material can never, for obvious reasons, be quite free from pollutants, such as dust, aerosols, hydrogen chloride (HCl), sulphur dioxide (SO_2), hydrogen fluoride (HF), nitric oxides (NO_x) and heavy metals.

Emissions from the flue gas cleaning system should be well below the limit values stipulated by law. The cleaning process can be reliably implemented by mechanical means, electric processes, or a variety of absorption methods. To achieve an optimal result by the most economical approach, various basic processes are often combined to create an over-all flue gas cleaning facility.

Dimensioning

The main task of a hazardous waste incineration plant is to convert the waste into end products which do not pollute the environment and can therefore be stored safely. In view of their impact on environmental safety, as highlighted above, special waste incineration plants are planned, designed and operated with very meticulous care. The design and arrangement of the various equipment must take account of operational safety, efficiency, and economy. As a result, incineration plants must fulfil the following demands: utilization of waste heat; high availability; low operational costs; and reasonable capital outlay.

Another aspect, which must be taken into account at the design stage, is the changing nature of the waste to be disposed of. It is very common to have to handle different kinds of waste at short notice, so that the special waste incineration plant must have a high degree of flexibility to deal with fluctuating waste compositions. In order to meet the above-mentioned demands, which are put on incineration plants, it is necessary to inspect, analyse, treat and store the waste in a suitable manner, prior to its disposal.

The essential initial values for the dimensioning of a hazardous waste incineration plant are the quantity and combination of the material to be burned. It is difficult to find out these initial values i.e. regarding the flow rate and the physical and chemical characteristic features of the materials and regarding the proportion of the groups of materials to each other. The hazardous waste incineration plants are thus equipped as flexibly as possible.

If there are no more exact details, then it has proved advisable for universal hazardous waste incineration plants to reckon each time with a third of the whole quantity for solid, pasty and liquid waste. The spectrum of the thermal power should be as follows:

Solid waste: 0-16,800 kJ/kg, average value 10,500 kJ/kg;
Pasty waste: 0-25,200 kJ/kg, average value 14,700 kJ/kg;
Liquid waste: 0-42,000 kJ/kg, average value 25,200 kJ/kg.

The dimensioning of the combustion air and the flue gas system is necessarily based on average values. Therefore the different incinerating characteristics of the waste components have to be adjusted. This is done by preparing and mixing before incineration as well as by separately using liquid, pasty and solid fuels.

Usually both possibilities are chosen. Thereby the constant thermal degree of utilization is guaranteed. In the case of universal hazardous waste incinerating plants the different types of waste are not being mixed before putting them into the incinerating system as the separate incinerators can be used for regulation during the liquid phase.

Description of the production process

To build a rotary kiln incineration plant, general workshop equipment is required for the tank construction and apparatus engineering. The production and delivery time for a whole plant is about 18 months, for a rotary kiln alone about 12 months. The entire plant consists of the following components.

Cone for delivery, storing and sorting out. The cone is equipped with all necessary feeding and batching facilities (bridge crane fitted with an orange-peel bucket, dosing chain conveyor, weighing system).

Rotary feeding with barrel elevator and transfer canal. The movable front face, mounted on a travelling car, constitutes the principal item of the furnace feeding system. Refractory-lined, it seals off the rotary kiln at the feeding end. All equipment required for the incineration process such as feed shute, drum feeding system, burners, automatic burner control, flame monitors and combustion-air supply system, is prefabricated and installed on the site.

Rotary container (approx. 4.5 × 12 m, weight approx. 130 t). The furnace is delivered in a prefabricated form and is installed on the site. Simultaneously the driving machinery (gear rim, pinion, reducer, electric motor etc.) is installed. The furnace is lined with fireproof bricks at the site.

Post-combustion chamber with lining. The sheet elements are prefabricated in the workshop and bent to shell elements. They are welded to courses on site.

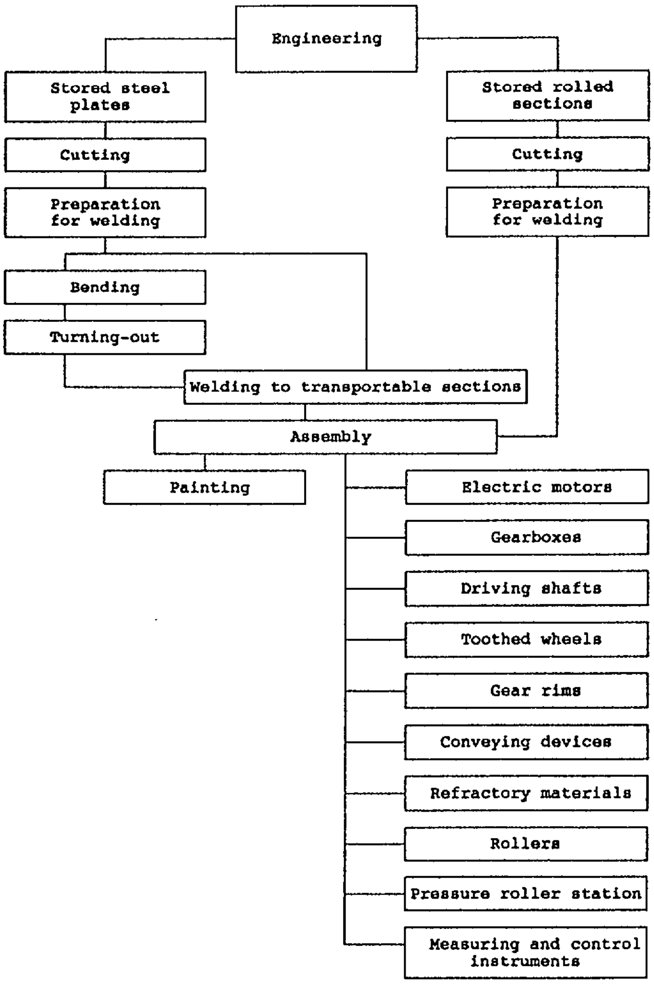
Wet de-slagger. The wet de-slagger is prefabricated in the workshop including the assembly of the driving gear.

According to the availability of the components on the market the manufacturing company will take on the parts not offered elsewhere. In the present case the rotary kiln and the actual rotary feedings are manufactured by the company.

The steel sheets bought from outside with a thickness of approx. 10-20 mm are cut to size with a flame cutting machine and the corresponding edges are prepared for welding. The parts to be bent are brought to a bending machine. Then the coat of the rotary kiln as well as the necessary stiffenings are welded on the dolly. Having finished the rotary kiln blank it is hollowed out by turning it on the facing lathe in order to obtain a perfect curve everywhere.

Simultaneously, whilst manufacturing the rotary kiln, the rotary feeding is welded into transportable parts. In a further part of the production the necessary steel profiles are cut and prepared for welding. They are necessary for the supporting framework.

Figure 3. Flow chart



The self-produced parts of the plant are brought to the location of the hazardous waste incineration plant and are fitted and erected in the final position. In addition further equipment, components and elements bought from outside, such as electric motors and gearing, motor shafts, toothed wheels, gear rims, measuring and control instruments, conveying devices as well as the fireproof bricks necessary for lining the rotary kiln and the charging system, fireproof mortar and monolithic lining material, are also brought to the site. Only then are the above-mentioned components fitted and assembled to an entire plant.

Example of a production plant

Required machinery and equipment

Description	*Pieces*
Flame cutting machine	1
Bending machine	1
Welding machine	2
Welding apparatus	3
Cutting installation	2
Grinding machine	3
Facing lathe with at least 6000 mm turning diameter and approx. 14000 mm turning height	1
Drilling machine	2
Dolly machine with driven roller	1
Workbenches	5
Crane	1
Fork lift truck (5 tonne)	1

FOB-price for machinery and equipment (1993) Approx. US$ 2,100,000

Required manpower

Manager	1
Works engineer	1
Engineer (works preparation and control)	1
Managerial and administration staff	4
Foreman	2
Welders	5
Metalworkers	12
Semi-skilled workers	10
Electricians	2
Painters	2
Assembly and installation	
Foreman	1
Metalworkers	5
Electricians	2
Bricklayer	1
Painter	1

Required area

	Square metres
Production hall	1200
inside storage	200
Administration and facilities	250

Required energy

Electric power	300 kW

Required inputs

Steel plates (10-20 mm)
Rolled steel sections
Electric Motors
Gearboxes
Bearings
Driving shafts
Toothed wheels
Gear rims
Electrical material
Measuring and control systems
Conveying devices
Refractory materials
Rollers
Switch and control cubicle
Pressure roller station
Paints
Welding material

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How to Start Manufacturing Industries

Sewage sludge incineration

Introduction

The protection of lakes, rivers, seas and underground water as well as legal regulations is imposing ever more complex demands on the efficiency of waste management systems. In the field of waste water treatment it means that high demands are made on the quality of the cleaned waste water. In particular in congested areas, large quantities of sewage sludge are occurring, which are in addition often highly polluted with heavy metals and other toxic substances.

Traditional waste disposal methods, such as composting, land-filling, ocean dumping and the use of sewage sludge as a fertilizer in agriculture, are facing ever increasing restrictions. As a result, the thermal treatment of waste has been gaining central importance, as it provides an efficient means of reducing the large volumes of waste to small quantities of inert ash. Combustion of sewage sludge is considered to be a technically appropriate and proved non-polluting form of disposal. The slag arising from the combustion is free of organic harmful substances and almost inert. It can easily be disposed of or recycled as building material.

Of the incinerator systems available for the treatment of such waste, multiple hearth and fluidized bed furnaces have proved to be the most efficient, as they both offer maximum exposure of the solids' surface to the gas phase and a large area of refractory radiation for water evaporation. Multiple hearth and fluidized bed incinerators are employed for burning all kinds of sewage sludge from municipal and/or industrial waste water treatment plants, shredded household refuse in combination with sewage sludge, oily and greasy wastes, grit, bark, and sludge from pulp and paper production.

When burning the sewage sludge the following steps have to be carried out either separately or together: mechanical dewatering of the sludge and its processing; thermal drying; incineration; and further utilization of residues. The aim of sludge and residue incineration is to reduce the volume to a minimum.

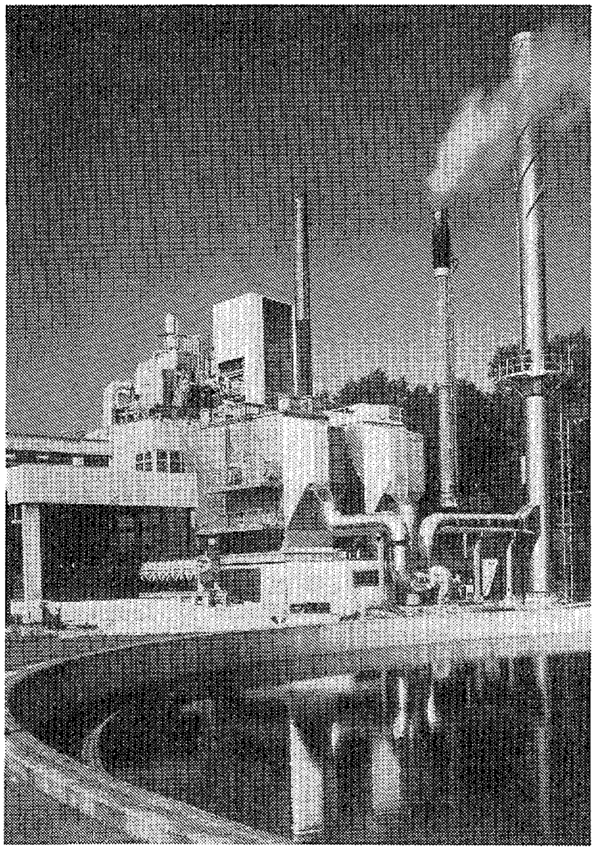
The incineration of sewage sludge is nowadays usually preceded by draining or the drying is integrated into the incineration process. Especially firing temperatures, insufficient for effective exhaust deodorizing, cause process-technological problems, when burning merely mechanically pre-desiccated sewage sludge or even wet sludge. Exhaust vapours are arising, which have to be handled; furthermore a considerable amount of secondary energy might be necessary in order to vaporize the sludge liquor.

For the thermal treatment of sewage sludge different incineration methods are available. In practice manufacturers offer complete plants for draining and incineration due to the already mentioned energy and process-technological problems. This is thus not a pure tandem connection of the different methods but draining and incineration of sludge have rather to be regarded as a process-technological unit.

Description of the sewage sludge incineration process

Modern sewage sludge and residue incineration facilities employing multiple hearth furnaces or fluidized bed incinerators are commonly designed to provide largely self-sustained combustion, i.e. without the need for firing support fuels, such as fuel oil, natural gas or biogas. After gravity thickening, the sludge undergoes mechanical dewatering, usually in centrifuges, continuous belt presses or filter presses. In cases where the dry substance content after mechanical dewatering is insufficient to ensure self-sustained combustion, a thermal dryer has to be provided upstream of the incinerator. The thermal dryer is normally operated with heat, recovered from the flue gases. Rotary disc dryers or thin-film dryers operated with steam, hot water or other heat transfer media have rendered excellent service in this application.

The task of the subsequent incineration is to reduce the volume of the sludge to a minimum. In addition there is a further aspect, essential for a secured dis-

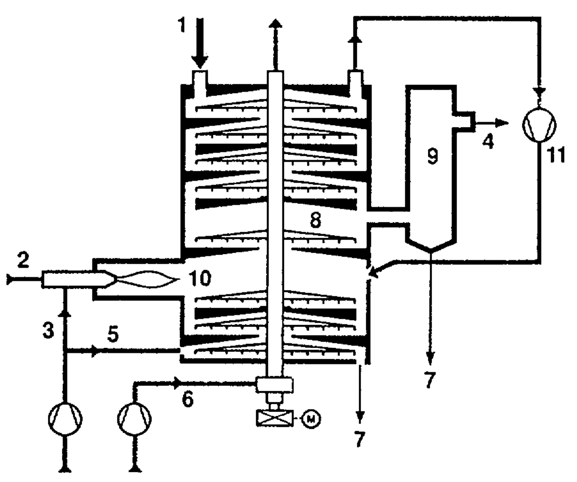


posal of waste: by integrating heavy metals into the slag, the residues can be recycled in such a way that they do not have to be disposed of as a problematic substance but can be re-used, for example, as aggregate for road building. The incineration requires a large amount of energy. Therefore the preceding treatment of sludge should have reached the highest possible degrees of draining. The additional power consumption can thereby be reduced by using the exhaust gas heat for the pre-drying of the filter cakes and the pre-heating of the air.

In multiple hearth furnaces drying and incineration take place in one plant. As these furnaces work on inverse current, they use heat very well. In comparison to the fluidized bed incinerator, the conditions of burning out in the multiple hearth furnace are more difficult to control. Partly to overcome this, secondary air is being blown separately into the firing hearths.

Besides the combustion of different kinds of waste the fluidized bed incinerator is also used, relatively often, for sewage sludge incineration. It is especially a great advantage that there is only a small amount of organic matter in the ashes, i.e. the combustible material is almost completely burned in the fluidized bed incinerator.

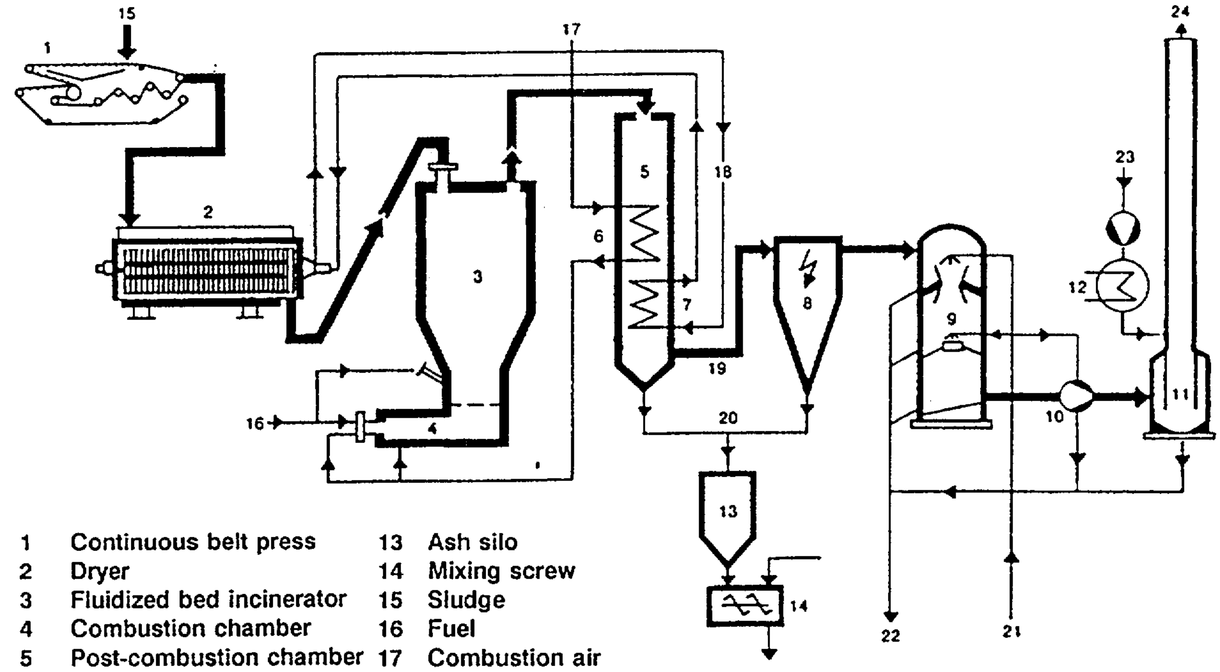
Figure 2. Multiple hearth furnace



1 Sludge or residue
2 Fuel
3 Combustion air
4 Flue gas
5 Ash cooling air
6 Cooling air
7 Ash
8 Multiple hearth furnace
9 Post-combustion chamber
10 Start-up combustion chamber
11 Recirculation fan

In the *multiple hearth furnace,* the moist sludge is charged onto the top hearth, from where it is moved downward from hearth to hearth, while being continuously turned over by rabble arms. The hot gas, which is usually produced in separate burners, is fed in below the middle of the furnace, where the sludge is being burned. The hot flue gases from incineration, moving upwards through the incinerator and in a countercur-

Figure 1. Process chart



1 Continuous belt press
2 Dryer
3 Fluidized bed incinerator
4 Combustion chamber
5 Post-combustion chamber
6 Air heater
7 Heat recovery
8 Electrostatic filter
9 Radial flow scrubber
10 Induced-draught fan
11 Stack
12 Air heater
13 Ash silo
14 Mixing screw
15 Sludge
16 Fuel
17 Combustion air
18 Heat transfer medium
19 Flue gas
20 Ash
21 Scrubbing liquor
22 Scrubber effluent
23 Air
24 Cleaned flue gas

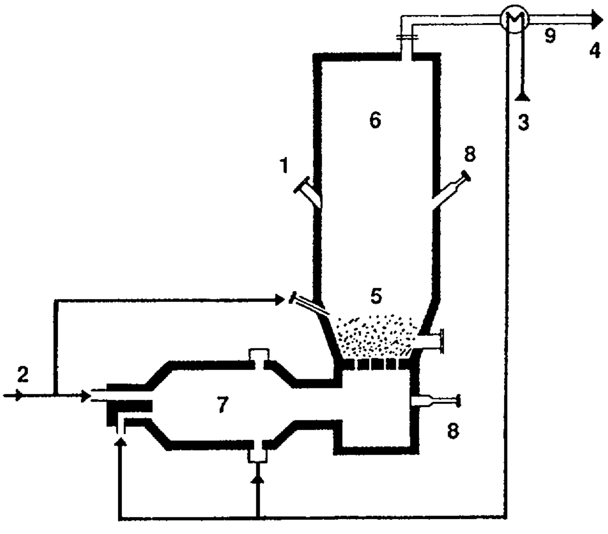
rent to the sludge, are drying the sludge in the top section of the incinerator. The organic sludge constituents are burnt through the addition of combustion air on the central firing hearths at a temperature of 800-900 °C. In the bottom section of the incinerator, the greater part of the ash is cooled with air before being discharged. The enormous mass of the incinerator brick-lining provides an excellent heat store.

Figure 2 shows a schematized sectional view of a multiple hearth furnace. Smouldering processes are avoided by the jump in temperature from 80-90 °C on the lowest drying hearth to 700-900 °C on the highest incinerating hearth. In order to deodorize effectively the exhaust gases (exhaust vapours) they can either be led into a post-combustion chamber or be fed back into the actual combustion chamber, from where they are then taken off.

Due to their outstanding heat economy and good part load behaviour at constant destruction efficiency, multiple hearth incinerators are the first choice, whenever it comes to handling highly fluctuating sludge rates and, especially, high-ash sludges.

Fluidized bed incinerator. On a ceramic or metallic grate there lies a layer of granulated, inert material, e.g. sand. With considerable pressure the combustion air is blown into a collection chamber below the grate. In the case of a metallic grate the air is pressed into the bed over a milled narrow split and in the case of a ceramic grate through distributing nozzles where air gets its necessary outlet velocity to whirl the goods to be whirled. Thus the air is like a boiling liquid. The sludge to be incinerated is either brought into the bed by nozzles at a low height over the grate at right angles to the upcoming air, or it is simply allowed to fall down on to the bed surface. The temperature of the bed is kept at 750-900 °C. Due to an intensive heat exchange between the incinerating matter and the whirling bed material, it burns out almost completely. The solid and combustible residues keep moving in the bed as long as they are small and light enough to burn while hovering in the post-combustion area above the bed. In order to avoid larger particles being dragged along, the velocity of the gas does not exceed 2 m/s.

Figure 3. Fluidized bed incinerator



1 Waste
2 Fuel
3 Combustion air
4 Flue gas
5 Fluidized bed
6 Post-combustion chamber
7 Start-up combustion chamber
8 Viewing glas
9 Air heater

When burning sewage sludge, which has a weak thermal power, an additional fuel (oil or coal) has to be burned in addition either temporarily or permanently in order to keep the bed temperature. To bring the fluidized bed incinerator to the necessary combustion temperature an additional firing is always required. The target is to place the incineration as far as possible into the fluidized bed. The major part of the ash is discharged along with the flue gases.

Fluidized bed incinerators are particularly useful for burning low-ash sludges and those sludges which are free of troublesome constituents. With a temperature of 800-900 °C, the flue gases from the incinerator and the post-combustion chamber offer a substantial potential for heat recovery. It is usual, that the air necessary for the incineration of the sludge is heated by these flue gases in such a way, that, in connection with the draining and drying of the sludge, an autothermic combustion is guaranteed. Therefore air pre-heaters are usually designed to heat up air to 400-600 °C.

The remaining thermal content is available for other uses, such as the thermal drying of the sludge, or for external use. Heat recovery systems incorporating steam generation or the pre-heating of heat transfer media are nowadays state of the art.

Functioning of a sewage sludge incinerator

In the following the structure and the functioning of a fluidized bed incinerator are described in detail. The fluidized bed incinerator—a steel sheet casing with interior lining—consists of a fluidized bed chamber, combustion area and post-combustion chamber.

The fluidized bed chamber and the combustion area are positioned in the lower part of the incinerator, above them are the post-combustion chamber and the top part of the furnace. The floor of the incinerator, on which the sand bed lays, is made up of air nozzles of heat-resistant material. The tuyère bottom is manufactured from steel or built of bricks whereby the steel bottom can be lowered by means of a frame-work construction. The heat feeding system is flanged below the tuyère bottom segments and is connected by compensators with the hot air flue.

The fluidized bed discharge system consists of the gate stop valve at the sand outlet muff of the incinerator and of the water-cooled extracting screw. For heating up the incinerator or for starting the plant after intermissions there are burners, arranged with a slight ascent to the vertical on the top of the furnace.

A number of lances are spread on the furnace walls right over the tuyère bottom near the fluidized bed in order to be able to fire in addition to fuel oil, manure gas, natural gas or used oil, if necessary. The amount of additional fuel is regulated as a function of the temperature in the combustion chamber. The lances themselves are double tubes, the annulus of which between the outside pipes and the inside pipes serves as a cooling jacket.

The fluidized bed incinerator is the main part of an incineration plant. Furthermore the following components are important in the construction of a plant:

Sludge dewatering with frame presses, continuous belt press, centrifuges or others;

Silos for delivered sludges and the sludge transport;

Flue gas channels, suction draught, chimney, combustion air ventilator.

According to environmental standards and the required energy demand further components can be added.

Dimensioning

Using a fluidized bed incinerator as an example the dimensioning of a sewage sludge incinerator is shown as follows. An economic sludge incineration requires a certain minimum size of the plant. This is for:

Dewatered sludge (DS = 25%) = 0.6 t/h DS
Dried sludge (DS > 33%) = 0.9 t/h DS.

DS means dry substance; i.e. 0.6 t/h DS corresponds to 15-30 t/h of sewage sludge with a water content of 96-98%. The maximum flow rate capacity of a fluidized bed incineration plant amounts to about 10 t/h DS, however it might be more favourable to provide several smaller incinerators.

For the design of an incineration plant the following information is required.

Fuels

Type, e.g. municipal sewage sludge, industrial sewage sludge, contaminated soil, waste oil, etc.;

Water content;

Combustible proportion of the dry substance;

Thermal power and analysis of the DS (proportion of C, H, N, O, Cl, F).

Output

Required flow rate of waste; or

Desired output of vapour or heat of the plant;

Operating time of the plant (hours per day, days per week).

Energy production

Type (vapour, hot water, electricity, etc.);

Energy data (temperature, pressure, electric voltage).

Auxiliary materials

Additional fuel for start-up (oil, gas);

Hazardous waste with high thermal power (waste oil, dissolvents), if available;

Cooling water, electricity (existing circumstances).

Available room

Site plan of existing buildings, plant components, etc.

Laws/regulations/norms

National, regional, local regulations regarding environmental protection, protection of labour.

Table 1. Proportions of the costs of investment

Variants	*Accumulative (percentage)*
Delivery, storing, draining of sludge, incineration, extraction of flue gas	100
In addition with spray cooler, electrostatic filter	115
Without spray cooler, with air pre-heater and scourer	133
In addition with waste heat boiler and economizer	165
In addition with sludge draining	200
In addition with process control system	225
In addition with activated carbon filter and heat exchanger	260
In addition with DeNOX-plant	275

Description of the manufacturing process of a fluidized bed incinerator

For manufacturing the sheet steel jacket of a fluidized bed incinerator the general workshop equipment is necessary for large tank construction and apparatus engineering. From the beginning of construction until delivery of the incinerator jacket it takes approximately six months. The brick-lining carried out on the site and the drying take about four months.

The entire fluidized bed incinerator consists of the following components:

Air chamber for distributing the combustion air;

Horizontal section through the tuyère level with the appropriate tuyères;

Conical lower part of the fluidized bed incinerator;

Straight middle part of the fluidized bed incinerator;

Upper part of the fluidized bed incinerator;

Post-combustion chamber;

The framing of the fluidized bed incinerator, isolation (protection against touch);

Supply pipes, combustion air blowers, electric installation, measuring and control instruments;

Oil or gas lances for additional fuel, start-up incinerator;

Sludge charge.

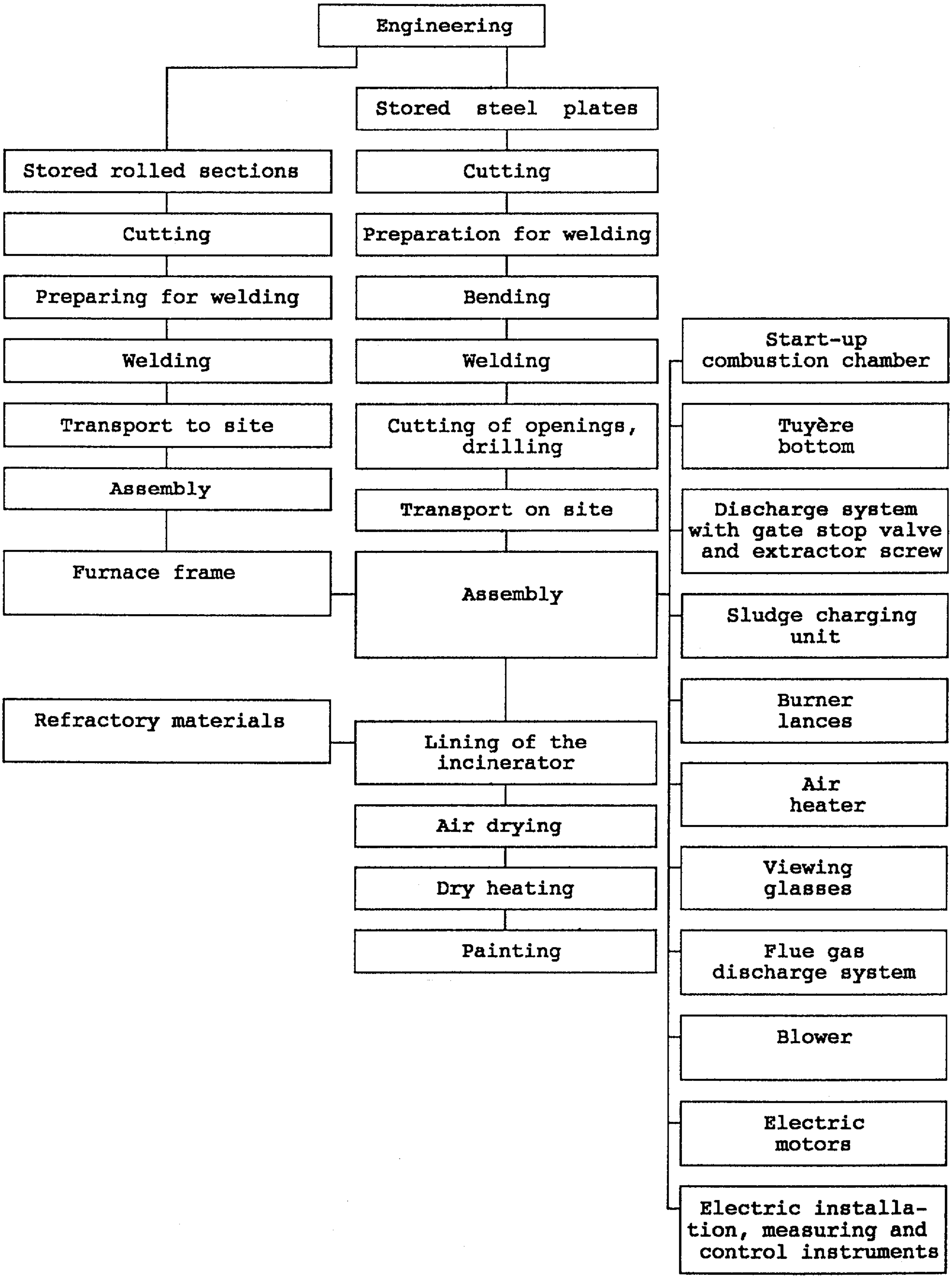
According to the specifics of the incinerator the jacket is made of sheet steel 10-20 mm thick. Therefore the sheet steel is cut to measure with the cutting machine and the edges are prepared for welding. The parts to be bent are brought to a bending machine. Then the air chambers, the lower, middle and upper parts and the post-combustion chamber with its necessary stiffenings are welded together on the dolly.

The next steps are the cutting and drilling of openings for, amongst others, the sludge charge, the fuel lances, the slag and ash discharge, the viewing glasses and the flue gas exit as well as preparing the inside of the incinerator jacket for the lining.

At the same time the incinerator framework is produced. The steel sections are cut, prepared for welding and welded into transportable parts. The components for the incinerator jacket can be transported to the site either individually or as a completely welded incinerator jacket. There the fluidized bed incinerator is fitted into the incinerator framework (which was prepared in the workshop and welded together at the site) and is equipped with a—mostly triple-lining. This lining is first air-dried and then dry-heated according to a defined heating curve.

While the incinerator is being lined, the other abovementioned components are fitted, so that the dry-heating can be started without delay. Finally the operation can be commenced as soon as the other aggregates of the sludge incinerating plant are ready for operation.

Figure 4. Flow chart



Example of a production plant

The following information is for the production of approx. 6 fluidized bed incinerators in one year with approx. 2 t/h throughput (dry substance).

Required machinery and equipment

Description	*Pieces*
Flame cutting machine	2
Bending machine	1
Welding machine	2
Drilling machine	2
Dolly machine with driven roller	1
Workbench with hand machines and tools	1
Cranes (25 tonne)	2
Fork lift truck (5 tonne)	1
FOB-price for machinery and equipment (1993)	Approx. US$ 2,500,000

Required manpower

Manager	1
Managerial and administration staff	4
Engineers	3
Workshop	
Welders	2
Metalworkers	2
Semi-skilled workers	2
Assembly and installation	
Welders	2
Metalworkers	2
Semi-skilled workers	2
Bricklayer	1
Electrician	1
Painter	1

Required area

	Square metres
Production hall	1,200
Administration and facilities	250
Free space for installation	1,500

Required energy

Electric power 300kW
Welding gas (Acetylene) 50 bottles at 10 kg
Oxygen 100 bottles at 15 kg
Compressed air

Required inputs

Steel plates
Rolled steel sections
Electric motors
Tuyère bottom with nozzles
Electrical installation, measuring and control instruments
Blower
Lining material (chamotte, corundum bricks, refractory concretes, monolithic lining material, anchor)
Supply wirings
Oil or gas lances
Start-up heater
Extracting screw
Isolating material
Cooler
Air heater
Paints

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Recovery of metals from metal sludges

Introduction

The industrial demand for metals is covered by extraction from primary raw materials such as ores and ore concentrates and by extraction from secondary raw materials, such as scraps and residuals. The limited availability of minerals (primary raw materials) is only one of many reasons for implementing recycling processes in order to recover metals. The importance of such processes will increase when ecological and economic factors make the treatment of valuable and/or hazardous substances viable and necessary.

Metal sludges belong to the potential secondary raw materials. Three main types of secondary raw materials are common:

New scraps: wastes from the production of metals and wrought products without considerable impurities;

Old scraps: wastes from the return of used economic goods like cars, batteries, washing machines, cables etc. with various but known amounts of impurities;

Residuals and intermediates: wastes from electrolytic refining, metal surface treatment, galvanizing, plating and other sludges with various metal contents, impurities and compositions.

Prerequisites for design, construction and selection of a suitable recycling plant for sludge treatment are: *(a)* financial data such as costs and revenues, *(b)* information on the composition of the sludge, and *(c)* information on the standard requirements for the secondary metal products.

Condition and composition of galvanic sludges

Galvanic sludges represent the biggest share in the total amount of metal sludges. In practice, they result from chemico-technical waste water treatment corresponding to the concepts of end-of-the-pipe technologies from metal processing enterprises, such as electroplating units, circuit printing units, zinc coating units, pickling units, hardening shops, paint-, enamelling- and graphic shops, rolling mills and other industries. Galvanic sludges occur during the detoxication and neutralization of solutions and waste waters as well as during the precipitation of heavy metals. As end-products of such processes, galvanic sludges are bulky, have high water contents, are thixotrope and vary considerably in their composition.

At first, hydroxide sludges which originate from the neutralization of galvanic waste water are liquid (thin sludges) and have water contents of between 95-99%. The total metal content is only about 1%. After partial dewatering in a chamber filter press, galvanic sludges are pasty to compact (dense sludges) with water contents of between 60-85%. Below 60% water content, hydroxide sludges have a crumbly and lumpy consistency. A classification of these sludges can be made by correlation with the quantitatively predominating main constituents, such as, for example in the German Waste Catalogue:

I. mineral sludges
    (a) sludges from phosphatizing processes
II. metal sludges
    (a) zinc sludges
    (b) other metal sludges
III. oxides, hydroxides, salt sludges
    (a) galvanic sludges
        cyanide containing galvanic sludges
        chromium-(VI)- containing galvanic sludges
        chromium-(III)- containing galvanic sludges
        copper containing galvanic sludges
        zinc containing galvanic sludges
        cadmium containing galvanic sludges
        nickel containing galvanic sludges
        cobalt containing galvanic sludges
        precious metals containing galvanic sludges
    (b) other oxides and hydroxides sludges
        zinc oxide sludges
        zinc hydroxide sludges
        tin oxide sludges
        manganese oxides sludges
        aluminium oxide sludges
        aluminium hydroxide sludges
        chromium-(III)- oxide sludges
        copper oxide sludges
        iron oxide sludges

Table 1. Average metal concentration of dried galvanic sludges

Metal	*Weight (percent)*	*Metal*	*Weight (percent)*
Aluminium	0.74	Nickel	2.10
Calcium	10.70	Lead	0.33
Cadmium	0.04	Vanadium	0.003
Cobalt	0.15	Zinc	7.50
Chromium	2.20	Tin	0.22
Copper	2.80	Sodium	2.10
Iron	11.00	Potassium	0.21
Manganese	0.18		

The thixotrope metal and galvanic sludges (mainly hydroxides, oxides, oxihydrates but also hydrooxicarbonates, organosulfides and others) contain, besides a lot of water, inert and associated matters as well as subversive elements, especially numerous non-ferrous metals. The non-ferrous metals chromium, copper, nickel and zinc arise in higher quantities of up to 10% weight and exceptionally of up to 50% weight. Therefore, they can be seen as valuable substances (Cu, Ni, Zn) and as potential secondary raw materials. Table 1 gives an idea of possible metal contents in galvanic sludges.

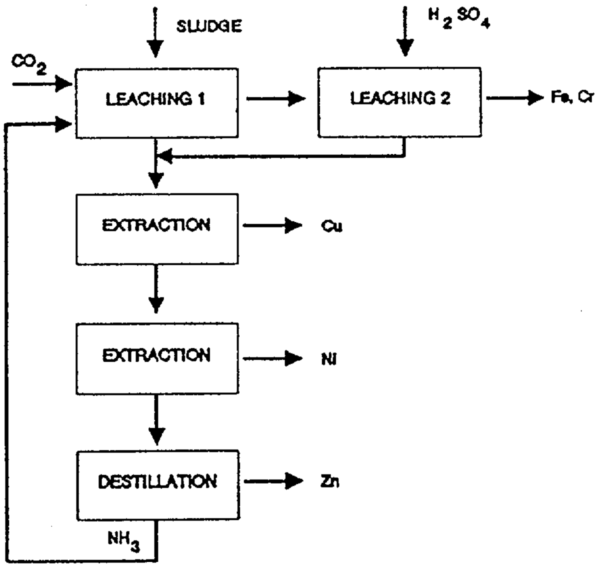
Process approaches for the recovery of metals from galvanic sludges

For the recovery of metals from galvanic sludges, principally hydro-metallurgical processes, like MAR (Metal Acid Recovery), the TNO process and the Goldschmidt process are available. Up to now, these three different processes were only tested at laboratory stage and in pilot plants. A fully commercial realization did not take place because of a lack of operational effectivity and economic efficiency. A sequence of different leaching, extraction, precipitation, distillation and ion exchange steps to separate the metals into salts and oxides, is typical for these processes. Further processing follows these steps, depending on the specifications which the end products have to meet. Considering the high water content of galvanic sludges, it is more feasible to recover the metals by leaching, followed by selective separation of the metals dissolved in the leaching solution by known separation methods, such as fixed-bed ion-exchange and solvent extraction.

The MAR process

The aim of the MAR process is to separate the non-ferrous metals from the iron and chromium content of the neutralization sludge. Figure 1 shows a simplified flow chart for this process. In the first leaching step, approximately 80% of the metals contained in the charge are dissolved by ammonia carbonate. A sulphuric post-leaching raises the yield of metals up to 98%. Iron and chromium remain as hydroxides in the residue, which should then be suitable for waste storage. The combined leaching solutions are supplied to a solvent extraction, where copper and nickel are separated. The residual $ZnCO_3$ solution is decomposed thermally, recovering pure $ZnCO_3$ and stripping ammonia and CO_2, both of which are brought back to the leaching stage by an absorption step. Copper and nickel re-extraction is selective, and pH-controlled with sulphuric acid, so that $NiSO_4$ crystallizes and copper metal is recovered electrolytically.

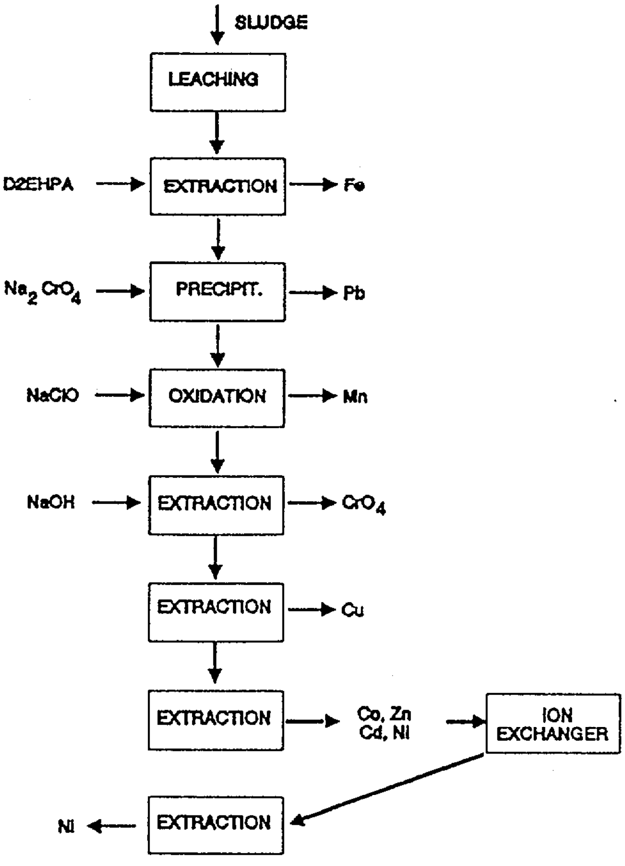
Figure 1. MAR process



The TNO process

Hydroxide sludges are leached with sulphuric acid (see figure 2) at pH-values between 0 and 1. Optionally, hydrochloric acid can be used in the case of higher lead contents. The residue consists of Ca, Si and other insoluble components only. Fe(III) is then extracted from the leaching solution with D2EHPA (Di-2-ethylhexyle phosphoric acid) and is converted in a further TBP process with closed HCl-circuit into a $FeCl_3$ solution. Lead is precipitated as Pb-chromate with NaOH and, if necessary, with Cr(IV)-addition. In the next step, a chromium oxidation with sodium-hypochlorite (NaClO) follows under precipitation of manganese oxide (MnO_2), which allows a Cr-anion-extraction with a TOA/TBP-mixture (tri-octylamine/tributyle phosphoric acid ester). The re-extraction from that solution takes place with NaOH under Na-chromate formation. This is followed by the Cu-extraction with a special agent, consisting of cyclohexanoxime and oleic acid, which permits a recovery of $CuSO_4$.

Figure 2. TNO process



With this same extraction agent, Zn, Cd, Ni and Co separations follow. Then, corresponding chlorides are produced by anion exchange from the hydrochloric re-extraction solution (selective-elution with NaCl-solution). A further extraction from the remaining solution rounds up the upgrading of Ni to $NiSO_4$. The described process shows a variety of single steps which are run very expensively under a high consumption of chemicals and which lead to a high salt load of the waste water.

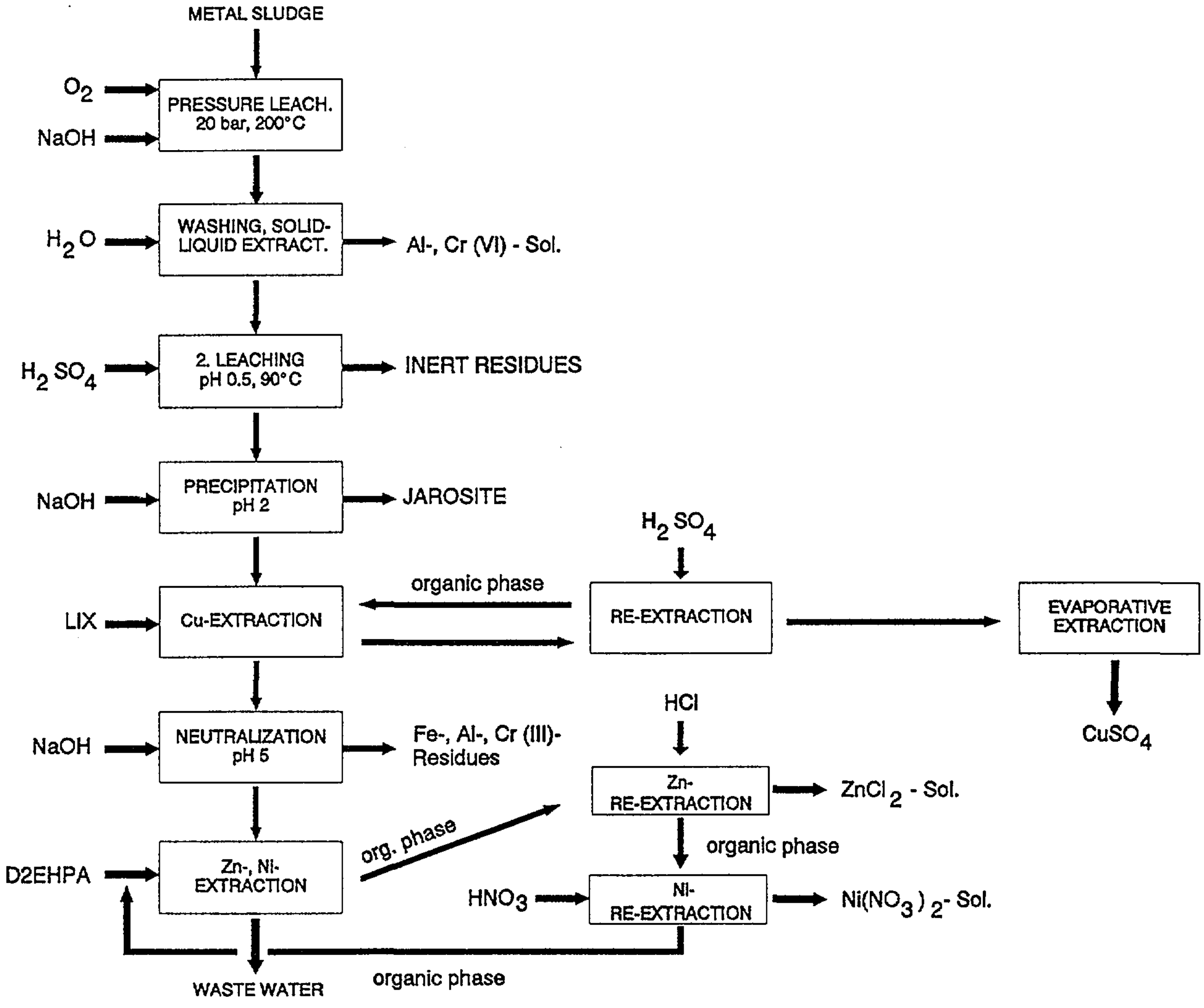
The Goldschmidt process

After suspension with caustic soda, the sludge is leached and oxidized with oxygen under a pressure of 200 °C, 20 bar (see figure 3). The resulting aluminate- and Na-chromate-solution is then filtered and the residue is leached with sulphuric acid, at pH 0.5 and 90 °C. The dissolved iron is precipitated as jarosite by pH adjustment. Subsequently, a Cu extraction with LIX takes place, followed by the recovery of $CuSO_4$-salt by means of evaporative crystallization. From the Cu extraction raffinate, the remaining Fe, Cr and Al contents are removed by neutralization with NaOH. Finally, the Zn and Ni separation is performed by extraction with D2EHPA. After this step, $ZnCl_2$ and $Ni(NO_3)_2$ solutions are produced through a selective re-extraction with HCl and HNO_3. The jarosite and the after-cleaning (hydrolytic reactions) precipitation are critical points of the Goldschmidt process. In these steps the purity of jarosite grades cannot be guaranteed because of the migration of valuable non-ferrous metals into the jarosite. Moreover, a warping of Zn can be expected at the alkaline leaching step because the zincates are also water soluble.

Design of a plant for the recovery of metals from metal sludges

At present, the construction of commercial plants is still pending. In 1980, a pilot plant was built and run at Th. Goldschmidt AG, Mannheim, Germany. After the experimental demonstration, the project was abandoned due to its lack of efficiency. Therefore, general information can only be given for a possible lay-out of a metal sludge treatment facility. Prices given are updated 1980 information. Allowing for an average inflation rate of 3% and exchange rates as of 1993, the total capital investment is about 25 million US$: three million for buildings and 22 million for machinery (process facilities).

Figure 3. The Goldschmidt process for galvanic sludge processing



Buildings and site

The space required for a plant relating to the Goldschmidt process is shown in figure 4. The following rooms in building VIII are needed:

Room	*Square metres*
Central measuring station	25
Operational premises/electrics	40
Foremans office	20
Laboratory	120
Rest room	20
Locker and wash rooms	40
Offices for the shop manager, assistant, secretary	60
	325

Personnel required

Information on personnel requirements is based on the experiences made with the continuous operation of the sludge treatment plant at the experimental stage:

Area	*Personnel*
Transport, storage, mixing	1 worker/shift
Cr oxidation, leaching, filtration	2 workers/shift
Extraction, zinc area, nickel area	2 workers/shift
Copper area, chromium area	1 worker/shift
Supervision	1 shift foreman/shift
Administration	
shipping control	1 worker
plant management	1 shop manager 1 assistant 1 secretary

Operational capacity

The capacity of the Goldschmidt sludge treatment plant is designed for the following raw material throughput (in tonnes per month):

	Galvanic sludge	*Mixed sulphates*	*Cu leach*	*Used catalysts*	*Total*
Material	2 000	15	588	62	2 665
Cu-content	57.8	2.5	23.5	3.5	87.3
Cr-content	43.0	–	–	–	43.0
Ni-content	17.4	0.5	–	10.0	27.9
Zn-content	48.6	1.0	11.8	–	61.4

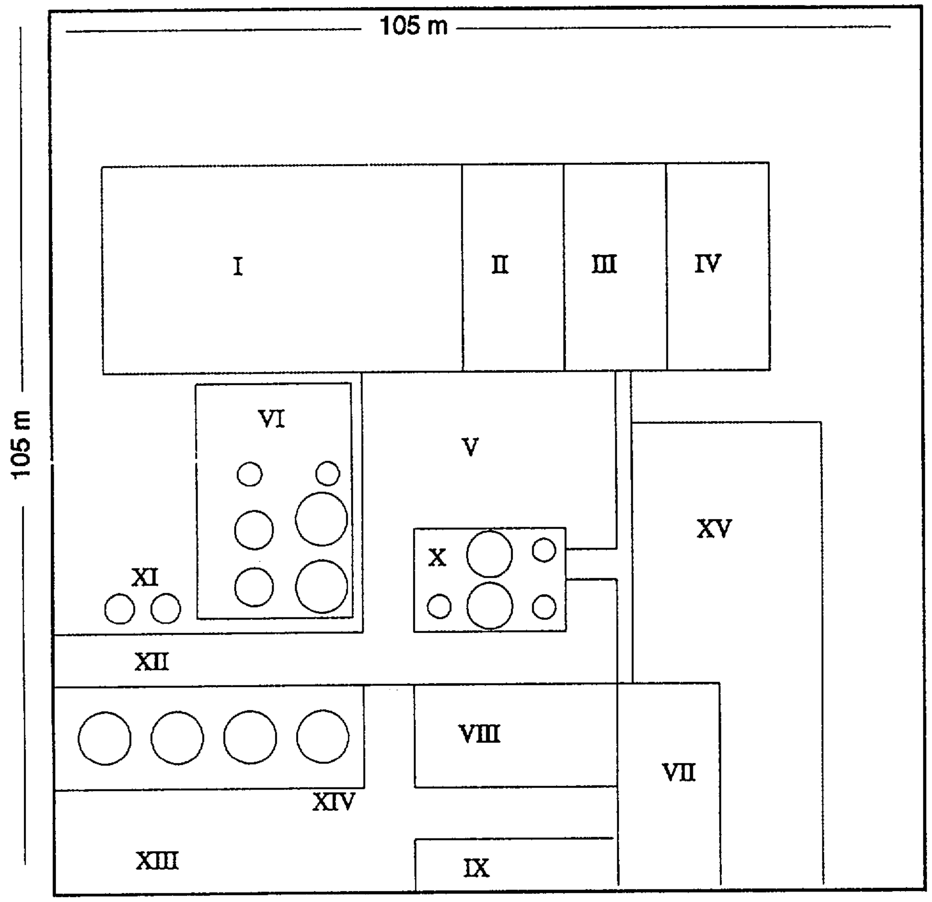
The Cu leach (crude caustic solution) comes up during the processing of residues containing Cu and Zn, such as flue dusts.

Products

Given the raw materials throughput described above, the following amounts of end products occur:

Copper sulphate (crystalline; 25% Cu)	346 t/month = 86.5 t/month Cu
Nickel nitrate-solution (12,8% Ni)	216 t/month = 27.6 t/month Ni
Zinc chloride (crude caustic solution, 40% $ZnCl_2$)	313 t/month = 60 t/month Zn
Sodiumdichromate solution	175 t/month = 41 t/month Cr

Figure 4. Sketch of the pilot plant



I	potential enlargement area
II	Ni-step
III	Zn-step
IV	Cu-step
V	driving and storage area
VI	raw material and finished product tanks
VII	apparatus scaffold
VIII	mixer, mashing
IX	social section, instru - ment & control room
X	leaching of valuable metals
XI	CO_2-, O_2- tanks
XII	driving area
XIII	truck shunting area
XIV	non-ferrous metal sludge dumping
XV	potential scaffold enlargement

Energy and Water

For the specified raw materials throughput, the following amounts of energy and water are required for continuous operation of the plant:

Electricity	300,000 kWh/month
Gas	60,000 m³/month
Diesel oil	0.8 t/month
Pressured air	225,000 m³/month
Demineralized water	1,000 m³/month
Cooling water	105,000 m³/month
Vapour	2,630 t/month
Process water	4,200 m³/month

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How to Start Manufacturing Industries

Vitrification process for the inertia of residue products from refuse incineration plants

Introduction

In the utilization and disposal of refuse, incineration takes an ever increasing part, leading to emissions and residue. Stricter environmental regulations, especially with regard to emissions, lead to increased volumes of residue and to higher concentrations of harmful substances in the residual content, independent of which industrial flue gas treatment process is used.

Residue consists mainly of the following products:

Slag and ash (approx. 30% by weight of the refuse input);

Filter dust (approx. 3% by weight);

Reaction salts.

In contrast to the slag, the other residue products contain high to very high contents of mobilizable heavy metals, harmful organic substances, chlorides and sulphates, creating disposal problems, i.e. they make special refuse tips necessary.

In order to avoid these problems different processing procedures have been developed, such as consolidation, sintering, melting and vitrification processes. The melting and vitrification processes represent safe, but also expensive, process alternatives. The advantages of these processes are:

Wide range of employment (treatment of fly ash and residue products from refuse incineration, ash from sewage sludge incineration, rotary kiln ash, galvanic sludges, filter dust, wastes containing asbestos, contaminated soil after pre-treatment, nuclear waste);

Almost complete integration of heavy metals into the end product;

Destruction of dioxin and furane;

Reduction in volume and weight;

Small waste gas volume;

Limited release of harmful gases bound to fly ash and reaction product;

Concentration of the remaining salts.

Glass as the end product offers, because of its solid and amorphous structure, the possibility of integrating various metal oxides into its network. The binding strength is so great that only very small traces can be eluted.

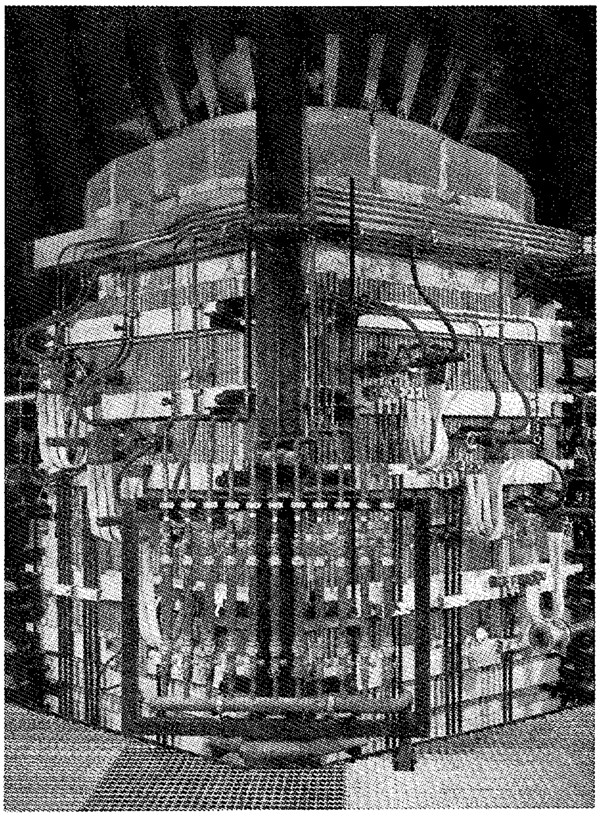
By special moulding the vitrificated material can be used in the building and cement industries or in road building.

Functioning of the process

In the vitrification process boiler and filter ash as well as reaction products (e.g. salts from dry or conditioned dry processes) are melted at temperatures between 1,300 °C and 1,400 °C together with the additives necessary for the control of the process parameters and the desired product quality, as for example sand and ponolith. The melting process of this mixture takes place in a glass melting furnace, which can be heated by gas, oil, coal, electricity or other fuels.

If the furnace is heated by gas, oil or coal, the heat is produced outside the furnace, thus heating the top of the furnace as well. Consequently, any gases produced by the melting process can escape much more easily than in the case of a furnace heated electrically by immersed electrodes. Here the top can be kept cool, thus allowing a mixture layer to form, whereby the condensable gas components are kept back.

The plasma melting process represents a different type of electricity based melting technology. A three-phase current system, working on three electrodes,



offers the possibility to form the plasma arc immediately between the plasma burners. The advantage is that non-conducting filter and flue dust can also be used. The dust is fed in between the three plasma burners, directly into the starpoint of the plasma arcs. Through the high arc temperature (> 2000° C) the dust has already melted when it reaches the melting bath.

The best results can be achieved in a melting furnace that is completely electrically heated and has a high heat density as this method is environmentally friendly and allows for the application of cold top technology.

In this process, where only minimal amounts of waste gas occur, the glass melting reacts as an electrical resistance. The electricity flows through immersed molybdenum electrodes into the glass melting, the conductibility of which depends on the ionic conduction. The liquid glass mass is kept in a basin lined with special fireproof brick material, the type of which is dependent on the type of products to be melted and on the melting itself.

To reach an optimal heat charge and to integrate the harmful substances, bound to the residue product, into the glass matrix in a concentrated and leach-proof way, a special measure has to be taken: the use of melting basins with a cold top.

The gases produced by the melting process and leaving the melting surface have to pass through a thick mixture layer, swimming on the melting, which thus cools the gases down to approx. 150 °C. Condensable components of the waste gas are kept back in the mixture layer. These condensation products eventually return to the melting together with the mixture.

A high vapour pressure over the melting leads to a complete integration of the metal oxides (as cations) and to a partial integration of the residue products, such as SO_4, chlorine and fluorine (as anions). Chlorinated organic compounds are thermally destroyed by the high melting temperatures.

The gall of glass layer, mainly formed when using saliferous residues, which swims on the melted glass because of its lower density, supports the reactions mentioned above.

The remaining waste gas from the vitrification furnace is treated according to regulation and mostly fed back into the incineration furnace or is released through the stack.

From the melting, under intense cooling, a vitrified material is formed, where the cations and anions, introduced with the mixture, are integrated into the glass matrix until the saturation limit is reached. The liquid glass mass can be processed to make small pressed particles by means of suitable forming processes, so that it can be used in the building industry as well as in road works.

The only residue product besides the waste gas is the gall of glass (approx. 4% by volume) which has to be dumped.

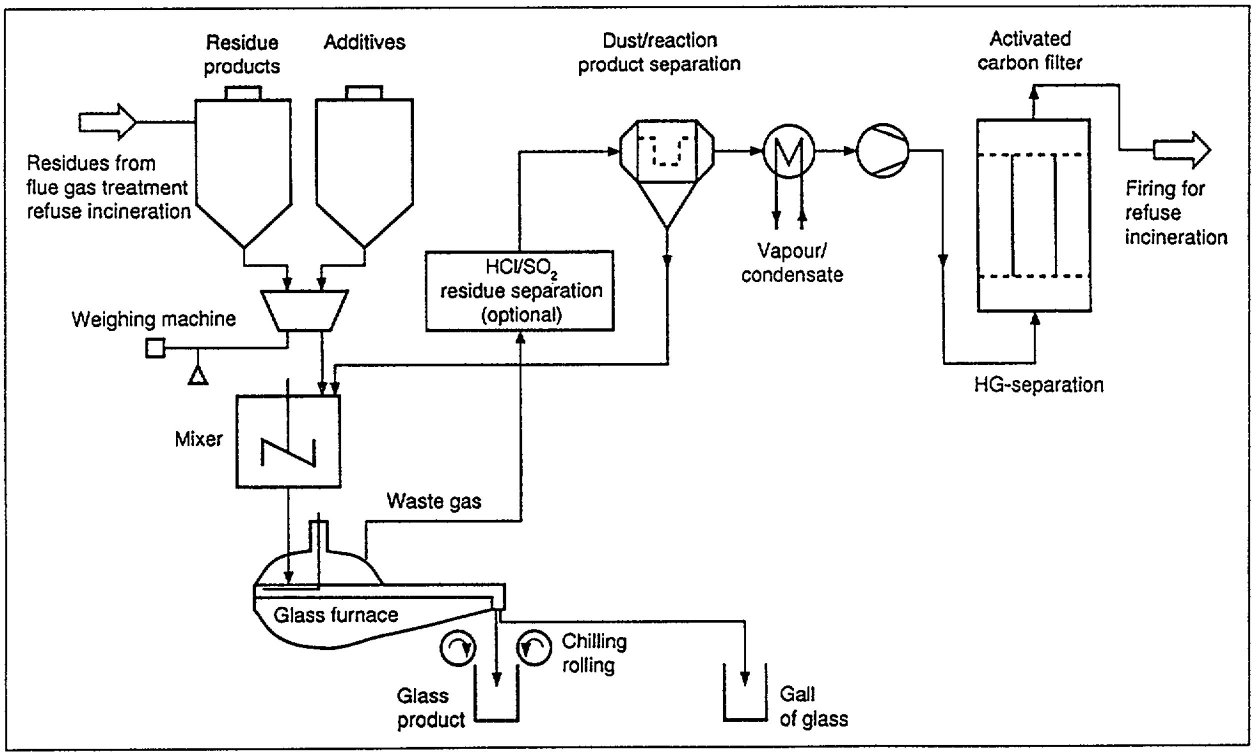
Description of the plant

For a refuse volume of 10 t/h a vitrification plant with a capacity of 0.5 t/h residue product is necessary. The total plant comprises three parts: mixture processing; vitrification; and waste gas treatment.

Mixture processing

The residues from the refuse incineration plant are usually taken from the bunker and conveyed into the intermediate silos of the mixture processing plant.

Figure 1. Vitrification process



Depending on the composition of the residue product, the additives are ordered and stored in separate silos.

The materials are drawn from the storage silos with the help of dosing units and fed into a container weighing machine. The weighed mixture is then passed into a collecting bunker for the melting trough and mixed together with the recirculated material. From here the mixture is transported by a feed screw into the vitrification furnace.

Vitrification

The vitrification plant is completely electrically heated with electrodes that are immersed in the melting furnace. Depending on the capacity of the plant and the composition of the residue product the melting process needs approx. 1 kWh/kg of residue.

The top part of the furnace covering the melting area is almost airtight and connected to the melting trough underneath. The feeder screw, from the mixture processing plant, is attached to the top part of the furnace, and a rotating arm provides for an equal distribution of the mixture over the surface of the glass melting. The top part also contains an opening for the release of the waste gas.

The melting basin has an overflow on its side, which is separately heated by electrodes or electrical heating elements. In the front part of this overflow there is an arrangement to drain the salt melting (gall of glass) when necessary. This salt melting has to be further processed or has to be dumped. Its volume is, however, only 4% of the original volume of the residue. In the back section of the overflow a stone is built in, over which the melted glass can flow into the devices below, where it is cooled off and formed.

Waste gas treatment plant

For a vitrification plant with a melting capacity of 0.5 t/h the waste gas treatment plant has to be designed for a volume of approx. 100-150 nm³/h. The waste gas contains besides vapour, CO_2 and N_2 also SO_2, HCl and gaseous mercury.

The waste gas, cooled to 150 °C, is fed into a dust separator, where the solid particles in the gas are retained. This dust is fed back into the mixer.

By suction draught the waste gas is transported to an activated carbon adsorber, where the separation of mercury takes place. This is necessary, because mercury almost completely evaporates in the vitrification process. The remaining waste gas is either recycled into the furnace of the refuse incineration or is fed into the stack.

The relatively small amount of activated carbon loaded with mercury has to be dumped.

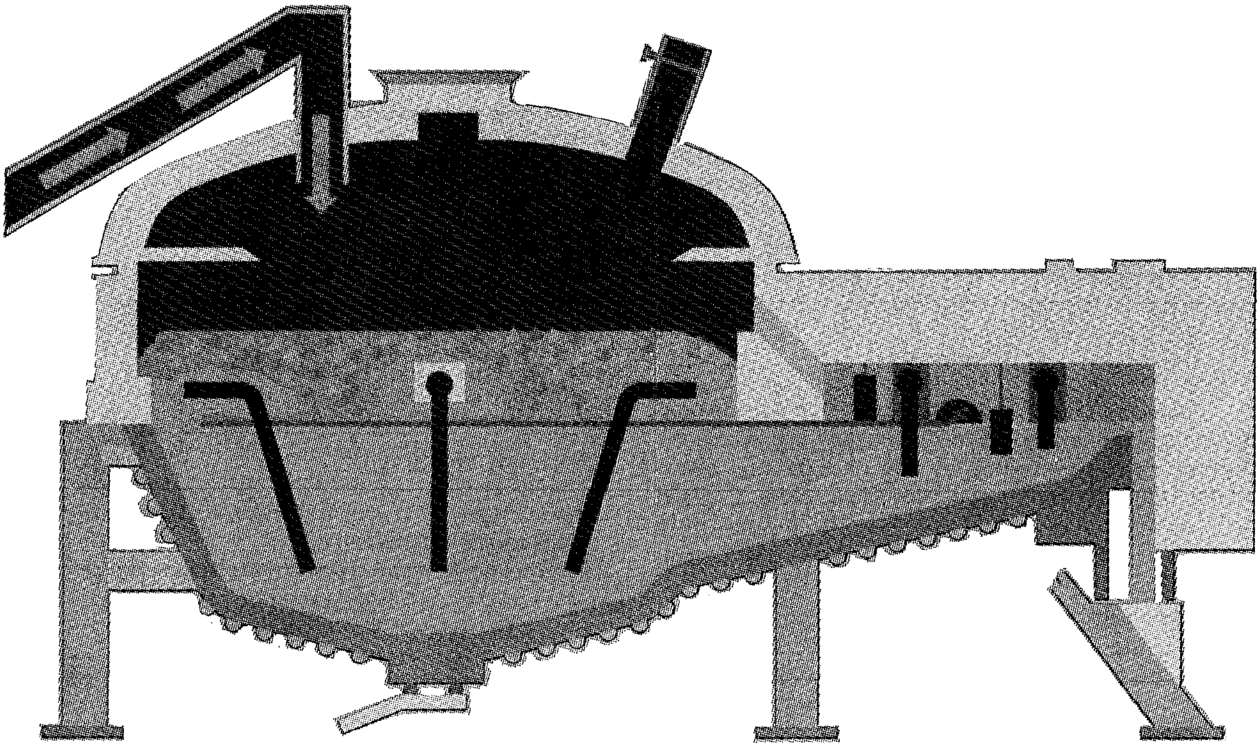
The inertia process described is an expensive process. High investment costs meet with high operation costs. The operation costs for vitrification are widely determined by the specific energy consumption in the melting process. The consumption can be calculated at 1-1.2 MWh/t of input product.

Description of the manufacturing process

Melting trough

The steel plates, ordered from outside, are cut into segments by a flame cutting machine. The edges are prepared for welding by a longitudinal planing machine.

Figure 2. Vitrification furnace



Depending on the type, size and task of the trough its outer casing may also be made either of flat steel, a suspending steel grid or a double-walled steel body construction. The latter type is especially favourable for the vitrification of residue products from refuse incineration plants.

The rolled steel sections are sawn to size and shaped to form the support for the furnace trough. All parts are brought to the site and assembled there. Only then is the trough lined with bricks and tamp material.

Mixture preparation plant

The steel plates are cut to size and shape by a cutting machine, the edges are prepared for welding by a planing machine. Where necessary the plates are bent to form the cylindrical or conical casings for the silos or the casing for the mixer.

The casings are stiffened and supported by rolled sections, sawn to the required length and welded onto the outside. Openings are cut, holes are drilled and flanges are welded on.

Finally the installation for the mixer is prepared. This consists of a bridge on top of the unit, onto which the stirring device is mounted. In the case of smaller silos and mixer, the units are welded and assembled at the works and then transported to the site. Bigger units are assembled at the site. The finished units are painted to protect them against corrosion.

Assembly

The assembly of the whole vitrification plant takes place at the site. All units are erected in their final position and interconnected by pipes, valves, dosing units, weighing machines, feed screws etc.

The melting trough is lined with bricks and tamp materials, fitted with electrodes and connected to the furnace transformer.

The waste gas treatment plant is usually bought from outside and installed at the site.

The outside of the furnace has to be cooled. In the case of a single-walled furnace, the cooling takes place by fitting waterpipes to the outside of the furnace. In the case of a double-walled furnace baffles inside the casing guide the flow of water through it and then out to a cooling tower.

Tempering

Tempering is the last task before the vitrification plant can go into production. The tempering, where the furnace is slowly heated by gas or light fuel oil to about 1200° C, takes 3 or 4 days to complete. Cleaned and prepared glass cuttings are put into the trough in order to seal the surface and to start up the vitrification process.

When a satisfactory condition of the trough has been reached, the electrodes can be switched on and the mixed residue material fed in. For the running of the furnace, electricity (380 V, 100 A) and water for cooling (5 to 6 bar, 20 l/min) are needed.

Example of a manufacturing plant

The example is based on the assumption that the firm produces the melting furnace, the silos for the mixture processing and the collecting bunker for the trough itself, and that all special devices, like weighing machines, electrodes, waste gas treatment plant, control units etc. are bought from outside. Also the design for the vitrification plant is not made by the firm itself.

The listings below have been made on the basis that three medium-sized vitrification plants are produced and installed per year. Medium-sized means that the furnace can manage 40 t of residue products per day, which would suit an incineration plant of approx. 8 to 10 t/h. This is based on the assumption, that about 300 kg of residue products occur per 1 t of refuse.

Required machinery and equipment

Description	*Pieces*
Circular metal saw	1
Cutting machine	1
Flame cutting machine	1
Longitudinal planing machine	1
Welding apparatus	3
Drilling machine	1
Hand grinding machine	3
Hand drilling machine	2
Workplace (including hand tools, masonry tools)	6
Mortar mixer	1
Lifting gear	
Lifting device (5 tonne)	1
Fork lift truck (2.5 tonne)	1
For assembly at the site:	
Assembly van	1
Lifting device (5 tonne)	1
Welding apparatus	2
FOB-price for machinery and equipment (1993)	Approx. US$ 850,000

Required manpower

Manager	1
Managerial and administrative staff	2
Foreman	1
Welders	5
Metalworkers	3
Semi-skilled workers	3

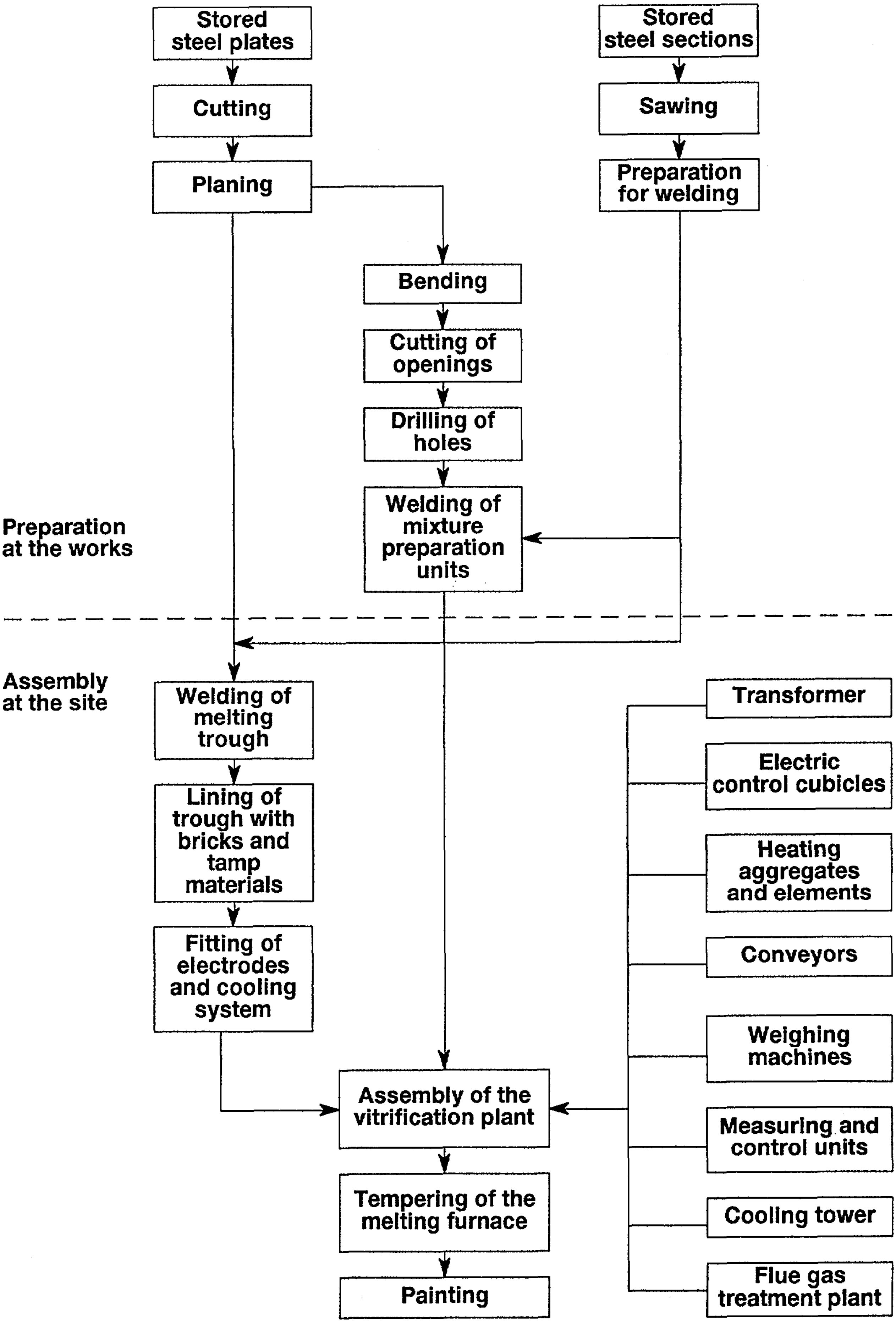
Required area

	Square metres
Production hall	1,000
inside storage	300
Outside storage	300
Facilities and administration	100

Required energy

Electric power	40 kW
Pressurized air	6-8 bar

Figure 3. Flow chart



Required inputs

Steel plates (10 mm)
Rolled steel sections (I, U, L)
Threaded rod and nuts
Flanges (different sizes)
Pipes (different sizes)
Mountings
Welding electrodes
Electrodes and holders
Electric cable and rods
Electric control cubicles
Transformer for melting furnace
Mica folium
Heating aggregates and heating elements
Vibratory conveyors/elevators
Weighing machines
Valves
Rotary valves
Measuring and control units
Cooling tower
Water pumps
Water tank
Water distribution system
Water hose (electrically isolated)
Mobile gas burner (for waste gas heating/burning)
Fan (for air cooling of furnace)
Refractory material (moulded bricks, standard bricks, mortar, tamp material; different qualities dependent on tasks)
Cleaned and prepared glass cuttings
Flue gas treatment plant

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Treatment of mixed paint sludges

Introduction

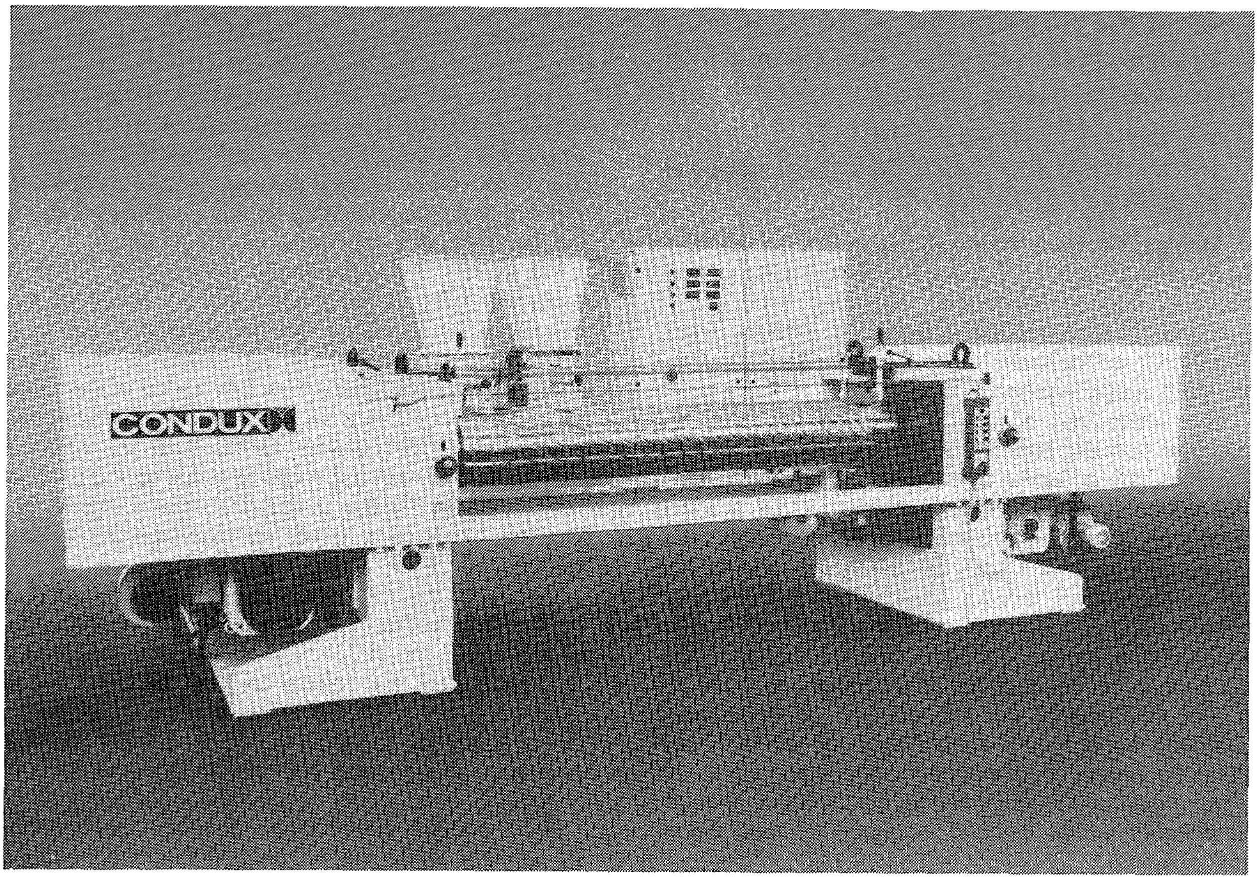
In industrialized countries some 100,000 to 1,000,000 tonnes of paint sludge occurs every year that has to be disposed of in an adequate way for reasons of environmental protection. The necessary technologies and installations are partly available, and work is still being carried out on recycling solutions for particular cases.

This problem, namely the disposal of paint sludge and the economic and ecological aspects, also arises in a number of developing countries. This applies in particular to the so-called newly industrializing countries, where the chemical, engineering and automobile industries, the building and structural steel engineering industries already play an important economic role.

In paint sludge disposal it is important to know whether the sludges are homogeneous or mixed. Adapted technological processes have to take into account the chemical composition and the physical characteristics of the paint sludges. Therefore it is necessary to distinguish between single-component and two-component paints, polyaddition and polycondensation systems, resin combinations, filler types, as well as reaction temperatures and pot lifes of the different paints.

Paint sludges can occur, for example, as coagulates or as kneadable or non-kneadable substances. Paint sludges can have a water content of 60-80%. They contain varying amounts of solvents with different temperatures of ebullition and ignition levels. The disposal of paint sludges is further burdened through resins, pigments, fillers as well as heavy metals.

As far as homogeneous paint sludges are concerned, there are relevant technologies and installations already available, as, for example, for the "overspray process" in the automobile, motorcycle and bicycle production. For the disposal of mixed paint sludges the following alternatives are still mostly used today: incineration in special furnaces; pyrolysis or gasification; depositing above or underground; or incineration at sea. An important criterion in selecting the right system for disposal are the costs involved.



In principle, the incineration of paint sludges is, from the aspect of energy use, a very suitable method because of its high calorific value of 35,000 kJ/kg. However, because of the high cost of the incineration plant in connection with the flue gas treatment, this concept for a solution for the developing countries has only a limited use.

Pyrolysis and gasification are technologically demanding processes and are also combined with high investment and operation costs.

The possibility of incinerating the paint sludges at sea has to be considered according to location and transport; the pollution aspects, connected with this, are problematic in any case. For this reason, most developing countries can only use depositing for the disposal of paint sludges, especially as depositing costs are considerably lower in developing countries as opposed to industrialized countries.

Depositing liquid, pasty or sludgy residues can endanger the general stability of the dump. In many cases also the danger of explosion or fire through solvent residues in non-compact wastes can hinder the depositing of untreated paint sludges. That is why paint sludges have to be dried before depositing. Such a predepositing drying process leads also to a reduction in volume of up to 60%, where the volume and cost of dumping can be reduced considerably. Such a drying process is shown in the following.

Description of the technology

When treating mixed paint sludges containing solvents and other above-mentioned components, the following tasks have to be solved:

Dewatering and concentration;

Steaming-out solvents without danger of explosion;

Separation of reactive products;

Interruption of rotting processes;

Manufacturing of a product able to be granulated and milled.

To execute these tasks, the technical installations have to be able to realize the following: compressing, melting, homogenizing and dispersing materials of medium to high viscosity. Such installations work, depending on the materials to be processed, in a temperature range between 20°-280 °C.

One technology adapted to this task processes the material between two rollers, running horizontally on bearings. It is essential that these rollers can be heated, that they rotate against each other and that between them a gap of a few millimetres can be adjusted in order to correspond to the specific material demands. The rollers themselves have longitudinal nerves and thread-like shearing and conveying grooves on their surface. It should be possible to heat or cool them from inside over their whole length to different temperatures.

The charging of the material can, in the case of pasty or liquid materials such as paint sludges, take place by means of screw conveyors or pumps. In the case of powdery material the drying installation can be charged by means of spiral dosing or vibration dosing installations.

The treatment of the charged material is controlled by different adjustments of the two rollers both in temperature and speed of revolutions. On the surface of the front roller a plastified product layer is formed; the gap between the two rollers is sealed by the material, while the back roller stays free of the plastified material.

The webs of the back roller press the untreated material into the soft product layer of the front roller. The product is now continuously transported from the charging to the discharging position. During this process the grooves and webs separate and turn the material.

The self-cleaning of the shearing rollers has to be assured even in the case of extreme colour and product changes. Decisive for the dispersing and homogenizing of the product are: shear gap; gap pressure and friction; temperature; and a high shearing rate. All parameters should be adjustable independently and should be controlled, registered and stored by an electronic data acquisition system.

Constuction and functioning of a shear roller compactor

The essential components of a shear roller compactor (shown in figure 1) are:

Store tank;

Conveying and dosing installation;

Two shearing rollers with temperature control;

Stripping device;

Container for the dried material.

The paint sludges to be processed are stored in the store tank and conveyed to the charging tank by means of a dosing screw/diaphragm pump.

The two parallel and individually driven rollers, running horizontally on bearings, are separated by the roller gap, occluded at both ends by sphenoid limiting jaws. One roller has fixed bearings, while the opposite roller can be adjusted either by a hydraulic cylinder or mechanically to a gap width of 0.3-10 mm.

The rollers are individually driven with different revolution speeds. The higher surface speed of one roller leads to the effect that the material clings more to this roller surface than to the slower turning opposite roller. In operation the surface speed of the material roller is dependent on product and product status, adjusted to 5-35% higher speeds than the opposite roller. The real working speed depends on the installation, especially on the geometrical measurements, the diameter of the two rollers and the capacity of heat transfer.

The roller surfaces are intensely heated, via rotary transmission leadthroughs from inside by steam, compressed water or circulating turpentine. The surface temperatures of the rollers are adjustable to values between approx. 120°-200 °C or higher. As a guide it can be assumed, that approx. 50 kg of water and solvents can be converted into steam using 40 kWh of energy.

The hot roller surfaces cause first the water and then the solvents in the contact zone to vaporize leaving a

Figure 1. Shear roller compactor

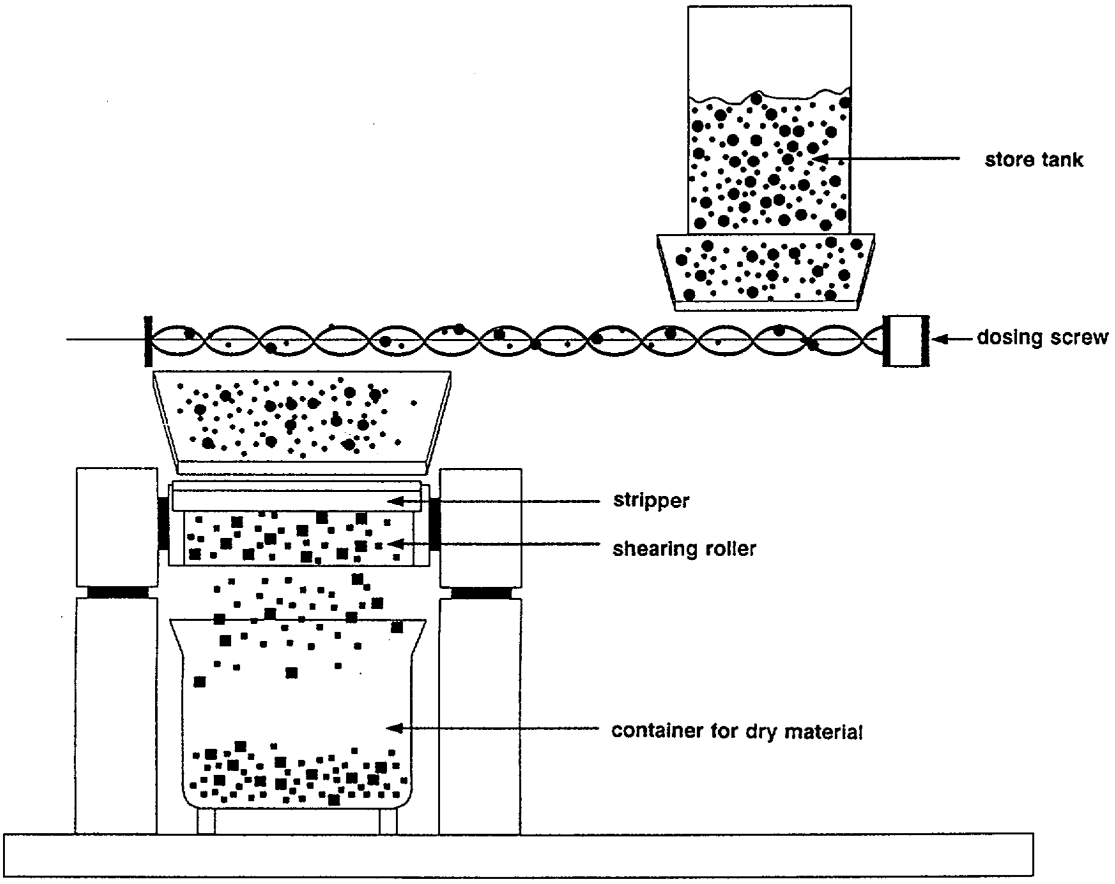
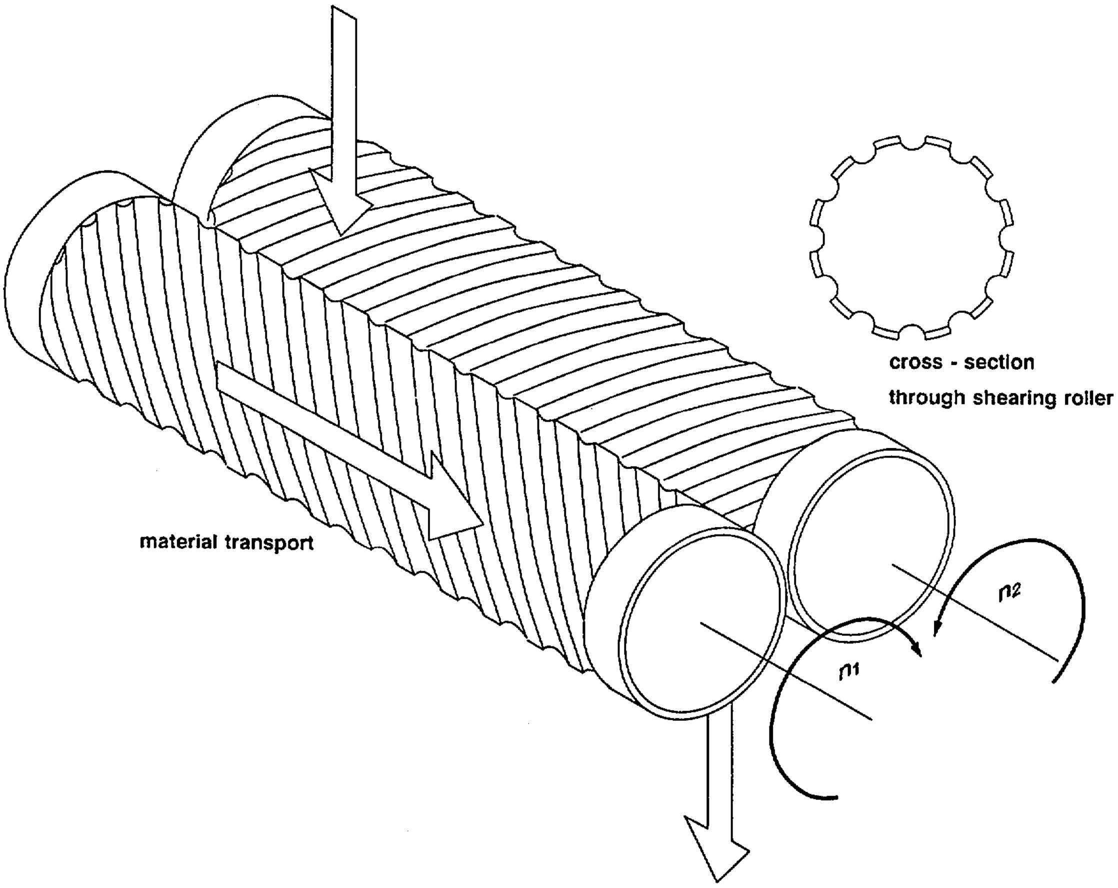


Figure 2. Processes in the roller gap



growing material layer built-up in the contact zone between metal and sludge. This layer is formed on both roller surfaces. Because of the contra-rotation, the material on both roller surfaces is transported towards the narrow gap, where a considerably high pressure is created, which can amount to between 2000 and 5000 N per cm gap length. The material cake is intensively compressed, thereby sealing the gap and preventing the passing of any liquid.

While passing through the gap under high pressure, the solid material cake is heated differently from both the roller surfaces. The temperature of the material-free roller is often adjusted to values 20°-40 °C higher than that of the material roller. A layer of vapour bubbles is created in the boundary layer, on the material-free roller between metal surface and material cake, with a higher pressure than on the material roller. On leaving the narrowest zone of the gap the vapour bubbles expand in the boundary layer of the material-free roller, thus loosening the product and pressing it against the surface of the material roller.

These breaking-up vapour bubbles develop, in the outside layer of the material surface, a porous, vapour permeable solid material layer, which clings to the more quickly rotating material roller. During the now following drying process a great amount of energy is transferred to the solid material from the inside of the material roller. The material layer becomes dry to brittle on the roller surface. The strippers are, like the rollers, fixed to the casing of the installation; here also the electric motors for the driving and heating of the rollers are to be found. The dried paint residue, taken off by the strippers, falls in the form of flakes into a collecting container, where it steams out further. The cleaned metal surfaces of the rollers reheat immediately and enter the sludge store created in the roller gap. The material-free counter roller is also fitted with a stripper to continuously remove the very fine caking from the surface.

The dried paint residues, collected in the container, are transportable as bulk material. For controlled incineration the product is milled like coal dust so that it can be conveyed into the furnace via burners. This dried paint residue contains enough energy so no additional firing is necessary.

Depending on the specific paint sludges the waste gases, created during the drying process, have to be examined for harmful and health-endangering substances. If such dangers occur, the shear roller compactor has to be encapsulated, provided with a suction device and a cooler, and an after-burning has to take place.

If instead of dumping the incineration of the milled paint residues is envisaged, the materials to be burnt and the occurring waste gases also have to be examined for polluting harmful substances, and, if needed, waste gas treatment plants have to be installed.

Dimensioning

For the shear roller compactor, used for the drying of paint sludges, the following components have to be dimensioned:

Store tank;

Charging device;

Length, diameter and profile of the shearing rollers;

Strippers and their mounting;

Driving installations for the rollers;

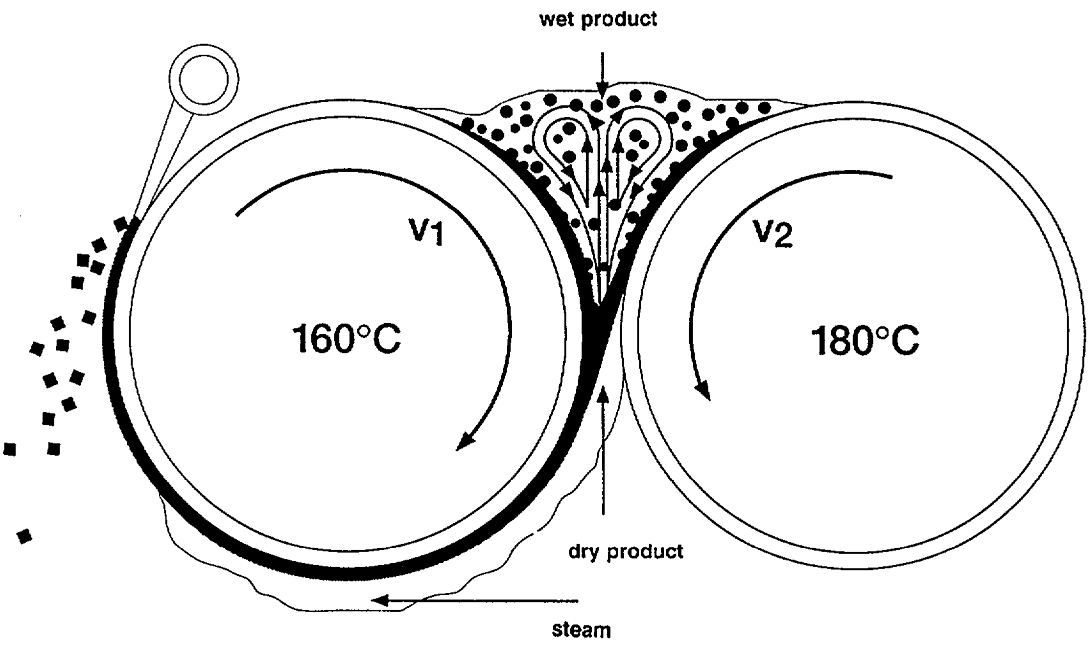
Heating devices and the circuit for the heating medium;

Container for the dried material.

In dimensioning the following important influential factors have to be considered:

The daily/hourly occurring amount of paint sludge to be dried;

Figure 3. Drying processes on the rollers



The constant or changing composition of the sludges;

The character of the material components and their chemo-physical properties;

The viscosity of the paint sludges;

The water and solvent content of the paint sludges.

At present there are no comprehensive experimental values and therefore no generally available calculation methods for the dimensioning of individual components of shear roller compactors of different capacities that could be used for a wide spectrum of different paint sludges. Only a few firms are able to dimension shear roller compactors because of their specific know-how. Up to now only a relatively few such compactors are in practical use.

The most important standard values for the dimensioning of the type of shear roller compactor, dealt with here, which have already proven successful in practical use are listed below:

Size of store tank approx. 300-500 l

Conveying capacity of material charging approx. 100 l/h

Length of the rollers approx. 1500-2000 mm

Diameter of the rollers 150-300 mm

Connected load 50-80 kW

Collecting container for paint residue approx. 500 l.

With the plant described above the following results have been achieved.

In a technical experiment 35 t of galvanic sludge with an alternating material content of 10-30 % were dried; 28 t of water evaporated and the remaining dried mass of approx. 6 t was disposed of.

In a continuous operation, 100 kg/h of paint sludge of varying composition were dried to a residual moisture of 2%.

Also, in a continuous operation, 100 kg/h of galvanic sludge were dried, leading to 25 kg of solid material with a residual moisture of 5%.

There are further types of plants available capable of drying 120-150 kg/h paint sludges with a 60% share of solid material; there are also plants designed for an evaporating capacity of 200-250 kg/h water or solvent. The spectrum lies between a low solid material content of approx. 10% dry substance up to a very high solid material content of approx. 80% dry substance. In the case of a higher solid material content higher rotating speeds of the rollers are used; in the case of a lower solid material content the rotating speed is diminished in order to increase the dwelling time between the rollers and thereby secure steaming-out.

Description of the production process

The shear roller compactor contains a number of components not produced in the firm itself but bought from outside. Those parts bought from outside are:

The screw conveyors for the material charging and their driving units or the diaphragm pump for fluid sludges;

The two shearing rollers and their driving units;

The heating device for the shearing rollers including the circuit for the heat medium and the controlling unit;

The hydraulic device for adjusting the roller distance.

The firm's own production comprises:

The supporting framework for the total compactor including the bearings and the mounting devices for the components;

The store tank with the charging unit for the screw conveyor;

The interim storage tank and the material conveying to the rollers;

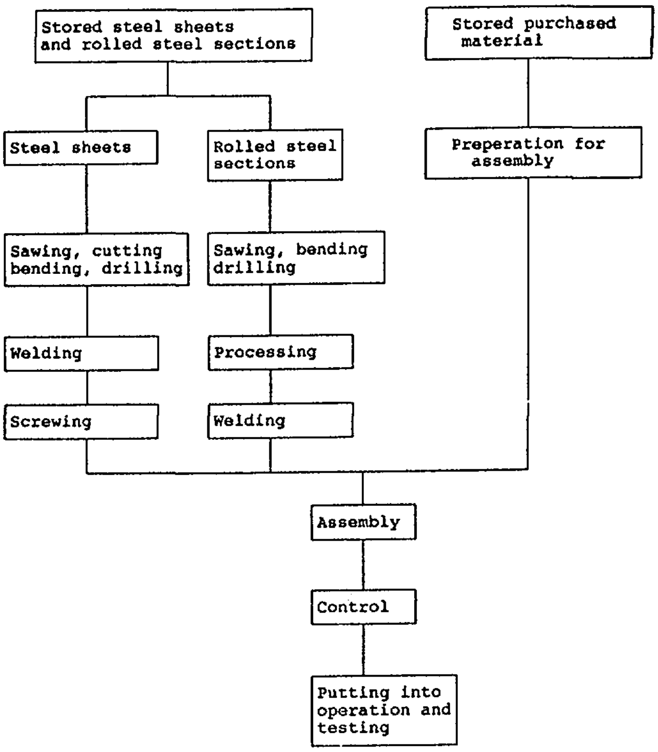
The strippers for the rollers;

The collecting container for the dried material.

For the self-produced components steel sheets of 0.5-2 mm as well as rolled steel sections of different dimensions are used. Furthermore, flanges and devices for the seating of the bearings are produced from steel plates.

To produce the total compactor the following work has to be carried out: cutting and sawing of sheets and sections; bending, folding and fixing; welding, drilling, screwing; grinding and smoothing of surfaces; filling, priming and painting. Furthermore the total electrical installation including the installation of the control equipment has to be carried out. Finally the machine has to be put into operation and tested with different materials.

Figure 4. Flow chart



Example of a production plant

The following lists illustrate the required number of machinery, personnel, energy and space for a production plant for shear roller compactors. It is assumed that 12 workers produce within 5 days and in one shift per day 2 shear roller compactors.

The machinery, material and personnel listed below are not necessarily fully used. To reach full capacity an increase in production is necessary or the additional production of other machines or equipment.

Required machinery and equipment

Description	*Pieces*
Metal cutting saw	2
Cutting and folding bench	1
Press for steel sheets	1
Bending machine	1
Drilling machine	1
Milling machine	1
Cutting torch	2
Thread cutting machine	2
Grinding machine	3
Screwing machine	4
Spraying gun	4
Transfer car	6
Crane and hoisting gear	6
Mounting frames	3
Small tools for metal working	
FOB-price for machinery and equipment Approx. US$	300,000

Required personnel

Technical manager	1
Mechanical engineers	3
Designer	1
Managerial and administrative staff	3
Skilled workers	5
Semi-skilled workers	10
Storeman	1

Required area

	Square metres
Production	300
Paint shop	150
Storage	300
Administration	60

Required energy

Electric power	75 kW

A stand-by unit for emergency power supply (50 kW) and devices for voltage stabilization should be provided.

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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How to Start Manufacturing Industries

Processing of used plastic material from refuse

Introduction

There is a large amount of plastic waste today coming mainly from two sources: industrial production and processing; and refuse. The main part of plastic waste coming from industrial production and processing is not considered here, as this waste still in its pure state is usually processed in the respective firms themselves. It is either melted down and processed as secondary granulate or it is recycled using hydrolysis. It is a different situation with the plastic waste from industrial production and processing, which cannot be recovered in pure form: this is part of the refuse dealt with here.

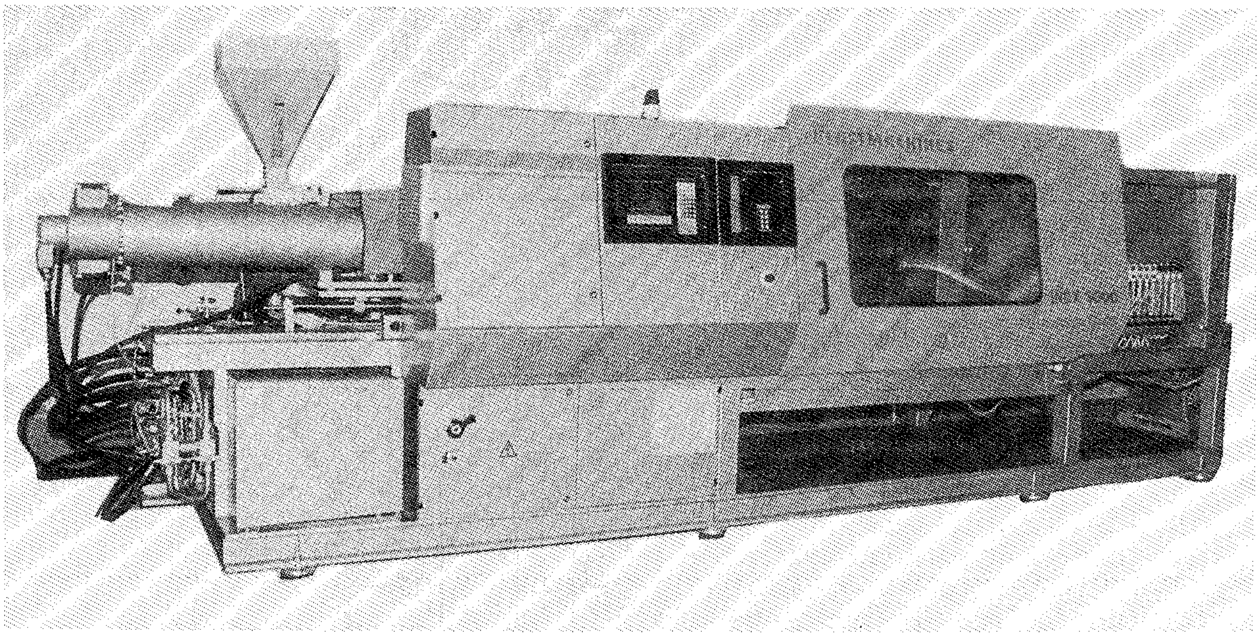
Refuse from industry, households and trade today contains a considerable amount of plastic waste. This comprises numerous types and groups. The largest amounts fall into the following categories, strongly depending on the characteristics of the country concerned:

Polyethylene and polypropylene	60-80%
Polystyrene	2-20%
Polyvinyl chloride	2-15%

There are two basically different methods of processing: the use of the plastic mixture for less demanding formed parts; and the separation of the mixed plastic waste into pure sorts of used plastics, which can then be regranulated. The first method is technically and economically feasible, but a market has to be developed for the products. The second method is technically possible but it is costly and therefore only interesting from an economic aspect, if the price for new plastics is correspondingly high. Besides this, it has to be taken into consideration that the quality of recycled plastic material is lower.

For the above-mentioned reasons, the energy content of the plastic waste is still nowadays often used by burning the plastics in refuse incineration plants, which is not sensible considering the present day conditions and the value of the plastic. In the following the utilization of plastic mixtures from refuse for the production of formed parts will be described. Such formed parts could be: drainage pipes; fences and palisades; road hazard markers; floor plates; park seats and tables; flower containers; noise protection walls; roof tiles; containers for trade and industrial use etc.

For the recycling of plastic mixtures it is important that the main component of the mixture, polyethylene, is used as matrix material into which the other plastics and waste, like paper etc., still contained in the mixture, are embedded in the form of a filling material. The processing temperature lies between 180-200 °C. From this the problem can arise, especially with a higher PVC-content, that the PVC disintegrates in the mixture, thereby separating chloric acid gas (at approx. 150 °C). This can lead to corrosion problems at the production plant, to cost intensive treatment of the exhaust air and to considerable porosity of the product through gas release. Because of the low specific firmness of the heterogenous material the products have to be thick-walled.



Description of the process

With the process considered here new products can be manufactured without costly separating and sorting systems, from mixed and still dirty plastic, waste from household and trade refuse. The material qualities of the recycled plastic correspond more or less with those of simple plastics. The plastic recovered by plastification and deformation is resistant against weathering and acids, is flexible, secure against fracture, easy to maintain and can widely be handled like wood (sawing, drilling, nailing, planing).

Products are mostly produced with thick walls, giving sufficient strength in spite of low thermoplastic contents. The amount of foreign material (non-thermoplastic components) should not exceed 30%.

The processing of plastic mixtures directly by melting is—from the energy point of view—most favourable, as only about 10-40% of the energy needed for the production of new plastics is necessary. For the processing of mixed and dirty plastic waste from household or trade refuse, two processes can be found today: a diecast process; or an injection moulding process.

In the *diecast process* the total plastic material, separated from the refuse, is first comminuted. This takes place in a slow turning two-shaft mill. From a buffer container under the mill a dosing screw lifts the rough plastic material into a perforated washing drum serving as the pre-wash unit. By means of a jet bar with regulatable single jets the plastic material is thoroughly washed with treated circulated water. Because of its greater specific weight, the dirt settles in a sedimentation tank. This step is necessary to protect the blades of the mill.

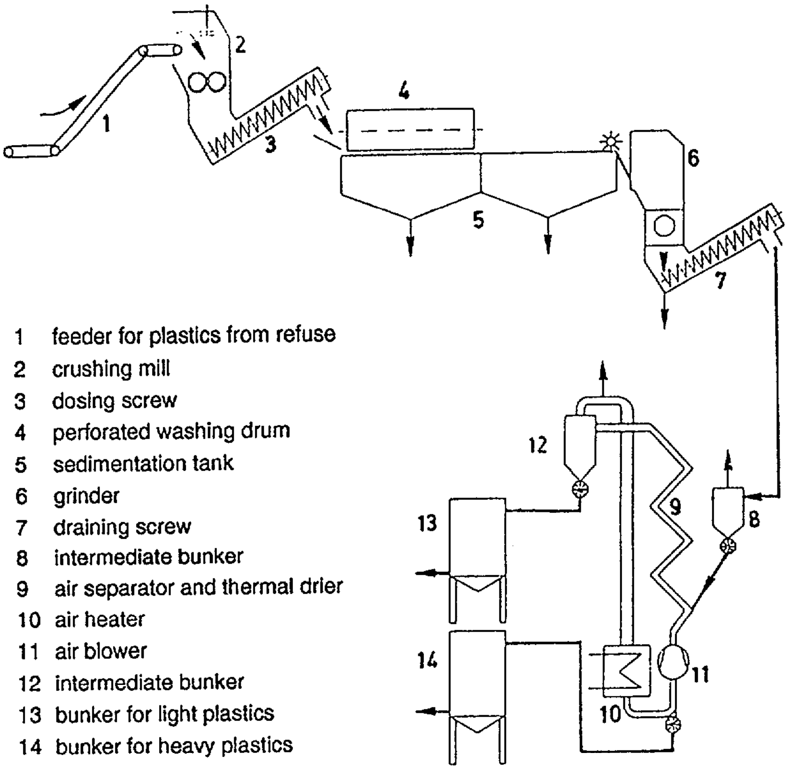
The plastic particles are, by means of a paddle wheel, flushed into a quick turning rotor cutting mill. The distance between rotor and stator blades determines the size of the particles and is very small. This is the reason why hard and damaging particles should be removed beforehand. In order not to rub in dirt into the sheared edge of the plastic particles and to minimize the wear of the blades, the cutting process mostly takes place under the addition of water.

Depending on the quality of the product to be reached, a second thorough wash might be necessary. There are several technical possibilities for this step, such as a quick rotating draining screw, whereby washing water is added in the upper part and drained off in the lower part through a sieve basket. This can be supplemented by a friction washer, a voluminous mixing tub, sometimes in multi-cell structure, fitted with stirring devices.

After draining the fine plastic material is thermally dried. During this process it can also be divided into hard and soft plastic fractions through air separation. Warm air is blown in from the bottom of the unit, taking the soft and light particles into a bunker at the top, while the hard and heavy particles fall against the airstream to the bottom and are discharged by a star feeder into a separate silo. The soft plastic particles are often agglomerated and also stored in a separate silo.

In a further step the undivided plastic material or the two divided materials are taken from the silos in a desired ratio and mixed. This mixture is then slowly heated to 180-200 °C by friction heat to form a well-mixed and fictile melting, in which contaminations and non-melted parts are embedded. The melting is filled continuously or discontinuously into forms by means of a single-screw extruder. After a short cooling-off period the cast part can be taken out of the form.

Figure 1. Processing plastic from refuse



The washing water is circulated in an enclosed circuit and any contamination is separated by means of a special treatment phase. In the *injection moulding process* mixed plastic materials, even with different melting points, can be processed. Should the plastic material still be heavily contaminated with non-plastic substances, then it is, as in the diecast process, comminuted, dried, homogenized and compressed. It is then fed into a plastification unit.

If the plastic material is mainly coming from industry, washing and cleaning is not necessary, thereby saving work and expenses. However, a certain amount of contamination, especially paper, has proven advantageous, because a paper content of up to 25% in the mixture diminishes the extension factor considerably. In the particular case of industrial plastic waste, the material is only comminuted and then directly fed into the plastification unit.

Friction heat, created in the comminuting process, is used for the pre-heating of the material, thus saving a considerable amount of heating energy in the extrusion process. The plastified material, or the melting, is pressed by the extruder screw via a connection pipe, fitted with heating strips, into the injector, a storage cylinder under the extruder, where the piston moves backwards, while the stop valve remains closed. In this phase colouring or the adding of other additives is possible, without any problem, by means of automatic dosing stations.

After reaching the pre-set value, corresponding with the volume of the article to be produced, the valve opens and the melting is injected into the partially closed form under low pressure. After the piston has pressed the melting from the cylinder completely into the form, the stop valve shuts again and the filling process can start once more. At the same time the press gets the command to close the form. The melting cake is brought by the increased pressure into the final shape of the article to be produced. The moulding is kept under continuous pressure and cooled at the same time. After a fixed cooling period the article is taken out of the mould, which can be done via an ejector or other handling device.

Two advantages of the injection moulding process as against the diecast process are: greater parts can be produced; thinner wall thicknesses can be reached because of higher pressures, 2 mm and under.

When a smooth surface of the plastic part is needed, or when resistance against ultraviolet light should be improved, the part can be sprayed with paint or can be dipped. Painting is also cheaper than colouring in the plastified stage. The plant outline without the washing and milling facilities is shown in figure 2.

Working process of an injection moulding machine for recycling plastics

The plastic particles, coming from a shearing mill in grain sizes between 1-15 mm, enter, via a charging hopper, the extruder with a screw specially designed for the processing of mixed and contaminated plastic material.

The homogenized and plastified material is conveyed into a heated storage room, from where it is pressed by a piston into the mould at a controlled pressure and speed. Should it be required, additional material can be added by means of a dwell pressure control unit.

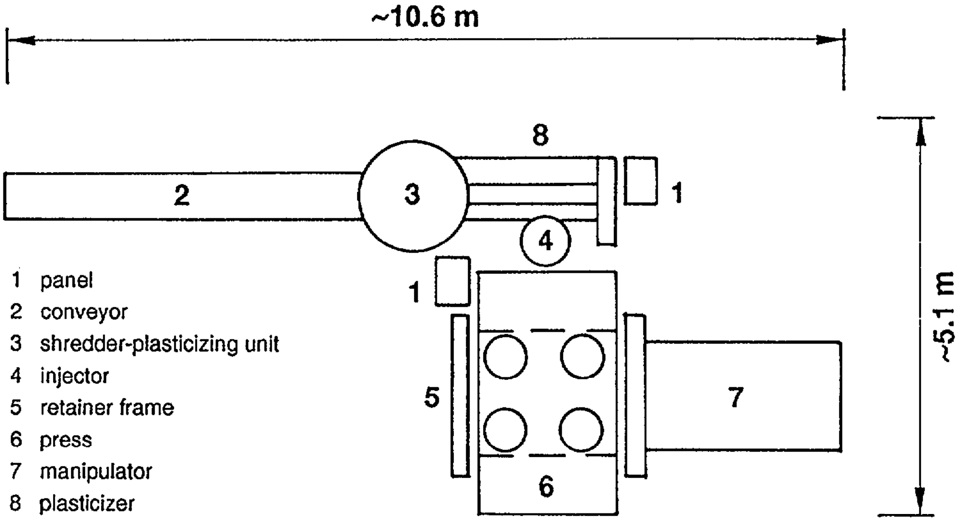
The screw is driven by a slowly revolving and maintenance-free oil pressure motor with adjustable speed. Mould and storage pistons are hydraulically operated and controlled by proportional valves.

A further speciality of the injection moulding machine is the extrusion die. It has to be designed and constructed in such a way that the die can close without problems in spite of foreign matter in the melting, like aluminium or steel particles. Also the extrusion die is hydraulically controlled.

Because of the geometry of the screw a wide range of different plastic materials can be processed, even material mixtures can be processed in turn.

In order to make a continuous process possible, different machine sizes are necessary. These can vary from a locking pressure of 500-12 000 kN, from a storage volume of 1.2-60 l and from clamping plate sizes from 400 × 400 mm to 1600 × 1800 mm.

Figure 2. Outline of plant



Description of the production process

The production process comprises several production lines. The frame of the injection moulding machine and the knee-lever system consist of rolled steel sections, sawn to length by a circular saw, prepared for welding and finally welded together.

In a second line steel plates are cut to their necessary shape by a flame cutting machine; these steel plates are used for the base of the machine, some other machine parts, for the clamping plates and the moulding plates. Where necessary, openings are cut and holes drilled.

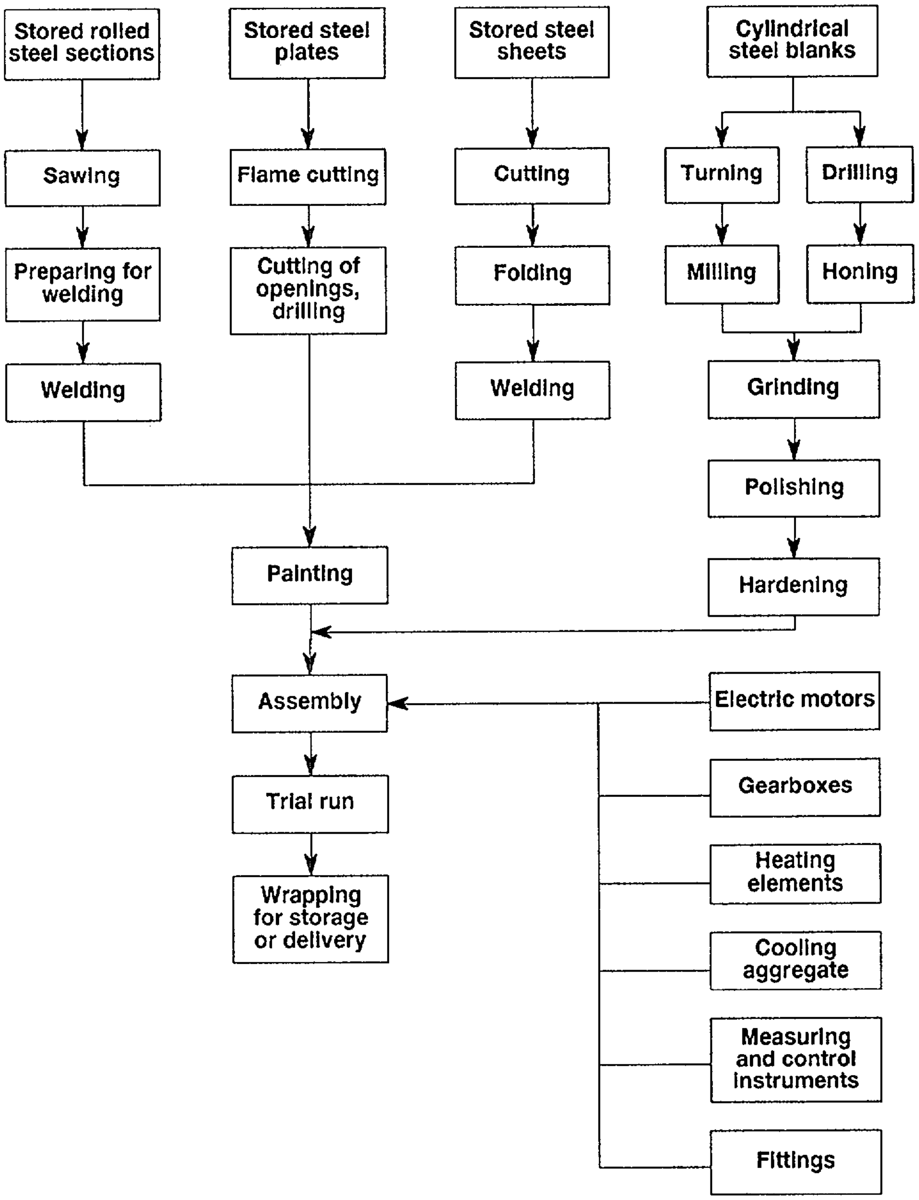
A third line processes the steel sheets, which are cut by plate shears, if necessary they are then bent on a folding machine, finally being welded together to form the machine covering, the input funnel, the control cubicle or other parts.

In a fourth line the extruder screw is turned on a lathe, also the piston, piston shaft and motion rods, starting from cylindrical steel blanks. The extruder screw is then milled on a profile milling machine. All parts are finally ground, polished and hardened in a gas nitriding furnace.

A fifth line manufactures the cylinders for the extruder screw and for the storage chamber. Here also cylindrical steel blanks are used, which are drilled on a gun drilling machine and then smoothened off on a honing machine before being polished.

After having finished the frame, plates and sheets, these parts are sprayed with paint in a spray booth and dried. Then all parts are assembled, incorporating also the parts delivered from outside. When everything has been checked, the machine electrically wired up and connected to the mains, a trial run and final adjustments are the last duties on the machine, before it is packed for transport.

Figure 3. Flow chart



Example of a manufacturing plant

The plant considered here will be able to produce 12 medium-sized injection moulding machines per year, whereby most parts are manufactured at the works. Only easily obtainable parts are bought from outside, such as, for example, electric motors, gearboxes, heating elements, cooling aggregates, measuring and control instruments, bearings and necessary hardware. It has to be stated, that most machines are not used to their full capacity.

Required machinery and equipment

Description	*Pieces*
Flame cutting machine	1
Plate shears	1
Folding machine	1
Circular saw	1
Lathe	1
Gun drilling machine	1
Profile milling machine	1
Grinding machine	1
Honing machine	1
Welding apparatus	2
Hand grinding machine	3
Hand drilling machine	3
Hand polishing machine	2
Gas nitriding furnace	1
Crane (10 tonne)	1
Fork lift (2 tonne)	1

FOB-price for machinery and equipment
Approx. US$1.5 million

Required area

	Square metres
Production hall	1500
inside storage	200
spray booth	50
Administration	100
Facilities	200
Outside storage	200

Required manpower

Manager	1
Engineer	1
Salesman	1
Administrative staff	2
Foreman	1
Welders	2
Metalworkers	10
Electricians	2
Semi-skilled workers	10
Engineer } for machine instalment	1
Electrician } for machine instalment	1

Required energy

Electric power	400 kW
Compressed air (10 bar)	
Water	

Required inputs

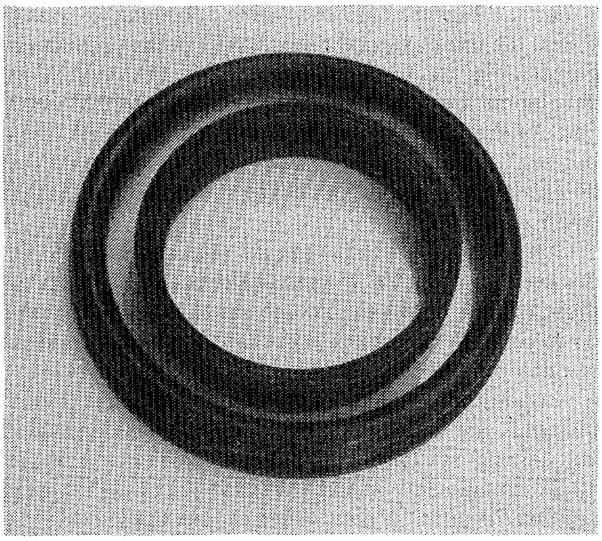
Steel sheets (2-3 mm)
Steel plates (6-10 mm)
Rolled steel sections (different profiles)
Cylindrical steel blank (200-1200 mm)
Welding electrodes
Electric motors
Gearboxes
Bearings
Seals
Valves
Pipes
Water hoses
Fittings
Switches, fuses
Electric wire and cable
Measuring and control instruments
Heating elements
Cooling aggregate
Polishing material
Abrasive material
Paint

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

File: J 8
ISIC CODE 2519
October 1990

How to Start Manufacturing Industries

Rubber sealing rings for water and waste water pipes



Introduction

In the supply and disposal of water in continuous volumes transport is done through pipes which, depending on their intended use and the soil composition, are made from cast metal, solid drawn steel, concrete or plastic.

Diameters vary from 40-2000 mm. For installation reasons and due to the thermal expansion of their length, no continuous pipes can be laid, so sealings must be placed between single segments. At the joint between one segment and another an interaction between what is being transported and the environment must be avoided. In the case of waste water this would mean pollution of the environment, and in the case of fresh water a contamination of the water as well as a loss of raw material. Thus elastomer sealings are used. Various pipe lengths and diameters are used, depending on the location of the installation. In a building whether residential, business or industrial, approx. one sealing ring per metre of pipe, with a diameter of 40-200 mm, is required. Large halls (industrial production, fairs etc.) require approx. 25 rings per 100 metres of pipe. To pipe water over longer distances approx. 15 sealings per 100 metres of pipe (diameter 200-2000 mm) are used. In a residential area with 30 houses, 400-550 small rings and approx. 40-50 middle-sized rings are required.

These examples show that a considerable and expanding market for sealing rings of various types also exists in developing countries.

Description of the product

Sealings are required in the various sizes of pipe diameters and their shapes are dependent on the type of pipe joint used. Sealing standards are issued by several countries, which are partly in use worldwide. The important standards to note are those fixed by the:

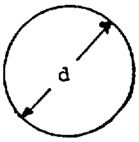
American Waste and Water Association (AWWA);
British Standards (BS);
Deutsche Industrie-Norm (DIN);
International Standardization Organization (ISO).

Shapes

Roll ring

The simplest shape is the roll ring (a large O-ring). It is used with almost all socket joints.

Figure 1. Cross-section of a roll ring



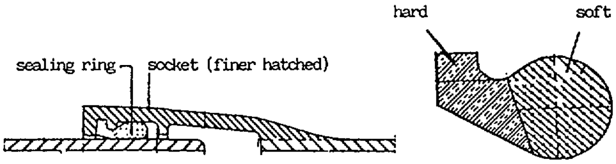
Diameter d = dependent on diameter of ring/pipe D

Tyton-ring

Sockets with restricted longitudinal motion can be made with Tyton-rings. These consist of two rubber components (a roll ring and a holding neck) which are bound tightly to each other:

Soft rubber sealing head;
Hard rubber holding neck.

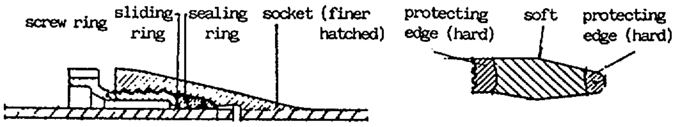
Figure 2. Tyton-ring



Screwed joint (Union ring)

Because shearing force is exerted on the rubber, when two pipe sections are screwed together, hard segments are used at these places. The middle section then takes over the function of the seal (soft rubber).

Figure 3. Union ring



Attainable profits for the rings are dependent on the market, their sizes and type. Table 1 illustrates the price relations of size and type based on an 80 mm roll ring with a starting value of 100 currency units.

Table 1. Comparison of ring types and prices

Size/Type	*Roll ring*	*Tyton*	*Union*
80 mm	100	200	220
1000 mm	1500	3000	3400

Product input

Rubber mixtures

Sealing rubber is a soft elastic mixture. The hard section possesses a hardness which corresponds approximately to that of ordinary plastic. The types of rubber used depend on what is being transported through the pipes as shown in table 2.

Table 2. Rubber pipes and conveyed material

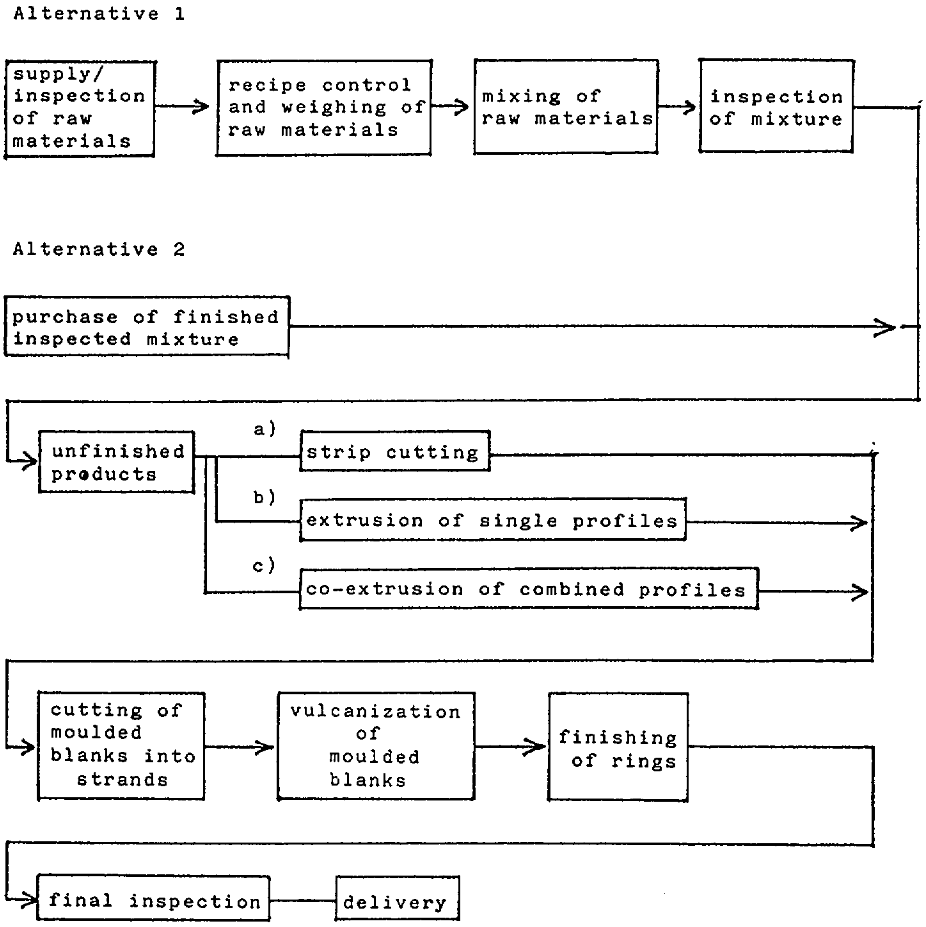
Transported materials/medium	*Rubber type*
Drinking or waste water	Natural rubber (NR) and/or synthesized rubber (SBR)
Hot water or steam	Ethylene-propylene-copolymer (EPDM)
Hydrocarbon products	Nitril-rubber (NBR)
Air	NR, SBR, NBR

For the biggest market volume (drinking or waste water) the use of natural rubber (NR) in the production process plays a considerable role. In the context of development policy it is interesting to note that large parts of the Third World lie within the so-called "rubber belt", that is, on both sides of the Equator in the humid Tropics up to 30 degrees latitude north and south.

Construction of production installations for specific market sectors could trigger positive effects, such as those related to growth, income, employment and profits in foreign currencies, especially by using the local resource of natural rubber.

In addition to rubber (approx. 60-80%) other raw materials are necessary, e.g. soot, anti-oxidents and vulcanizing systems (e.g. sulphur). There are about 10-20 components in each mixture. To finish a ring approx. 70 different raw materials are used.

Figure 4. Production scheme



Production process

Production steps in detail

Supply and inspection of raw materials

Depending on their intended use, the required chemicals are ordered and undergo an initial inspection. The inspection can be substituted instead by a supplier's certificate of approval.

Recipe control and weighing

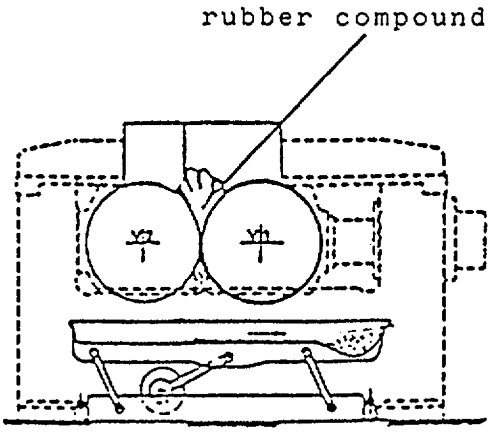
The compounding of a mixture is fixed in a recipe; the raw materials and their proportions as well as the duration and type of mixing are also set in the recipe.

Depending on their use, 10-20 raw materials for each mixture are necessary, which are weighed out corresponding to the amount specified in the recipe and to the production volume.

Mixing the raw materials

There are two basic methods of mixing raw materials: by the two-roll mill or an internal mixer. Both methods correspond to the kind of mixing used in large bakeries. The two-roll mill is used for quantities up to approximately 60 kg. Larger quantities (40 kg and more) can be produced in an internal mixer. Investment expenditure multiplies; however, production time is reduced from around 30 minutes (per 40-60 kg) to 8 minutes (per 50-100 kg). Mixing lasts until all of the raw materials have been evenly distributed.

Figure 5. Two-roll mill



Inspection of mixture

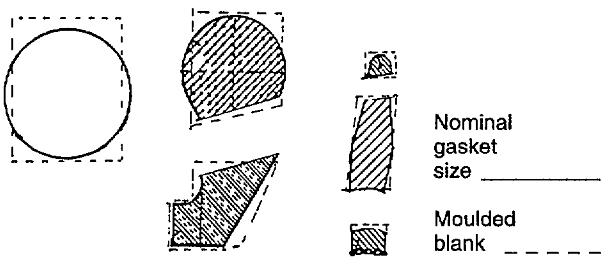
A test sample of the mixture is inspected for attainable characteristics of the finished products. This serves to minimize the number of defective products because raw (unvulcanized) rubber can be re-worked while finished parts cannot.

Production of unfinished products

In order to be able to load raw rubber into the vulcanization mould it must first be pre-formed. Depending on the required capacity and the investment volume several methods can be considered. Three are presented as follows.

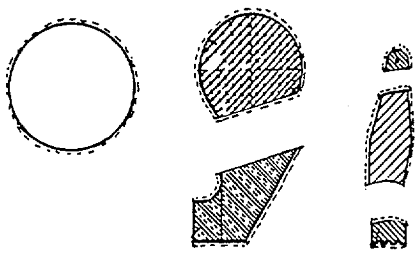
Rectangular inserts. Because its shape is ill-fitting the result is a high degree of material loss: a moulded blank can be produced with low investment costs (extruder not necessary) and high personnel expenditure (manual cutting and packaging).

Figure 6. Moulded rubber, rectangular shaped



Fitted shape, separately extruded. Required moulded blanks are produced by an extruder in slightly larger sizes. Material surplus is slight and personnel expenditure for vulcanization somewhat lower than the first method because extrusion occurs much faster.

Figure 7. Moulded rubber, separately extruded



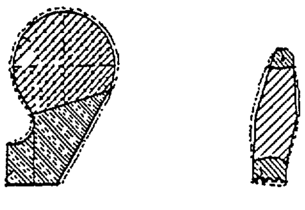
Fitted shape, co-extruding. Here the combined profile is extruded by a twin extruder so that the unfinished product is inserted as a whole. Productivity and safety increases as only 50% of time is required with hard/soft rings.

For each ring size the corresponding cross-sections must be produced. The desired lengths are cut depending on the diameter of the ring.

Vulcanization

Vulcanization (the cross-linking of polymer) of moulded blanks takes place in metal mouldings at temperatures of 130°-160 °C. During heating a locking pressure of 40-80 N/mm^2 is required.

Figure 8. Moulded rubber, co-extruded



Heating duration depends on the temperature and the cross-section of the ring: the higher the temperature and the smaller the cross-section, the shorter the time.

Various types of presses can be used depending on the required capacity. For smaller quantities screw presses are used, which are manually operated but heatable. For medium capacities hydraulic presses are used, and for still larger quantities hydraulic presses with several levels are used.

Figure 9. Multiple daylight press

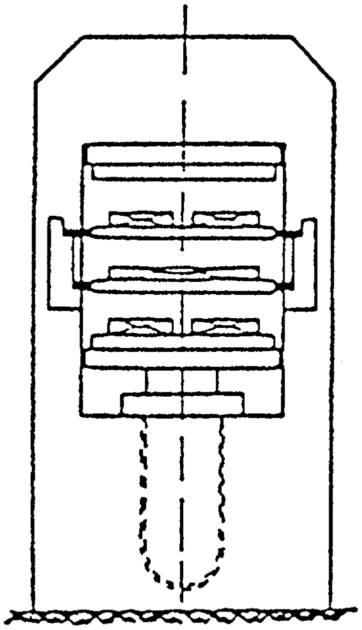
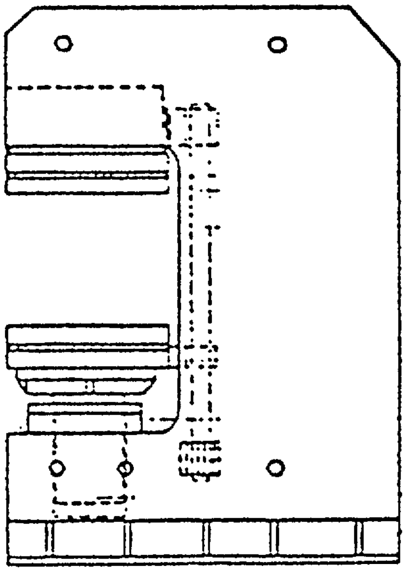


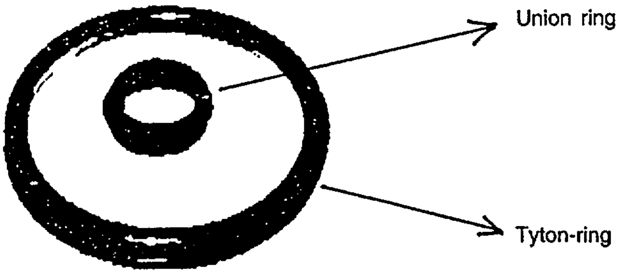
Figure 10. Vertical cylinder press



Finishing and final inspection

Following vulcanization the hot rings are taken from the mould and excess rubber is removed. The rings must finally be inspected for critical properties. The required costs for this (personnel, equipment and time) are largely dependent on those governing conditions (standards, laws, etc.) specific to a country.

Figure 11. Union and Tyton rings



Examples of alternative plants

Due to the multitude of shapes, sizes and capacities no specifics are possible. Three different plants are characterized as follows:

Minimal Equipment

Purchase of mixture
Manual confection
A screw press, depending on the desired capacity (15-40 rings/d)
Personnel: 1-4 persons
Required area: 40 m²
Power supply: electric or steam
Capital: approx. US$ 20,000 (FOB-price 1990)

Medium Size

Mixing in a mill
Extruded unfinished products, multiple parts
Hydraulic presses, approx. 4 per extruder
Power: electric or steam
Personnel: 1-4 persons
Required area: 100 to 200 m²
Capacity: 50 to 200 rings/d (up to 400 pieces for small pieces)
Capital: US$ 50,000-200,000 (FOB-price 1990)

Large Capacity

Mixing with kneader
Co-extruder
Multi-level presses, approx. 4 per extruder
Personnel: up to 6 persons
Required area: 150 to 1000 m²
Capacity: more than 100 rings/d
Capital: US$ 150,000-1,000,000 (FOB-price 1990)

Note: All equipment is available in a used condition on the world market with costs at 15-50% of new prices.

This information has been prepared by UNIDO as a result of the financial contribution to UNIDO from the Government of Germany and the close cooperation extended to UNIDO by the relevant industries in Germany. Any inquiry should be sent to Registry file no. 312/07 (003), UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

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October 1990

How to Start Manufacturing Industries

Conical multiway gate valves

Introduction

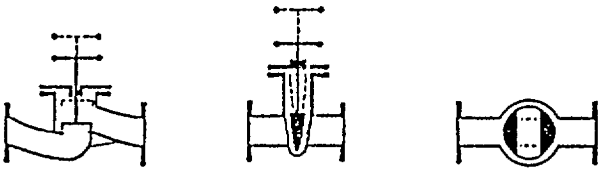
Shut-off units are manually or remote controlled devices which either seal off or release flowing liquids, gases or vapour. Depending on the sealing element's direction of closure, the types of valves used are essentially differentiated as follows:

Stop valves and flaps, which close against the flow-way;

Gate valves, which operate by moving the sealing element at right angles to the flow-way;

Plug cocks, which are operated by turning the spool on its axis which lies at right angles to the flow-way.

Figure 1. Diagrams of different valves



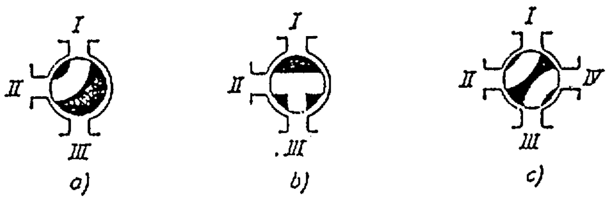
a) stop valve *b) shut-off gate valve* *c) cut-off cock*

Plug cocks (spools) allow for fast opening and closing of pipes by turning the conical or cylindrical spool which results in its bore, lying at right angles to its rotational axis, either linking inflow and outflow or interrupting it.

The advantages of plug cocks are: a simple and sturdy construction; little required space; quick closure and change-over; slight flow loss; and suitability for its further application as a multiway gate valve with several connecting flanges. The disadvantages are: the large seal surfaces, which slide against each other, and the wear which results from this.

The multigate valve, for example, as three-way or four-way gate valves, offers the following possible shifting positions for the change-over into different flow-ways.

Figure 2. Multigate valve shift positions



I-II
II-III
all blocked

I-II
I-III
II-III
I-II-III
all blocked

I-II and III-IV
I-IV and II-III
all blocked

Product description

Features and functions

Multiway gate valves have been critically advanced and improved in the last years. Conventional cylindrical multiway gate valves have a tendency to leak during high capacity performance, often as a result of natural wear and tear.

To eliminate this problem conical spool multiway gate valves have now been developed which feature self-lubricating body and spool casting. Consequently, the wear is uniform and slight whilst achieving an optimum sliding performance. As the flow-ways inside the valve casing are not restricted by projecting edges or angular sections, they are designed for optimum flow.

If the spool is moved by manual or actuator operation, a tight closure and a facilitated opening of the valve cannot be prevented by either solid, flexible, pasty or any other highly viscous media: solids are shifted to and fro through the spool wall, flexible and fibrous materials are shredded between the acute action of the spool edges, and pasty products are separated—all without the medium becoming compressed. No particles (sand) can get between the spool and the spool wall.

An automatic take-up device ensures that the spool is always pressed flexibly into the body, thus eliminating leakage under normal conditions of wear.

A lubricating nipple allows for grease to be packed between the body and the spool in cross-groves to the slideway, thus ensuring the necessary easy sliding action.

With the three-way, four-way and five-way gate valves the following shifting positions are possible (figure 3):

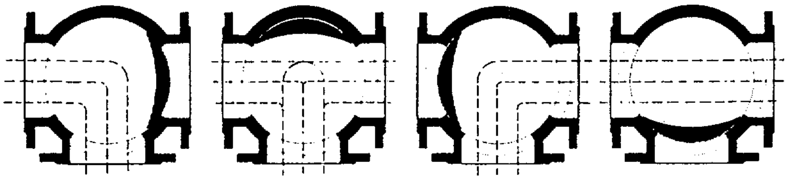
Components

The essential components of a multiway gate valve and those materials used in its production are listed in table 1:

Table 1. Components of a multiway gate valve

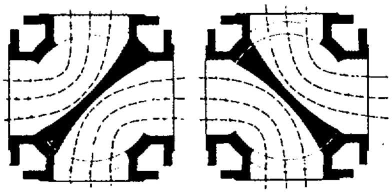
Components	*Materials*
Valve casing	Grey cast iron
Spool	Grey cast iron
Valve cover	Grey cast iron
Hexagon bolt	Steel
Retaining ring	Buna N
Disk spring	Steel
Lubricating nipple	Steel

Figure 3. Shifting position



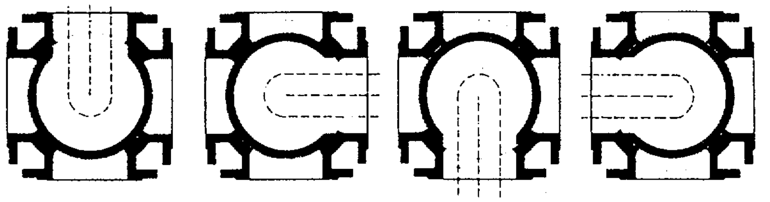
Three-way Gate Valve

T-housing with L-spool.
The L-spool always closes on one side.



Four-way Gate Valve

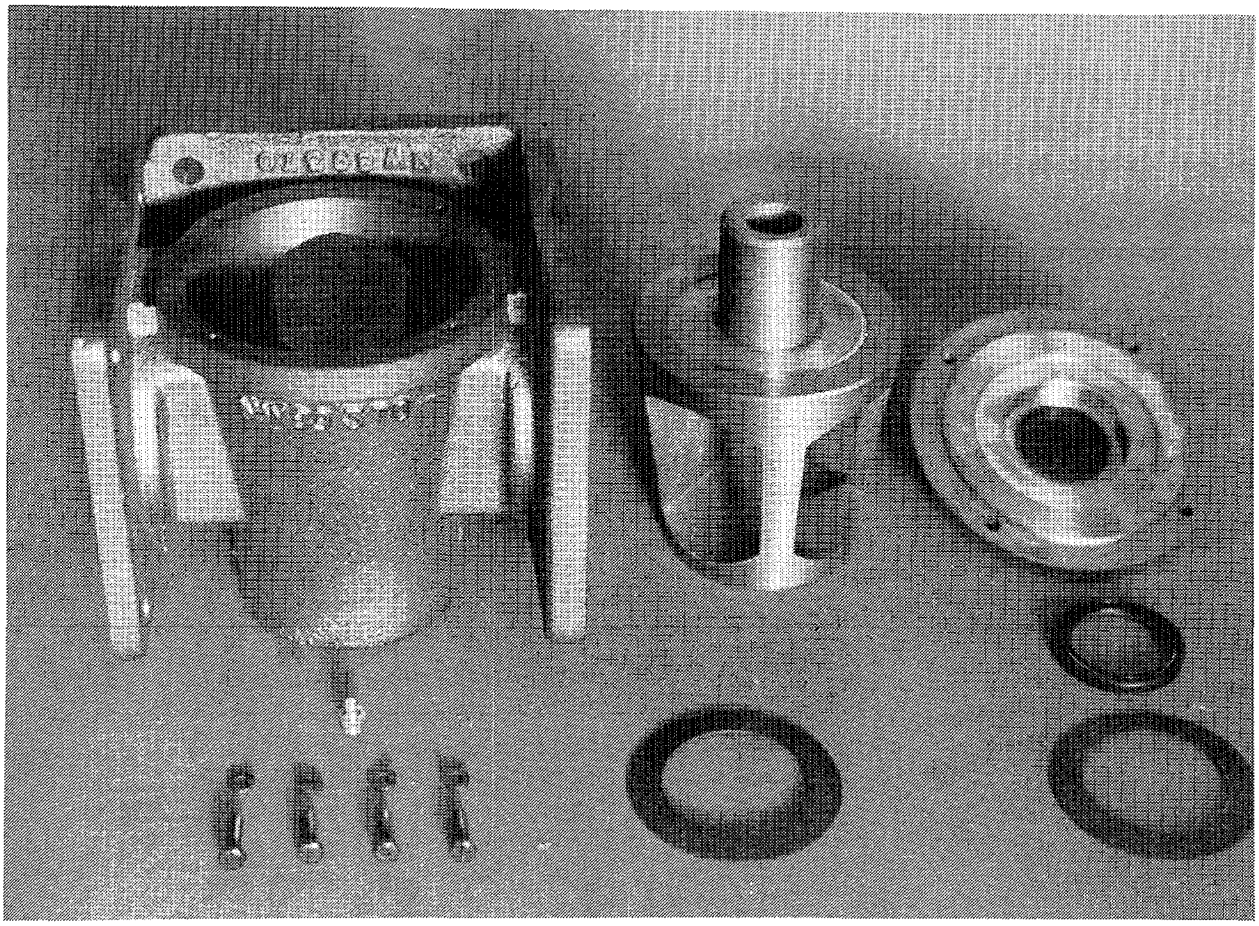
Spool with two separate channels.



Five-way Gate Valve

Housing with inflow-flange at the bottom and discharge at four sides.

Figure 4. Three-way gate valve



Parts for assembling a three-way gate valve DN 89 with a quadrilateral flange: casing, spool, cover, shaft sealing ring, disk springs, hexagon bolts with spring rings, lubricating nipple.

Depending on the area of application, specifically suited materials must be used for each component. Thus, for example, in the chemical industry as well as in the food and luxury goods industries, acid and corrosion resistant materials are used.

Area of Application

Multiway gate valves in several variations are basically used everywhere where liquid, flowing or gaseous media must be transported (see figure 5).

Waste water treatment is a major priority in various sectors of application. Listed in the following are some of these sectors and their respective media.

Agriculture

- The most commonly resulting media are mud and liquid manure. Here multiway gate valves are used with both stationary pipe systems and vehicles, such as tankers and trucks which distribute the mud and liquid manure.
- Use with all types of water tank trucks and trailers, as well as everywhere in an irrigation plant.

Purification plants

- Generally in pipe systems, where waste water or mud streams must be distributed (container, tanks, sedimentation basin, pump systems).
- City vehicles for transporting mud, waste water and sewage.

Drinking water processing

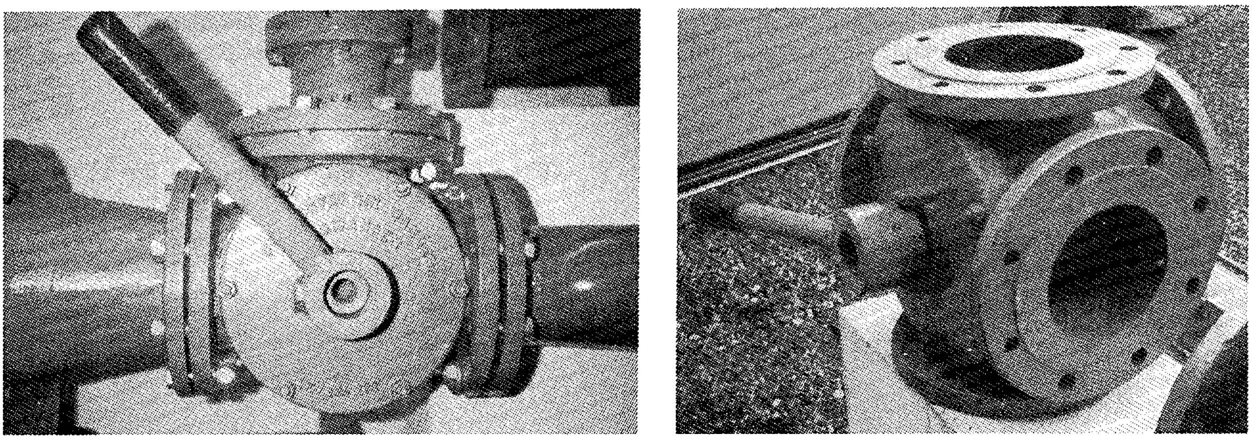
In clarifying filtration or sedimentation of drinking water, especially in filters (or clearing basins).

Description of production process

The production of multiway gate valves in this case is characterized by the processing of tertiary parts which are then assembled to make the end product.

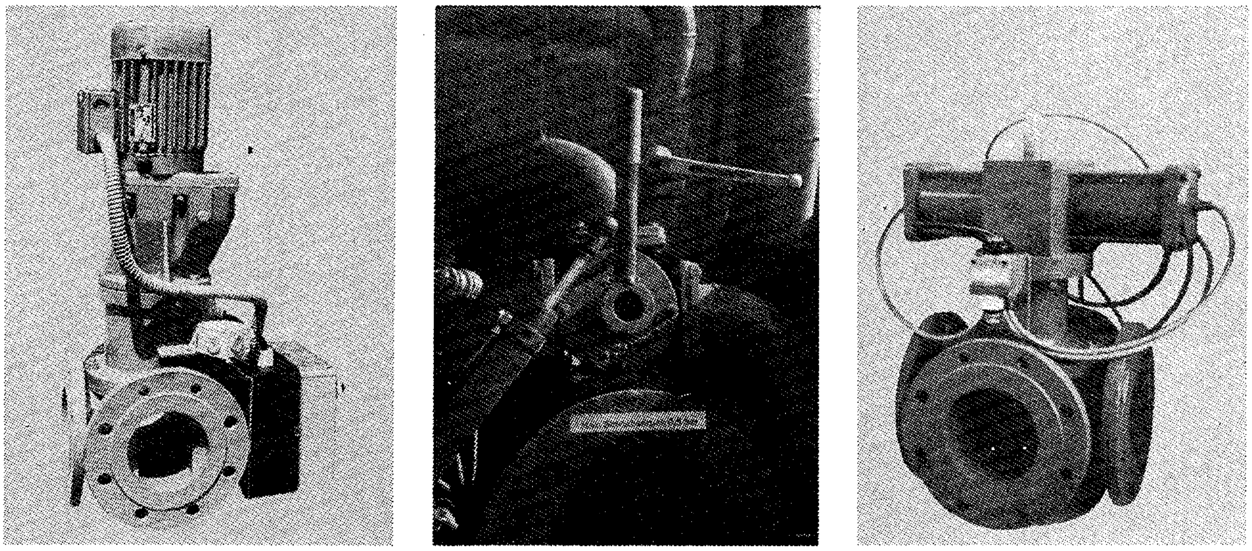
Prior to processing, these tertiary parts undergo quality control, after which the production process itself begins. The essential steps are schematized in the following flow chart.

Figure 5. Multiway gate valves with pumps and compressors



Three-way gate with hand lever mounted on the discharge flange of a pump

Five-way gate valve with hand lever

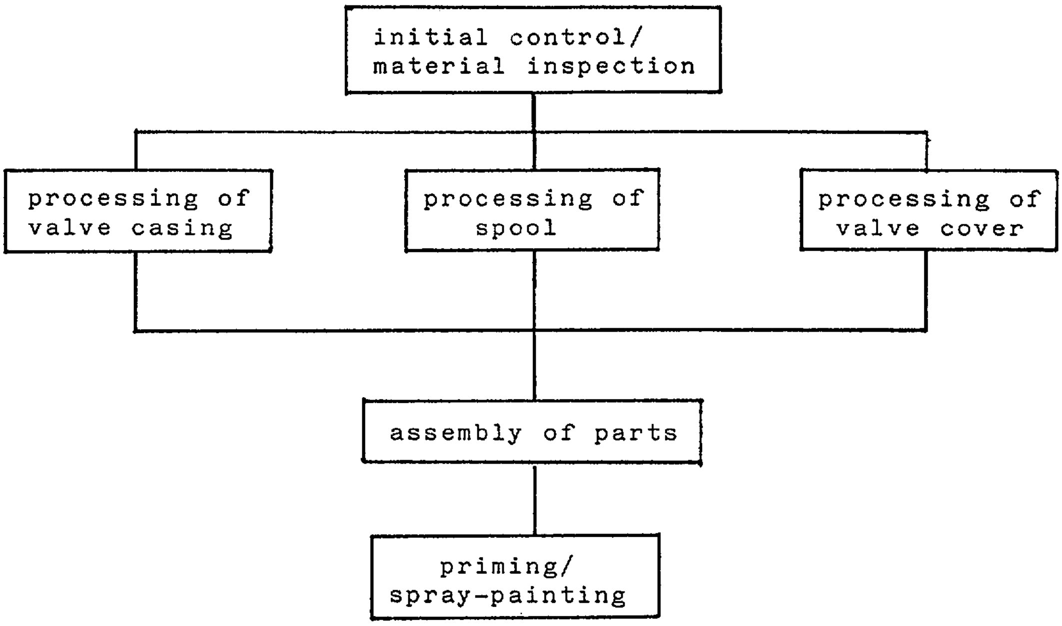


Three-way gate with electric drive

Four-way gate with hydraulic drive and hand lever

Four-way gate valve with pneumatic drive

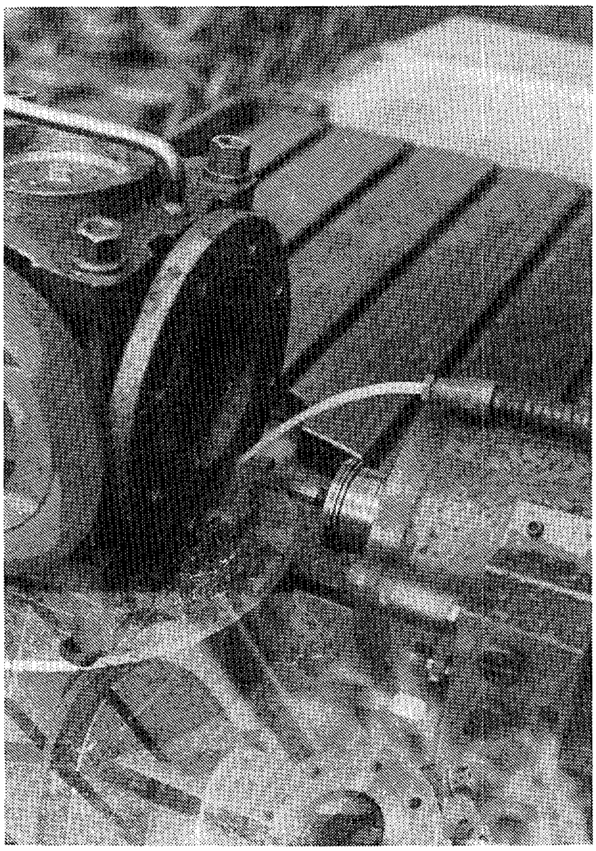
Figure 6. Production process of multiway gate valve



Processing of the valve casing includes, in particular, milling, drilling and thread cutting. On a CNC-operated automatic lathe a cone is first moulded from the casing blank. Further processing of the valve casing is done on a CNC-operated automatic milling machine, whereby the seal faces and screw holes of flanges are milled and drilled. Drilling for the cover screws is done with a second setting, and the thread for the cover screws and the lubricating nipples are cut.

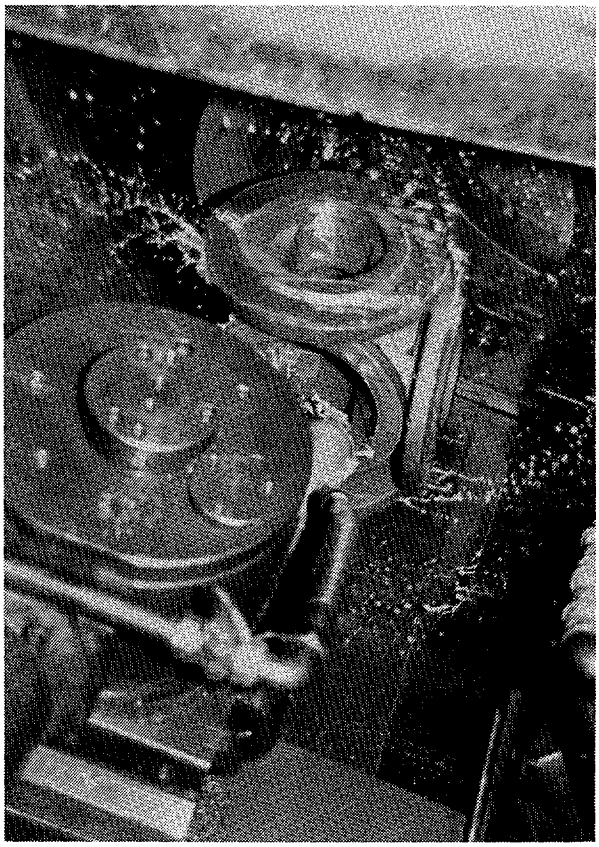
The spool is lathed on the automatic lathe in two phases with the same gradient as the cone of the valve casing.

Figure 7. Valve casing mounted on an automatic lathe



The casing is set on an automatic lathe for processing. The cover surface and cone are first lathed

Figure 8. Drilling and milling of the valve casing



The circular flanges are already milled over. After drilling the thread is drilled with the same setting

Processing of the valve cover is first done on the automatic lathe. Drilling in the cover is carried out on a multi-spindle machine.

The operations carried out on the automatic lathe and milling machine can also be done on conventional milling and lathe machines respectively with the appropriate auxiliary devices. These alternatives are especially suited for processing smaller quantities.

After processing the individual components are assembled, primed and, if required, spray-painted.

Dimensioning

Assuming that the unprocessed individual parts are externally produced and supplied, the following machines in particular are used for the production of a three-way gate valve:

CNC-operated automatic lathe;
CNC-operated milling machine;
Multi-spindle drilling machine.

Table 1. Average production times

Item	*Description*	*Approximate time in minutes*
Valve casing	lathing	30
	milling and drilling	40
	drilling and thread cutting	20
Spool	two operations	50
Valve cover	lathing	20
	drilling	10
Assembly and priming		30

Examples of alternative plants

In modern manufacturing, assuming that individual main parts for a multiway gate valve are supplied as undressed castings, and various individual parts for assembly (screws, springs etc.) are obtained from suppliers, the table below shows what is necessary to equip a production plant.

In conventional manufacturing the required investment capital is reduced by up to 50%.

Required machinery and equipment

Description	*Pieces*
Automatic lathe	1
Milling machine	1
Multi-spindle drilling machine	1
Additional equipment, especially testing equipment	
FOB-price for machinery and equipment (1990)	Approx. US$ 200,000-600,000

Required manpower

Mechanic	1
Workers	1-2

Required area

	Square metres
Total	1000

Required power

Electric power	80 kW
Including:	
automatic lathe	40 kW
milling machine	20 kW

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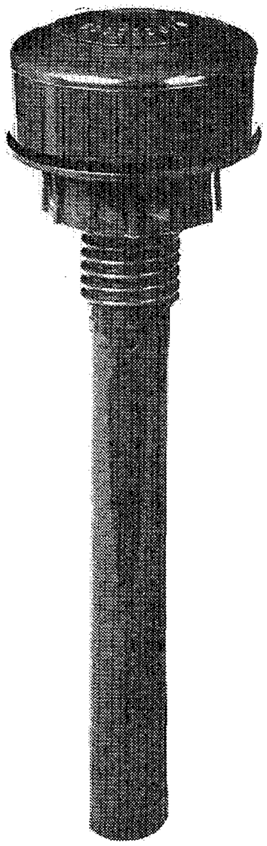
File: V 2
ISIC CODE 4100
October 1990

How to Start Manufacturing Industries

Filter nozzle for fast-run filters in water purification



Introduction

In choosing water extraction sites for a water supply system, sites where water corresponds in its natural state to the standards of purify for drinking and service are used first. However, with the growth of the central water supply system and the increase in water consumption, those water deposits, which are favourably located and chemically suitable, are often fully exploited. Consequently more water has to be used which does not in its natural state comply to health and to hygienic standards. Therefore, it must be suitably processed before use.

One procedure used by processing technology is filtration. Filtration is understood to be the separation of fine, insoluble substances from liquids by the use of filters.

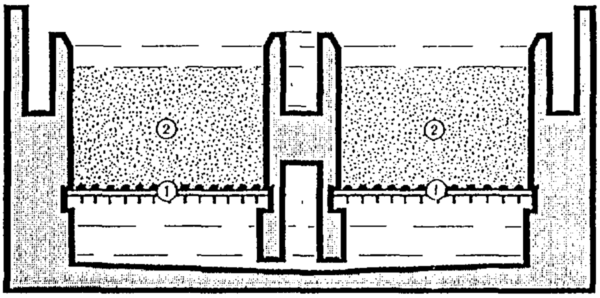
In water purification, one differentiates between slow-run filters and fast-run filters in terms of performance (filter speed), as well as between open and closed filters in terms of type of construction.

Slow-run filters today, because of their need for a large working space and their low production, are as good as obsolete in water processing and water purification plants. Fast-run filters of open and closed type are used both at municipal water processing plants and for industrial water processing.

Filter nozzle as part of a fast-run filter

In both the concrete open type fast-run filter (see figure 1) and the closed type fast-run filter made from steel sheet, the filter nozzles (1) installed in the filter bottom or nozzle bottom are important components for the filtration process, above all for the rinsing of the filter i.e. the cleaning of the filter bed. The material of the filter bed (2) consists of, according to the intended purpose of the filter, quartz sand or gravel (with grain sizes between 0.5 and 30 mm), and anthracite or activated carbon. Thus quartz sand is sufficient, for example, for such simple tasks as the deferrization/demanganization of weakly polluted water as the grain size of an effective filter layer has basically to match the type of solids which are to be filtered out. That is to say, it should not be smaller than is necessary to achieve the perfect filtering effect.

Figure 1. Open type fast-run filter made from concrete

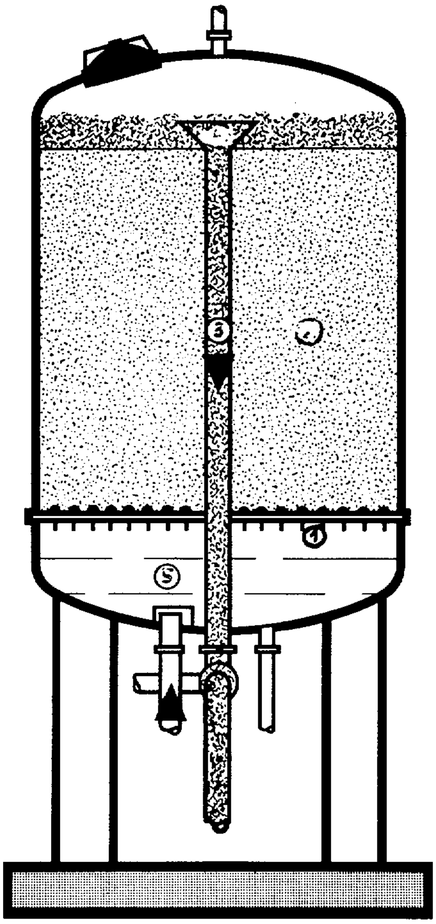


Whichever of the two filter types (open or closed) is chosen can only be decided on the basis of local conditions, or on the properties of the water to be processed.

Filtration process

During filtration in a closed fast-run filter (see figure 2) water enters from below through the central vertical pipe (3) via the mud hopper (4) into the filter bed; it flows through this and passes into the clean water chamber (5) via the built-in filter nozzles (approx. 50-60 per m^2 filter bottom). The filter nozzles are screwed into an equal number of threaded bushes which are welded (or cemented) into the filter bottom.

Figure 2. Closed type fast-run filter made from steel



Rinsing of the filter

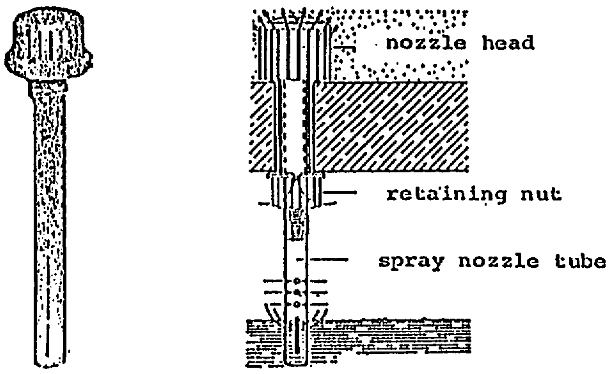
At certain times, depending mainly on the properties of the water to be filtered, cleaning of the filter bed (2), which consists mainly of a 3000-4000 mm high layer of gravel, is necessary due to increasing siltation and in order to maintain constant water permeability. The rinsing of the filter is done by a mixture of pressurized air and water (scavenging air 60-90m^3/hr per m^2 filter area, rinsing water 15-20 m^3/hr per m^2 filter area), being introduced from below for approx. 10-15 minutes into the filter bottom through the nozzle heads, which cover the entire filter bottom and are shielded laterally. By using the filter nozzles the result is a good mixture of pressurized air and water, on the one hand, and a balanced distribution of the mixture over the entire filter area, on the other.

The main task falls to the pressurized air. The rinsing water's only purpose is to transport the mud separated by the pressurized air out of the filter bed. This occurs via the centrally positioned vertical pipe (3) with the mud hopper (4) on top. This cleaning process is very highly effective and saves a lot of water.

Product description

A filter nozzle (see figure 3) consists of the nozzle head, the spray nozzle tube and the retaining nut. The nozzle headpiece has vertical slits all around which must be impermeable to the filter material used. The spray nozzle tube fitted into the nozzle head has a hole at the top and at the bottom two vertical slits, one on each side of the tube. Both parts are fastened to the filter (or nozzle) bottom by a plastic nut using washers, made of special rubber, between the nozzle head and filter (or nozzle) bottom, and between the retaining nut and filter (or nozzle) bottom.

Figure 3. Filter nozzle with spray nozzle tube



The size of the nozzle head and the width of the slits depend basically on the grain size of the filter material used.

Accordingly, the size of the nozzle head can vary between 5 cm and 10 cm and the width of the slits between 0.30 mm and 0.75 mm.

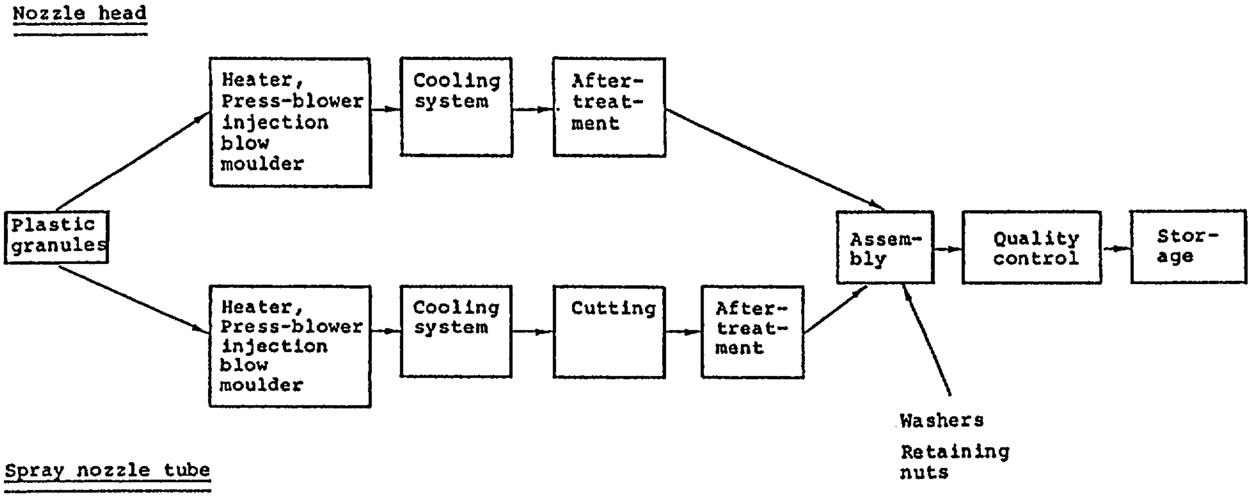
The length of the spray nozzle tube depends on the height of the filter (or nozzle) bottom, which is determined by static calculations.

Description of the production process

The production process described here refers to the production of nozzle heads and spray nozzle tubes from plastic, regardless of their size. Raw materials (i.e. plastic in the form of granules), washers made from special rubber and mounting screws must be supplied.

The production process of the nozzle heads and spray nozzle tubes is partly carried out on two separate production lines, whereby the products are transported from station to station by conveyor belts. The common starting point is the granule container, from where the raw material is advanced to the moulding press, after it has been heated to the processing temperature. After this, the individual nozzle heads and the endless nozzle tube enter a cooling system where the temperature of both parts is reduced to about 20^0 C. The nozzle heads are then finished. The endless nozzle tube is cut into specified lengths by a cutting machine, thus forming the individual spray nozzle tubes, which are then ready for finishing off. The nozzle heads and spray nozzle tubes are then assembled, and the supplied washers and retaining nuts attached. The finished filter nozzles are transferred into storage after passing quality control.

Figure 4. Production process of nozzle heads and spray nozzles



Example of a production plant

In describing the production plant it should be pointed out that all specifications refer only to the production of filter nozzles, whereby at full capacity approx. 80-100 pieces can be produced per hour. It is generally possible, with some re-adjustment to the machinery, also to produce other plastic products.

Required machinery and equipment

Description	*Pieces*
Press-blower injection blow moulders including heaters and toolsets	2
Cooling system	2
Compressor	2
Cutting machine	1
Conveyor	8

FOB-price for machinery and equipment (1989) Approx. US$ 450,000-500,000

In addition, other tools, materials and simple transportation facilities are also required.

Required manpower

The production of filter nozzles is possible with the following minimal number of personnel:

Supervisor (business and technical)	1
Secretarial and administerial employee	1
Foreman	1
Unskilled workers	6

Required area and buildings

Simple buildings with adequate electricity and water supplies are sufficient.

	Square metres
Production buildings	200
Storage (raw materials, finished products, replacement parts etc.)	100
Office, rest area, WC, washing facilities, workshop etc.	80

Required power and utilities

Electric power	220 kW
Pressurized air	2500 l/hr at 6-10 bar
Water	3 m³/hr

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How to Start Manufacturing Industries

Filter cartridge for domestic water filters

Introduction

The purpose of a water supply lies in covering the needs of the home and workplace at all times (in terms of the requisite volume and adequate pressure), whilst guaranteeing the appropriate physical, chemical and bacterial properties of the water, according to use.

Water in its natural state is chemically impure. During its course through the atmosphere and the water bearing rock-bed to the extraction site it picks up elements and particles, which alter its properties, depending on where it originates.

The supply of hygienically pure drinking and utility domestic water, i.e. water that can be both consumed and used safely for household purposes, can generally only be acquired through public central water supply plants. In these plants, apart from extraction, storage and distribution of water, water purification (neutralization, deferrization, disinfection etc.) also takes place. Clean and uncontaminated domestic water is, therefore, released by the water supply plant (water works). However, during its journey through the pipe system water can pick up a variety of particles. In developing countries especially, domestic water can be contaminated by frequent pipe bursts, servicing and maintenance work, as well as by heavy rainfall. The insoluble materials carried along by the water settle inside the pipe system and become the main cause of corrosion in domestic pipes, as well as the main cause of malfunctioning valves, shower heads, boilers etc. By installing a domestic water filter at the point of a pipe's entry into a house, these materials are largely held back, thus preventing system breakdowns and sparing expensive repairs.

In addition to their domestic use, mainly in the municipal water supply, domestic water filters can also be used in developing countries for public standpipes at nurseries and at car wash installations.

The filter cartridge as a part of the domestic water filter

As shown in figure 1 below, a domestic water filter consists of the following parts:

Filter head made from brass;

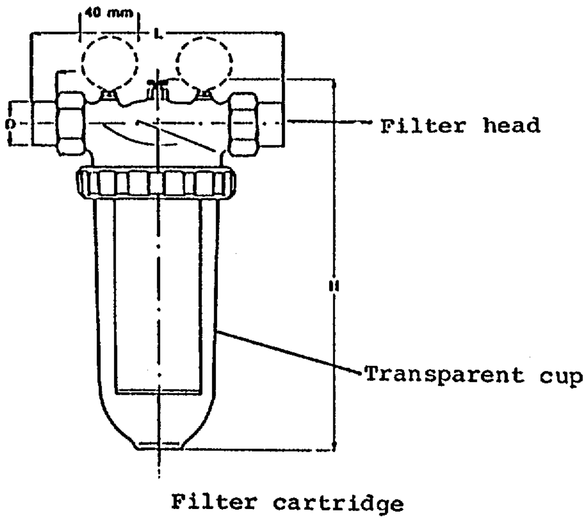
Transparent cup with an internal thread on top;

Filter cartridge.

The measurements of the domestic water filter (standard type) are as follows:

Pipe connections	D	=	1"
Length of the filter head	L	=	130 mm
Height of the filter	H	=	309 mm
Manometer link		=	1/8"

Figure 1. Domestic water filter



The domestic water filter is connected to the pipe system by the filter head. In order to measure the pressure difference, and thus to gauge the degree of the soiling of the filter, it can be fitted with 2 manometers with a range of 0-10 bar. The transparent cup, which can be unscrewed from the filter head, is made from plastic, usually Trogamid T, which should be highly shock resistant against outside impacts and shock pressure from within, permanently transparent and stress resistant.

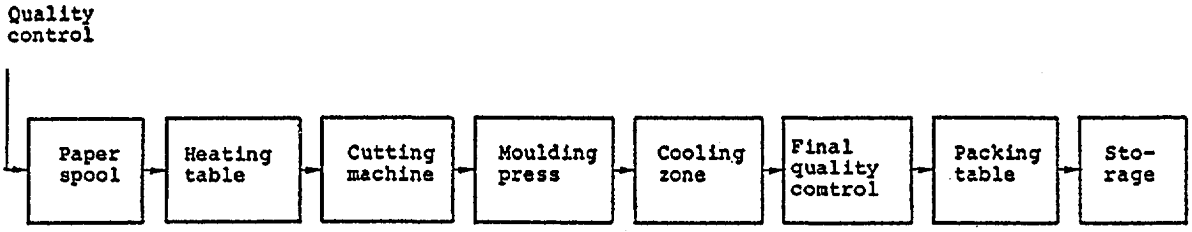
The filter cartridge is fitted over a rim located on the underside of the filter head and held in place by the filter cup which is screwed onto the filter head. It is in this part of the domestic water filter that the actual cleaning takes place. The production of this filter is described in greater detail below.

Product description

The filter cartridge, in the shape of a cylinder with one open and one closed end, is made from tear resistant wood pulp paper approx. 3 mm thick, which is porous but not perforated. The standard type has a diameter of 70 mm and a length of 223 mm.

This filter cartridge allows a maximum water flow of 5 m^3/hr. Standard filter cartridges are used basically in supplying residential areas with domestic water. Larger filter cartridges (diameter 60 mm, length 300 mm; diameter 70 mm, length 300 mm; diameter 70 mm, length 350 mm) are used in breweries and plants for the production of mineral water.

Figure 2. Production plant flow chart



Description of the production process

The production plant, described in the following, is suitable not only for the production of standard filter cartridges but also for filter cartridges of other sizes. Therefore, space requirement and personnel are not specifically tailored to the production of standard filter cartridges.

The most important raw material for the production process is wood pulp paper, which must be supplied and whose quality should be constantly controlled.

The supplied filter paper, which is quality controlled, is placed on a spool and is transported over a heating table to the cutting machine by means of a conveyor belt. There the individual filter papers are cut to size. The cut rectangular pieces are then conveyed into the moulding press where they are shaped into the cylindrical form of the filter cartridge.

After leaving the moulding press the filter cartridges pass through the cooling zone on a conveyor belt where they are brought down to room temperature. Then they reach the final quality control station. Those filter cartridges, which pass inspection, are further transported by conveyor belt to the packing area, where they are packed into cartons and sent into storage.

Example of a production plant

The following figures are based on an output of 420 units per hour at full production capacity.

Required Machinery and Equipment

Description	*Pieces*
Paper spool	1
Heating table	1
Cutting machine	1
Moulding press	1
Cooling zone	1
Packing table	1
Conveyor belts	8
FOB-price for machinery and equipment (1989)	Approx. US$ 700,000-750,000

Required manpower

Business supervisor	1
Technical supervisor	1
Typist	1
Foremen	3
Unskilled workers	12
Mechanic	1

Required area and buildings

To set up the production area the following is an approximation of what is required:

	Square metres
Production building	800
Storage (for raw materials, tertiary products, replacement parts, finished products etc.)	300
Offices and social rooms	100

Required Power and Utilities

Electric power	180 kW
Pressurized air	
Pressure	8-10 bar
Consumption	2000 l/hr

Required Inputs

(Per eight hour day at full production capacity)

Filter paper	50 t/year
Cartons	1.1 million units/year

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