CHAPTER 7

THE SOLID WASTE PROBLEMS

7.1. SOURCES, MANAGEMENT AND METHODS.

7.1.1. Classification of solid waste.

The disposal of solid waste has become a galloping problem in all highly developed countries due to a number of factors:

1. Increased urbanization has increased the concentration of solid waste.
2. Increased use of toxic and refractory material.
3. Increased use of "throw away" mass produced items.

P.7.1. **Solid wastes include an incredible miscellany of items and materials, which makes it impossible to indicate one simple solution to the problem. It is necessary to apply a wide spectrum of solutions to the problems according to the source and nature of the waste.**

Table 7.1 shows a classification of solid waste. Typical quantities in the technological society per inhabitant are included.

TABLE 7.1
Classification of solid waste

Type of waste	kg/inhabitant/day (approx.)
Domestic garbage	4
Agricultural waste (1)	12
Mining waste (2)	18
Wastes from construction (3)	0.1
Industrial waste	1.5
Junked automobiles	0.1

(1) Not mentioned further in this context. Recycling is recommended and also widely in use.
(2) A substantial part is used for landfilling.
(3) Not mentioned further in this context. Recycling is possible and recommended, but a part is also used for landfilling.

7.1.2.   Examination of mass flows.

A universal method for treatment of solid waste does not exist, and it is necessary to analyze each individual case to find a relevant solution to the problem.

The analysis begins with an examination of mass flows (principle 2.1) to ascertain whether there is an economical basis for **reuse** (for example, bottles), **recovery of valuable raw materials** (paper and metals) or **utilization of organic matter,** as a soil conditioner or for the production of energy. These considerations are illustrated in Fig. 7.1. Mass balances for important materials, as demonstrated in section 2.8, must therefore be set up. Fig. 7.2 provides another very relevant example.
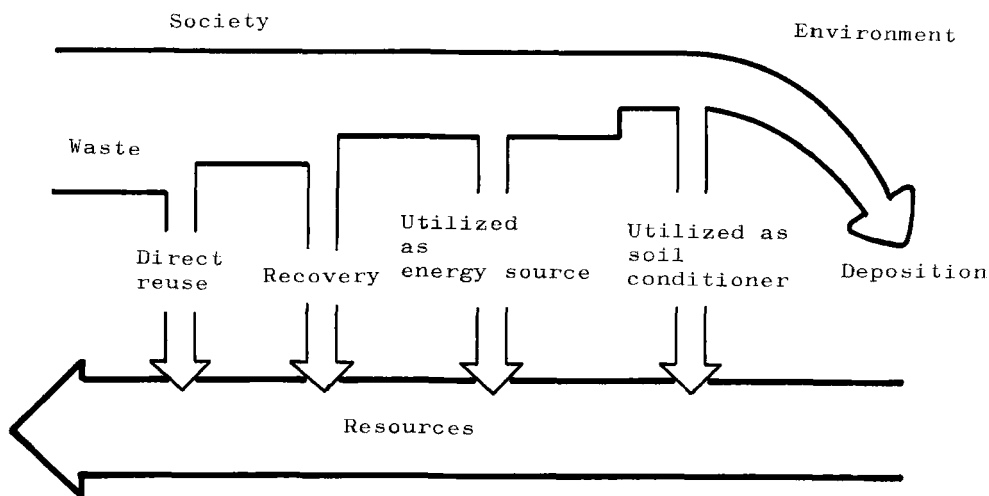

Fig. 7.1.   Principles of recycling of solid waste.

The analysis of mass flows is the framework for a feasible solution, which takes economy as well as environmental issues into consideration. However, legislation and economical means are required to achieve the management goals. For instance, the use of returnable bottles can be realized **either by banning the use of throw-away bottles or by placing a purchase tax on throw-away bottles and not on returnable bottles.**

The management problems are highly dependent on the technological methods used for solid waste treatment. The classification mentioned in the introduction to Part B of this book (p. 286) might be used in this context.
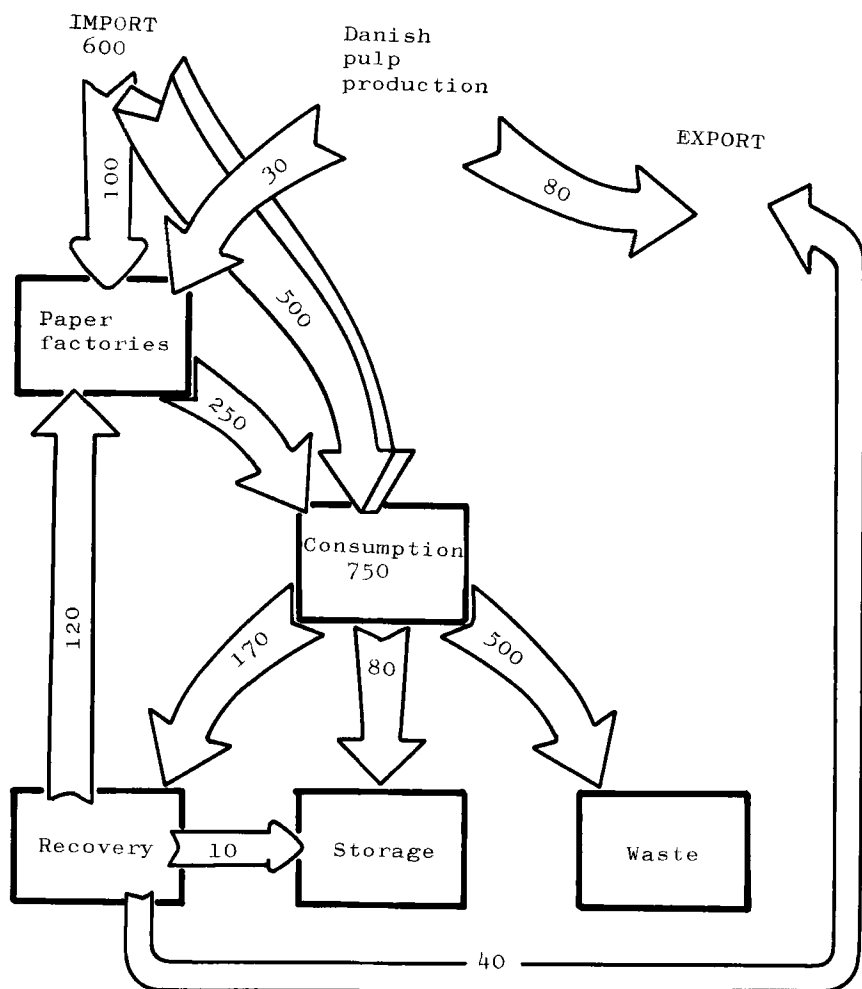
Fig. 7.2. Recovery of paper in Denmark. The mass flows are shown. All number 1000 t/y.

P.7.2. Methods based on alternative technology and recycling, to reduce the amount of waste produced, often require environmental legislation or economical means to guarantee success.
Methods based on deposition will require a comprehensive

**knowledge of the environmental effects on the ecosystems involved.
Complete decomposition to harmless components is not possible for most solid waste.**

For instance incineration will produce a slag, which might cause a deposition problem, and smoke, which involves air pollution.

7.1.3.   Methods for treatment of solid waste.

P.7.3.   Table 7.2 gives an overview of the methods applicable to solid waste. The table indicates on which principle the method is based - recycling, deposition or decomposition to harmless components. It also shows the type of solid waste the method is able to treat.

TABLE 7.2
Methods for treatment of solid waste

Method	Principle	Applicable to
Conditioning and composting	Decomposition before deposition	Sludge, domestic garbage, agricultural waste
Anaerobic treatment	Decomposition, deposition, utilization of biogas	Sludge, agricultural waste
Thickening, filtration, centrifugation and drying	Dewatering before further treatment and deposition	Sludge
Combustion and incineration	Decomposition and deposition. Utilization of energy	All types of waste
Separation	Recycling	Domestic garbage
Dumping ground	Decomposition and deposition	Domestic garbage
Pyrolysis	Recycling, utilization of energy, decomposition	Domestic garbage
Precipitation and filtration	Deposition or recycling	Industrial waste
Landfilling	Deposition	Industrial-, mining- and agricultrual waste
Aerobic treatment	Decomposition and deposition	Sludge, agricultural waste

In the following sections the problems of solid waste will be discussed in four classes: A. Sludge, B. Domestic garbage, C. Industrial, Mining and Hospital waste, D. Agricultural waste. The methods used for the four classes are, to a certain extent, different, although there is some overlap, between them.

7.2. TREATMENT OF SLUDGE.

7.2.1. Sludge handling.

P.7.4. **In most waste water treatments the impurities are not actually removed, but rather concentrated in the form of solutions or a sludge. Only when a chemical reaction takes place does real removal of the impurities occur, e.g. by chemical or biochemical oxidation of organics to CO_2 and H_2O, or denitrification of nitrate to nitrogen gas.**

Compare also with principles 2.1 and 2.6.

Sludge from industrial waste water treatment units in most cases requires further concentration before its ultimate disposal. In many cases two- or even three-step processes are used to concentrate the sludge. It is often an advantage to use further thickening by gravity, followed by such treatments as filtration or centrifugation. There are a number of ways of reducing the water content of the sludge that might be used to provide the most suitable solution of how to handle the sludge in any particular case. The final arrangement must be selected not only from consideration of the cost, but also by taking into account that the method used must not cause pollution of air, water or soil.

7.2.2. Characteristics of sludge.

The characteristics of a sludge are among the factors that influence the selection of the best sludge-treatment method. The sludge characteristics vary with the waste water and the waste water treatment methods used.

One of the important factors is **the concentration of the sludge**. Table 7.3 lists some typical concentrations of various types of sludges.

The specific gravity of the sludge is another important factor, since the effect of gravity is utilized in the thickening process. The specific gravity of activated sludge increases linearly with the sludge concentration. This corresponds to a specific gravity of 1.08 g/ml for actual solid. How-

ever, sludge is normally in sufficiently high concentration to exhibit zone-settling characteristics, which means that laboratory measurement of the settling rate must be carried out in most cases before it is possible to design a thickener.

TABLE 7.3
Typical concentrations of different types of sludge

Type of sludge	Concentration of suspended matter (w/w%)
Primary sludge (fresh)	2.5 - 5.0
Primary sludge (thickened)	7.5 - 10.0
Primary sludge (digested)	9.0 - 15.0
Trickling filter humus (fresh)	5.0 - 10.0
Trickling filter humus (thickened)	7.0 - 10.0
Activated sludge (fresh)	0.5 - 1.2
Activated sludge (thickened)	2.5 - 3.5
Activated sludge (digested)	2.0 - 4.0
Chemical precipitation sludge (fresh)	1.5 - 5.0
Chemical precipitation sludge (digested)	7.0 - 10.0

The rate with which water can be removed from a sludge by such processes as vacuum filtration, centrifugation and sand-bed drying is an important factor (Nordforsk, 1972), and is expressed by means of the **specific resistance**, R_s, which is calculated from laboratory observations of filtrate production per unit time:

$$R_s = \frac{2b * \Delta P \cdot A^2}{\mu * W} \tag{7.1}$$

where b = the slope of a plot t/v versus V, t = time, V = filtrate volume, ΔP = the pressure difference across the sludge cake, A = the filter area, μ = viscosity, W = weight of solids deposited per unit filtrate volume.

However, the specific resistance can change during filtration due to compression of the sludge. This is expressed by means of the **coefficient of compressibility**, s, using the following relationship:

$$R_s = R_0 \cdot \Delta P^s \tag{7.2}$$

where R_0 = the cake constant. When s = 0, sludge is incompressible and $R_s = R_0$ = a constant.

Table 7.4 gives the dewatering characteristics of variuos sludges.

Studies by Parker et al. (1972) have shown that the filtration time increases with the time of anaerobic storage and with the chloride concentration. Furthermore, it was shown that the filtration time is at a minimum after 5 to 8 days' aeration. The filtration time increases (12-15°C) after aeration for more than 8 days. At higher temperatures the minimum filtration time is reached after a shorter aeration time.

TABLE 7.4
Dewatering characteristics of various sludges

Type of sludge	Specific resistance (sec^2/g)	Pressure (atm)	Compressibility coefficient	Reference
Activated sludge	$2.88 \cdot 10^{10}$	0.5	0.81	Coackley, 1960
Conditioned digested primary and activated sludge	$1.46 \cdot 10^8$	0.5	1.10	Trubnick and Mueller, 1958
Conditioned digested sludge	$1.05 \cdot 10^8$	0.5	1.19	Trubnick and Mueller, 1958
Conditioned raw domestic sludge	$3.1 \cdot 10^7$	0.5	1.00	Trubnick and Mueller, 1958
Thixotropic mud	$1.5 \cdot 10^{10}$	12	-	Gale, 1968
Digested domestic sludge	$1.42 \cdot 10^{10}$	0.5	0.74	Coackley, 1960
Raw domestic sludge	$4.7 \cdot 10^9$	0.5	0.54	Coackley, 1960
Alum coagulation sludge	$5.3 \cdot 10^9$	1.0	-	Gale, 1968
Gelationous $Al(OH)_3$	$2.2 \cdot 10^9$	3.5	-	Gale, 1968
Gelatinous $Fe(OH)_3$	$1.5 \cdot 10^9$	3.5	-	Gale, 1968
Water coagulation sludge	$5.1 \cdot 10^8$	0.7	-	Neubauer, 1966
Colloidal clay	$5 \cdot 10^8$	3.5	-	Gale, 1968
Lime neutralized mine drainage	$3 \cdot 10^8$	1.0	-	Gale, 1968
Conditioned activated sludge	$1.65 \cdot 10^8$	0.5	0.80	Eckenfelder and O'Connor, 1961
Vegetable tanning	$1.5 \cdot 10^8$	1.0	-	Gale, 1968
Ferric oxide	$8 \cdot 10^7$	3.5	-	Gale, 1968
Calcium carbonate	$2 \cdot 10^7$	3.5	-	gale, 1968

The heat value of the sludge is of importance for combustion processes. Fair et al. (1968) have developed the following empirical equation for the heat value of sludge; Q_B (kJ/kg dry solid):

$$Q_B = E \left(\frac{100 P_V}{100 - P_c} - B \right) \left(\frac{100 - P_c}{100} \right) \tag{7.3}$$

where

E and B = empirical constants

P_V = % volatile solid

P_c = dose of conditioning chemical used in dewatering as a percentage of the weight of sludge solid

B = in general 5-10

E = in the range 500-600

When sludge is being considered for use as a soil conditioner, its **chemical properties** are of prime importance. The nutrient content (nitrogen, phosphorus and potassium), in particular, is of interest. Furthermore, knowledge of the heavy metals in sludge is important because of their toxicity.

As shown in Table 7.5, even domestic waste contains certain amounts of heavy metals, and municipal sludge from industrial areas contains a higher concentration of heavy metals. The upper allowable limit for heavy-metal concentration in sludge to be used as a soil conditioner is dependent on the amount of sludge used per ha and on the properties of the soil (Jørgensen, 1975 and 1976).

TABLE 7.5
Characteristic concentration of metals in g per 1000 kg of sludge (dry matter)

	Cr	Ni	Co	Zn	Cd	Cu	Pb	Hg	Ag	Bi
Typical domestic sewage	42	20	6	1380	7	123	218	5.2	13	<25
Mixed domestic and industrial sewage	163	33	10	3665	10	514	317	33	100	<25

Hansen and Tjell (1978) present guidelines used in Scandinavia on sludge application to land; they have taken the present knowledge on this field into consideration.

Finally, **the concentration of pathogenic organisms** in the sludge must be considered. Normal waste water treatment processes, such as sedimentation, chemical precipitation and biological treatments, remove considerable amounts of pathogens which are concentrated in the sludge. A significant reduction in the number of pathogenic organisms has been found to occur during anaerobic digestion, but they are not destroyed entirely.

Combustion, intensive heat treatment of sludge or treatment with calcium hydroxide would eliminate the hazard of pathogenic micro-organisms.

7.2.3. Conditioning of sludge.

P.7.5.   Sludge conditioning is a process which alters the properties of the sludge to allow the water to be removed more easily. The aim is to transform the amorphous gel-like sludge into a porous material which will release water. Conditioning of the sludge can be accomplished by either chemical or physical means.

Chemical treatment usually involves the addition of coagulants or flocculants to the sludge. Inorganic as well as organic coagulants can be used, the difference between typical conditioning by polymers or inorganic chemicals being in the amounts of the chemicals used.

Typical doses of inorganic coagulants, such as alunimium sulphate, ferric chloride and calcium hydroxide, are as much as 20% of the weight of the solid, while a typical dose of organic polymer is less than 1% of the weight of the solid. This does not necessarily mean that the cost of using synthetic polymers is lower, since the polymers cost considerably more per kg than the inorganic chemicals used as conditioners.

The amorphous gel-like structure of the sludge is destroyed by heating. Lumb (1951) indicates that the filtration rate of activated sludge is increased by more than a thousand-fold after heat treatment. Typically, the heat-treatment conditions are 30-minutes' treatment at 150-200°C under a pressure of 10-15 atmospheres. A great advantage of heat conditioning is, of course, that the pathogens are destroyed.

Conditioning by freezing has also been reported by Klein (1966) and by Burd (1968), but the process seem to be uneconomic.

7.2.4. Thickening of sludge.

Sludge thickeners are designed on the basis of surface area, which is determined from the material balance:

$$\frac{A}{Q_0 \cdot C_0} = \frac{1/C_1 - 1/C_u}{u} \tag{7.4}$$

where

A = area of the surface

O_0 = flow of sludge with the concentration C_0

C_u = the underflow concentration

C_1 and u = the concentration and velocity of any interfacial layer of the settling sludge

The depth of the sludge in the thickener is also a significant design parameters. Roberts (1949) has expressed the rate of sludge thickening by means of the following equation:

$$\log \frac{H - H_\infty}{H_c - H_\infty} = K \cdot (t - t_c) \tag{7.5}$$

where

H_∞ = the minimum height after infinite time

H = the depth of the sludge after time t

H_c = the depth after time t_c

K = a constant, which must be found experimentally

P.7.6. Vacuum filtration is used to remove water from a sludge by applying a vacuum across a porous medium.
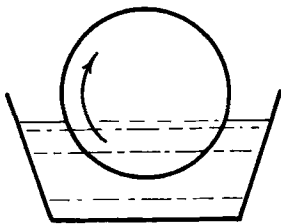
The vacuum filter is shown in Fig. 7.3.

Fig. 7.3. Vacuum filtration.

As the rotary drum passes through the slurry in the slurry tank, a cake of solid is built up on the drum surface and the water is removed by vacuum

filtration through the porous medium on the drum surface. As the drum emerges from the slurry the deposited cake is dried further. The cake is removed from the drum by a knife edge. Often the porous filter is washed with water before it is reimmersed in the slurry tank.

Since the specific resistance varies widely with the type of sludge and the waste water treatment used, *it is often best to find the filtration characteristics of the sludge in the laboratory by the Büchner funnel test.*

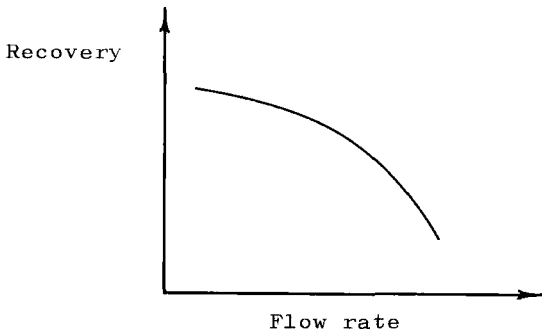## 7.2.5. Centrifugation of sludge.

Fig. 7.4. Recovery versus flow rate for centrifugation of sludge.
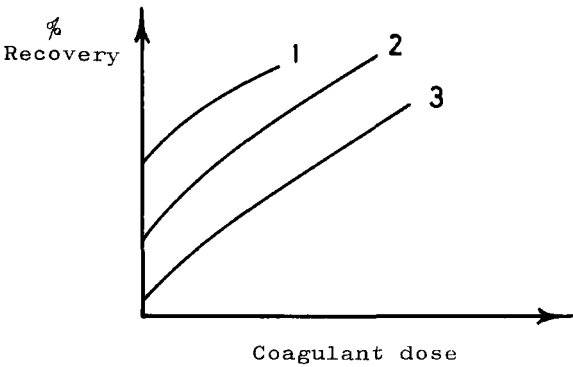

Fig. 7.5. % recovery versus coagulant dose for three flow rates:
1: 1x; 2: 2x; 3: 3x. x = a given amount of electrolytes.

Centrifugation is one of the more recent methods used in the removal of water from waste water sludge.

Of the various types of centrifuge, the solid-bowl centrifuge is considered to offer the best clarification and water-removal properties. It is an important advantage of the centrifugation process that the centrifuge conditions can be adjusted to the concentration of the volatile material (Albertson and Sherwood, 1968). The disadvantage of using a centrifuge is that the cake concentration is generally slightly less than that obtained by vacuum filtration.

The prediction of the behaviour of sludge in a centrifuge is largely a matter of experience. However, some general trends can be noted. If the mass flow rate is increased, recovery is reduced (see Fig. 7.4). The use of electrolytes will increase the recovery at a given flow rate or increase the flow rate for a given recovery. This is illustrated in Fig. 7.5.

7.2.6. Digestion of sludge.

P.7.7. **If the sludge contains biodegradable organic material it may be advantageous to treat the sludge by aerobic or anaerobic digestion.**

Anaerobic digestion is by far the most common method of treating municipal sludge. It creates good conditions for the growth of micro-organisms. The end products of anaerobic digestion are carbon dioxide and methane. The temperature is commonly set at about 35°C, in order to maintain optimum conditions in the digestor. Unfortunately, anaerobic digestion results in considerable quantities of nutrients going into solution (Dalton et al., 1968), which means that a significant amount of nutrient material will be returned to the treatment plant if the supernatant is separated from the sludge.

The principal function of anaerobic digestion is to convert as much as possible of the sludge to end products: liquids and gases. Anaerobic decompositions generally produce less biomass than aerobic processes.

The microorganisms can be divided into 2 broad groups: **the acid formers and the methane formers.**

The acid formers consist of facultative and anaerobic bacteria and soluble products are formed through hydrolysis. The soluble products are then fermented to acids and alcohols of lower molecular weight.

The methane formers are strictly anaerobic bacteria that convert the acids and alcohols, along with hydrogen and carbon dioxide, to methane. A COD-balance for a complete conversion is shown in Fig. 7.6.

Reactors for anaerobic digesters consist of closed tanks with airtight

covers. A typical anaerobic digester for a single-stage operation is shown in Fig. 7.7. The digested sludge accumulates in the bottom.

Design parameters for anaerobic digesters are given in Table 7.6.

High-rate digesters are more efficient. The contents are mechanically mixed to ensure better contact between substrate and microorganisms, thus accelerating the digestion process.

TABLE 7.6
Design parameters for anaerobic digesters

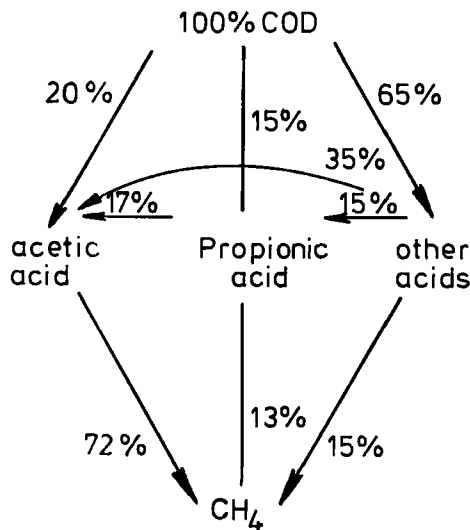| Parameter	Normal rate	High rate
Solid retention time	30 - 60	10 - 20
Volatile solid loading (kg/m^3 d)	0.5 - 1.5	1.6 - 6.0
Digested solids conc.%	4 - 6	4 - 6
Volatile solid reduction (%)	35 - 40	45 - 55
Gas production m^3/kg	0.5 - 0.6	0.6 - 0.65
Methane content	65%	65%

Fig. 7.6. COD-balance for a complete conversion of organic matter. Usually 60-65% of the organic fraction is converted in accordance with the scheme shown.

The properties of aerobically digested sludge are similar to those of an-aerobically digested sludge. An advantage is that some of the operational

problems attending anaerobic digestors are avoided, but the disadvantage compared with anaerobic digestion is that the process is more expensive since oxygen must be provided and energy recovery from methane is not possible. Since aerobic digestion is less used in industrial waste water processes than in treatment of municipal waste water, it is not appropriate here to go into further details. For more extensive coverage of these processes, readers are referred to McCarthy (1964) and to Walker and Drier (1966).
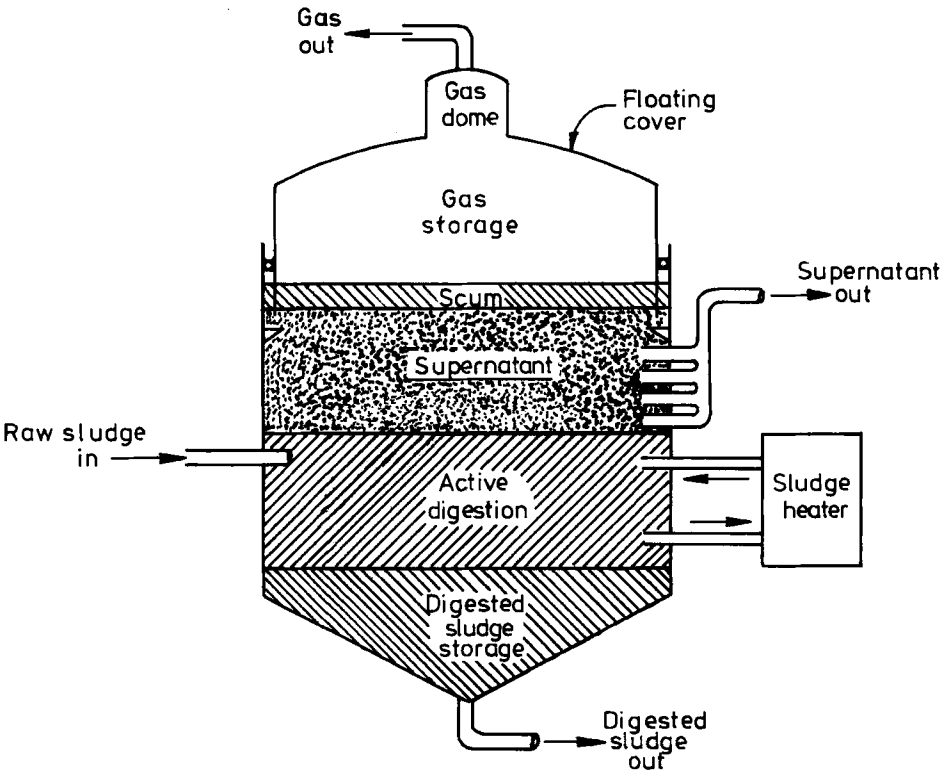

Fig. 7.7.   Diagram of standard-rate anaerobic digester.

7.2.7.   Drying and combustion.

P.7.8.   The purpose of drying sludge is to prepare it for use as a soil conditioner or for incineration.

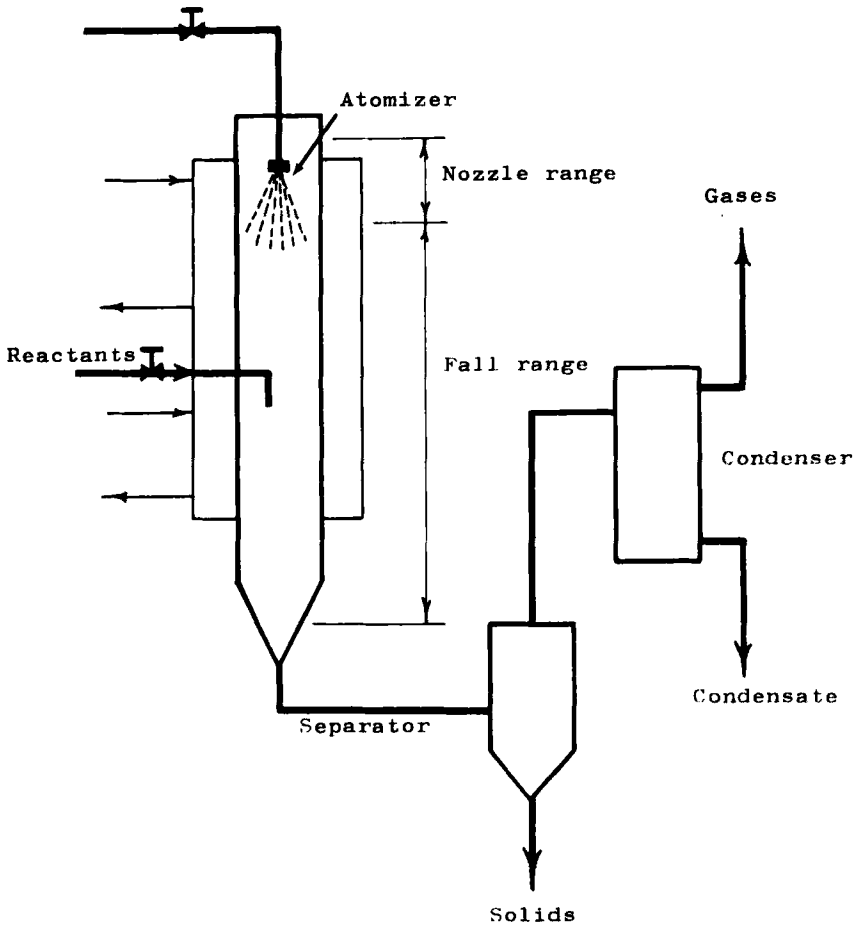Air drying of the sludge on sand beds is often used to reach a moisture content of about 90%.

Fig. 7.8.   Flow diagram of atomized suspension technique.

Also, such drying techniques as flash drying and rotary drying are used to remove water from sludge. Often waste heat from the incineration process itself is used in drying. However, it has been reported by Quirk (1964) that the cost of combined drying and combustion is higher than the cost of incineration alone. The economy of sludge drying has recently been reviewed by Burd (1969). He reports that at the present cost of heat drying, it should only be considered if the product (soil conditioner) can be sold for at least US$ 20.00 a ton (1986-dollars).

P.7.9. Combustion serves as a means for the ultimate disposal of the sludge.

Two techniques should be mentioned: the atomized suspension technique (Gauvin, 1947), and the Zimmerman process (Zimmerman, 1958).
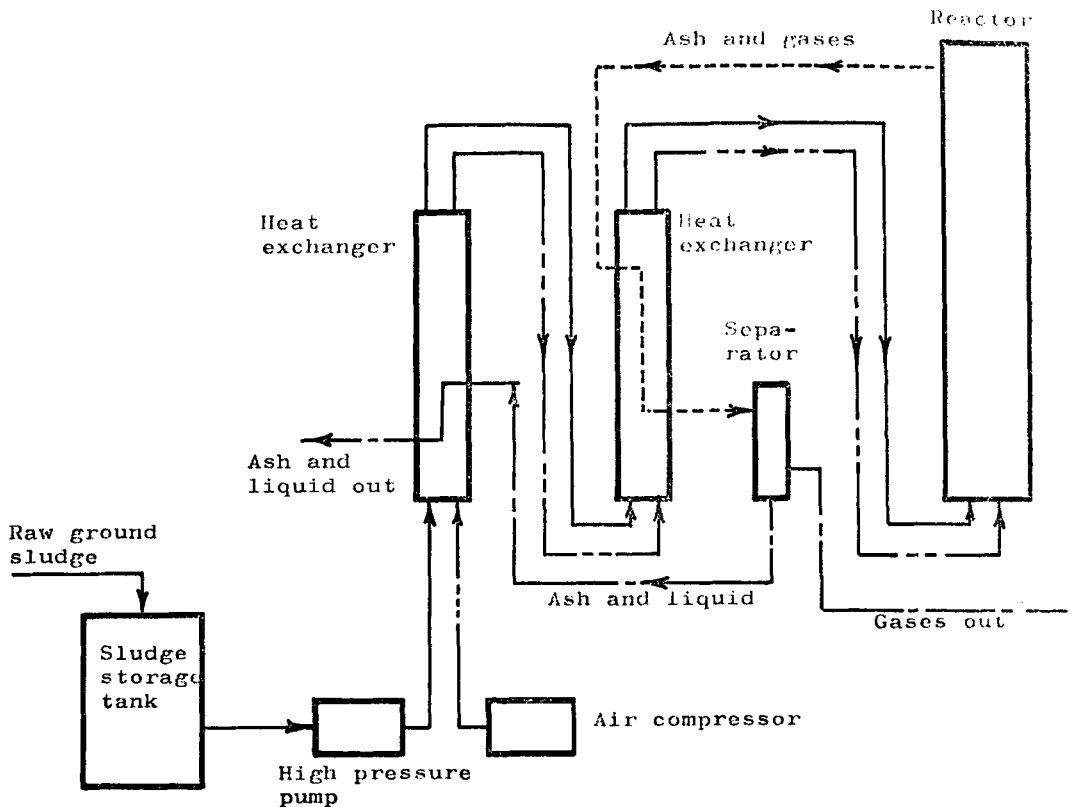

Fig. 7.9. Flow diagram of the Zimmerman process.

In this process the sludge is atomized at the top of the tower, and droplets pass down the tower where the moisture evaporates. The tower walls are maintained at 600-700°C by hot circulating gas. The solid produced is collected in a cyclone and the heat recovered from the stream and gas, as shown in Fig. 7.8.

The Zimmerman process is a wet-air oxidation at high temperature and pressure (Fig. 7.9). Oxidation of organics occurs at 200-300°C and the high pressure is used to prevent evaporation of the water.
The degree of oxidation at various temperatures is plotted in Fig. 7.10. As the oxidation process is an exothermic reaction, *heat is produced,* and it has been calculated that the system is self-sustaining at 4.5% solid of which *70% is volatile matter.* By means of a heat exchanger the heat developed is used to raise the temperature of the incoming sludge.
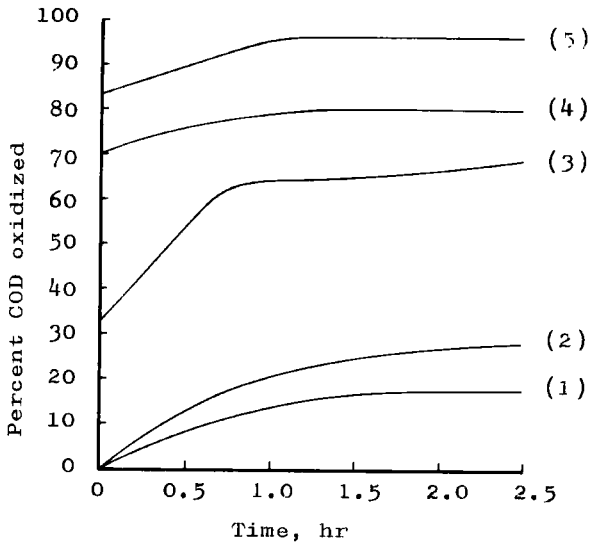

Fig. 7.10. The degree of oxidation at various temperatures plotted against treatment time. (1) 100°C, (2) 150°C, (3) 200°C, (4) 250°C, (5) 300°C.

TABLE 7.7
Composition of domestic garbage

Country	Ash %	Paper %	Org. matter %	Metals %	Glass %	Sun-dries %	kg/m^3	kg/inh./year
Belgium (Brussels)	48	20.5	23	2.5	5	3		
Canada	5	70	10	5	3	5	115	380
Czechoslovakia (Prague)	6-65	14-7	39-22	2-1	11-3	18-2	200-400	190-430
Finland (Helsinki)	-	65	10	5	5	15	100-150	310
France (Paris)	24.3	29.6	24	4.2	3.9	14	120-180	300-360
Israel	1.9	24	71.2	1.1	1.0	1.8	255	190
Holland (Hague)	9.1	45.2	14	4.8	4.9	22	160-250	165-190
Norway	0-12	56-24	35-56	3.2-2.6	2.5-5.1	8.4-0	100-280	200
Poland	10-21	2.7-6.2	35-44	0.8-0.9	0.8-2.4	-	250-390	180-240
Spain (Madrid)	22	21	45	3	4	5	330	200
Sweden	0	55	12	6	15	12	140	210
Switzerland	20	40-50	15-25	5	5	-	120-200	150
England	30-40	25-30	10-15	5-8	5-8	5-10	150-250	240-300
USA	10	42	22.5	8	6	11.5	280	520-690
F.R. Germany (West Berlin)	30	18.7	21.2	5.1	9.8	15.2	330-380	210-230
Denmark	10	45	13	4	8	20	150-250	210-310

7.3.   DOMESTIC GARBAGE.

7.3.1.   Characteristics of domestic garbage.

P.7.10. The composition of domestic garbage might vary from country to country, as illustrated in Table 7.7. To a certain extent the environmental legislation and the economic level of the nation is reflected in this composition.

The amount of domestic garbage per inhabitant is increasing. In most developed countries the growth has been 2-4% from the mid 1950s to 1973, while it has been lower since then (1-2%).

It is often advantageous to carry out a more comprehensive analysis than the one presented in Table 7.7. The analysis will in this case include the following items: *(1) food waste, (2) paper, (3) textiles, (4) leather and rubber, (5) plastics, (6) wood, (7) iron, (8) aluminium, (9) other metals, (10) glass and ceramic products, (11) ash and dust, (12) stone, (13) garden waste, (14) other types of waste.* The knowledge obtained by this analysis can be used to select the most relevant treatment methods.

7.3.2.   Separation methods.

P.7.11.   Separation of solid waste can be achieved either in a central plant or by the organization of a separate collection of paper, glass, metals and other types of domestic waste.

TABLE 7.8
Collection of paper in some contries

Country		G_p (%)	A_p (%)	I_p (kg/inh./year)
USA	1971	22.7	21.6	57
Canada	1971	21.0	5.9	33
U.K.	1971	27.7	42.3	35
F.R. Germany	1971	30.1	26.4	40
France	1971	27.7	35.1	27
Holland	1971	42.1	40.0	56
Japan	1971	35.9	33.8	44
Sweden	1971	23	6.4	44
Norway	1971	17	7.1	abt. 20
Finland	1971	23	3.3	abt. 30
Denmark	1970	20	41	30
	1971	27	57.7	33
	1987	30	65	50

G_p = percentage recovery, A_p = percentage of returnal paper relatively to the total paper production, I_p = amount of returned paper per inhabitant and year.

This latter method is widely in use for paper and pulp, as demonstrated in Table 7.8, where the percentage recovery, G_p, the percentage of returned paper relative to the total paper production, A_p, and the amount of returned paper per inhabitant and year, I_p, are shown.

A mass flow diagram for a separation plant in Franklin, Ohio, is shown in Fig. 7.11. **After wet grinding, separation of paper fibres, glass,**

iron and other metals occurs. The remaining part of the solid waste is used for heat production.
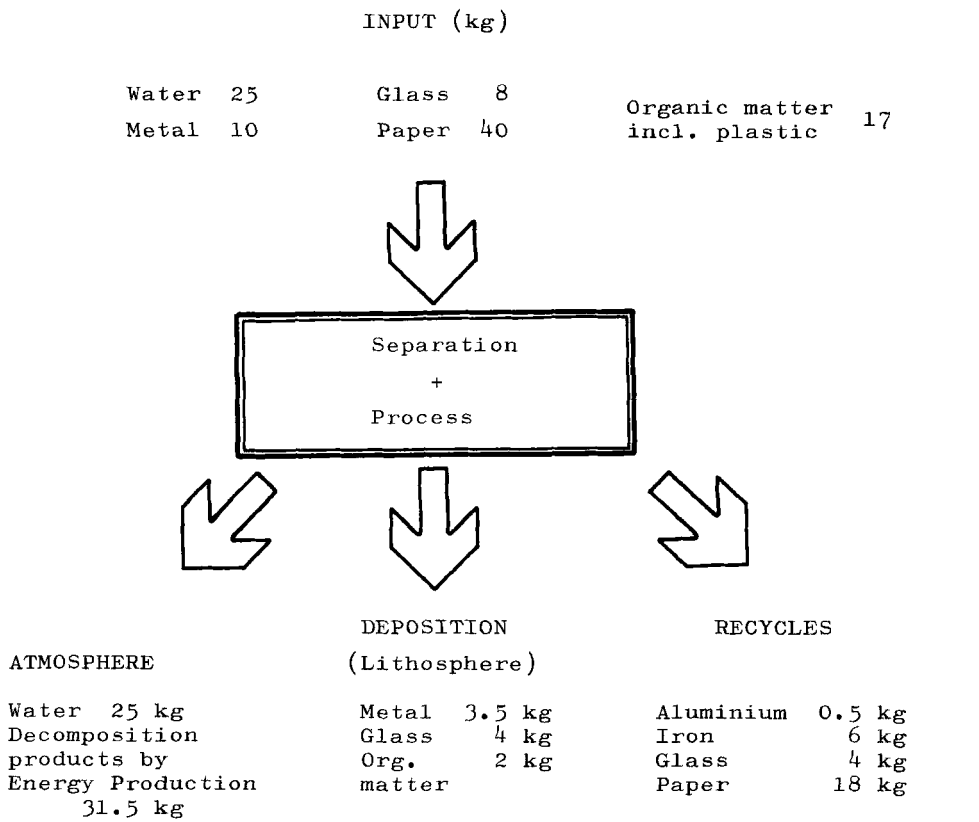
INPUT (kg)

Water 25   Glass 8
                                    Organic matter 17
Metal 10   Paper 40   incl. plastic


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                    +-------------------------+
                    |      Separation         |
                    |           +             |
                    |        Process          |
                    +-------------------------+
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                    DEPOSITION   RECYCLES

ATMOSPHERE   (Lithosphere)

Water 25 kg   Metal   3.5 kg   Aluminium 0.5 kg
Decomposition   Glass   4 kg   Iron   6 kg
products by   Org.   2 kg   Glass   4 kg
Energy Production   matter   Paper   18 kg
     31.5 kg

Fig. 7.11.   Separation plant, Franklin, Ohio. 150 t/d. Mass flow diagram (Basis 100 kg solid waste).

7.3.3.   Dumping ground (landfills).

This was previously the most common handling method for solid waste. Today it is mainly in use in smaller towns, often after grinding or compression, which reduce the volume 60-80%.

Deposition of solid waste on dumping ground is an inexpensive method, but it has a number of disadvantages:
1. Possibilities for **contamination of ground water.**
2. Causes inconveniences due to **the smell.**

3. **Attracts noxioux animals,** such as flies and rats.

During the deposition several processes take place:
1. *Decomposition* of biodegradable material.
2. *Chemical oxidation* of inorganic compounds.
3. *Dissolution and wash out* of material.
4. *Diffusion processes.*

Where the decomposition takes place in the aerobic layers carbon dioxide, water, nitrates and sulphates are the major products liberated, while decomposition in anaerobic layers leads to the formation of carbon dioxide, methane, ammonia, hydrogen sulphide and organic acids.

Water percolation from dumping grounds has a very high concentration of BOD and nutrients (see Table 7.9) and *can therefore not be discharged into receiving waters.* If it cannot be recycled on the dumping ground, theis waste water must be subject to some form of treatment. For further details see Persson and Nylander (1974).

7.3.4. Composting.

Composting has been applied as a treatment method in agriculture for thousands of years. The method is still widely applied for treatment of agricultural waste.

P.7.12. Organic matter from untreated solid waste cannot be utilized by plants, but it is necessary to let it undergo a certain biological decomposition, by the action of micro-organisms.

Again we can distinguish between **aerobic and anaerobic processes.** A number of factors control these processes:
1. **The ratio of aerobic to anaerobic processes,** which, of course, is determined by the available oxygen (diffusion process).
2. **Temperature.** Different classes of micro-organisms are active within different temperature ranges (see Table 7.10). Heat is produced by the decomposition processes. The thickness of the layer determines to what extent this heat can be utilized to maintain a temperature of 60-65°C, which is considered to be the optimum. Fig. 7.12 shows a typical course of the temperature by composting in stacks. In this context it is also important to mention that composting at a relatively high temperature means a substantial reduction in the number of pathogenic micro-organisms and parasites.

TABLE 7.10
Classification of micro-organisms

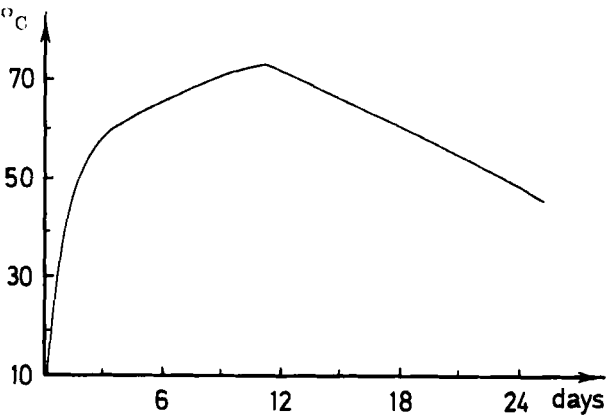|	Temperature optimum	Temperature range
Psychrophile	15-20°C	0-30°C
Mesophile	25-35°C	10-40°C
Thermophile	50-55°C	25-80°C

Fig. 7.12. Temperature versus composting time.

3. **The water content** should be 40-60%, as this gives the optimum conditions for the processes of decomposition.
4. **The C/N ratio** should be in accordance with the optimum required by the micro-organisms. Domestic garbage has a C/N ratio of 80 or more due to the high content of paper, while the optimum for composting is 30. It is therefore advantageous to add sludge from the municipal sewage plant to adjust the ratio to about 30. Sludge usually has a C/N ratio of 10 or even less. During the composting the C/N ratio is decreased as a result of respiration, which converts a part of the organic matter to carbon dioxide and water.
5. The optimum conditions for the micro-organisms include a **pH around 7 (6-8)**. Usually pH increases as a result of the decomposition processes. If pH is too low calcium hydroxide should be added and if pH is too high sulphur should be added. Sulphur activates sulphur bacteria, which produce sulphuric acid.

Fig. 7.13 shows a flow chart for a composting plant. Composting with

addition of *air accelerates* the decomposition processes, but this process might be excluded in smaller plants.
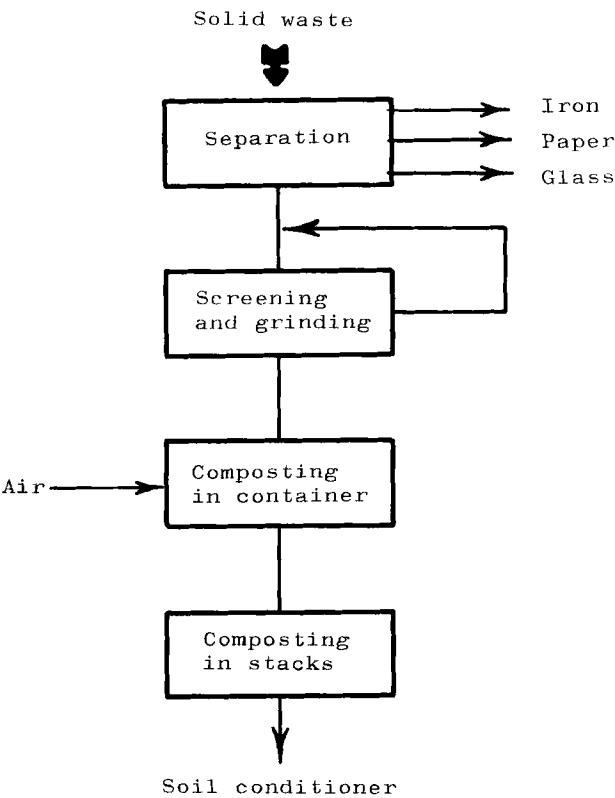

Fig. 7.13. Flow chart of composting plant.

7.3.5. Incineration of domestic garbage.

Incineration is very attractive from a sanitary point of view, but it is a very *expensive method,* which has some environmental disadvantages. Valuable material such as *paper is not recycled, a slag, which must be deposited,* is produced and air pollution problems are involved. Nevertheless, incineration has been the preferred method in many cities and larger towns. This development might be explained by the increasing amount of combustible material in domestic garbage and the possibilities of combining incineration
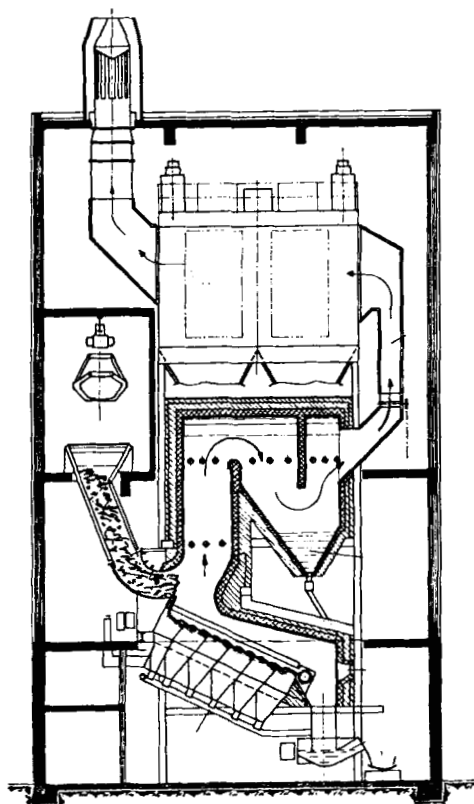
plants with district heating.

Fig. 7.14. Incineration plant. Type Martin, capacity 1 t hr^{-1}

The optimum combustion temperature is 800-1050°C. If the temperature is below this range incomplete combustion will result (dioxines may be produced), and a higher temperature the slags will melt and prevent an even air distribution. The composition of the solid waste determines whether this combustion temperature can be achieved without using additional fossil fuel. If the ash content is less than 60%, the water content is less than 50% and the combustible material more than 25%, no additional fossil fuel is required.

The heating value can be calculated from the following equation:

$$H_u = H^1 \frac{100 - W}{100} - 600 \frac{W}{100} \qquad\qquad (7.6)$$

where
H^1 = the heat value of dry matter
H_u = the heat value
W = the water content (weight %)
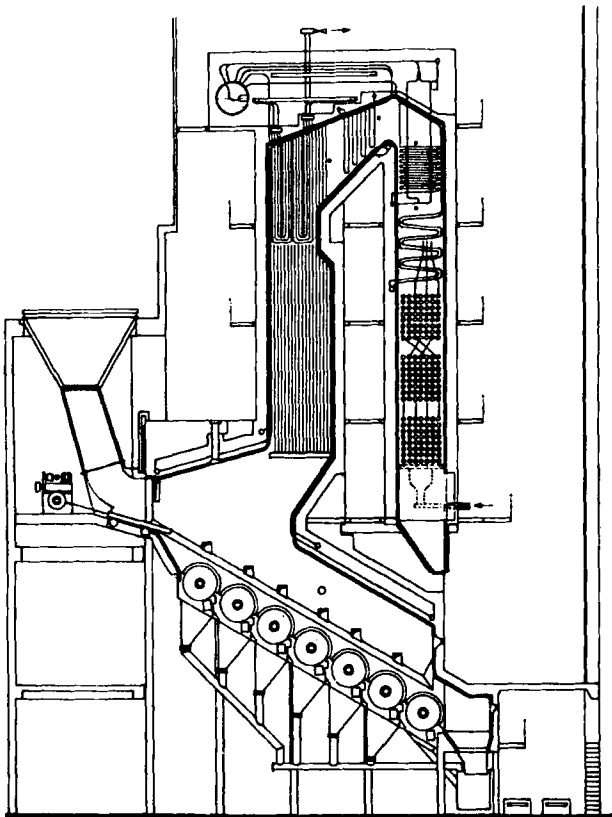
Figs. 7.14 and 7.15 show two typical incineration plants.

Fig. 7.15. Incineration plant with boiler and screen. System Düsseldorf, capacity 12.5 t hr^{-1}.

The composition of the slag and the flyash, which is collected in the filter, is, of course, dependent on the composition of the solid waste. Table 7.12 gives an analysis of an average sample and also shows the chemical composition of flyash alone. It is notable that a minor amount of the slag and the flyash is unburned material. Slags and flyash comprise 25-40% of the weight of the solid waste.

Although all modern incineration plants have filters, the air pollution problem is not completely solved. Table 7.11 gives a typical analysis of the smoke from an incineration plant. Hydrogen chloride, in particular, can cause difficulties, because it is toxic and highly corrosive.

TABLE 7.11
Typical analysis of the smoke from an incineration plant

Component	Dried slag (65°C) ppm $\cdot 10^{-4}$/w-%	Gas Before washer ppm $\cdot 10^{-4}$	After washer vol.-%	Smoke After gas burning ppm
C	25			
CO		5	11	
CO_2	(2.9)	8	18	$7 \cdot 10^4$
CH_4		5	10	
C_nH_m		1	2	
H_2O	abt. 40	55	4	
H_2		25	55	
H_2S		0.06		
HCl		0.01		6-40
HF		0.0001		0.1-0.8
HCN		0.001		
NH_3		1		
$SO_2 + SO_3$				2-10
NO_x				100-150
N	1.0			
Cl^-	1.1			
S	0.2			
SO_4^{2-}	0.22			
P	0.7			
Ca	4.5			
Fe	2.0			
Si	15			
Al	4			
Mg	0.3			
K	0.8			
Pb	0.1			
Cu	0.03			
Co	0.006			
Cr	0.0026			
Ni	0.0025			
Cd	0.0011			
As	0.0002			
Hg	0.0001			

7.3.6.   Pyrolysis.

P.7.13.   Pyrolysis is a decomposition of organic matter at elevated temperature without the presence of oxygen.

For pyrolysis of solid waste a temperature of 850-1000°C is generally used. The process produces gas and a slag, from which metals easily, due to the anoxic atmosphere, can be seperated.

Pyrolysis is a relatively expensive process, although less expensive than incineration. The smoke problems are the same as those of incineration, but the easy recovery of metals from the slag is, of course, an advantage.

The gas produced has a composition close to coalgas and in most cases can be used directly in the gas distribution system without further treatment. Approximately 500 m^3 of gas are produced per ton of solid waste, but 300-400 m^3 are used in the pyrolysis process to maintain the temperature.

TABLE 7.12

Chemical composition of dried slag and ash from incineration		Chemical composition of flyash from electrofilter	
Component	w % slag	Component	w % flyash
C	8.79	C	9.8
SiO_2	48.53	SiO_2	40.5
Al_2O_3 + TiO_2	11.59	Al_2O_3	10.0
Fe_2O_3	16.08	SiO_2	1.6
CaO	6.90	Fe_2O_3	13.1
MgO	1.36	CuO	trace
K_2O	5.01	MnO	0.2
SO_3	0.82	CaO	10.4
S	0.16	Mg	0.1
Cl	0.32	BaO	0.8
P_2O_5	0.56	K_2O	3.3
		Na_2O	2.4
		SO_3	6.9
		S	trace
		P_2O_5	0.9

7.4.   INDUSTRIAL, MINING AND HOSPITAL WASTE.

7.4.1.   Characteristics of the waste.

This types of waste causes particular problems because it may contain toxic matters in relatively high concentrations. Hospital wastes are especially suspect because of contamination by pathogens and the special

waste products, such as disposable needles and syringes and radioisotopes used for detection and therapy.

The waste from industries and mining varies considerably from place to place, and it is not possible to provide a general picture of its composition. It the composition permits, it can be used for landfilling, but if it contains toxic matter specia treatment is prequired. The composition may be close to domestic garbage in which case the treatment methods mentioned in section 7.3 can be applied.

Hospital solid waste is being studied in only a few locations to provide data on current practices and their implications. Most hospital waste is now incinerated and this might, in many cases, be an acceptable solution. However, if the solid waste contains toxic matter it should be treated along the lines given for industrial waste in the next paragraph. At least, waste from hospital laboratories, should be treated as other types of chemical waste.

7.4.2. Treatment methods.

Industrial and mining waste containing toxic substances, such as heavy metals or toxic organic compounds, should be treated separately from other types of solid waste, which means that it cannot be treated by the methods mentioned in section 7.2 and section 7.3. A number of countries have built special plants to handle this type of waste, which could be called chemical waste. Such plants may include the following treatment lines:

1. Combustion of toxic organic compounds. The heat produced by this process might be used for district heating. Organic solvents, which are not toxic, should be collected for combustion, because discharge to the sewer mght overload the municipal treatment plant. For example, acetone is not toxic to biological treatement plants, but 1 kg of acetone uses 2.2 kg of oxygen in accordance with the following process:

$$(CH_3)_2CO + 4O_2 \rightarrow 3CO_2 + 3H_2O \qquad (7.7)$$

A different combustion system might be used for pumpable and non-pumpable waste.
2. Compounds containing halogens should be treated only in a system which washes the smoke to remove the formed hydrogen halogenids.
3. Waste oil can often be purified and the oil reused.
4. Waste containing heavy metals requires deposition under safe conditions after a suitable pretreatment. Recovery of precious metals is often economically viable and is essentioal for mercury because of its high

toxicity. The pretreatment consists of a conversion to the most relevant oxidation state for deposition, e.g. chromate should be reduced to chromium in oxidation state 3. Furthermore metals should be precipitated as the very insoluble hydroxides, (see also 6.5.2) before deposition.

5. Recovery of solvents by distillation becomes increasingly attractive from an economical view-point due to the growing costs of oil products, as most solvents are produced from mineral oil.

7.5. AGRICULTURAL WASTE

7.5.1. Characteristics of agricultural waste

Particular animal waste causes great problems by intensive farming. The productions of chickens, pigs and cattles are in many industrialized countries concentrated in rather large units, which implies that the waste from such production units requires hundreds of hectars for a suitable distribution and feasible use of its value as fertilizer.

Animal waste has a high nitrogen concentration 5-10% based on dry matter (2-4% dry matter).

If the nitrogen is not used as fertilizer it may
1) either evaporate as ammonia
2) be lost to deeper layers, where it contaminates the ground water or
3) be lost by surface run off to lakes and streams.

Agricultural waste has therefore become a crucial pollution problem in many countries with intensive agriculture.

7.5.2. Treatment methods

Many of the methods described above may be used for treatment of animal waste.

The following possibilities give a summary of the available methods to reduce the pollution originated from agricultural waste.

1. Storage capacity for animal waste to avoid spreading on bare fields.

2. Green fields in winter to assure the use of the fertilizing value of agricultural waste.

3. Composting of agricultural waste assure conditioning before it is used. The composting heat may be utilized.

4. Anaerobic treatment of agricultural waste for production of biogas and conditioning before use as fertilizer.

5. Chemical precipitation of agricultural (animal) waste with activated benthonite is applied to bind ammonium and obtain a solid concentration of 6-10%. This process gives 2 advantages:
   A. The needed storage capacity is reduced by a factor 2-4 (the solid concentration is increased from 2-4% to 6-10%)
   B. The loss of nitrogen by evaporation of ammonia is reduced by a factor 3-8 corresponding to an adsorption of about 60-90% of the ammonium on the added benthonite.

6. In China animal waste is applied in fish ponds. Zooplankton eats the detritus and fish feed on the zooplankton.

QUESTIONS

1. Set up a mass flow diagram for iron and glass in a selected district.

2. Discuss the analytical data in Table 7.5 from an ecological view-point.

3. A selected town or district is considered. Compare from both an ecological and an economical point of view the following solutions to the solid waste problem of domestic garbage and sludge: A. Separation of paper, metals and glass followed by either 1) incineration, 2) composting, og 3) pyrolysis. B. Incineration (no preseparation). C. Pyrolysis followed by metal separation from the slag.

4. Estimate (roughly) the loss of nitrogen from agricultural waste used
   a) on a bare field
   b) on a green winterfield
   c) after composting
   d) after chemical precipitation by use of activated benthonite.