CHAPTER 12

TREATMENT OF SLUDGE

SLUDGE HANDLING

In most industrial 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.

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 which might be used to give 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.

Characteristics of sludges

The characteristics of a sludge are among the factors which 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 naturally the concentration of the sludge. Table 12.1 lists some typical concentrations of various types of sludge.

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 the actual solid. However, 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 12.1

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 ease 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:

$$R_s = \frac{2b \cdot \Delta P \cdot A^2}{\mu \omega} \qquad (12.1)$$

where

b = the slope $\frac{t}{V}$(versus time)

t = time

V = filtrate volume

ΔP = the pressure difference across the sludge cake

A = the filter area

μ = viscosity

ω = 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:

$$R_s = R_O \cdot \Delta P^s \qquad (12.2)$$

where R_O = the cake constant.

Table 12.2 gives the dewatering characteristics of various sludges.

TABLE 12.2

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
Gelatinous $Al(OH)_3$	$2.2 \cdot 10^{9}$	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

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.

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):

$$Q_B = E\left(\frac{100P_V}{100 - P_c} - B\right)\left(\frac{100 - P_c}{100}\right) \quad (12.3)$$

where

E and B = empirical constants

P_V = % volatile solid

P_c = dosage of conditioning chemicals used in dewatering as a per cent 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 12.3, 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 12.3

Characteristic conc. of metals in g per 1000 kg of sludge (dry matters)

	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

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.

Conditioning of sludge

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 aluminium 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 atm. 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 seems to be uneconomical.

Thickening of sludge

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

$$\frac{A}{Q_0 \cdot C_0} = \frac{1/C_1 - 1/C_u}{U} \tag{12.4}$$

where

A = area of the surface

Q_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 also are of the significant design parameters. Roberts (1949) has expressed the rate of sludge thickening by means of the following equation:

$$\log \frac{H - H_\infty}{H_c - H_\infty} = K \cdot (t - t_c) \tag{12.5}$$

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

Vacuum filtration

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. 12.1.

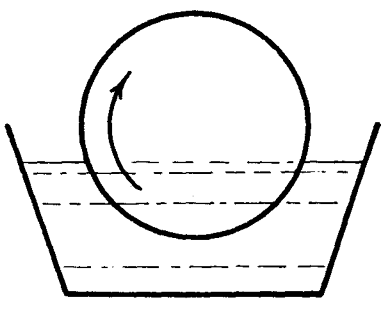

Fig. 12.1. Vacuum filtration.

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 re-immersed in the slurry tank.

The rate of filtration can be calculated in accordance to Poiseuille and D'Arcy's Law (see Coackley, 1956):

$$\frac{dV}{dt} = \frac{P \cdot A^2}{\mu(R_s \omega V + R_f \cdot A)} \qquad (12.6)$$

where V, t, A, μ, R_s, w are defined above (see p. 174 equation 12.1), P is the vacuum and R_f the initial resistance of the filter medium. Often $R_f \sim 0$.

Integration yields:

$$\frac{t}{V} = \frac{\mu R_s \cdot \omega}{2PA^2} \cdot V + \frac{\mu R_f}{PA} \qquad (12.7)$$

The specific resistance can be calculated from equation (12.1) using a plot of $\frac{t}{V}$ versus V.

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.

Centrifugation of sludge

Centrifugation is one of the more recent methods used in the removal of water from industrial 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. 12.2). 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. 12.3.

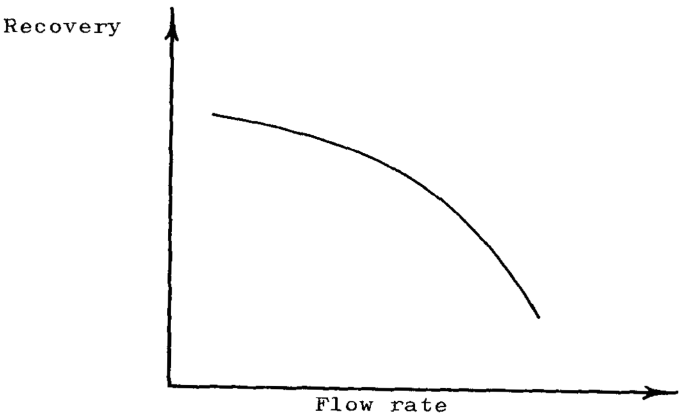

Fig. 12.2. Recovery versus flow rate for centrifugation of sludge.

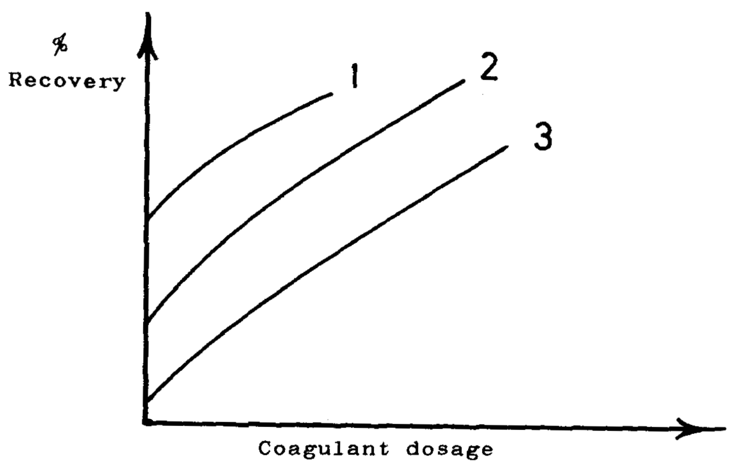

Fig. 12.3. % recovery versus coagulant dosage for three flow rates. 1: 1x; 2: 2x; 3: 3x. x = a given amount of electrolytes.

Digestion of sludge

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 $35^{\circ}C$, in order to maintain optimum conditions in the digestor. Unfortunately, anaerobic digestion results in the solubilization of considerable quantities of nutrients (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 properties of aerobically digested sludge are similar to those of anaerobically 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 approbiate 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).

Drying and combustion

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%.

Also, such drying techniques as flash drying and rotary drying are used to remove water from sludge. Often is combination with waste heat from the incineration process 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 $. 20.00 a ton (1978-dollars).

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).

The atomized suspension technique is shown in Fig. 12.4.

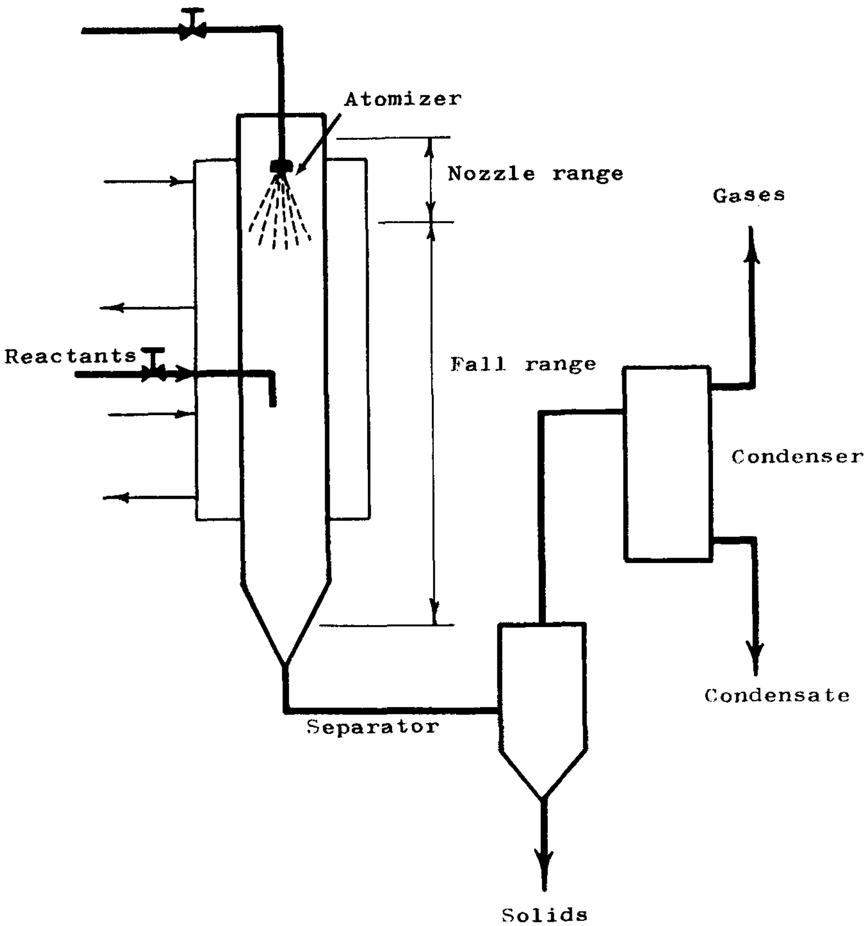

Fig. 12.4. Flow diagram of atomized suspension technique.

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 steam and gas as shown in the figure.

The Zimmerman process is a wet air oxidation at high temperature and pressure (Fig. 12.5). Oxidation of organics occurs at 200-300°C and the high pressure is used to prevent evaporation of the water.

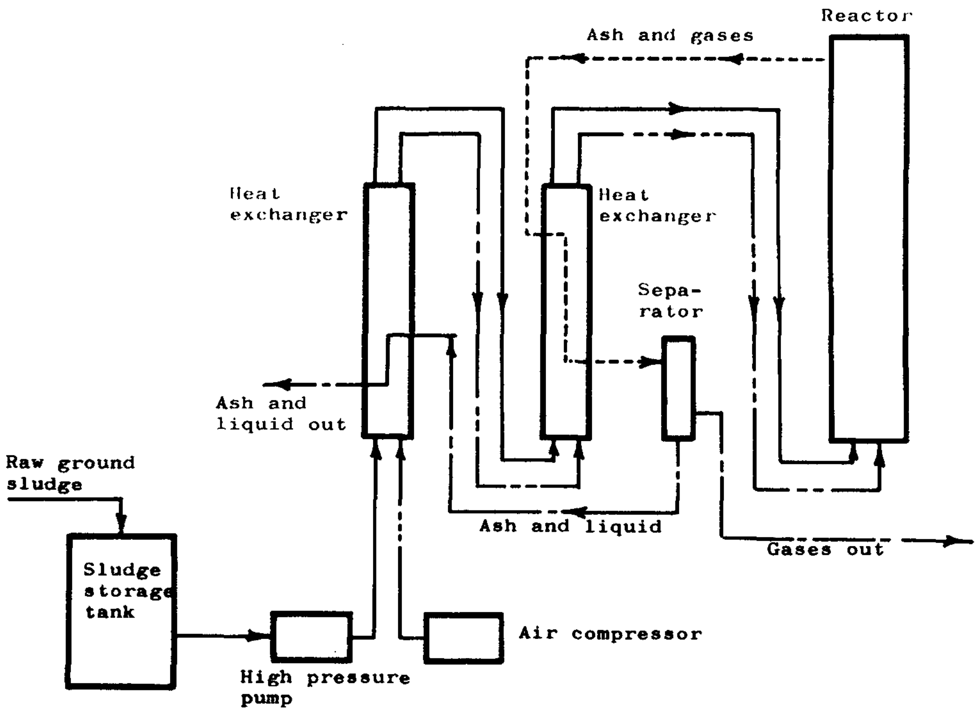

Fig. 12.5. Flow diagram of the Zimmerman process.

The degree of oxidation at various temperatures is plotted in Fig. 12.6. 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.

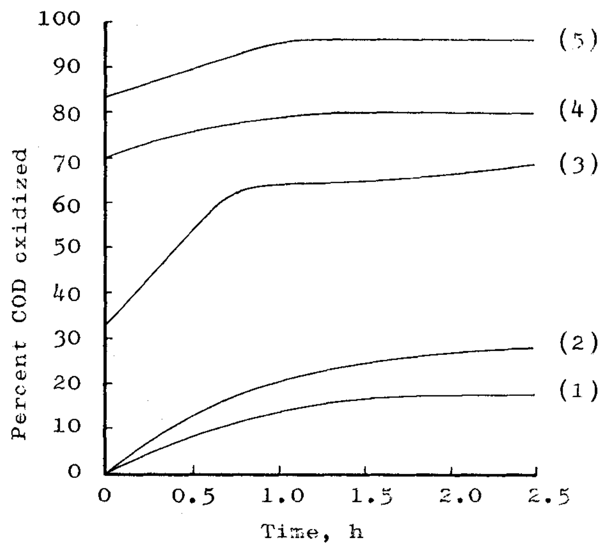

Fig. 12.6. The degree of oxidation at various temperatures plotted against treatment time. 1, 100°C; 2, 150°C; 3, 200°C; 4, 250°C; 5, 300°C.

REFERENCES

Albertson, O.E. and Sherwood, R.J., 1968. Improved sludge digestion is possible. Water Wastes Eng., 5: 8, 43.

Burd, R.S., 1968. Study of sludge handling and disposal. Water Poll. Contr. Res. Ser., Fed. Water Poll. Contr. Adm., Publ. WP-20-4, Washington, D.C.

Coackley, P. and Jones, B.R.S., 1956. Sewage Ind. Wastes, 28: 8, 963.

Coackley, P., 1960. Principles of Vacuum Filtration and Their Application to Sludge-Drying Problems. Waste Treat., Isaac, P. (Ed.), Pergamon Press, London.

Dalton, F.E.Stein and Lynam, B.T., 1968. Land reclamation - a complete solution to the sludge and solids disposal problem. J. Water Poll. Contr. Fed., 40: 5, 789.

Eckenfelder, W.W. Jr. and O'Connor, D.J., 1961. Biological Waste Treatment. Pergamon Press, New York.

Fair, G.W., Geyer, J.C. and Okun, D.A., 1968. Water and Waste Water Engineering, vol. II., John Wiley and Sons, Inc. New York.

Gale, R.S., 1968. Some aspects of the mechanical dewatering of sewage sludges. Filtr. Separ., 5: 2, 133.

Gauvin, W.H., 1955. Tappi, 40: 11, 866-877 (November 1947); Chem. Can.

Jørgensen, S.E., 1975. Do heavy metals prevent the agricultural use of municipal sludge. Water Res., 9: 163-170.

Jørgensen, S.E., 1976. An ecological model for heavy metal contamination of crops and ground water. Ecological Modelling 2: 59-67.

Klein, L., 1966. River Pollution 3. Control Butterworth and Co. Ltd., Washington D.C.

Lumb, C., 1951. Heat treatment as an aid to sludge dewatering - ten years' full-scale operation. J. Proc. Inst. Sew. Purif., part 1, 5.
McCarty, P.L., 1964. Anaerobic waste treatment fundamentals. Publ. Works 95: 9, 107; 95: 10, 123; 95: 11, 19; 95: 12, 95.
Neubauer, W.K., 1966. Waste alum sludge characteristics and treatment. N.Y. State Dept, Health Res. Rep. 15.
Nordforsk, 1972. Sludge problems. Naturvårdsverket, Solna, Sweden.
Parker, David D., Clifford, W.Randall and King, Paul H., 1972. Biological conditioning for improved sludge. Filter ability. J. Wat. Poll. Contr. Fed., 44: 266-277.
Quirk, T.P., 1964. Economic aspects of incineration vs. incineration-drying. J. Wat. Poll. Contr. Fed., 36: 11, 1355.
Roberts, E.J., 1949. Thickening - art or science?. Mining Eng., 1: 61.
Trubnick, E.H. and Mueller, P.K., 1958. Sludge dewatering practice. Sew. Ind. Wastes, 30: 11, 1364.
Walker, J.D. and Drier, D.E., 1966. Aerobic digestion of sewage sludge solids. Paper presented at 35th Annual Meeting of Georgia Water Pollution Association, Walker Process Equipment, Inc., Publ. 26.130.
Zimmerman, F.J., 1958. Chem. Eng., 65: 17, 117.