CHAPTER 2

SLUDGE SOURCES, CHARACTERISTICS AND QUANTITIES

To design solids processing, treatment, and disposal, and disposal facilities properly, the sources, characteristics and quantities of the solids to be handled must be known [1].

SOURCES

The sources of solids in a treatment plant vary according to the type of plant and its method of operation [1]. The principal sources of solids and the types generated are reported in Table 1.

Table 1. Sources of solids from conventional wastewater treatment plants [1].

Unit operation or process	Type of solids	Remarks
Screening	Coarse solids	Coarse solids are removed by mechanical and hand-cleaned bar screens. In small plants, screenings are often comminuted for removal in subsequent treatment units.
Grit removal	Grit and scum	Scum-removal facilities are often omitted in grit-removal facilities.
Pre-aeration	Grit and scum	In some plants, scum-removal facilities are not provided in pre-aeration tanks. If the pre-aeration tanks are not preceded by grit-removal facilities, grit deposition may occur in pre-aeration tanks.
Primary sedimentation	Primary solids and scum	Quantities of solids and scum depend upon the nature of the collection system and whether industrial wastes are discharged to the system.
Biological treatment	Suspended solids	Suspended solids are produced by the biological conversion of BOD. Some form of thickening may be required to concentrate the waste sludge stream from the biological treatment system.
Secondary sedimentation	Secondary biosolids and scum	Provision for scum removal from secondary settling tanks is a requirement of the U.S. EPA
Solids processing facilities	Solids, compost and ashes	The characteristics of the end products depend on the characteristics of the solids treated and operations and processes used. Regulations for the disposal of residuals are stringent.

CHARACTERISTICS

To treat and dispose of the solids produced from wastewater treatment plants in the most effective manner, it is important to know the characteristics of the solids that will be processed. The general characteristics of the wastewater sludges are given in the Table 2 according to processes they are produced.

Table 2. Sludge characteristics [1].

Screenings	Screenings include all types of organic and inorganic materials large enough to be removed on bar racks. The organic content varies, depending on the nature of the system and the season of the year
Grit	Grit is usually made up of the heavier inorganic solids that settle with relatively high velocities. Depending on the operating conditions, grit may also contain significant amounts of organic matter, especially fats and grease
Scum/grease	Scum consists of the floatable materials skimmed from the surface of primary and secondary settling tanks and from grit chambers and chlorine contact tanks, if so equipped. Scum may contain grease, vegetable and mineral oils, animal fats, waxes, soaps, food wastes, vegetable and fruit skins, hair, paper and cotton, cigarette tips, plastic materials, condoms, grit particles, and similar materials. The specific gravity of scum is less than 1.0 and usually around 0.95
Primary sludge	Sludge from primary settling tanks is usually gray and slimy and, in most cases, has an extremely offensive odor. Primary sludge can be readily digested under suitable conditions of operation
Sludge from chemical precipitation	Sludge from chemical precipitation with metal salts is usually dark in color, though its surface may be red if it contains much iron. Lime sludge is grayish-brown. The odor of chemical sludge may be objectionable, but is not as objectionable as the odor of primary sludge. While chemical sludge is somewhat slimy, the hydrate of iron or aluminum in it makes it gelatinous. If the sludge is left in the tank, it undergoes decomposition similar to primary sludge, but at a slower rate. Substantial quantities of gas may be given off and the sludge density increased by long residence times in storage
Activated sludge	Activated sludge generally has a brown flocculent appearance. If the color is dark, the sludge may be approaching a septic condition. If the color is lighter than usual, there may have been underaeration with a tendency for the solids to settle slowly. Sludge in good condition has an inoffensive "earthy" odor. The sludge tends to become septic rapidly and then has a disagreeable odor of putrefaction. Activated sludge will digest readily alone or when mixed with primary sludge
Trickling-filter sludge	Humus sludge from trickling filters is brownish, flocculent, and relatively inoffensive when fresh. It generally undergoes decomposition more slowly than other undigested sludges. When trickling-filter sludge contains many worms, it may become inoffensive quickly. Trickling-filter sludge digests readily
Aerobically digested biosolids	Aerobically digested biosolids are brown to dark brown and have a flocculent appearance. The odor of aerobically digested sludge is not offensive; it is often characterized as musty. Well-digested aerobic sludge dewaters easily on drying beds
Anaerobically digested biosolids	Anaerobically digested biosolids are dark brown to black and contain an exceptionally large quantity of gas. When thoroughly digested, they are not offensive, the odor being relatively faint and like that of hot tar, burnt rubber, or sealing wax. Primary sludge, when anaerobically digested, produces about twice as much methane gas as does waste activated sludge. When drawn off onto porous beds in thin layers, the solids first are carried to the surface by the entrained gases, leaving a sheet of comparatively clear water. The water drains off rapidly and allows the solids to sink down slowly onto the bed. As the solids dry, the gases escape, leaving a well-cracked surface with an odor resembling that of garden loam
Compost	Composted solids are usually dark brown to black, but the color may vary if bulking agents such as recycled compost or wood chips have been used in the composting process. The odor of well-composted solids is inoffensive and resembles that of commercial garden-type soil conditioners

Sewage sludges exhibit wide variations in their properties depending on origin and previous treatment, but their characterization based on history only gives qualitative information. Many parameters have therefore been introduced and tests developed to measure specific properties of sludge in relation to particular methods of treatment [2].

Conventional characterization parameters can be grouped in physical, chemical and biological parameters [2]:

- physical parameters give general information on sludge processability and handlability;
- chemical parameters are relevant to the presence of nutrients and toxic/dangerous compounds, so they become necessary in the case of utilization in agriculture;

- biological parameters give information on microbial activity and organic matter/ pathogens presence, thus allowing the safety of use to be evaluated.

A list of parameters which can be used, and their relevance to treatment and disposal steps, is presented in Table 3.

Table 3. Parameters which can be used, and their relevance to treatment and disposal steps [2].

Method of Treatment and Disposal													
		Stabilisation											
Parameter	Sedimentation	aerobic	anaerobic	chemical	thermal	Thickening	Dewatering	Drying	Transportation	Landfilling	Composting	Agriculture	Incineration
Temperature		x	x				x	x			x		x
Density						x		x	x				
Rheological prop.							x	x	x	x		x	x
Settleability	x					x	x						
Solids concentr.	x	x	x	x	x	x	x	x	x	x	x	x	x
Volatile solids		x	x	x	x				x	x	x	x	x
Digestability			x										
pH		x	x	x			x				x	x	
Volatile acids			x										
Fats and oils		x	x									x	
Heavy metals			x							x	x	x	x
Nutrients		x	x								x	x	
Particle size	x					x	x						
CST						x	x						
Spec. resistance						x	x						
Compressibility							x						
Centrifugability							x						
Calorific value													x
Leachability										x			
Microbiol. prop.		x	x								x	x	

Some Sludge Characteristics:

Specific gravity [3]:

Most sludges have a specific gravity of 1.0, i.e. they are almost equal to the weight of the water.

Solids concentration [3]:

It defines the relative fraction of solids and liquid in a slurry. Generally expresses as mg/L or %solids. If we assume specific gravity of the slurry is 1.0, then

1% = 10,000 mg/L

Settling characteristics:

Sludge can also be characterized by how well it settles. Most settling tests are conducted in a 1L-graduated cylinder. A quick and simple test to measure the sludge settleability is developed by Mohlman (1934) and called the *Sludge Volume Index* (SVI).

SVI is conducted with a homogeneous sludge mixture. The sludge is settled out in 1L Imhoff Cone for 30 minutes. Settled sludge volume (V) at the bottom of the cone is measured. Knowing the concentration of solids in the sludge suspension (MLSS) in terms of mg/L, SVI is calculated as [3]:

$$SVI = \frac{Vx1000}{MLSS}$$

Typically SVI is used without a unit, but its unit is mL/g.

Typical SVI values and their meanings [4]:
Sludge Volume Index (SVI) values: pin floc potential less than 50 ml/g
Sludge Volume Index (SVI) values: good range 50 to 100 ml/g
Sludge Volume Index (SVI) values: Filament growth 100 to 150 ml/g
Sludge Volume Index (SVI) values: Bulking at high flows 150 to 200 ml/g
Sludge Volume Index (SVI) values: Bulking 200 to 300 ml/g
Sludge Volume Index (SVI) values: Severe bulking higher than 300

Particle size:

Measurement of particle size in sludge is a big problem. In the past, methods like filtration through a series of different sized filters, photographic techniques, scattering laser light have been all used, but each of these have their own handicaps. Sizing of Karr (1976) is generally used. It is as following:

Sludge
↓
100 µm mesh →→→ rigid settleable solids
↓
(flocculate 15 minutes)
↓
Settle for one hour →→→ fragile settleable solids
↓
1.0 µm membrane →→→ suppracolloidals
↓
0.001 µm membrane →→→ true colloidals
↓
Dissolved solids

Sludge particle size affects sludge properties like [3]:

- dewatering
- settling
- rheology

Distribution of water in sludge:

Sludge is a two-phase slurry, consisting of water and solids. When this itself is a problem to be handled, a more important problem is that this water in sludge is not only in one form in terms of its binding characteristics with solids.

Water in sludge appears to exist in four forms [5]:

1. Free water: water that is not attached to sludge solids and that can be separated by simple gravitational settling. It is about 75% of the total volume.
2. Interstitial water: water that is trapped within the floc structure and travels with the floc or perhaps water trapped within a cell. This water can be released when the floc is broken up or the cell is destroyed. Some interstitial water might be removed by mechanical dewatering devices such as centrifuges. It is about 20% of the total volume.
3. Vicinal water: water that is associated with solid particles. This water is held on particle surfaces by virtue of the molecular structure of the water molecules and cannot be removed by centrifugation or other mechanical means. Vicinal water will not be free and it will exist as long as there is a surface. It is about 2% of the total volume [3].
4. Water of hydration: water that is chemically bound to the particle and can be released only by thermo-chemical destruction of the particles. It is about 2.5% of the total volume.

Rheology:

Science of flow and deformation properties of the fluids. Commonly it is measured in terms of viscosity, which is defined as the internal resistance offered by the relative motion of different layers of the fluid [3].

Viscosity can be calculated by measuring the shear rates by applying certain shear stresses as the ratio of shear stress to shear rate [3].

Sludge is a pseudoplastic fluid (neither Newtonian nor non-Newtonian). Pseudoplastic fluids are characteristics of flocculated slurries. As the shear stress on the system increases, the flocs are broken down into smaller particles and viscosity decreases [3].

Fuel value of sludge:

Wastewater sludges contain high quantities of organics so they should have a fuel value. The fuel value of a dry sludge ranges between 10,000 - 20,000 kJ/kg [6]. In order to decide if this is a good number or not, the fuel value of house coal, crude oil and LPG is given below [7]:

House coal: 27,000 - 31,000 kJ/kg

Heating oil: 42,500 kJ/kg

Butane and propane (LPG): 46,300 kJ/kg

<u>Sludge Dewaterability:</u>

Dewaterability can be evaluated by general parameters and specific tests, the latter referred to as a specific technique. The most known tests are SRF (Specific Resistance to Filtration) and CST (Capillary Suction Time).

The classical parameter used to evaluate filterability is the Specific Resistance to Filtration, which represents the resistance offered to filtration by a cake deposited on the filter medium having a unit dry solids weight. Values of the order of 10-12 m/kg or less are indicative of good industrial filterability (raw sludges generally exceed 10-14 m/kg); specific resistance can be reduced by conditioning, most commonly performed by chemicals (organic or inorganic). By measuring resistance at different pressure, the compressibility coefficient is obtained, which provides information on the most suitable operating pressure level.

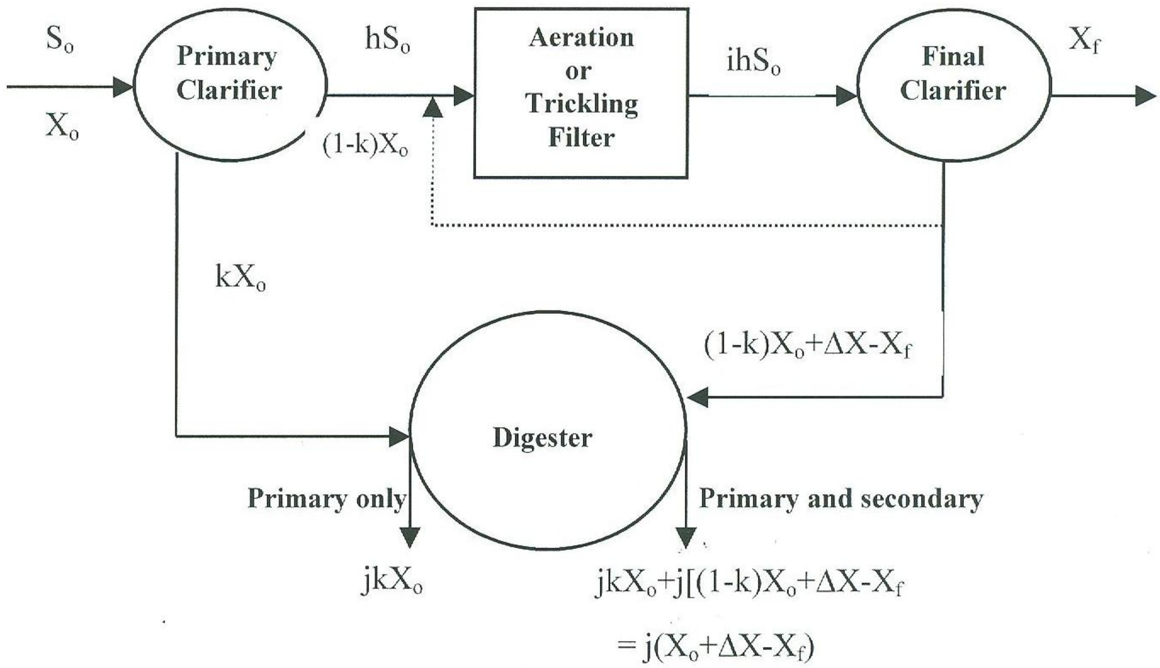
The CST (Capillary Suction Time) is a simple, useful and rapid way to evaluate filterability, but only for comparative evaluations [2].

SLUDGE QUANTITIES

To estimate quantities of sludge from a typical wastewater treatment plant, Figure 1 can be used.

Typical values for the constants used below [3]:

h = 0.7
i = 0.1 for well operated activated sludge
i = 0.2 for trickling filters
k = 0.6
j = 0.8 (assuming no supernatant withdrawal)
Y = 0.5 for activated sludge
Y = 0.2 for trickling filters



S_o = influent BOD (mg/L)
X_o = influent suspended solids (kg/h)
h = fraction of BOD not removed in the primary clarifier
i = fraction of BOD not removed in the aeration tank
X_f = plant effluent suspended solids (kg/h)
k = fraction of X_o removed in the primary clarifier
j = fraction of solids not destroyed in digester
ΔX = net solids produced by biological action (kg/h)
Y = Yield = $\Delta X/\Delta S$, where $\Delta S = hS_o - ihS_o$

Figure 1: Typical sludge quantities from a typical wastewater treatment plant [2].

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