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An Introduction to Sludge Handling, Treatment and Disposal

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AN INTRODUCTION TO SLUDGE HANDLING, TREATMENT AND DISPOSAL

1. GENERAL CONSIDERATIONS. Sludge, or residual solids, is the end product of wastewater treatment, whether biological or physical/chemical treatment. Primary sludge is from 3 to 6 percent solids. Treatment objectives are reduction of the sludge and volume, rendering it suitable for ultimate disposal. Secondary objectives are to utilize the generated gas if anaerobic digestion is selected as part of the sludge management strategy. In addition, an attempt should be made to sell/utilize the sludge as a soil conditioner rather than paying to dispose of it.

2. SLUDGE PUMPING. Sludges with less than 10 percent solids can be pumped through force mains. Sludges with solids contents less than 2 percent have hydraulic characteristics similar to water. For solids contents greater than 2 percent, however, friction losses are from 1-½ to 4 times the friction losses for water. Both head losses and friction increase with decreasing temperature. Velocities must be kept above 2 feet per second. Grease content can cause serious clogging, and grit will adversely affect flow characteristics as well. Adequate clean-outs and long sweep turns will be used when designing facilities of these types.

2.1 PIPING. Sludge withdrawal piping will not be less than 6 inches in diameter. Minimum diameters for pump discharge lines are 4 inches for plants less than 0.5 million gallons per day and 8 inches for plants larger than 1.0 million gallons per day. Short and straight pipe runs are preferred, and sharp bends and high points are to be avoided. Blank flanges and valves should be provided for flushing purposes.

2.2 PUMPS. Sludge pumps will be either plunger, progressing-cavity, torque-flow, or open-propeller centrifugal types. Plunger and progressing-cavity pumps generally should be used for pumping primary sludges; centrifugal pumps are more suitable for the lighter secondary sludges. Centrifugal and torque-flow pumps are used for transporting digested sludge in most cases; plunger and progressing-cavity pumps are used when a suction lift is involved. Plunger pumps are also well suited to sludge elutriation. Standby pumps are required for primary and secondary sludge pumps as well as for sludge elutriation pumps. The pump information provided is for guidance only and does not represent design criteria.

2.2.1 PLUNGER. The advantages of plunger pumps may be listed as follows:

- Pulsating action tends to concentrate the sludge in the hoppers ahead of the pumps.
- They are suitable for suction lifts of up to 10 feet and are self-priming.
- Low pumping rates can be used with large port openings.
- Positive delivery is provided unless some object prevents the ball check valves from seating.
- They have constant but adjustable capacity regardless of large variations in pumping head.
- Large discharge heads may be provided for.
- Heavy-solids concentrations may be pumped if the equipment is designed for the load conditions.

Plunger pumps come in simplex, duplex, triplex models with capacities of 40 to 60 gallons per minute per plunger, and larger models are available. Pump speeds will be between 40 and 50 revolutions per minute, and the pumps will be designed for a minimum head of 80 feet since grease accumulations in sludge lines cause a progressive increase in head with use. Capacity is decreased by shortening the stroke of the plunger; however, the pumps seem to operate more satisfactorily at, or near, full stroke. For this reason, many pumps will be provided with variable-pitch, vee-belt drives for speed control of capacity.

2.2.2 PROGRESSING-CAVITY. The progressing-cavity pump can be used successfully, particularly on concentrated sludge. The pump is composed of a single-threaded rotor that operates with a minimum of clearance in a double-threaded helix of rubber. It is self-priming at suction lifts up to 28 feet, is available in capacities up to 350 gallons per minute, and will pass solids up to 1.125 inches in diameter.

2.2.3 CENTRIFUGAL. With centrifugal pumps, the objective is to obtain a large enough pump to pass solids without clogging but with a small enough capacity to avoid pumping a sludge diluted by large quantities of the overlying sewage. Centrifugal pumps of special design can be used for pumping primary sludge in large plants (greater than 2 million gallons per day). Since the capacity of a centrifugal pump varies with the head, which is usually specified great enough so that the pumps may assist in dewatering the tanks, the pumps have considerable excess capacity under normal conditions. Throttling the discharge to reduce the capacity is impractical because of frequent stoppages, hence it is absolutely essential that these pumps be equipped with variable-speed drives. Centrifugal pumps of the bladeless impeller type have been used to some extent and in some cases have been deemed preferable to either the plunger or screw-feed types of pumps. Bladeless pumps have approximately one-half the capacity of conventional non-clog pumps of the same nominal size and consequently approach the hydraulic requirements more closely. The design of the pump makes clogging at the suction of the impeller almost impossible.

2.2.4 TORQUE-FLOW. This type of pump, which uses a fully recessed impeller, is very effective in conveying sludge. The size of the particles that can be handled is limited only by the diameter of the suction or discharge valves. The rotating impeller develops a vortex in the sludge so that the main propulsive force is the liquid itself.

2.2.5 PUMP APPLICATION. Types of sludge that will be pumped include primary, chemical, trickling-filter and activated, elutriated, thickened, and concentrated. Scum that accumulates at various points in a treatment plant must also be pumped.

2.2.6 PRIMARY SLUDGE. Ordinarily, it is desirable to obtain as concentrated a sludge as practicable from primary tanks. The character of primary raw sludge will vary considerably depending on the characteristics of the solids in the wastewater, the types of units and their efficiency, and, where biological treatment follows, the quantity of solids added from the following:

- Overflow liquors from digestion tanks;
- Waste activated sludge;
- Humus sludge from settling tanks following trickling filters; and
- Overflow liquors from sludge elutriation tanks.

The character of primary sludge is such that conventional non-clog pumps will not be used. Plunger pumps may be used on primary sludge. Centrifugal pumps of the screw-feed and bladeless type, and torque-flow pumps may also be used.

2.2.7 CHEMICAL PRECIPITATION SLUDGE. Sludge from chemical precipitation processes can usually be handled in the same manner as primary sludge.

2.2.8 TRICKLING-FILTER AND ACTIVATED SLUDGE. Sludge from trickling filters is usually of such homogeneous character that it can be easily pumped with either plunger or non-clog centrifugal pumps. Return activated sludge is dilute and contains only fine solids so that it may be pumped readily with non-clog centrifugal pumps which must operate at slow speed to help prevent the flocculent character of the sludge from being broken up.

2.2.9 ELUTRIATED, THICKENED, AND CONCENTRATED SLUDGE. Plunger pumps may be used for concentrated sludge to accommodate the high friction head losses in pump discharge lines. The progressing-cavity type of positive displacement pump also may be used for dense sludges containing up to 20 percent solids. Because these pumps have limited clearances, it is necessary to reduce all solids to small size.

2.2.10 SCUM PUMPING. Screw-feed pumps, plunger pumps, and pneumatic ejectors may be used for pumping scum. Bladeless or torque-flow centrifugal pumps may also be used for this service.

2.3 CONTROLS. The pumping of sludges often requires operation at less than the required design capacity of the pump. For small treatment plants, the design engineer will evaluate the use of a timer to allow the operator to program the pump for on-off operation. For large treatment plants, the use of variable speed controls should be investigated.

3. SLUDGE THICKENING. Thickening is provided to reduce the volume of sludge. Two basic types of thickeners work by gravity or flotation and use either continuous or batch processes. Gravity thickeners are essentially settling tanks with or without mechanical thickening devices (picket fence type). Plain settling tanks can produce solids contents in sludges of up to 8.0 percent for primary sludges and up to 2.2 percent for activated sludge. Activated sludge can also be concentrated by resettling in primary settling tanks.

3.1 GRAVITY THICKENERS. A gravity thickener will be designed on the basis of hydraulic surface loading and solids loading. The design principles are to be the same as those for sedimentation tanks. Bulky sludges with a high Sludge Volume Index (SVI) require lower loading rates. The use of chemical additives (lime or polyelectrolytes) also allows higher loading rates. The minimum detention time and the sludge volume divided by sludge removed per day (which represents the time sludge is held in the sludge blanket) is usually less than two days. Table 1 gives mass loadings to be used for designing gravity thickeners.

3.2 FLOTATION THICKENING. Flotation thickening causes sludge solids to rise to the surface where they are collected. This is accomplished by using a dissolved air flotation process. The process is best suited to activated sludge treatment where solids contents of 4 percent or higher are obtained. Table 2 provides design values for flotation thickening.

Table 1
Mass loadings for designing thickeners

Type of Sludge	Mass Loading – lb/sq ft/day
Primary sludge	22
Primary and tricking filter sludge	15
Primary and waste activated sludge	6 – 10
Waste activated sludge	4 - 8

Table 2
Air flotation parameters

Parameter	Typical Value
Air pressure, psig	40 – 70
Effluent recycle ratio, % of influent flow	30 – 150
Detention time, hours	3
Air-to-solids ratio, lb air/lb solids	0.02
Solids loading, lb/sq ft/day	10 – 50
Polymer addition, lb/tom dry solids	10

4. SLUDGE CONDITIONING.

4.1 CHEMICAL CONDITIONING. Chemical additives may be used to improve sludge dewaterability by acting as coagulants. Chemicals commonly used for this are ferric chloride ($FeCl_3$), lime (CaO), and organic polymers. The application of chemical conditioning is very dependent on sludge characteristics and operating parameters; therefore, a treatability study will be used to determine specific design factors such as chemical dosages. Nevertheless, table 3 provides a range of dosages which are typical for various sludge types.

Table 3
Dosage of chemicals for various types of sludges
(conditioners in percentage of dry sludge solids)

Description	Fresh Solids		Digested	
	$FeCl_3$	CaO	$FeCl_3$	CaO
Primary	1-2	6-8	1.5-3.5	6-10
Primary and trickling filter	2-3	6-8	1.5-3.5	6-10
Primary and activated	1.5-2.5	7-9	1.5-4	6-12
Activated (alone)	4-6	-	-	-

4.2 PHYSICAL CONDITIONING. Physical conditioning is primarily by heat. Heat conditioning involves heating at 350 to 390 degrees Fahrenheit for 30 minutes at 180 to 210 pounds per square inch gauge. Dewaterability is improved dramatically and pathogens are destroyed as well. The main disadvantage is the return of high biochemical oxygen demand loading to the wastewater stream.

5. SLUDGE DEWATERING. Dewatering reduces the moisture content of the sludge so that it can more easily be disposed of by landfill, incineration, heat drying, composting or other means. The objective is a moisture content of 60 to 80 percent, depending on the disposal method. EPA Manual 625/1-82-014 provides information on the capabilities of the various dewatering devices and a methodology for selecting the cost-effective device. Because all dewatering devices are dependent upon proper sludge conditioning, a carefully designed chemical feed system should be included as part of the dewatering facility.

5.1 BELT PRESS FILTRATION. Belt filter presses employ single or double moving belts to continuously dewater sludges through one or more stages of dewatering. All belt press filtration processes include three basic operational stages: chemical conditioning of the feed sludge; gravity drainage to a non-fluid consistency; shear and compression dewatering of the drained sludge. When dewatering a 50:50 mixture of anaerobically digested primary and waste activated sludge, a belt filter press will typically produce a cake solids concentration in the 18-23 percent range.

5.1.1 PHYSICAL DESCRIPTION. Figure 1 depicts a simple belt press and shows the location of the three stages. Although present-day presses are usually more complex, they follow the same principle indicated in figure 1. The dewatering process is made effective by the use of two endless belts of synthetic fiber. The belts pass around a system of rollers at constant speed, and perform the function of conveying, draining and compressing. Many belt presses also use an initial belt for gravity drainage in addition to the two belts in the pressure zone.

5.1.2 PROCESS DESCRIPTION. Good chemical conditioning is very important for successful and consistent performance of the belt filter press. A flocculant (usually an organic polymer) is added to the sludge prior to its being fed to the belt press. Free water drains from the conditioned sludge in the gravity drainage stage of the press. The sludge then enters a two-belt contact zone where a second, upper belt is gently set on the forming sludge cake. The belts, with the captured cake between them, pass through rollers of generally decreasing diameter. This stage subjects the sludge to continuously increasing pressures and shear forces. Pressure can vary widely by design, with the sludge in most presses moving from a low pressure section to a medium pressure section. Some presses include a high pressure section which provides additional dewatering. Progressively more and more water is expelled throughout the roller section to the end where the cake is discharged. A scraper blade is often employed for each belt at the discharge point to remove cake from the belts. Two spray-wash belt cleaning stations are generally provided to keep the belts clean. Typically, secondary effluent can be used as the water source for the spray-wash. High pressure jets can be equipped with a self-cleaning device used to continuously remove any solids which may tend to plug the spray nozzles.

5.1.3 PERFORMANCE VARIABLES. Belt press performance is measured by the percent solids of the sludge cake, the percent solids capture, the solids and hydraulic loading rates, and the required polymer dosage. Several machine variables including belt speed, belt tension and belt type influence belt press performance.

5.1.4 ADVANTAGES AND DISADVANTAGES. Table 4 lists some of the advantages and disadvantages of the belt filter press compared to other dewatering processes.

5.1.5 DESIGN SHORTCOMINGS. Common design shortcomings associated with belt filter press installations and their solutions are listed in table 5.

5.2 SLUDGE DRYING BEDS. Sludge drying beds rely on drainage and evaporation to effect moisture reduction. These beds are open; and, as such, are very susceptible to climatic conditions such as precipitation, sunshine, air temperature, relative humidity, and wind velocity. For example, sludge drying in 6 weeks in summer would take at least 12 weeks to dry in the winter. Sludge bed drying efficiency can be improved significantly by covering the bed with glass or plastic and by providing artificial heat. Heat could be supplied using waste biogas as a fuel or waste heat from the base power plant. Figure 2 illustrates a typical bed.

5.2.1 DESIGN FACTORS. Area requirements can be interpreted in terms of the per capita values in table 6. These values are very arbitrary and depend largely on climatic conditions. Embankment heights will be 12 to 14 inches, using concrete or concrete-block walls. Underdrains are to be provided with lateral tiles 12 feet apart, and their transported leachate must be returned to the head of the treatment plant. An 8-18 inch bed of gravel, ranging in size from 0.1 to 1.0 inches, is placed on the underdrains. The sand placed on the gravel will have a depth of 18 inches, with the sand being washed and dirt-free. The sand will have an effective size between 0.3 and 0.75 millimeters, with a uniformity coefficient of not more than 4.0. Sludge distribution can be of various design, although an impervious splash plate of some kind is always provided. Sludge cake removal can be by hand or mechanical means. Bed widths may range from 15 to 25 feet, with lengths of 50 to 150 feet. if polymers are added for conditioning, the bed

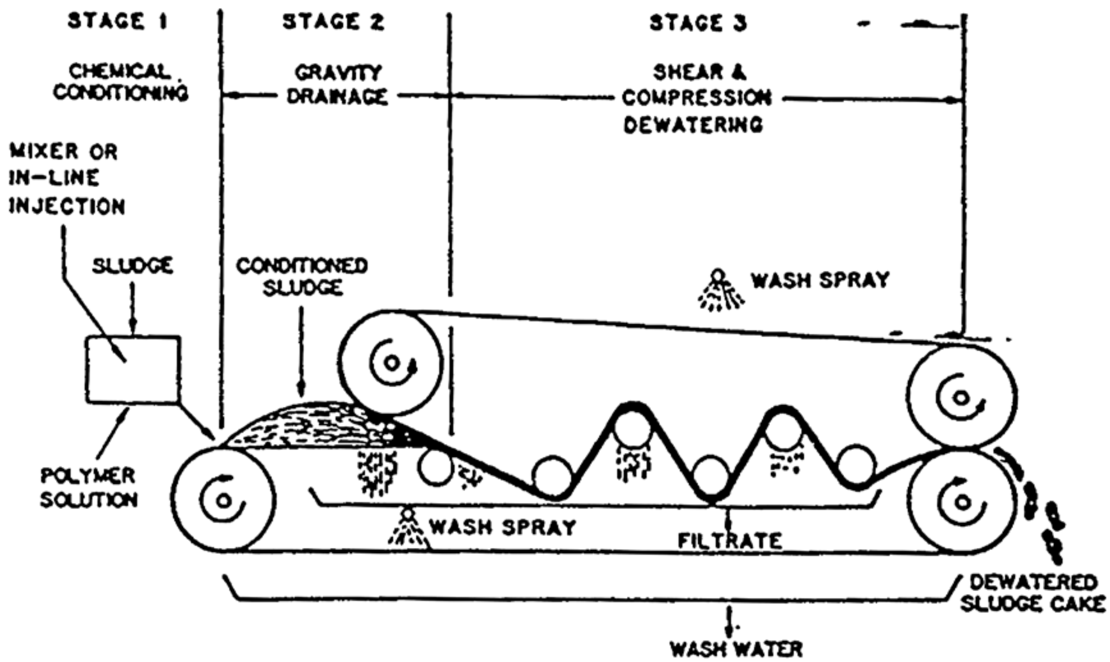

Figure 1
Three basic stages of a belt filter press

Table 4
Advantages and disadvantages of belt filter presses

Advantages	Disadvantages
• High pressure machines are capable of producing drier cake than any machine except a filter press • Low power requirements • Low noise and vibration • Operation easy to understand for inexperienced operators because all operational changes are quickly and readily apparent • Continuous operation • Media life can be extended when applying the low belt tension typically required for municipal sludges	• Very sensitive to incoming feed characteristics and chemical conditioning • Machines hydraulically limited in throughput • Short media life as compared with other devices using cloth media • Washwater requirement for belt spraying can be significant • Frequent washdown of area around press required • Requires prescreening or grinding of sludge to remove large objects and fibrous material • Can, like any filtration device, emit noticeable odors if the sludge is poorly stabilized • Requires greater operator attention than centrifuge • Condition and adjustment of scraper blades is a critical feature that should be checked frequently • Typically requires greater polymer dosage than a centrifuge

Table 5
Common design shortcomings of belt filter press installations

Shortcomings	Resultant Problems	Solution
Improper tracking of filter belt	Belt creeps off rollers and dewatering operation must be stopped for repair	Repair or adjust automatic tracking device, if one exists. If not, attempt to add such a device.
Inadequate wash water supply	Sludge buildup on belts and/or rollers	Increase spray water pressure or install new spray heads
Improper belt type	Frequent tearing or wrinkling or inadequate solids capture	Experiment with different belt types and install proper belt for actual conditions
Inadequate control of conditioning	Frequent under-conditioning or over-conditioning of sludge	Install a feedback control system which monitors sludge solids content and sets required polymer addition
Wash water not metered	Difficult to calculate solids capture	Install a water meter in wash water line
Spray wash unit poorly sealed	Fine mist escapes from spray wash unit increasing moisture/corrosion problems	Replace or modify spray wash unit to provide better seal around belt
Inadequate mixing time for polymer and feed sludge before belt press	Under-conditioning of sludge	Move polymer injection point upstream toward feed pumps to increase mixing time or install polymer/sludge mixing before belt presses
No flow meters on sludge feed lines	Process control is hampered	Install flow meters

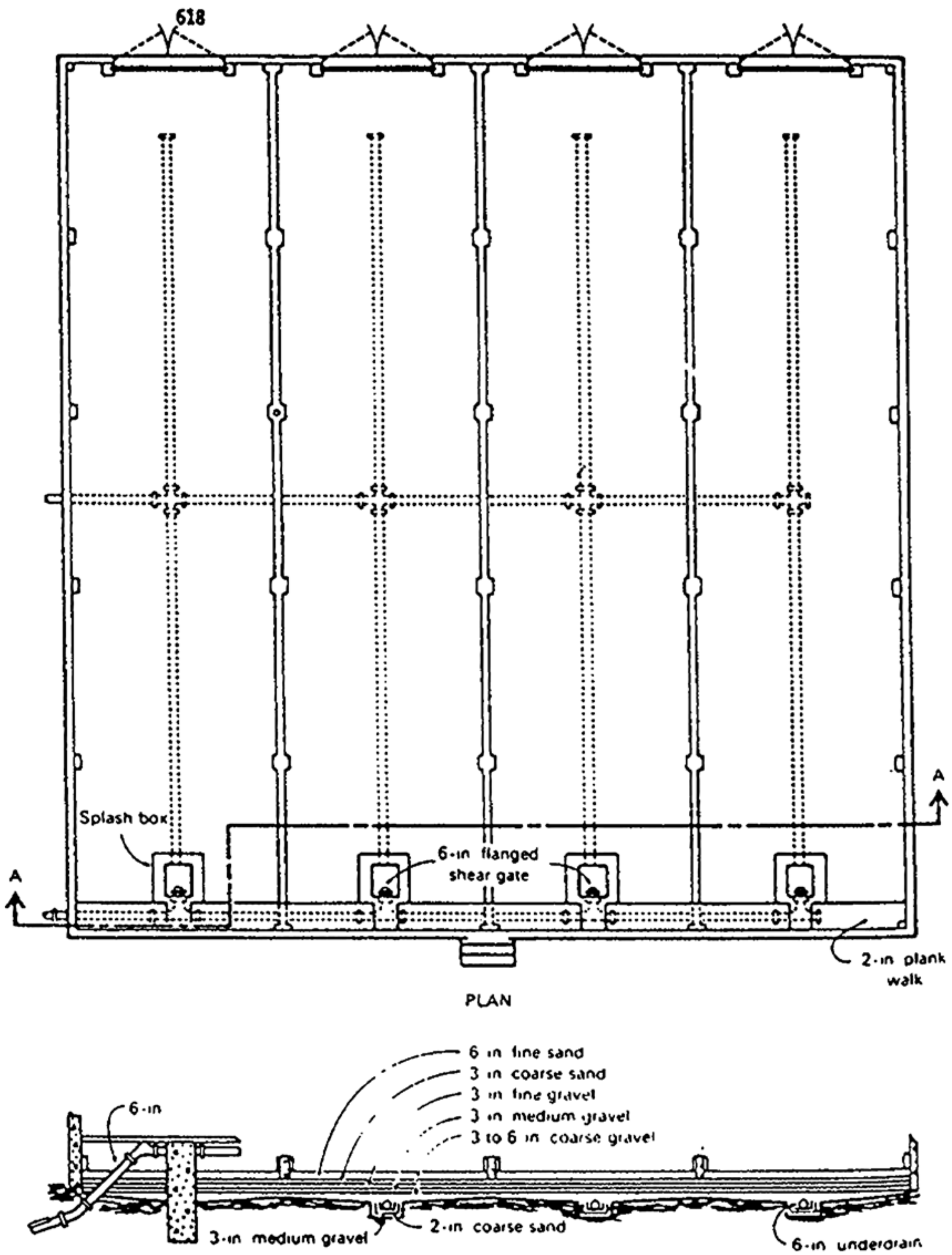

Figure 2

Plan and section of a typical sludge drying bed length can be reduced to 50-75 feet to prevent poor sludge distribution on the bed. Multiple beds provide operational flexibility and will be used if appropriate. Enclosed beds will have sides no higher than 18 inches so as not to shade the sludge. Open sides, forced ventilation and artificial heating are possible modifications. Usually, a combination of open and closed beds performs best in average situations. Odor and insects can be a problem unless the sludge is digested completely. Land requirements and sludge cake removal costs are other disadvantages.

Table 6
Area required for sludge drying beds (sq ft per capita)

Type of sludge	Open Beds	Covered Beds
Primary digested	1.5	1.0
Primary and humus digested	1.75	1.25
Primary and activated digested	2.5	1.5
Primary and chemically precipitated digested	2.5	1.5

Note: For facilities to be located in regions south of latitude 35 ^{o}, open bed area requirements may be reduced by 0.5 sf/capita for all types of sludge and 0.25 sf/capita for covered beds.

5.3 VACUUM FILTRATION. Vacuum filtration reduces sludge moisture content by applying a vacuum (10 to 25 inches mercury) through a sludge layer, using various equipment configurations. Vacuum filters can be drum type, belt type, string discharge type or coil type. The use of coagulant pretreatment is necessary for good dewatering efficiencies. $FeCl_3$ is the coagulant aid most commonly used. Generally, the higher the feed solids concentration, the higher the filtration rate and filter yield. Feed solids, however, will be limited to 8 to 10 percent to prevent difficulties in handling the sludge. Figure 3 shows typical vacuum filter applications.

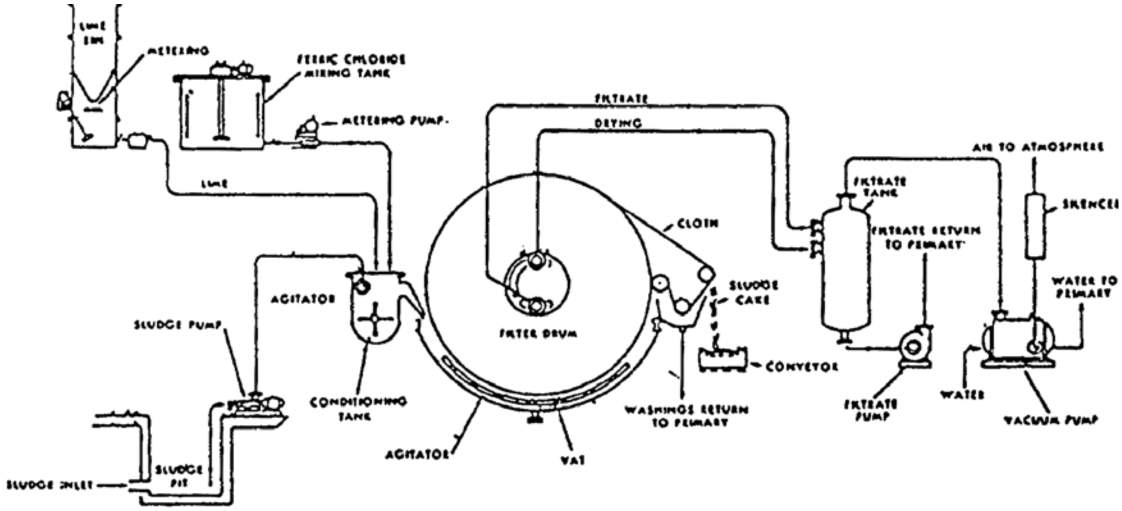

Figure 3

Rotary vacuum filter system

5.3.1 FILTER YIELDS. Filter yields vary from 2 to 15 pounds per square foot per hour for various types of sludge. Vacuum filters for digested activated sludge will be designed for a yield of 2 pounds per square foot per hour; while vacuum filters for raw primary sludge will be designed for a filter yield of 10 pounds per square foot per hour. The design filter area will be for the peak sludge removal rate required plus 15 percent area allowance for maintenance downtime. It will be assumed that the filter units will be operated 30 hours per week.

5.3.2 FILTER SIZES AND EQUIPMENT. Filter sizes cover a wide range and can be up to 12 feet in diameter, with filtering areas up to 700 square feet. Vacuum filtration units are normally supplied with essential auxiliary equipment from various manufacturers.

5.3.3 DISPOSAL OF FILTRATE. Dewatering liquids will be returned to the head of the treatment plant. For this reason, the solids concentrations of a vacuum filtrate must be kept as low as practical and can be assumed to be about 10 percent.

5.4 CENTRIFUGATION. Centrifugal dewatering of sludge is a process which uses the force developed by fast rotation of a cylindrical drum or bowl to separate the sludge solids from the liquid. In the basic process, when a sludge slurry is introduced to the centrifuge, it is forced against the bowl's interior walls, forming a pool of liquid. Density differences cause the sludge solids and the liquid to separate into two distinct layers. The sludge solids “cake” and the liquid “centrate” are then separately discharged from the unit. The two types of centrifuges used for municipal sludge dewatering, basket and solid bowl, both operate on these basic principles. They are differentiated by the method of sludge feed, magnitude of applied centrifugal force, method of solids and liquid discharge, cost, and performance.

5.4.1 BASKET CENTRIFUGE. The imperforate basket centrifuge is a semi-continuous feeding and solids discharging unit that rotates about a vertical axis. A schematic diagram of a basket centrifuge in the sludge feed and sludge plowing cycles is shown in figure 4. Sludge is fed into the bottom of the basket and sludge solids form a cake on the bowl walls as the unit rotates. The liquid (centrate) is displaced over a baffle or weir at the top of the unit. Sludge feed is either continued for a preset time or until the suspended solids in the centrate reach a preset concentration. The ability to be used either for thickening or dewatering is an advantage of the basket centrifuge. A basket centrifuge will typically dewater a 50:50 blend of anaerobically digested primary and waste activated sludge to 10-15 percent solids.

5.4.1.1 Process description. After sludge feeding is stopped, the centrifuge begins to decelerate and a special skimmer nozzle moves into position to skim the relatively soft and low solids concentration sludge on the inner periphery of the sludge mass. These skimmings are typically returned to the plant headworks or the digesters. After the skimming operation, the centrifuge slows further; to about 70 revolutions per minute, and a plowing knife moves into position to cut the sludge away from the walls; the sludge cake then drops through the open bottom of the basket. After plowing terminates, the centrifuge begins to accelerate and feed sludge is again introduced. At no time does the centrifuge actually stop rotating.

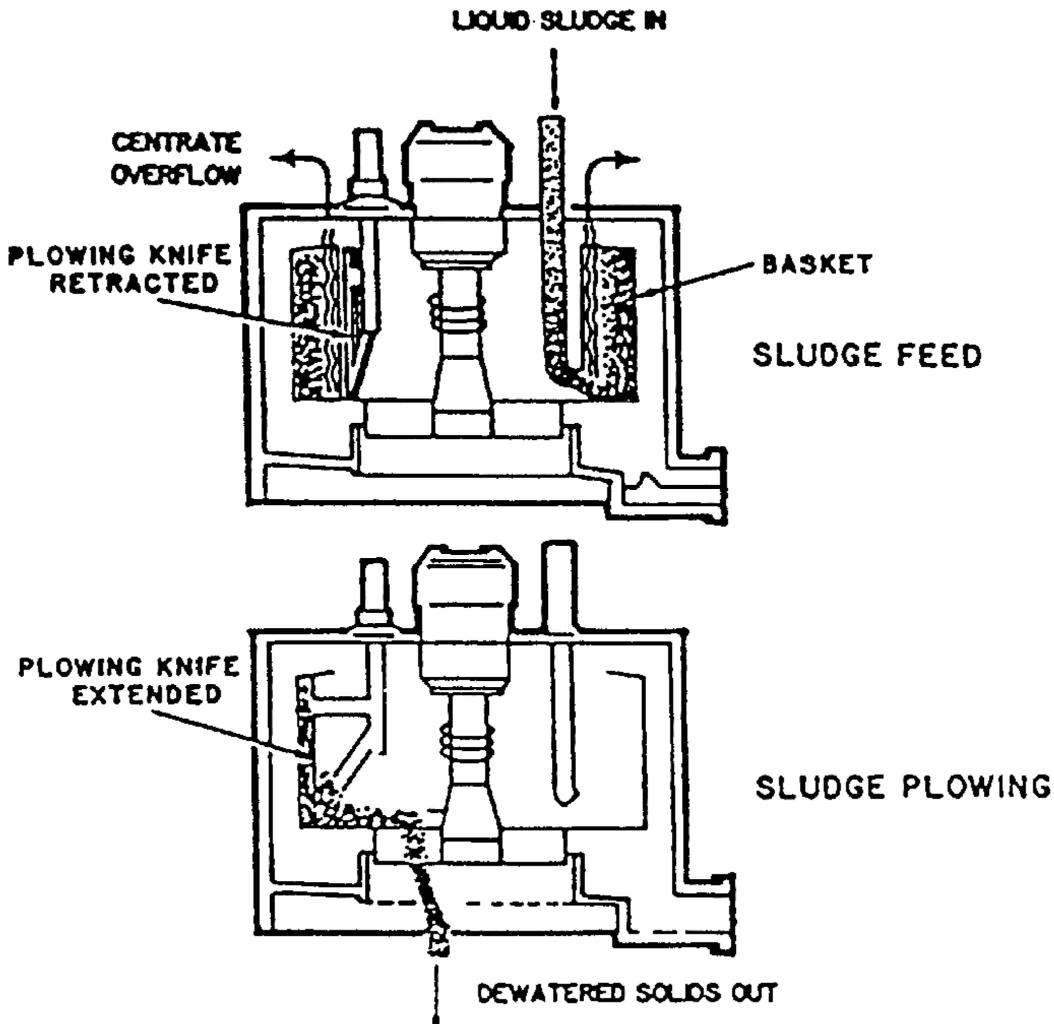

Figure 4

Basket centrifuge in sludge feed and sludge plowing cycles

5.4.1.2 Application. The cake solids concentration produced by the basket machine is typically not as dry as that achieved by the solid bowl centrifuge. However, the basket centrifuge is especially suitable for dewatering biological or fine solids sludges that are difficult to dewater, for dewatering sludges where the nature of the solids varies widely, and for sludges containing significant grit. The basket centrifuge is most commonly used for thickening waste activated sludge. A basket centrifuge can be a good application in small plants with capacities in the range of 1 to 2 million gallons per day where thickening is required before or after stabilization or where dewatering to 10 to 12 percent solids is adequate. The basket centrifuge is sometimes used in larger plants.

5.4.1.3 Advantages and disadvantages. Advantages and disadvantages of an imperforate basket centrifuge compared to other dewatering processes are presented in table 7.

Table 7
Advantages and disadvantages of basket centrifuges

Advantages	Disadvantages
• Same machine can be used for both thickening and dewatering • Is very flexible in meeting process requirements • Is not affected by grit • Little operator attention is required; full automation is possible • Compared to belt filter press and vacuum filter installations, is clean looking and has little or no order problems • Is excellent for dewatering hard-to-handle sludges, although sludge cake solids are only 10-15% for digested primary + WAS • Flexibility in producing different cake solids concentrations because of skimming ability	• Unit is not continuous feed and discharge • Requires special structural support, much more than a solid bowl centrifuge • Has a high ratio of capital cost to capacity • Discharge of wet sludge can occur if there is a machine malfunction or if the sludge is improperly conditioned • Provision should be made for noise control • Continuous automatic operation requires complex controls • Bowl requires washing once per shift

5.4.1.4 Design shortcomings. Common design shortcomings experienced in basket centrifuge installations and their solutions are presented in table 8.

Table 8
Common design shortcomings of basket centrifuge installations

Shortcomings	Resultant Problems	Solution
Engineered for rigid piping connections to centrifuge	Cracked or leaking pipes and joints	Use flexible connectors; consider vibration in design
Inadequate structural support	Cracks in supports, buckling of members	Redesign, reconstruct, or refurbish
Inadequate solids capture due to insufficient machine capacity or no provision for polymer feed	High solids content in centrate	Add more machines or properly condition sludge; consider other units in line
Electrical control panels located in same room with centrifuges, conveyor belts, filters or unit operations	Corrosive atmosphere deteriorates controls	Redesign and relocate controls in separate room away from corrosive atmosphere
No provision for centrate sampling	Process control is hampered	Install sample taps in the centrate line
No flow meters on sludge feed lines	Process control is hampered	Install flow meters as requested

5.4.2 SOLID BOWL CENTRIFUGE. Solid bowl centrifuge technology has greatly advanced in recent years, as both the conveyor life and machine performance have been improved. At many treatment plants in the U.S., older solid bowl centrifuge installations have required very high maintenance expense due to rapid wear of the conveyor and reduced performance. Recently the use of replaceable ceramic tile in low-G centrifuges (<1, 100 Gs) and sintered tungsten carbide tile in high-G centrifuges (>1, 100 Gs) have greatly increased the operating life prior to overhaul. In addition, several centrifuge manufacturers also offer stainless steel construction in contrast to carbon-steel construction, and claim use of this material results in less wear and vibration caused by corrosion. Revised bowl configurations and the use of new automatic backdrives and eddy current brakes have resulted in improved reliability and process control, with a resultant improvement in dewatering performance. Also in recent years, several centrifuge manufacturers have reduced the recommended throughput of their machines in direct response to competition from the belt filter press. This has allowed for an increase in solids residence time in the centrifuge and subsequent improvement in cake dryness.

5.4.2.1 Physical description. As opposed to the semi-continuous feed/discharge cycles of the imperforate basket centrifuge, the solid bowl centrifuge (also called decanter or scroll centrifuge) is a continuously operating unit. This centrifuge, shown in figure 5, consists of a rotating, horizontal, cylindrical bowl containing a screw-type conveyor or scroll which rotates also, but at a slightly lower or higher speed than the bowl. The differential speed is the difference in revolutions per minute (rpm) between the bowl and the conveyor. The conveying of solids requires that the screw conveyor rotate at a different speed than the bowl. The rotating bowl, or shell, is supported between two sets of bearings; and at one end, necks down to a conical section that acts as a dewatering beach or drainage deck for the screw-type conveyor. Sludge enters the rotating bowl through a stationary feed pipe extending into the hollow shaft of the rotating conveyor and is distributed through ports in this hollow shaft into a pool within the rotating bowl.

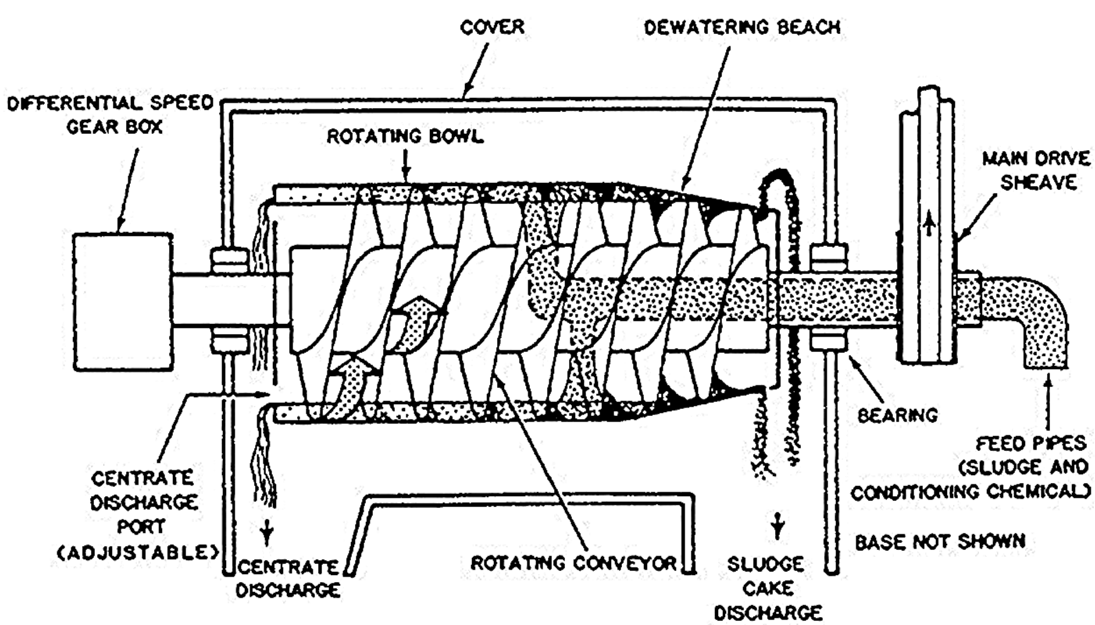

Figure 5

Continuous countercurrent solid bowl centrifuge

5.4.2.2 Countercurrent centrifuge. The centrifuge illustrated in figure 16-5 operates in the countercurrent mode. Influent sludge is added through the feed pipe; under centrifugal force, sludge solids settle through the liquid to the bowl wall because their density is greater than that of the liquid. The solids are then moved gradually by the rotating conveyor from left to right across the bowl, up the dewatering beach to outlet ports and from there drop downward into a sludge cake discharge hopper. As the settled sludge solids move from left to right through the bowl toward the sludge cake outlet, progressively finer solids are settled centrifugally to the rotating bowl wall. The water or centrate drains from the solids on the dewatering beach and back into the pool. Centrate is actually moved from the end of the feed pipe to the left, and is discharged from the bowl through ports on the left end, which is the opposite end of the centrifuge from the dewatering beach. The location of the centrate removal ports is adjustable and their location establishes the depth of the pool in the bowl.

5.4.2.3 Concurrent centrifuge. A second variation of the solid bowl centrifuge is the concurrent model shown in figure 6. In this unit, liquid sludge is introduced at the far end of the bowl from the dewatering beach, and sludge solids and liquid flow in the same direction. General construction is similar to the countercurrent design except that the centrate does not flow in a different direction than the sludge solids. Instead, the centrate is withdrawn by a skimming device or return tube located near the junction of the bowl and the beach. Clarified centrate then flows into channels inside the scroll hub and returns to the feed end of the machine where it is discharged over adjustable weir plates through discharge ports built into the bowl head.

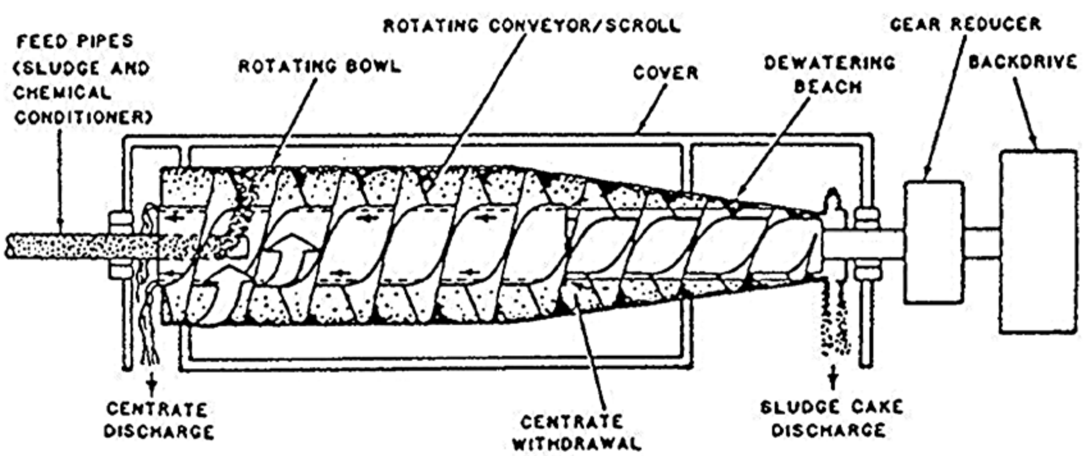

Figure 6

Continuous concurrent solid bowl centrifuge

5.4.2.4 Differential speed control. A relatively new development in solid-bowl decanter centrifuges is the use of a backdrive to control the speed differential between the scroll and the bowl. The objective of the backdrive is to control the differential to give the optimum solids residence time in the centrifuge and thereby produce the optimum cake solids content. a backdrive of some type is considered essential when dewatering secondary sludges because of the fine particles present. The backdrive function can be accomplished with a hydraulic pump system, an eddy current brake, direct current variable speed motor or a Reeves-type variable speed motor. The two most common backdrive systems are the hydraulic backdrive and the eddy current brake.

5.4.2.5 Installation. Most centrifuge installations have the centrifuge mounted a few feet above the floor and use a belt conveyor to move dewatered cake away. Other methods of installing a solid bowl centrifuge are to put the centrifuge on the second floor of a two-story building and drop the dewatered cake into either trucks or a storage hopper on the first level; to mount the centrifuge about a foot off the floor and to drop cake onto a screw conveyor built into the floor; or to let the centrifuge cake drop into an open-throated, progressive cavity-type pump for transfer of the cake to a truck, incinerator or storage.

5.4.2.6 Advantages and disadvantages. Some of the advantages and disadvantages of a solid-bowl decanter centrifuge compared with other dewatering processes are presented in table 9. The ability to be used for thickening or dewatering provides flexibility and is a major advantage of solid bowl centrifuges. For example, a centrifuge can be used to thicken ahead of a filter press, reducing chemical usage and increasing solids throughput. During periods of downtime of the filter press, the solid bowl centrifuge can serve as an alternate dewatering device. Another advantage of the solid bowl centrifuge for larger plants is the availability of equipment with the largest sludge throughput capability for single units of any type of dewatering equipment. The larger centrifuges are capable of handling 300 to 700 gallons per minute per unit, depending on the sludge's characteristics. The centrifuge also has the ability to handle higher-than-design loadings, such as a temporary increase in hydraulic loading or solids concentration, and the percent solids recovery can usually be maintained with the addition of more polymer (while the cake solids concentration will drop slightly, the centrifuge will stay online). Solid bowl centrifuges are typically capable of dewatering a 50:50 mixture of anaerobically digested primary and secondary sludges to a 15-21 percent solids concentration. Table 10 lists common design shortcomings and their solutions.

Table 9
Advantages and disadvantages of solid bowl decanter centrifuges

• Clean appearance, little to no odor problems, and fast start-up and shut-down capabilities • Easy to install and requires a relatively small area • Does not require continuous operator attention • Can operate with a highly variable feed solids concentration on many sludge types • High rates of feed per unit, thus reducing the number of units required • Use of low polymer dosages when compared to other devices, except the basket centrifuge • Can handle higher than design loadings with increased polymer dosage, although cake solids content may be reduced	• Scroll wear can be a high maintenance item. Hard surfacing and abrasion protection materials are extremely important in reducing wear • Prescreening or a grinder in the feed stream is recommended • Requires skilled maintenance personnel in large plants where scroll maintenance is performed • Noise is very noticeable, especially for high G centrifuges and hydraulic backdrive units • Vibration must be accounted for in designing electronic controls and structural components • High power consumption for a high G centrifuge • A condition such as poor centrate quality can be easily overlooked since the process is fully contained • Requires extensive pretesting to select correct machine settings before placement in normal service

Table 10
Common design shortcomings of solid bowl decanter centrifuge installations

Shortcomings	Resultant Problems	Solution
Improper materials used for scroll tips	Excessive wear	Replace with harder, more abrasion-resistant tips
Inability to remove bowl assembly during maintenance	Bowl is bulky and heavy and cannot be removed without using lifting equipment	Install overhead crane
Rigid piping used to connect feed pipe to centrifuge	Cracked or leaking pipes or pie connections	Replace with flexible connections
Grit present in sludge	Excessive centrifuge wear	Install a degritting system on the sludge or on the wastewater prior to sludge removal
Electronic controls, structural components, and fasteners not designed for vibration	Electrical connections become loose; structural components and fasteners fail	Isolate sensitive electronic controls from vibration; redesign and construct structural components and fasteners to resist vibrations
Electrical control panels located in same room with centrifuges, conveyor belts, etc.	Corrosive atmosphere deteriorates controls	Redesign and relocate controls in separate room away from corrosive atmosphere

5.5 FILTER PRESSES. The plate-and-frame press is a batch device that has been used to process difficult to dewater sludges. Recent improvements in the degree of automation, filter media and unit capacities have led to renewed interest in pressure filtration for application to municipal-type sludges. The ability to produce a very dry cake and clear filtrate are major points in favor of pressure filtration, but they have higher capital and operating costs than vacuum filters. Their use in preference to vacuum filters will be acceptable providing they can be economically justified. Figure 7 illustrates a cross-section of a filter press.

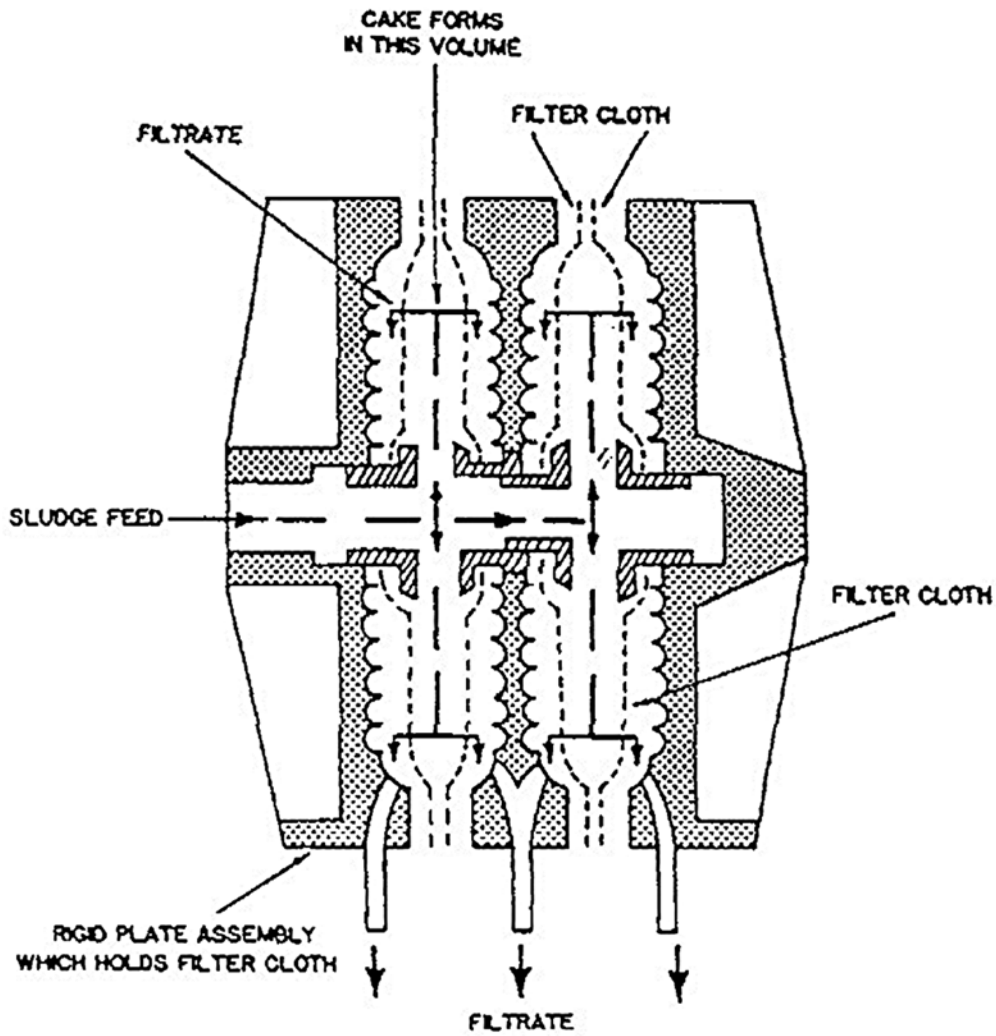

Figure 7

Cross-section of plate filter press

5.5.1 CONTROL. Control of filter presses may be manual, semi-automatic, or full automatic. Labor requirements for operation will vary dramatically depending on the degree of instrumentation utilized for control. In spite of automation, operator attention is often needed during the dump cycle to insure complete separation of the solids from the media of the filter press. Process yields can typically be increased 10 to 30 percent by carefully controlling the optimum cycle time with a microprocessor. This is important since the capital costs for filter presses are very high.

5.5.2 ADVANTAGES AND DISADVANTAGES. Table 11 presents the principal advantages and disadvantages of filter presses compared to other dewatering processes. Common design shortcomings associated with filter press installations are listed in table 12 along with solutions for these shortcomings. The fixed volume, recessed plate filter press will typically dewater a 50:50 blend of digested primary and waste activated sludge to between 35-42 percent solids, while a diaphragm press will produce a 38-47 percent solids cake on the same sludge. These cake solids concentrations include large amounts of inorganic conditioning chemicals.

Table 11
Advantages and disadvantages of filter presses

Advantages	Disadvantages
• High solids content cake • Can dewater hard-to-dewater sludges, although very high chemical conditioning dosages or thermal conditioning may be required • Very high solids capture • Only mechanical device capable of producing a cake dry enough to meet landfill requirements in some locations	• Large quantities of inorganic conditioning chemicals are commonly used for filter presses • Polymer alone is generally not used for conditioning due to problems with cake release and blinding of filter media. Experimental work on polymer conditioning is continuing. • High capital cost, especially for diaphragm filter presses • Labor cost may be high if sludge is poorly conditioned and if press is not automatic • Replacement of the media is both expensive and time consuming • Nose levels caused by feed pumps can be very high • Requires grinder or prescreening equipment on the feed • Acid washing requirements to remove calcified deposits caused by lime conditioning can be frequent and time consuming • Batch discharge after each cycle requires detailed consideration of ways of receiving and storing cake, or of converting it to a continuous stream for deliver to an incinerator

Table 12
Common design shortcomings of filter pressed

Shortcomings	Resultant Problems	Solution
Improper conditioning chemicals utilized	Blinding of filter cloth and poor cake release	Switch conditioning chemicals or dosages
Insufficient filter cloth washing	Blinding of filter cloth, poor cake release, longer cycle time required, wetter cake	Increase frequency of washing
Improper filter cloth media specified	Poor cake discharge; difficult to clean	Change media
Inadequate facilities when dewatering a digested sludge with a very fine floc	Poor cake release	(1) Try two-stage compression cycle with first stage at low pressure to build up thickened sludge "media" before increasing pressure (2) If this fails install precoat storage and feed facilities
Feed sludge is too dilute for efficient filter press operation	Long cycle time and reduced capacity	Thicken sludge before feeding to filter press
Sludge feed at only one end of large filter press	Unequal sludge distribution within the press	Use equalizing tank or centrifugal pump to feed at opposite end of press

6. SLUDGE DIGESTION.

6.1 AEROBIC SLUDGE DIGESTION. The major function of sludge digestion (and its principal advantage) is the stabilization of the sludge in terms of volatile content and biological activity. Aerobic digestion accomplishes this through biological oxidation of cell matter which is done without the production of volatile solids or high biochemical oxygen demand liquor associated with anaerobic digestion.

6.1.1 MODES OF OPERATION. Aerobic digesters can be either continuous or intermittent batch operations. With batch operation, waste sludge feed will be discontinued at a specified time before digested sludge withdrawal. In continuous operation, supernatant is constantly withdrawn. This mode of operation is used when phosphorus is a problem and low phosphorus levels are required in the effluent because batch operation produces high phosphorus concentrations in the supernatant.

6.1.2 DESIGN FACTORS. A summary of design factors is given in table 13. The tank is open, which can be a problem in cold climates with mechanical aeration; no heating is required although some increase in volatile solids reduction can be obtained with increased temperature. Tank design is similar to aeration basin design with the addition of a sludge thickening apparatus. A major disadvantage of aerobic digestion is the high energy requirement.

6.2 ANAEROBIC SLUDGE DIGESTION.

6.2.1 PROCESS DESCRIPTION. Anaerobic sludge digestion is the destruction of biological solids using bacteria which function in the absence of oxygen. This process produces methane gas which can be used as an energy source and can make anaerobic digestion more economically attractive than aerobic digestion. The larger the treatment plant, the greater the economic incentive to use anaerobic digestion. However; anaerobic digestion is considerably more difficult to operate than aerobic digestion. The methane produced could be of great benefit in cold regions as a supplemental source of heat. Appendix E presents detailed information concerning insulation of reactors and piping in cold climates. Therefore, the decision to use anaerobic digestion must carefully evaluate the operational capability of the installation.

6.2.2 OBJECTIVES. The objectives of anaerobic digestion are the stabilization of organic solids, sludge volume reduction, odor reduction, destruction of pathogenic organisms, useful gas production, and the improvement of sludge dewaterability. Volatile solids typically are reduced by 60 to 75 percent, with final volatile matter contents of 40 to 50 percent.

Table 13
Aerobic digestion design parameters using air

Parameter	Value	Remarks
Solids retention time, days	10-15 (a)	Depending on temperature, type of sludge, etc.
Solids retention time, days	15-20 (b)	
Volume allowance, cu ft/capita	3-4	
VSS loading, pcf/day	0.024-0.140	Depending on temperature, type of sludge, etc.
Air requirements		
Diffuser system, cfm/1000 cu ft	20-30 (a)	Enough to keep the solids in suspension and maintain a DO between 1-2 mg/l
Diffuser system, cfm/1000 cu ft		
Mechanical system, hp/1000 cu ft	1.00-1.25	This level is governed by mixing requirements. Most mechanical aerators in aerobic digesters require bottom mixers for solids concentration greater than 8000 mg/l, especially if deep tanks (>12 ft) are used
Minimum DO, mg/l	1.0-2.0	
Temperature, ^{o}C	>15	If sludge temperatures are lower than 15^{o} C, additional detention time should be provided so that digestion will occur at the lower biological reaction rates.
VSS reduction, percent	35-50	
Tank design		Aerobic digestion tanks are open and generally require no special heat transfer equipment or insulation. For small treatment systems (0.1 mgd), the tank design should be flexible enough so that the digester tank can also act as a sludge thickening unit. If thickening is to be utilized in the aeration tank, sock type diffusers should be used to minimize clogging.

(a) Excess activated sludge alone
(b) Primary and excess activated sludge, or primary sludge alone

6.2.3 CONVENTIONAL (STANDARD-RATE) DIGESTION SYSTEMS. This type of system will consist of a single or two-stage process for which tanks will provide for digestion, supernatant separation, and concentration under the following loadings. Two-stage processes are more applicable for plants having capacities of more than 1 million gallons per day. The retention period in the first stage tank will be 8 days and 22 days in the second stage tank. The minimum total retention time will be 30 days if the tank is heated to 95 degrees Fahrenheit. Unit capacities required for separate unheated tanks will be increased in accordance with local climatic conditions but not less than twice the value indicated for each of the three sludge sources in table 14.

Table 14
Standard-rate anaerobic digester capacity design criteria

Feed sludge source	Design capacity, cu ft/capita
Primary settling only	3
Trickling filter with primary settling	5
Activated sludge with primary settling	6

Table 15
High-rate anaerobic digester capacity design criteria

Feed sludge source	Design capacity, cu ft/capita
Primary settling only	2
Trickling filter with primary settling	4
Activated sludge with primary settling	4
Note: For two-stage systems, 25 percent of the total required design volume will be provided for the secondary tank and 75 percent for the primary tank.	

6.2.4 HIGH-RATE DIGESTION. The high-rate digestion process differs from the standard-rate process in that the solids loading rate is much greater (up to 4 times). The retention period is lower (one-half), mixing capacity is greater and improved, and the sludge is always heated. High-rate tanks will be those where the digestion process (accomplished separately from supernatant separation, and sludge concentration and storage) includes rapid and intimate mixing of raw and digesting sludge in the entire tank contents with an operating temperature of 95 degrees Fahrenheit. The process will be a two-stage system applicable for treatment plants with capacities greater than 1 million gallons per day and with the primary digestion tank considered the high-rate tank. If sludge drying beds or ponds are to be used for dewatering of the digested sludge, the retention time of the solids in the primary digester will be 15 days. If mechanical sludge dewatering processes are employed, the retention time in the primary digester may be reduced to 10 days. The secondary digester must be of sufficient capacity to provide for supernatant separation and storage of digested sludge.

The primary digestion tanks will be sized to provide 75 percent of the total design tank volume (table 15).

6.2.5 PH CONTROL. The pH level of the sludge inside the digester is a critical factor in anaerobic digestion and will be kept as near to 7.0 as possible, with a range of 6.6 to 7.4 considered acceptable. Also, monitoring of the volatile acids-to -alkalinity ratio is important. The pH is maintained with bicarbonate buffering and, when natural buffering fails and the pH becomes less than 6.6, hydrated lime (calcium hydroxide) should be added to the digester. Design provisions must be made that will provide a simple means for adding lime to the digester if and when needed. One of the more practical means is to provide for convenient manual addition of lime to the raw sludge pit before the raw sludge is pumped to the digester.

6.3 TANK ELEMENT DESIGN.

6.3.1 TANK DIMENSIONS. No particular shape possesses advantages over all others but circular tanks are more popular. Circular tanks will not be less than 20 feet or more than 100 feet in diameter. Side-wall water depths will be a minimum of 20 feet and a maximum of 30 feet. A 2.5 feet freeboard will be provided between the top of the wall and the working liquid level. With mechanisms for removing sludge, the bottoms of the tanks will be flat; otherwise, hopper bottoms with steep slopes of 3 feet horizontal to 1 foot vertical will be provided. All tanks designed for treatment plants rated at or above 1.0 million gallons per day will be multiple units.

6.3.2 COVERS. Two types of covers are used on sludge digestion tanks, fixed and floating. If a combination of covers is used, fixed covers will be used for the primary stage of a two-stage digestion process, and floating covers will be used for the secondary stage. In lieu of floating covers on separate digesters and in cold regions where freezing ice and snow are problems, fixed covers may be used provided a gas collection dome is installed in the top of the cover. At least two access manholes will be provided in the tank roofs. In addition, the tank covers will be provided with sampling wells, pressure and vacuum relief valves, and flame traps.

6.3.3 CONTROL CHAMBER. Entrance to the control chamber must be designed with the safety of the operator and the equipment foremost. The chamber will be well-lighted, ventilated, and equipped with a water service and drain. All sludge-heating equipment, gas piping, gas meters, controls and appurtenances will be locatedin a separate structure. All the above-mentioned structures will be of explosion-proof construction.

6.3.4 PIPING. The particular piping requirements for sludge digesters will include provisions for adding sludge, withdrawing sludge, multi-level supernatant removal points, heating, recirculating sludge or supernatant, flushing, sampling gas collection, and gas recirculating. All supernatant will be returned to process for further treatment. Supernatant draw-off facilities will be designed to provide variable-rate return to prevent plant upset.

6.3.5 HEATING. The method to be used for heating sludge digestion tanks is the circulation of the contents of the tank through a heat exchanger. Heated tanks will be insulated and the heating equipment sized to maintain a temperature of 95 degrees Fahrenheit during the coldest weather conditions.

6.3.6 CHEMICAL FEEDING. Practical means for feeding lime or other chemicals that are commonly used to correct digester operation problems must be included as part of the digester design.

6.3.7 GAS COLLECTION. Sludge gas will be collected from the digesters either for utilization or for burning it to waste. Two-stage units will provide interconnecting lines, permitting transfer and storage from one unit to the other. Gas withdrawal will be from a common point.

6.3.8 GAS UTILIZATION. Gas storage facilities will have to be provided if the gas is to be utilized and not wasted by burning. Sludge gas has a heat value of between 500 and 700 British thermal units per cubic foot. An average gas yield is 15 cubic feet per pound of volatile solid destroyed.

7. SLUDGE STORAGE.

7.1 SLUDGE TANKS. Sludge storage tanks may have depths no less than 15 feet and bottom slopes of 1 in 4. The tanks may be open or closed. Ventilation must be provided with closed tanks. Decanting lines as well as sludge withdrawal lines must be provided for all tanks.

7.2 SLUDGE RETENTION PONDS. Sludge retention facilities will be provided at either the treatment plant or land application site. The design detention period will be large enough to compensate for periods when sludge spreading is not feasible but will not be less than 30 days. Storage will permit operation flexibility, additional destruction of pathogens and further sludge stabilization.

7.3 SLUDGE STORAGE PONDS. Sludge storage ponds are applicable for storage of well-digested sludge when land area is available. Storage is usually long term (2 to 3 years), with moisture content being reduced to 50-60 percent. Lagoon storage can be used as a continuous operation or can be confined to peak load situations, and serves as a simple and economical sludge storage technique. Land requirements and possible groundwater pollution are the major disadvantages.

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