PDHonline Course C455 (2 PDH)

An Introduction to Primary Wastewater Treatment

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AN INTRODUCTION TO PRIMARY WASTEWATER TREATMENT

1. GENERAL CONSIDERATIONS. Wastewater treatment is usually characterized as consisting of four sequential processes: preliminary, primary, secondary and tertiary (sometimes called "advanced") treatment. This course is a discussion of primary treatment.

The purpose of primary treatment is to remove solids which are not removed during preliminary treatment. Processes which can be used to provide primary treatment include the following: 1) primary sedimentation, also called clarification; 2) microscreens; and 3) Imhoff tanks. In most facilities, primary treatment is used as a preliminary step ahead of biological treatment.

2. PRIMARY SEDIMENTATION. Sedimentation tanks are designed to operate continuously. They are usually rectangular or circular and have hoppers for sludge collection. Most sedimentation tanks are constructed with gently sloped bottoms and have sludge hoppers with relatively steep sides. Non-mechanized settling tanks are used only in very small installations; the sludge moves to hoppers by gravity, where it is removed.

2.1 FUNCTION. Primary sedimentation tanks may provide the principal degree of wastewater treatment, or may be used as a preliminary step in further treatment of the wastewater. When used as the only means of treatment, these tanks provide for removal of settleable solids and much of the floating material. When used as a preliminary step to biological treatment, their function is to reduce the load on the biological treatment units. Efficiently designed and operated primary sedimentation tanks should remove 50 to 65 percent of the suspended solids and 25 to 40 percent of the biochemical oxygen demand.

2.2 DESIGN PARAMETERS. The tanks will be designed for the average daily flow or daily flow equivalent to the peak hourly flow that requires the largest surface area. Table 1 shall be used to select the correct surface loading rate. All tank piping, channels, inlets, outlets and weirs will be designed to accommodate peak flows. Use 3.0 times the average hourly flow if specific peak flows are not documented.

Table 1
Surface loading rates for primary settling tanks

Plant Design Flow (mgd)	Surface Loading Rate* (gpd/sq ft)	
	Average Flow	Peak Flow
0-0.01	300	500
0.01-0.10	500	800
0.10-1.00	600	1000
1.00-10.0	800	1200
Above 10.0	1000	1200

* These rates must be based on the effective areas (figs 1 and 2)

Each tank will be sized, as a maximum, for 67 percent of the plant design flow (facility designs will normally include two tanks). At treatment plants with less than 0.1 million gallons per day treatment capacity, one unit is acceptable when an equalization tank or holding basin is constructed with adequate volume to dampen out peak inflow rates. Sedimentation tanks designed for chemical addition applications will utilize the overflow rates stipulated in table 4 regardless of the design plant size.

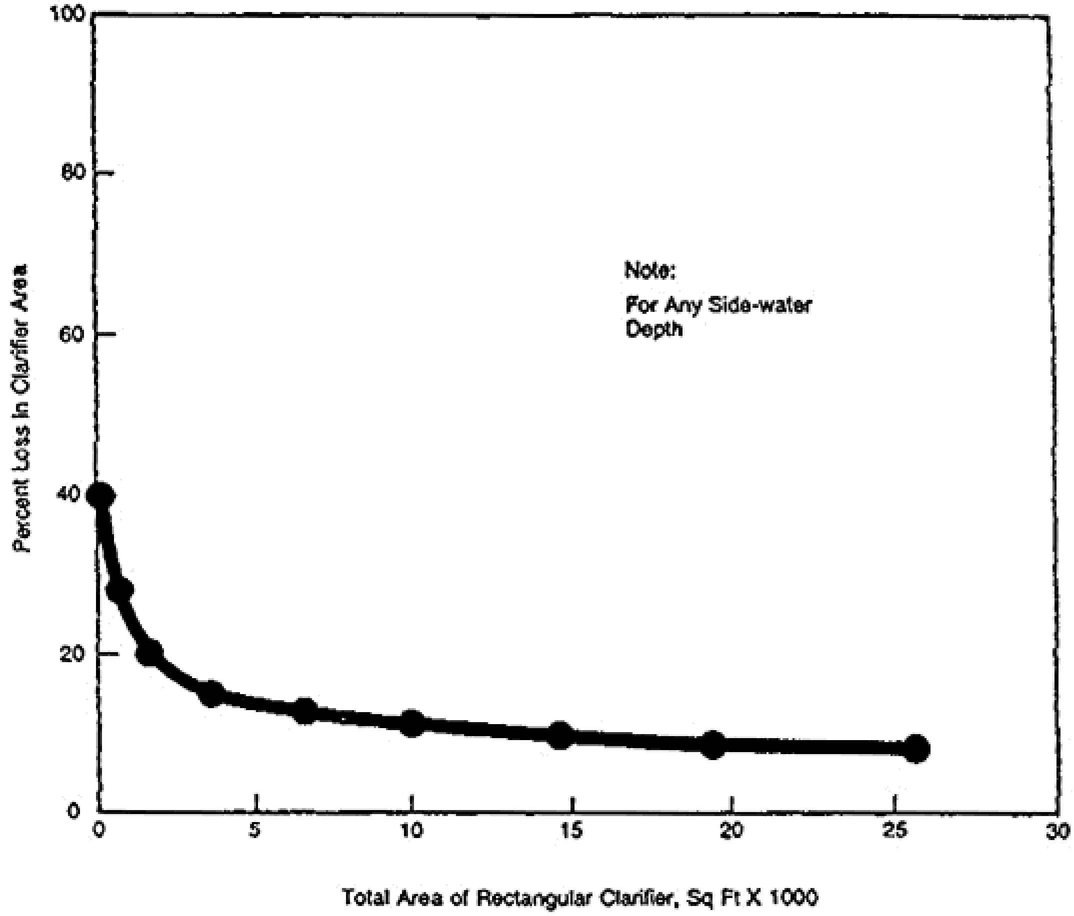

Figure 1

Effective Surface area adjustments for inlet-outlet losses in rectangular clarifiers, L:W = 4.

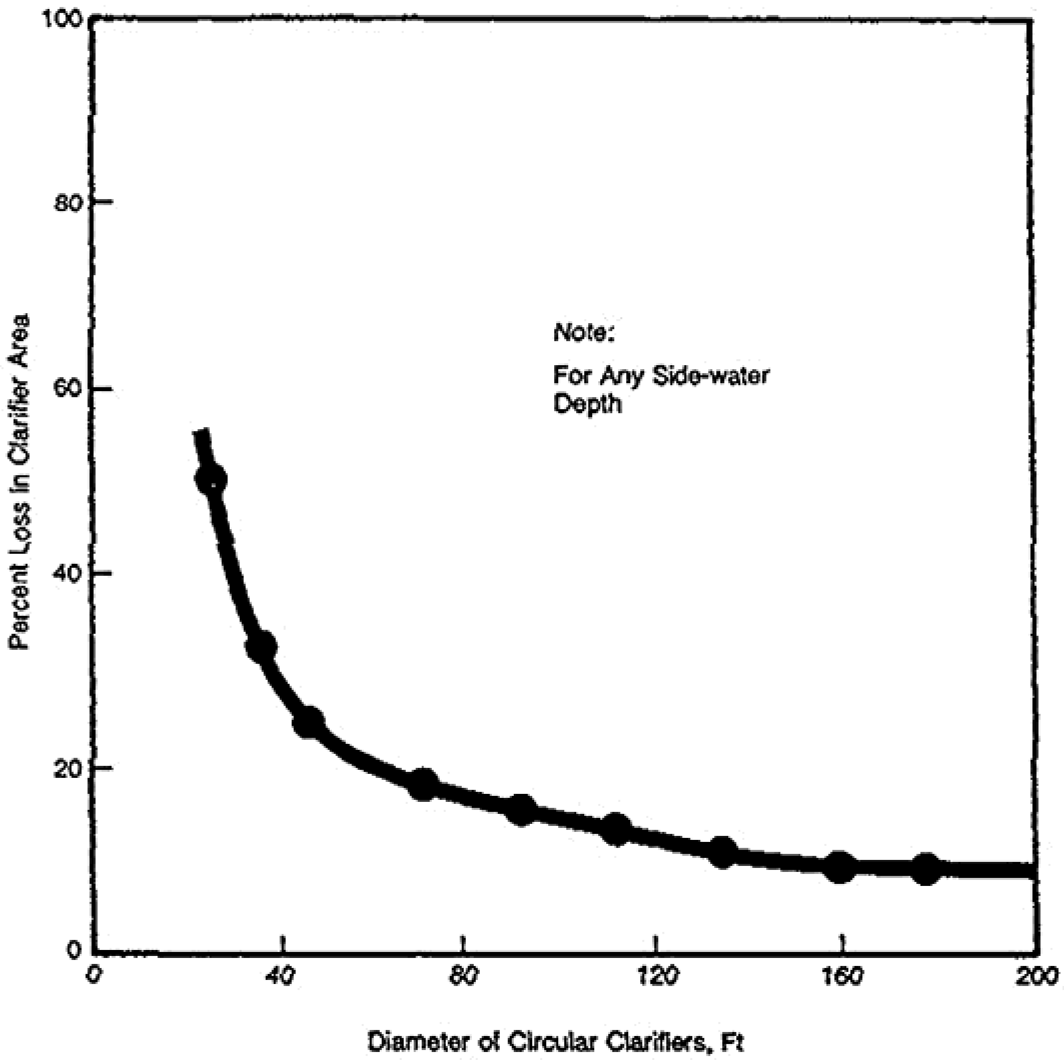

Figure 2

Effective surface area adjustments for inlet-outlet losses in circular clarifiers

2.2.1 DESIGN CONSIDERATIONS.

2.2.1.1 Detention period. Detention time is commonly specified as 2.5 hours for primary tanks serving all types of plants except when preceding an activated sludge system, where detention time is specified as 1.5 hours. Selection of optimum detention time will depend on the tank depth and the overflow rate. For those installations where the contributing population is largely non-resident, the detention period to be used in design of primary settling tanks is 2 hours, based on the average hourly rate for the 8-hour period when the maximum number of personnel will be contributing to sewage flow.

2.2.1.2 Weir rate. The overflow loading on weirs will not exceed 5,000 gallons per day per lineal foot for plants designed for less than 0.1 million gallons per day, or 10,000 gallons per day per lineal foot for plants designed between 0.1 and 1.0 million gallons per day. Weir loading for plants designed for flows of more than 1.0 million gallons per day may be higher, but must not exceed 12,000 gallons per day per lineal foot. When pumping is required, the pump capacity will be related to tank design to avoid excessive weir loadings.

3. SEDIMENTATION DESIGN FEATURES. Inlets to a settling tank will be designed to dissipate the inlet velocity, to distribute the flow uniformly, and to prevent short circuiting. The inlet and outlet channels will be designed for a minimum velocity of 2 feet per second at the average flow rate and will have corners filleted to prevent deposition and collection of solids. The guidelines shown in table 2 will be used for designing the depths of settling tanks.

Limit the use of circular clarifiers to applications greater than 25 feet in diameter. Where space permits, at least two units will be provided except as modified by guidance elsewhere in this discussion.

3.1 RECTANGULAR TANKS. The minimum length of flow from inlet to outlet of a rectangular tank will be 10 feet in order to prevent short circuiting of flow in the tank. In existing installations, tank length-to-width ratio varies between 3:1 and 5:1. Tanks will be designed with a minimum depth of 7 feet except final tanks in activated sludge plants, which will be designed with a 9-foot minimum depth. Figure 3 illustrates a typical rectangular sedimentation tank.

Table 2
Settling tank depths

Clarifier length or diameter, ft	Minimum liquid depth, ft	Sludge blanket depth, ft	Minimum total depth, ft
Rectangular up to 50 ft length	6	2	8
50 – 100	6-7	2	8-9
100-150	7-8	3	10-11
150-200	8-9	4	12-13
Circular up to 50 ft diameter	7	2	9
50-100	7-8	2	9
100-150	8-9	3	11-12
150-200	9-10	4	13-14

3.1.1 INLETS AND OUTLETS. Inlets to rectangular tanks will be designed so as to prevent channeling of wastewater in the tank. Submerged ports, uniformly spaced in the inlet channel, are an effective means of securing distribution without deposition or channeling. Outlet overflow weirs used in rectangular tanks will be of the adjustable type, and serrated weirs are preferred over straight ones. Overflow weirs will be used in most cases.

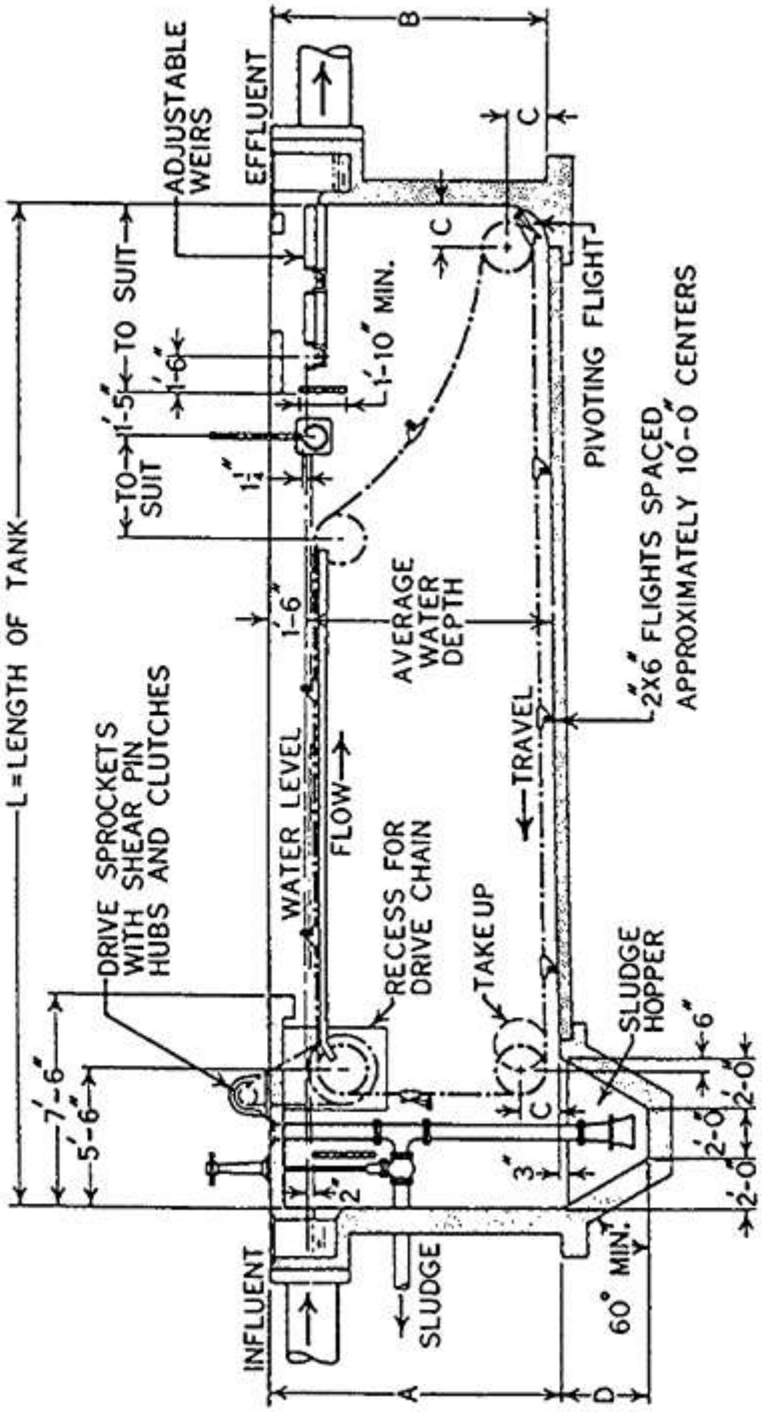

Figure 3

Typical rectangular primary sedimentation tank

3.1.2 COLLECTION AND REMOVAL OF SCUM AND SLUDGE. Means for the collection and removal of scum and sludge are required for all settling tanks. The removal of scum from the tank will take place immediately ahead of the outlet weirs, and the equipment may be automatic or manual in operation. Provisions will be made so that the scum may be discharged to a separate well or sump so that it can be either sent to the digester or disposed of separately. Rectangular tanks will be provided with scum troughs with the crest about 1 inch above maximum water surface elevation. For small installations (less than 1.0 million gallons per day), hand-tilt troughs consisting of a horizontal, slotted pipe that can be rotated by a lever or screw will be used. Proven mechanical scum removal devices such as chain-and-flight types may be used for larger installations. To minimize the accumulation of sludge film on the sides of the sludge hoppers, a side slope of at least 1½ vertical to 1 horizontal will be used. Separate sludge wells, into which sludge is deposited from the sludge hoppers and from which the sludge is pumped, are preferable to direct pump connections with the hoppers.

3.1.3 CIRCULAR TANKS. Circular tank diameters range from 25 to 150 feet. Side-water depths are 7 feet as a minimum, and tank floors are deeper at the center. Flocculator-clarifiers, gaining wide acceptance in recent years, require much greater depths to accommodate sludge collection mechanisms. Adjustable overflow weirs (V-notch type) will extend around the entire periphery of the tank. Scum baffles, extending down to 6 inches below water surface, will be provided ahead of the overflow weir; and the distance between scum collection troughs will not exceed 75 feet along the periphery of the clarifier. A circular sludge-removal mechanism with peripheral speeds of 5 to 8 feet per minute will be provided for sludge collection at the center of the tank. Figure 4 illustrates a typical circular clarifier.

3.1.4 TYPICAL DESIGN. Below illustrates a typical clarifier design.

3.1.4.1 Design requirements and criteria. Design a sedimentation unit to provide for a sewage flow rate of 4 mgd, with suspended solids concentration of 300 mg/L. The following conditions apply:

- Surface loading rate = 600 gpd/sq ft
- Suspended solids removal = 60%
- Sludge solids content = 4%
- Sludge specific density = 1.02

3.1.4.2 Calculations and results.

3.1.4.2.1 Calculate total tank surface area:

Surface Area = [Flow Rate]/[Surface Loading Rate] = 4,000,000 gpd/600 gpd/sq ft =
= 6,666,7; use 6,670 sq ft

3.1.4.2.2 Using a depth of 8 ft, calculate total volume:

V = 8 x 6670 = 53,360 cu ft

3.1.4.2.3 This volume can be divided among three rectangular tanks (in parallel), 20 ft wide and 120 ft long, with a satisfactory length-to-width ratio of 6:1. Two circular tanks (in parallel), 35 ft in diameter, would also be suitable. This will provide flexibility of operation during routine or emergency maintenance.

3.1.4.2.4 Calculate weir length requirement, assuming 3 rectangular tanks and allowable weir loading rate of 15,000 gpd/linear ft.

Design flow/tank = Total flow/3 = 4,000,000 gpd/3 = 1,333,333 gpd
Weir length/tank – 1,333,333 gpd/15,000 gpd/lin ft = 89 lin ft

3.1.4.2.5 Complete weight of solids removed, assuming 60% removal:

Weight removed = 4 mgd x 300 mg/L x .60 = 6,000 lb/day; therefore 1,500 lb are removed per 1 mgd flow

3.1.4.2.6 Calculate sludge volume, assuming a specific gravity of 1.20 and a moisture content of 96% (4% solids):

Sludge volume = 6,000 lb/day/[1.20(62.4 lb/cu ft)(0.04)] = 2,360 cu ft/day (@44mgd) =
= 17,700 gpd

3.1.4.2.7 Sludge handling in this example consists of removing sludge manually from settling tank sludge hopper, using a telescoping drawoff pipe which discharges the sludge into a sump from which it is removed by a sludge pump pr pumps. Assume that the sludge will be wasted every 8 hours and pumps for ½-hour to the digester.

Sludge sump capacity = daily sludge volume/number of wasting periods per day =
= 2,360 cu ft/3 = 787 cu ft (5,900 gal)

Increase capacity 10% to compensate for scum removal volumes:

Sludge pumping capacity = [Sludge and scum volume/wasting period]/[30 minutes pumping/wasting period] = 6,500/30 min = 217; use 220 gpm

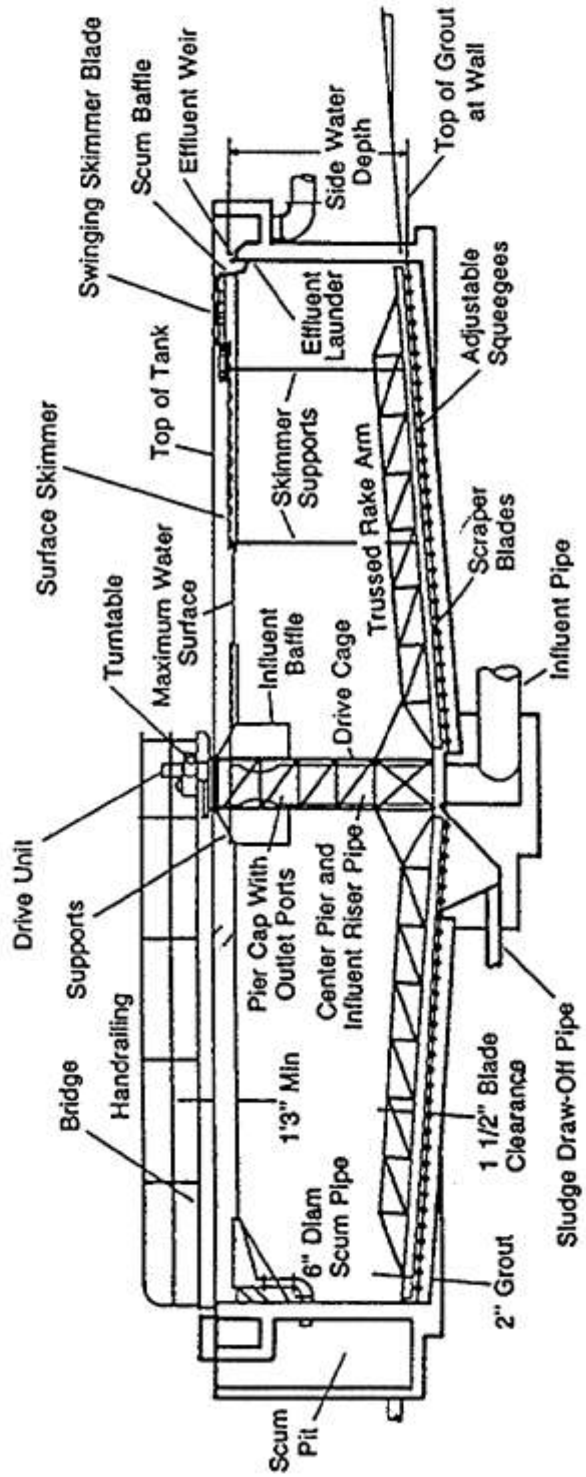

Figure 4

Typical circular primary sedimentation tank

4. CHEMICAL PRECIPITATION. Chemical treatment of wastewater may be advantageous when the following conditions exist:

- Wastewater flow and strength are intermittent and vary greatly;
- Space available for additional facilities is limited;
- Industrial waste that would interfere with biological treatment is present;
- The plant is overloaded;
- Plant odor is a problem;
- Phosphorus removal is desired; and
- Biological treatment processes are avoided.

Experience has shown that adding alum, iron or polyelectrolyte at either the primary or secondary clarifier is effective in increasing pollutant removal efficiencies. Lime addition is also effective if the effluent pH is adjusted (by recarbonation or acid addition) to acceptable limits for the subsequent treatment process or for final disposal. Jar tests will be made to determine optimum coagulants and dosages. Pilot studies should be made before selecting a coagulant.

4.1 CHEMICAL USED. The EPA *Process Design Manual for Suspended Solids Removal* provides criteria for the application of the chemistry and the use of the chemical precipitants discussed.

4.1.1 ALUMINUM SALTS. Alum (hydrated aluminum sulfate) is the most widely used aluminum salt. It is effective in many wastewater applications but the precipitate sludge is difficult to dewater. The primary use of aluminum salts is for the removal of suspended solids and phosphorus. When alum is used, clarifier overflow rates will not exceed 600 gallons per day per square foot.

4.1.2 IRON SALTS. Experience has shown that ferric salts are better coagulants than ferrous salts. Both ferrous and ferric salts are effective in the removal of suspended solids and phosphorous, but iron hydroxide carryover in the effluent can affect the effluent quality.

4.1.3 LIME. Lime addition will improve grit separation, suspended solids removal, phosphorus removal, and oil and grease removal, as well as reduce odors from dried sludge. Dosage of lime equal to the suspended solids in wastewater is a common practice.

4.1.4 POLYELECTROLYTES. These are used frequently, by themselves and in conjunction with other coagulant aids, to improve the solids-removal performance of sedimentation units. Their use should be based on jar test results and be reconfirmed by results in situ. They are more expensive on a unit-weight basis than the other chemicals in general use, but the required dosage is much lower. Polyelectrolytes—high molecular weight, water-soluble polymers classified as cationic, anionic, and nonionic—are highly ionized proprietary compounds. The cationic polymers are positively charged and will neutralize the negative surface charges on suspended particles, thus permitting agglomeration. Anionic (negatively charged) and nonionic (no charge) polyelectrolytes function as flocculants and must be used with a cationic material. The use of polyelectrolytes has been justified on the basis of improved water quality rather than cost savings. They can also permit higher flow rates through existing equipment.

4.2 EQUIPMENT FOR CHEMICAL PRECIPITATION. The following brief discussion on basic equipment required for chemical precipitation is useful for the design of such systems.

4.2.1 MIXING TANKS. The method for mixing wastewater and the chemical will be a flash mixing device in a mixing tank designed for 2 minutes detention time. The propeller will be specified so as to provide for the anticipated maximum flow in the mixing tank.

4.2.2 FLOCCULATION. Flocculation tanks will be designed for a detention time of 30 minutes.

4.2.3 SETTLING TANKS. The settling tanks involved in chemical treatment of wastewater will be designed for a minimum 2 hours detention time or the applicable maximum overflow rate stipulated in table 3.

4.3 CHEMICAL PRECIPITATION EXAMPLE PROBLEM.

4.3.1 DESIGN REQUIREMENTS AND CRITERIA. Calculate the sludge production, using chemical addition in primary sedimentation. Assume that addition of 60 lbs of ferrous sulfate and 700 lbs/mil gal of lime yields 70 percent suspended solids removal under the following conditions:

- Flow rate = 4 mgd
- Suspended solids concentration = 300 mg/l

4.3.2 CALCULATIONS AND RESULTS. All interim calculations are computed on the basis of a flow volume of 1 mil gal.

4.3.2.1 Determine the weight of suspended solids removed:

- Solids weight = (0.70)(300 mg/L)(8.34 [lb/mil gal]/[mg/L]) = 1,750 lb/mil gal

4.3.2.2 Determine weight of ferric hydroxide formed from ferrous sulfate:

- Mol Wt $Fe(OH)_3$ = 106.9
- Mol Wt $FeSO_4.7H_2O$ = 278.0
- $Fe(OH)_3$ = 60 lb $FeSO_4.7H_2O$ x (106.9/278.0) = 23 lb/mil gal

4.3.2.3 Determine weight of $CaCO_2$ formed in reacting with SO_4 hardness:

- 2 x Mol Wt CaO = 112
- Mol Wt $FeSO_4.7H_2O$ = 278
- Mol Wt $CaCO_2$ = 100
- Mol Wt CaO = 56
- $CaCO_2$ weight = 60 lb $FeSO_4.7H_2O$ x (112/278) x (100/56) = 43 lb/mil gal

$CaCO_3$ formed in reacting with CO and $Ca(HCO_3)_2$:

- Mol Wt CaCO = 56
- Mol WT $CaCO_2$ = 100
- 3 x Mol Wt $CaCO_3$ = 300
- 2 x Mol Wt CaO = 112
- $CaCO_3$ = [700 lb CaO – (43 lb $CaCO_3$ x (56/100))] x [300/112] = 1,810 lb/mil gal

Solubility of $CaCO_3$ (25 mg/L):

- $CaCO_3$ dissolved = 25 mg/L x 8.34 (lb/mil gal)/(mg/L) = 208 lb/mil gal

Total $CaCO_3$ weight = 43 + 1,810 – 208 = 1,645 lb/mil gal

Sum total solids weight = 1,750 SS + 23 $(Fe(OH)_3$ + 1,645 $CaCO_3$ = 3,418 lb/mil gal

At a flow rate of 4 MGD, the total solids weight = 3418 lb/mil gal x 4 mgd =
= 13,672 lb/day

Calculate sludge volume, assuming an overall specific gravity of 1.06 and a moisture content of 93% (7% solids):

Sludge volume = 3,418 lb/mil gal/(1.06)(62.4 lb/cu ft)(0.07) = 738 cu ft/mil gal =
= 2,952 cu ft/day.

5. IMHOFF TANKS. Imhoff tanks provide removal of settleable solids and the anaerobic digestion of these solids in the same unit. They are two-level structures which allow the solids to settle out in the upper level. The settled solids then fall through slots into the lower level where they undergo digestion. The gas produced during digestion escapes through the vent areas along the sides of the upper level. The upper level will be designed for a surface overflow rate of 600 gallons per day per square foot and a retention period of 3 hours at the average daily flow rate. The bottom of the lower digestion zone has sides which are sloped 1.4 vertical to 1.0 horizontal. The slot, which allows the solids to flow from the upper level to the lower level, is a 6-inch opening. An Imhoff tank can be designed so that a single digestion compartment can receive settled solids from multiple settling compartments. The digestion compartment should be designed to provide storage for 6 months accumulation of sludge.

6. SLUDGE CHARACTERISTICS. Table 4 represents typical characteristics of domestic sewage sludge.

Clarifier overflow design rates (gpd/sq ft)

Characteristic Waste	Clarifier Hydraulic Overflow Rate [1 2 3]	
	Primary Unit	Secondary Unit [4]
Raw Sewage	800	
Biologically Treated Waste		
Trickling Filter		600
Activated Sludge		700
Extended Aeration		600
Chemically Treated Waste[5]		
Alum Addition		500
Lime Addition		1,000
Iron Salts		800
Sludge Collection[6]		

[1]Seasonal temperatures exert a significant influence on basin performance. Allowance shall be made to the design factors shown in the table to compensate for the temperature. Ten State standards recommend an overflow rate of 600 gpd/sq ft or less for plants having a design flow of less than 1 mgd, but allow higher rates for larger plants.

[2]See design guidelines in paragraph 11-4 for guidance on use of circular versus rectangular tanks.

[3]Scum skimming to be provided on all settling tanks except in tertiary treatment. For secondary tanks in plants with primary settling, return skimmings to plant influent or wet well ahead of primary tanks. Use continuous gravity return if possible. If pumping is necessary, provide suction well at settling tank to receive discharge from skimming mechanism. Include provision for dilution of scum in well. For other applications, discharge scum to decanting-type containers in which it can be hauled to disposal.

[4]The most critical link in the operation of small plants (less than 1 mgd) is the secondary tank(s). The reason for this is inadequate solids separation at peak dry weather flows. Overflow rates are normally based on average design flows and carry-over of suspended material occurs at higher flows. Effluent criteria now limit suspended solids concentrations in the treated wastewaters discharges; therefore, in small plants overflow rates used in design should take into account the peak dry-weather flow. Additionally, special attention should be given the design of the solids removal facilities if problems of rising sludge are to be avoided. A vacuum-operated underflow removal system or screw conveyors should be used to return the sludge on activated sludge processes.

[5]EPA Technology Transfer Series Manuals recommend a limitation of 500 gpd/sp ft.

[6]Circular tanks will be provided with plow-type sludge-removal mechanisms with peripheral speeds of 5 to 8 fpm with sludge collection at the center of the tank. Suction-type sludge withdrawal mechanisms may be used for secondary biological sludge if primary settling is provided ahead of the secondary treatment with sludge-collection mechanisms consisting of endless conveyor chains with cross pieces of tank. Linear conveyor speeds of 2-3 fpm are common, with speeds of 1 fpm for activated sludge. Separate slugde wells, into which sludge is deposited from sludge hoppers and from which the sludge is pumped, are preferred to direct pump connections with the hoppers.

Table 3

Origin of Sludge	Solids Content of Wet Sludge[1] percent	Dry Solids[2] lb/day/capita
Primary Settling Tank	6	0.12
Trickling Filter Secondary	4	0.04
Mixed Primary and Trickling Filter Secondary	5	0.16
High Rate Activated Sludge Secondary	2.5-5	0.06
Mixed Primary and High Rate Activated Sludge Secondary	5	0.18
Conventional Activated Sludge Secondary	0.5-1	0.07
Mixed Primary and Conventional Activated Sludge Secondary	2-3	0.19
Extended Aeration Secondary	2	0.02

[1]Values based on removal efficiencies of well-operated treatment processes.

[2]Average 24-hr values. To estimate maximum 24-hr values, multiply given values by ratio of maximum 24-hr flow to average 24-hr flow.

Table 4

Typical characteristics of domestic sewage sludge

7. REFERENCES

7.1 GOVERNMENT PUBLICATIONS

- PL 92-500 Federal Water Pollution Control Act

7.1.1 DEPARTMENTS OF THE ARMY AND AIR FORCE

- AFM 88-15 Air Force Design Manual-Criteria and Standards for Air Force Construction
- AFP 19-5 Environmental Quality Control Handbook: Industrial Wastes
- AFR 19-1 Pollution Abatement and Environmental Quality
- AR 200-1 Environmental Protection and Enhancement
- TM 5-813-5/AFM 88-10, Vol.5 Water Supply Water Distribution Systems
- TM 5-814-1/AFM 88-11, Vol.1 Sanitary and Industrial Waste Sewers
- TM 5-814-2/AFM 88-11, Vol.2 Sanitary and Industrial Wastewater Collection—Pumping Stations and Force Mains
- TM 5-814-6 Industrial Wastes
- TM 5-814-8 Evaluation Criteria Guide for Water Pollution: Prevention, Control, and Abatement
- TM 5-852-1/AFR 88-19, Vol.1 Arctic and Subarctic Construction: General Provisions

  TM 5-852-4/AFM 88-19, Chap. 4 Arctic and Subarctic Construction: Building Foundations
- TM 5-852-5/AFR 88-19, Vol.5 Arctic and Subarctic Construction: Utilities

7.1.2 ENVIRONMENTAL PROTECTION AGENCY (EPA)

- R-2-73-199 Application of Plastic Media Trickling Filters for Biological Nitrification Systems
- 625/1-74-006 Process Design Manual for Sludge Treatment and Disposal
- 625/1-75-003a Process Design Manual for Suspended Solids Removal
- 625/1-76-001a Process Design Manual For Phosphorus Removal

- 625/1-80-012 Process Design Manual for Onsite Wastewater Treatment and Disposal Systems
- 625/1-81-013 Process Design Manual for Land Treatment of Municipal Wastewater
- 625/1-82-014 Process Design Manual for Dewatering Municipal Wastewater Sludges)
- 625/1-83-015 Process Design Manual for Municipal Wastewater Stabilization Ponds
- Process Design Manual for Carbon Absorption
- Process Design Manual for Nitrogen Control
- Process Design Manual for Upgrading Exist-Wastewater Treatment Plants
- Handbook for Monitoring Industrial Wastewater

7.2 NON-GOVERNMENT PUBLICATIONS

7.2.1 AMERICAN WATERWORKS ASSOCIATION (AWWA)
6666 West Quincey Avenue, Denver CO 80235

- Standard Methods for the Examination of Water and Wastewater
- Franson, M.A. (ed), APHA, WPCF (1984) Safety Practices for Water Utilities

7.2.2 WATER POLLUTION CONTROL FEDERATION (WPCF)
2626 Pennsylvania Avenue NW, Washington DC 20037

- Manual of Practice No.1 Safety and Health in Wastewater Works
- Manual of Practice No.8 Wastewater Treatment Plant Design

7.2.3 Hicks, T.G., and Edwards, T.W.**,** McGraw-Hill Publishing Company, New York NY**,** Pump Application Engineering