Introduction to Secondary Wastewater Treatment

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An Introduction to Secondary Wastewater Treatment

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AN INTRODUCTION TO

SECONDARY WASTEWATER TREATMENT

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AN INTRODUCTION TO
SECONDARY 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 discusses three principle approaches to secondary treatment: trickling filter plants, activated sludge plants, and waste treatment ponds.

2. TRICKLING FILTER PLANTS

2.1 GENERAL CONSIDERATIONS. Trickling filter plants have been justified by their low initial cost, low operating and maintenance costs, and relative simplicity of operation. Although the effluent from trickling filter plants of earlier design was of poorer quality than that from activated sludge plants, the performance of trickling filters designed more recently is comparable to that of activated sludge plants. Both processes offer certain advantages, with trickling filters providing good performance with minimal operator care and few, if any, energy requirements.

2.2 DESIGN BASIS AND CRITERIA. The designer will provide preliminary and primary treatment ahead of the filters, and circular or rectangular settling tanks with mechanical sludge removal equipment following the filters. Design criteria for settling tanks are discussed in paragraph 12-4 below. Chapter 4 of EPA*s process design manual, *Upgrading Existing Wastewater Treatment Plants*, provides design theory for trickling filters. Table 1 gives design data for the trickling filter process. The designer normally will use the average of the hydraulic or organic loading ranges presented in Table 1 for the design of each filter class unless special conditions warrant the use of values other than the average.

Item	Filter classification			
	Low-Rate	**Intermediate-Rate[1]**	**High-Rate**	**Super-Rate[3]**
Hydraulic loading[1] gpd/sq ft	25-90	90-230[4]	230-690	690-3440[4]
Organic loading[2] lbs BOD/day/1000 cu ft	5-20	15-30	30-60	50-100
BOD removal efficiency, percent	75-85	70-85	70-85	30-70
Temperature coefficient, Q	1.02-1.06	1.02-1.06	1.02-1.04	1.02-1.04
Depth, ft	5-7	5-7	3-6	20-40
Recirculation ratio, R/Q	None	1:1 to 2:1	1:1 to 4:1	1:1 to 4:1
Packing material	Rock, lag, random-placed plastic[6]	Rock, lag, random-placed plastic[6]	Rock, lag, plastic[5,6]	Plastic[5] or redwood
Dosing interval	Not more than 5 minutes	Not more than 5 minutes	Continuous	Continuous
Sloughing	Intermittent	Intermittent	Continuous	Continuous
Nitrification	Usually highly nitrified	Usually nitrified at lower loadings	Not fully nitrified	Not fully nitrified

1 – Hydraulic loading range rates based on plant average flow, expressed as gallons/day/sq ft
2 – Loading range (not including recirculation) to produce highest quality effluent after settling
3 – Also referred to as a roughing filter
4 – Includes recirculation flow
5 – Stacked plastic media may be used when installed according to manufacturer's recommendations at proper depth
6 – Random placed plastic media

Table 1

Design data and information for tricking filter processes

2.2.1 FILTER DEPTH. Stone media trickling filters will be designed with depths of 5 to 7 feet for low-rate and depths of 3 to 6 feet for high-rate applications. Synthetic media manufacturers recommend depths of 10 to 40 feet for columnar or stacked module media. Randomly placed polypropylene media filters are designed within the depth ranges of the low and intermediate-rate filters. The deeper trickling filters can improve nitrification potential and can be used as the second stage in two-stage biological system designs for nitrification.

2.2.2 Recirculation. This is a recommended method of increasing the biochemical oxygen demand removal efficiency of high-rate trickling filter processes. Figure 1 shows acceptable recirculation systems for single-stage and two-stage trickling filters treating domestic wastewater. Table 2 lists recommended recirculation rates for high-rate filters. Whether to use recirculation and the amount to be recycled when used are matters of economics which may involve either first cost or annual costs of various designs providing equal treatment. Unless other conditions control, recirculation should provide continuous dosing at a minimum surface application rate of 10 million gallons per acre per day. In flow diagrams B, C and D (Figure 1), fluctuations in the organic loading applied to the filter are dampened. Filter sloughings are recycled to the filter in flow diagram A but little, if any, dampening of variations in organic loading is provided. Flow diagram E may include a low-rate filter for the second stage unit. Intermediate settling tanks will always be provided between first and second stage filters. Flow diagrams G and H attempt to improve treatment by developing greater biological activity on the second stage filter but are not acceptable for military installations because there are no intermediate clarifiers. Flow diagrams E, F, G and H require inclusion of the recirculated flow in the forward flow used for design of any tanks through which it passes.

2.2.3 HYDRAULIC AND ORGANIC LOADINGS. Loading rate is the key design factor whether the surface application is continuous, intermittent, constant rate, or varying rate. The BOD removal efficiencies obtainable for specific wastewater organic and hydraulic loading from trickling filter installations can be compared when the loadings are within the ranges presented in Table 1 and the trickling filter performance formula described.

Single Stage

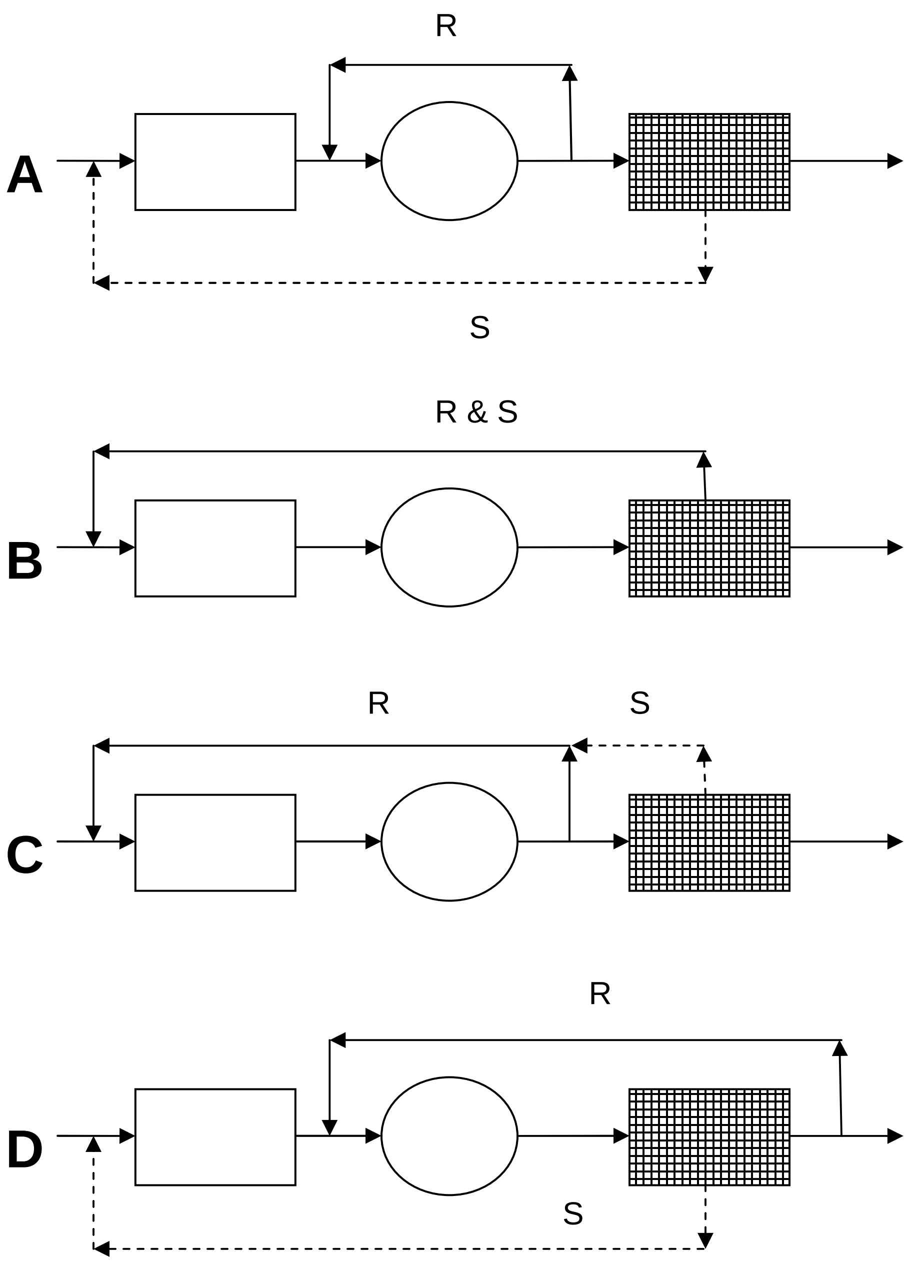


Figure 1

Common flow diagrams for trickling filter plants

Two Stage

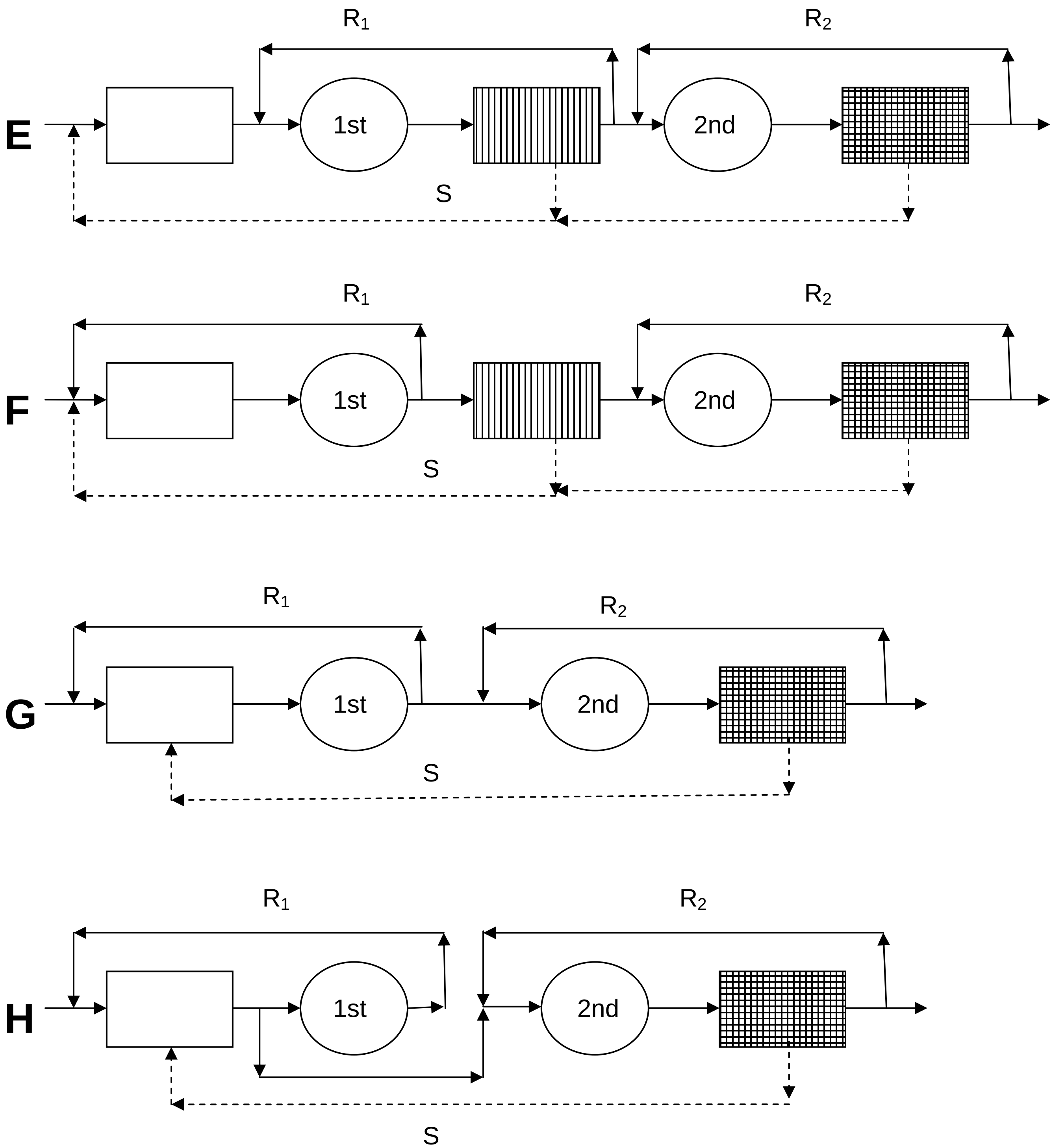


Figure 1 (continued)

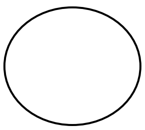
Common flow diagrams for trickling filter plants

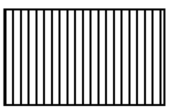
LEGEND

S Sludge Return

R Recirculated Flow


Primary Clarifier


Trickling Filter


Intermediate Clarifier

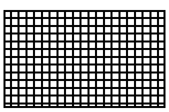

Final Clarifier

Figure 1 (continued)

Common flow diagrams for trickling filter plants

Raw Sewage BOD, mg/L	Recirculation[1] Single–Stage	Two–Stage[2]
Up to 150	1.0	0.5
150 to 300	2.0	1.0
300 to 450	3.0	1.5
450 to 600	4.0	2.0

[1] Ratio of recirculated flow to raw wastewater flow.
[2] Ratio for each stage; one half of the single–stage rate.

Table 2

Design recirculation rates for high-rate filters

2.2.4 VENTILATION. Ventilation provides aerobic conditions required for effective treatment. Design for ventilation will provide the following:

- Underdrains and collecting channels designed to flow half full at maximum design flow;
- Ventilating manholes with open grate covers installed at both ends of the central collecting channel;
- Branch collecting channels with ventilating manholes or vent stacks installed at the filter periphery for units over 50 feet in diameter;
- Open area of slots in the top of the underdrain blocks not less than 15 percent of the area of the filter;
- Peripheral duct (or channel) interconnecting vent stacks and collecting channels;

- One square foot of gross area of open grating in the ventilating manholes and vent stacks for each 250 square feet of filter surface; and

- When the trickling filter is constructed with top of media or distributor arms at or near grade, with under-drain system more than 3 feet below grade or when normal climatic conditions do not include adequate air movement, ventilation shafts will be provided.

2.2.5 TEMPERATURE. The performance of trickling filters will be affected by temperature changes in the wastewater and filter films. Filter efficiency changes attributed to temperature variations are expressed by Equation 1.

$$E_1 = E_{20} \times 1.035^{(T-20)} \qquad \text{(Eq 1)}$$

Where:

E_1 = BOD removal efficiency @ T^oC
E_{20} = BOD removal efficiency @ 20^oC
T = wastewater temperature, ^oC

Winter conditions—In areas that experience prolonged cold and/or icing, windbreaks or dome covers for trickling filters to prevent freezing problems will be considered.

2.2.6 PLANT EFFICIENCIES. Performance efficiencies, given as biochemical oxygen demand removal, or single-stage and two-stage filters are to be estimated using formulas in the following section.

2.2.6.1 NATIONAL RESEARCH COUNCIL (NRC) FORMULAS. The NRC formulas have resulted from extensive analysis of operational records from stone-media trickling filter plants serving installations. Based on its data analyses, NRC developed the following formulas for predicting the stone-media trickling filter performance at 20^oC.

First of Single Stage:

$$E_1 = 100/[1 + 0.0085(W/VF)^{0.5} \qquad \text{(Eq 2)}$$

Second Stage (includes intermediate clarifier):

$$E_2 = 100/[1 + (0.0085)/(1 – E_1 \text{ x } \{W/VF\}^{0.5})] \qquad \text{(Eq 3)}$$

Where:

E_1 = Percent BOD removal efficiency through the first or single-stage filter and clarifier

W = BOD loading (lb/day) to the first or second-stage filter, not including recycle

V = Volume of the particular filter stage (acre-feet)

F = Recirculation for a particular stage, where

$$F = (1 + R)/(1 + 0.1 R)^2$$

R = Recirculation ratio = Recirculation flow/Plant Influent Flow

E_2 = Percent BOD removal through the second-stage filter and clarifier

W = BOD loading (lbs/day) to the second-stage filter, not including recycle.

2.2.6.2 OTHER DESIGN FORMULAS. Other design formulas have been developed and used for design of trickling filters and for performance prediction. Such expressions include the Ten-States Standards Formula and those of Velz, Schulze, Germain, Galler and Gotaas, and Eckenfelder. Detailed descriptions and evaluations of these formulas are presented in the *Manual of Practice No. 8*, published by the Water Pollution Control Federation.

2.2.7 ROUGHING FILTERS. This type of super-rate filter is generally used for very strong wastewaters and may not be applicable to conventional domestic wastewater treatment plants.

2.3 HYDRAULIC COMPONENTS.

2.3.1 INFLUENT DISTRIBUTORS. Rotary reaction distributors consisting of two or more horizontal pipes supported by a central column are available for dosing filter beds ranging from 20 to more than 200 feet in diameter. Distributors will be sealed by pressurized oil, neoprene gaskets or air-gap “non-seal” methods. Hydraulic head requirements for distributors are gradient usually 12 to 24 inches above the centerline of the distributor arms at minimum flow. Distributor design must provide: 1) a means for correcting alignment; 2) adequate structural strength; 3) adequate pipe size to prevent velocities in excess of 4 feet per second at maximum flow; 4) bearings; 5) drains for dewatering the inflow column; and 6) pipe and openings at the end of each arm for ease of removing ice buildups during winter operation. A minimum clearance of 6 inches between media and distributor arms will be provided. Motor-driven rotary distributors will be used only if the minimal hydraulic head to drive the distributor is not available. Positive drive will be provided by a totally enclosed electric motor and gear arrangement.

2.3.2 DOSING SIPHONS. Wastewater may be applied to the filters by pumps, by gravity discharge from preceding treatment units when suitable flow characteristics have been developed, and by siphons. Frequently during the day the flow will be less than the minimum set by the distributor. If this is the case, a dosing tank and alternating siphons will be required for each filter unit. Each siphon will have a dosing tank with a volumetric capacity equal to the average flow rate for a 4-minute period so that dosing is nearly continuous.

2.3.3 HEAD LOSS COMPUTATIONS. The net available head on the horizontal centerline of the distributor arms will be calculated by deducting the following applicable losses from the available static head:

- Entrance loss from the primary settling tank.
- When using dosing siphons: the drop in tank level dosing as distributor pipes are filled; the friction losses in the siphon itself; and the velocity head imparted from the siphons.
- Friction losses in piping and fittings.
- Loss through distributor column rise and center port.
- Friction loss in distributor arms and velocity head of discharge through nozzles necessary to start reactor- type rotary distributors in motion.

The hydraulic head requirements of distributors are specified by the manufacturers. The major head loss is the elevation difference between the distributor arms and the lowest water surface in the main underdrain channel. Approximately 8 feet of head is lost in a 6-foot deep filter.

2.4 SECONDARY SEDIMENTATION TANKS.

The purpose of secondary sedimentation tanks is to allow the biological solids in the wastewater leaving the trickling filter to settle out. This produces an effluent for discharge, and the settled solids can be recirculated to the trickling filter to enhance its performance.

2.4.1 DESIGN PHILOSOPHY. The tanks will be designed for either the average daily flow rate or the daily flow equivalent to the peak 3-hour flow rate, whichever is greater. All of the appurtenant piping, channels, inlets, outlets and weirs will be designed to handle the peak flow rate. If there are no data for peak flow rates available, then a value of 3 times the average flow rate will be used. Two tanks, operating in parallel, will be used in all treatment plants with a design capacity greater than 0.1 million gallons per day. Each tank will be designed to treat 67 percent of the design flow. A single tank may be used in treatment plants with design capacity less than 0.1 million gallons per day but an equalization tank or holding basin must be provided to provide some settling capacity for those times when the secondary sedimentation requires maintenance.

2.4.2 DESIGN CRITERIA. The sedimentation tanks should be designed for either the average flow rate or peak flow rate, whichever requires the largest surface area. The following table presents the design criteria for various size treatment plants:

Table 3
Surface loading rates for secondary sedimentation tanks

Plant design flow, mgd	Surface loading rate, gpd/sf	
	Average flow	Peak flow
0.00-0.01	100	200
0.01-0.1	300	500
0.1-1.0	400	600
1.0-10.0	500	700
Above 10	600	800

Note that the surface area calculated from the above table must sometimes be increased to allow for inlet and outlet inefficiencies.

2.5 OTHER FILTER COMPONENTS. Table 4 gives a list of other components normally associated with trickling filters and for which design requirements are specified. Trickling filter design must include provisions for flooding the filter and the filter walls, and appurtenances must be able to structurally withstand the resulting hydrostatic pressure forces when the filter is flooded. In northern regions that are subject to extreme and/or prolonged freezing conditions, including high wind chill factors, design considerations must be given to providing filter dome covers or windbreaks. Figure 2 is a sectional view of a trickling filter.

Filter Component	Design Requirement
Underdrains	The underdrains will have a minimum slope of 1 percent. Use the larger size openings for high rate filters.
Drainage Channel	Either central or peripheral drainage channels will be used. The channels will be designed to provide 2 feet per second minimum velocity at the average daily application rate to the filter and so that no more than 50 percent of their cross-sectional area will be submerged under the design hydraulic loading.
Wind Break* (if utilized)	The windbreak will be constructed on the side of the prevailing winter wind. Its length will be three filter diameters for each filter diameter it is located away from the filter's near edge. Its height will be a minimum of 10 feet above the surface of the filter, plus an additional 0.1 times the filter diameter for each filter diameter it is located away from the filter's near edge.
Dome Cover (if utilized)	Consult approved manufacturers.

Table 4

Miscellaneous filter component design criteria.

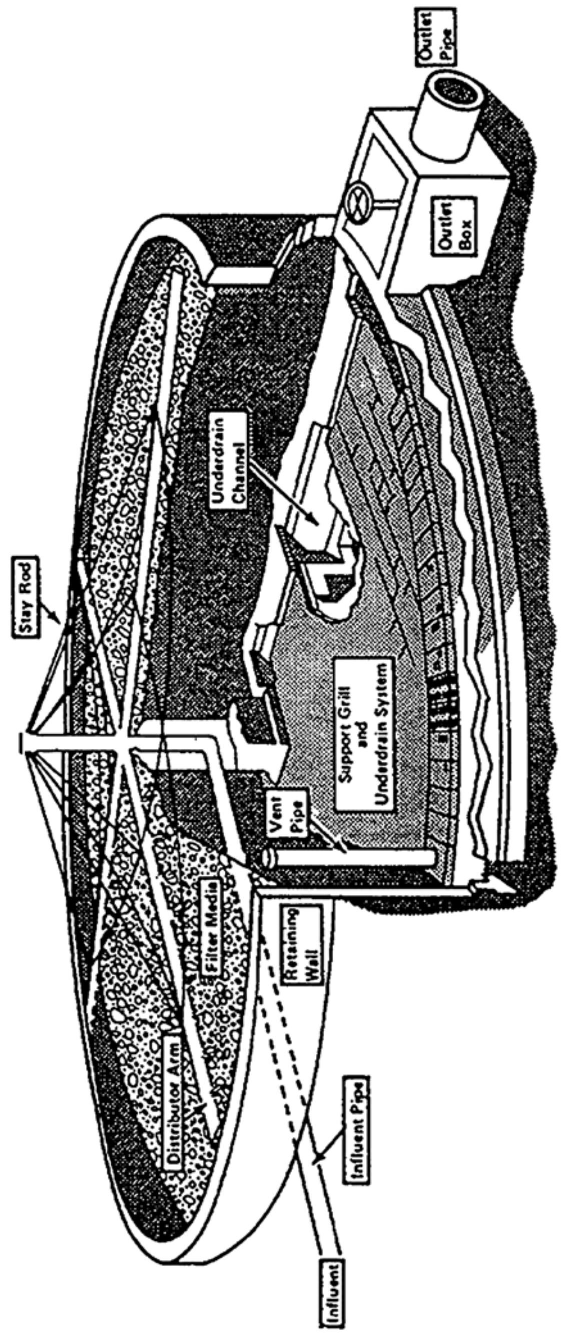


Figure 2

Trickling filter sectional view

3. ACTIVATED SLUDGE PLANTS

3.1 GENERAL CONSIDERATIONS. The activated sludge process has been employed extensively throughout the world in its conventional form and modified forms, all of which are capable of meeting secondary treatment effluent limits. This discussion presents the different modifications of the conventional activated sludge process, including general bases for design, methods of aeration, and design factors for aeration tanks, final sedimentation units and sludge handling systems. Figures 3 through 6 are schematic diagrams of the conventional and modified processes. All designed processes will include preliminary treatment consisting of a bar screen as a minimum and a comminutor, a grit chamber, and oil and grease removal units, as needed.

3.2 ACTIVATED SLUDGE PROCESSES.

3.2.1 CONVENTIONAL ACTIVATED SLUDGE. In a conventional (plug-flow) activated sludge plant (Figure 3), the primary-treated wastewater and acclimated micro-organisms (activated sludge or biomass) are aerated in a basin or tank. After a sufficient aeration period, the flocculent activated sludge solids are separated from the wastewater in a secondary clarifier. The clarified wastewater flows forward for further treatment or discharge. A portion of the clarifier underflow sludge is returned to the aeration basin for mixing with the primary-treated influent to the basin and the remaining sludge is wasted to the sludge handling portion of the treatment plant. The portion recirculated is determined on the basis of the ratio of mixed liquor volatile suspended solids (MLVSS) to influent wastewater biochemical oxygen demand which will produce the maximum removal of organic material from the wastewater. Recirculation varies from 25 to 50 percent of the raw wastewater flow, depending on treatment conditions and wastewater characteristics.

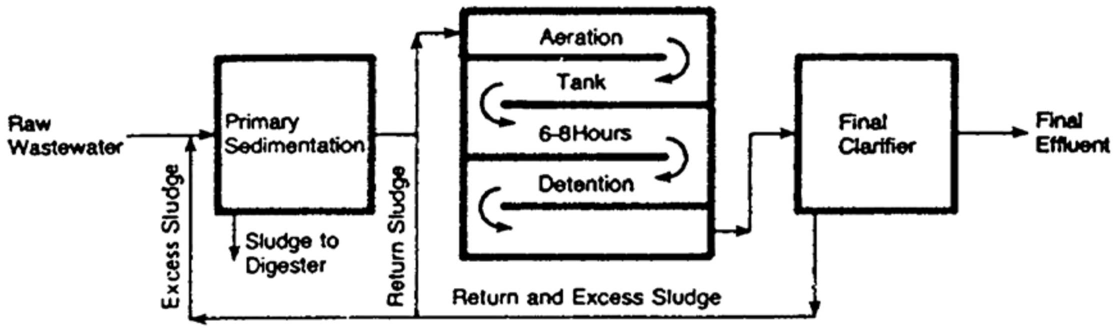


Figure 3

Conventional plug flow activated sludge flow diagram

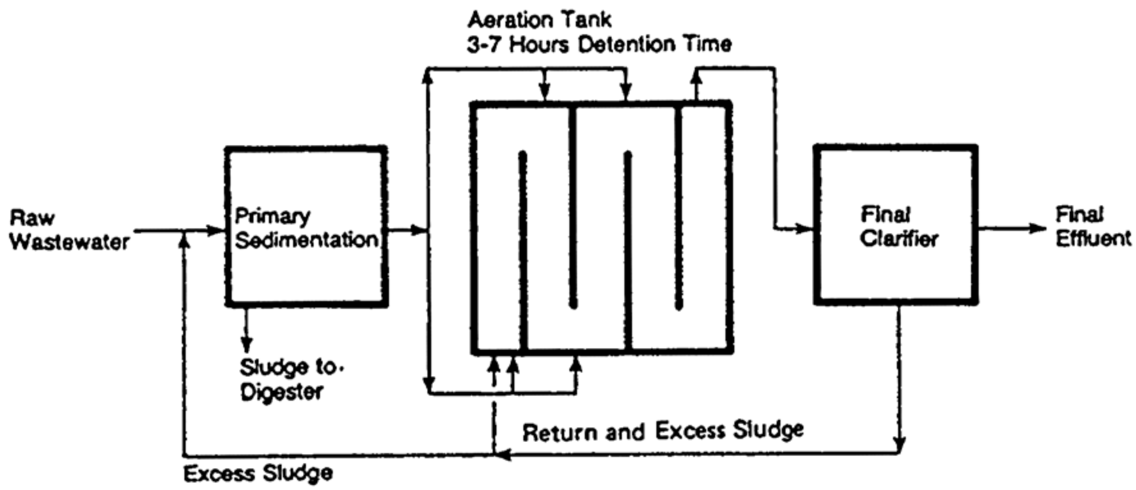


Figure 4

Step aeration flow diagram

3.2.2 STEP AERATION. In this process (Figure 4), the influent wastewater is introduced at various points along the length of the aeration tank. Sludge return varies between 25 and 50 percent. Aeration or the oxygen requirement during step aeration (3 to 7 hours) is about half that required for the conventional process. This is due to a more effective biomass utilization in the aeration basin, allowing organic loadings of 30 to 50 pounds biochemical oxygen demand per 1,000 cubic feet per day as compared to loadings of 30 to 40 pounds. biochemical oxygen demand per 1,000 cubic feet per day permitted for conventional systems.

3.2.3 CONTACT STABILIZATION. The contact stabilization activated sludge process (Figure 5) is characterized by a two-step aeration system. Aeration of short duration (½ to 2 hours) is provided in the contact tank where raw or primary-settled wastewater is mixed with the activated sludge in the contact tank. The effluent from the contact tank is then settled in a final settling tank. The settled activated sludge to be recycled from the final clarifier is drawn to a separate re-aeration in a stabilization basin for 3 to 8 hours of aeration time. It is then returned to the contact aeration basin for mixing with the incoming raw wastewater or primary settled effluent. In addition to a shorter wastewater aeration time, the contact stabilization process has the advantage of being able to handle greater shock and toxic loadings than conventional systems because of the buffering capacity of the biomass in the stabilization tank. During these times of abnormal loadings, most of the activated sludge is isolated from the main stream of the plant flow. Contact stabilization plants should generally not be used where daily variations in hydraulic or organic loadings routinely exceed a ratio of 3:1 on consecutive days or for plants with average flows less than 0.1 million gallons per day.

3.2.4 COMPLETELY-MIXED ACTIVATED SLUDGE. In the completely-mixed process (Figure 6), influent wastewater and the recycled sludge are introduced uniformly through the aeration tank. This allows for uniform oxygen demand throughout the aeration tank and adds operational stability when treating shock loads. Aeration time ranges between 3 and 6 hours. Recirculation ratios in a completely-mixed system will range from 50 to 150 percent.

3.2.5 EXTENDED AERATION. Extended aeration activated sludge plants are designed to provide a 24-hour aeration period for low organic loadings of less than 20 pounds biochemical oxygen demand per 1,000 cubic feet of aeration tank volume. This approach, which can be used for treatment plants of less than 0.1 million gallons per day capacity, reduces the amount of sludge being wasted for disposal.

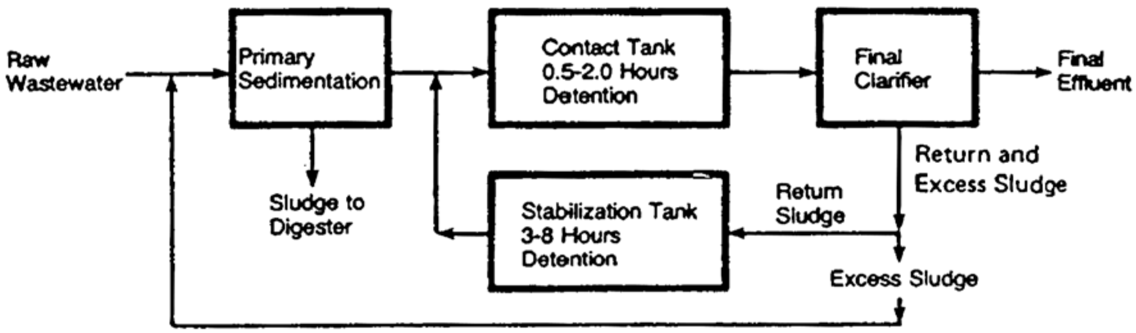


Figure 5

Contact stabilization flow diagram

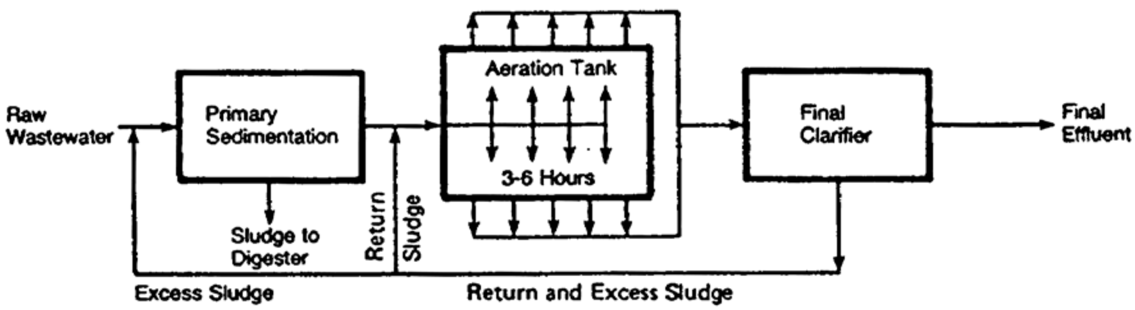


Figure 6

Completely mixed process flow diagram

3.2.6 OXIDATION DITCH. The closed-loop reactor, also known as an oxidation ditch (Figure 7), is a form of the extended aeration process. The wastewater is propelled around an oval racetrack-configured basin by mechanical aerator/mixing devices located at one or more points along the basin. These devices can be either brush aerators, surface aerators or jet aerators. The velocity in the basin is designed to be between 0.8 and 1.2 feet per second.

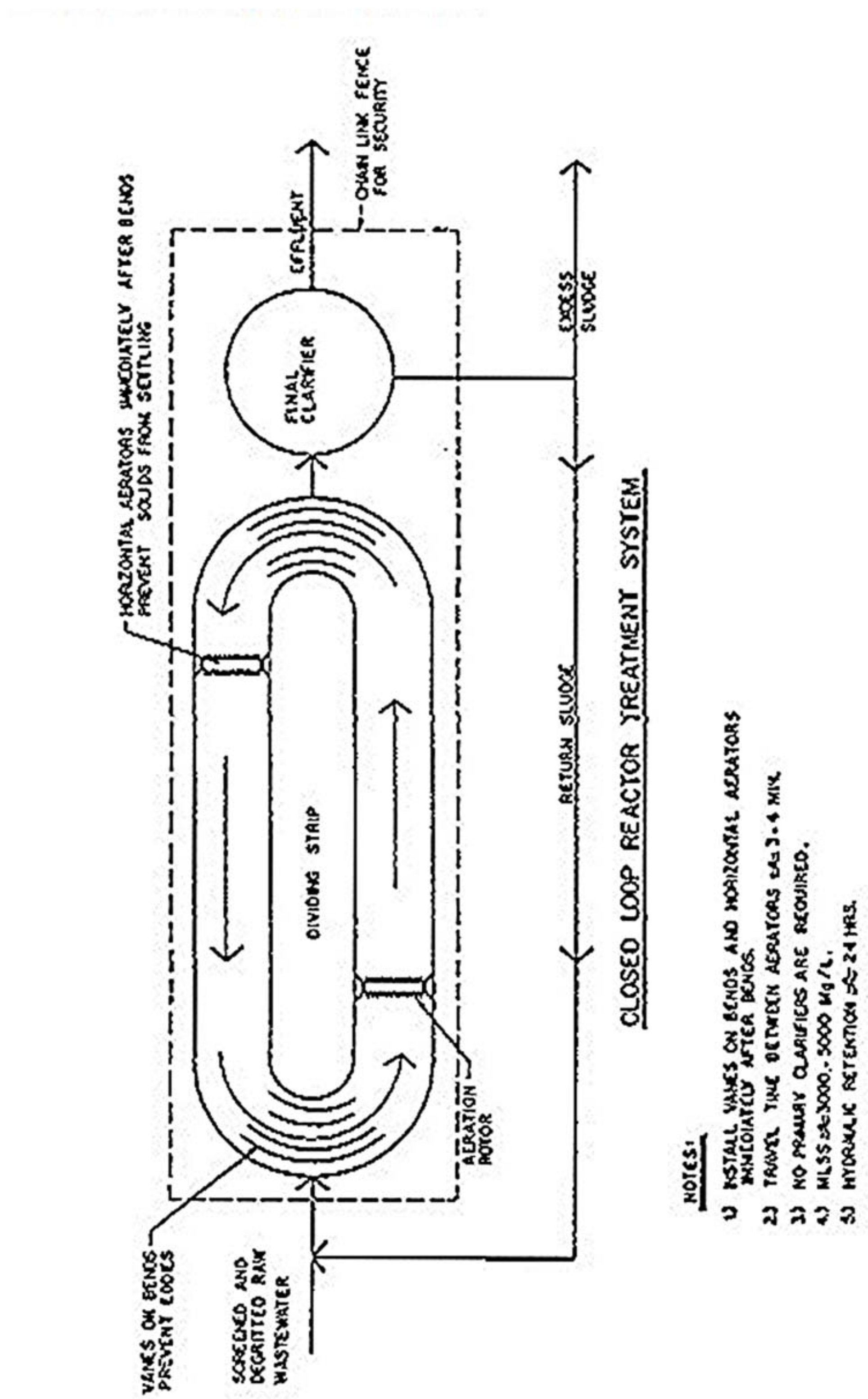


Figure 7

Closed-loop reactor treatment system

3.3 CLOSED-LOOP REACTOR DESIGN CRITERIA.

3.3.1 GENERAL. Table 5 presents the design criteria to be used for the design of a closed-loop reactor plant.

Table 5 Closed-loop reactor design criteria	
Parameter	Value
Primary clarifier	None required
Hydraulic retention time	18 – 24 hours
Sludge retention time	20 – 30 days
Secondary clarifier	
Overflow rate	450 gpd/sq ft
Solids loading rate	15 lb/sq ft/day

3.3.2 AERATION TANK DESIGN. All oxidation ditch plants use looped channels or ditches. A looped channel with a partition in the middle may be shaped like an oval or a concentric ring. The design engineer may adopt a specific channel configuration and flow scheme recommended by the equipment manufacturer or supplier.

3.3.2.1 CHANNEL DEPTH. The number of loops and the channel depth are dependent upon the size of the plant. A shallow channel, less than 14 feet deep, is used for smaller plants with unlimited land area available. A deep channel, greater than 20 feet, should be designed for larger plants or to conserve heat.

3.3.2.2 NUMBER OF CHANNELS. Multiple-channel or multiple-loop is the preferable design so that part of the plant can be shut down for repair and maintenance.

3.3.2.3 DRAINAGE. A drain should be provided for each channel. This provision allows mixed liquor or accumulated grit material to be drained from the channel without expensive pumping. Many oxidation ditch plants do not have drains in their channels and are having maintenance problems.

3.3.2.4 CHANNEL LINING. Deep channels are to be built exclusively with reinforced concrete. A concrete liner can be placed against the earth backing in shallow channels by pouring concrete or gunite (shotcrete) to a thickness of 3 to 4 inches. The concrete or gunite should provide a minimum compressive strength of 3,000 pounds per square inch in 28 days.

3.3.3 AERATION. Depending on the width and depth of the channel, various types of aerators can meet the oxygenation and mixing requirements.

3.3.3.1 ROTOR AERATOR. A rotor aerator is a horizontal shaft with protruding blades which rotates, thereby transferring oxygen into the wastewater and propelling it around the ditch. Figure 8 illustrates a typical horizontal-shaft aerator. The minimum length of shaft is 3 feet; the maximum length of shaft is 30 feet. This type of aerator is suitable for shallow channels.

3.3.3.2 INDUCTION AERATOR. This type of aerator, which is available in various sizes, draws the mixed liquor and air down a U-tube and discharges it for a distance downstream in the channel. Compressed air at low pressure can be injected near the top of the down-draft tube to enhance oxygenation. A bulkhead (which should be partially opened at the bottom) is required to separate the channel to maintain the flow circulation. This type of aerator is suitable for shallow to moderately deep channels.

3.3.3.3 JET AERATION. Jet aeration is specifically designed for deep channels. Both air and the mixed liquor are pressurized (by aspirator pumping) into a mixing chamber from where the mixture is discharged as a jet stream into the surrounding channel liquid. Deep channels are used to take advantage of better oxygen transfer. Figure 9 illustrates a jet aerator, among various other types of aerators.

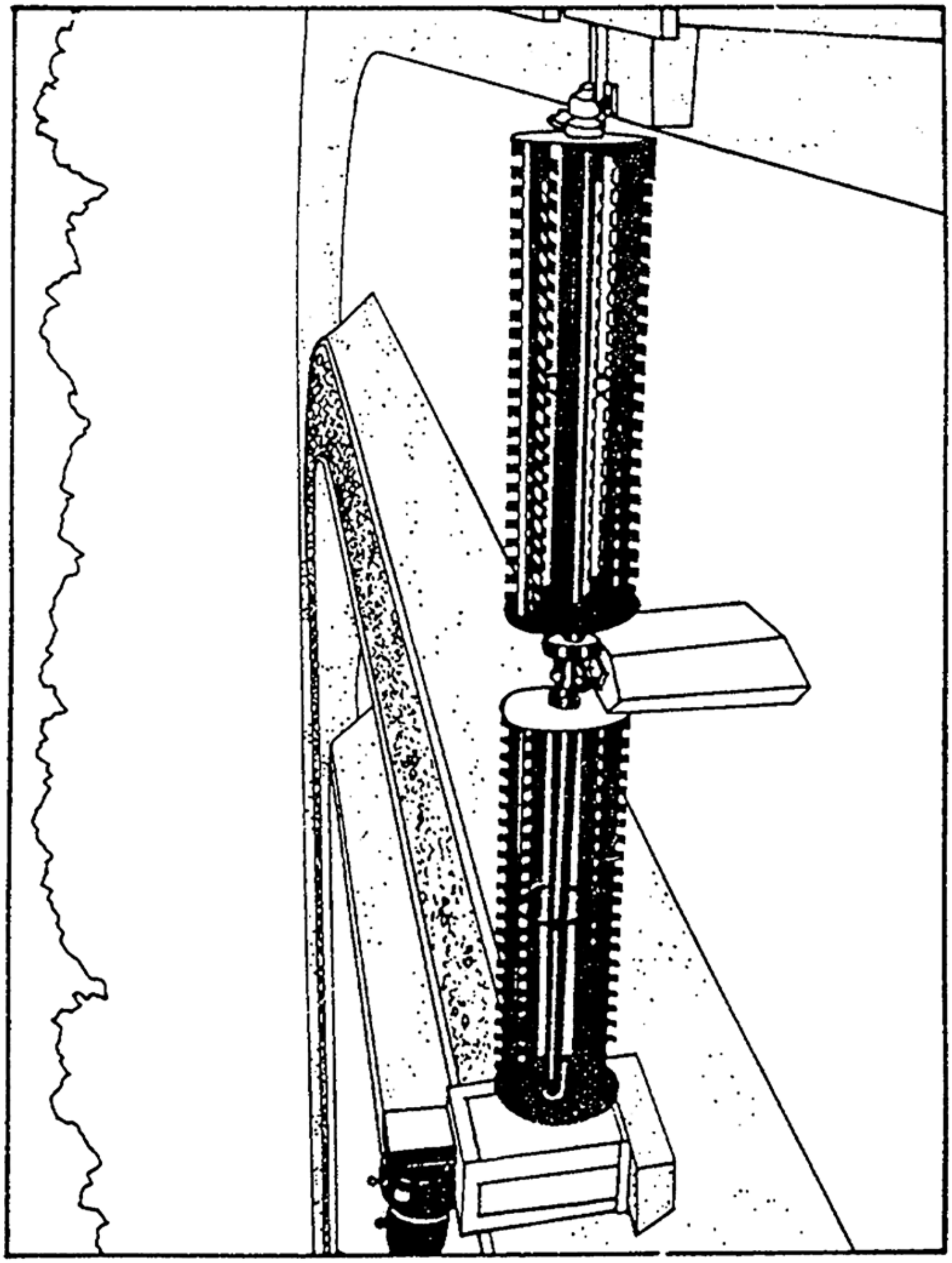


Figure 8

Horizontal shaft aerator

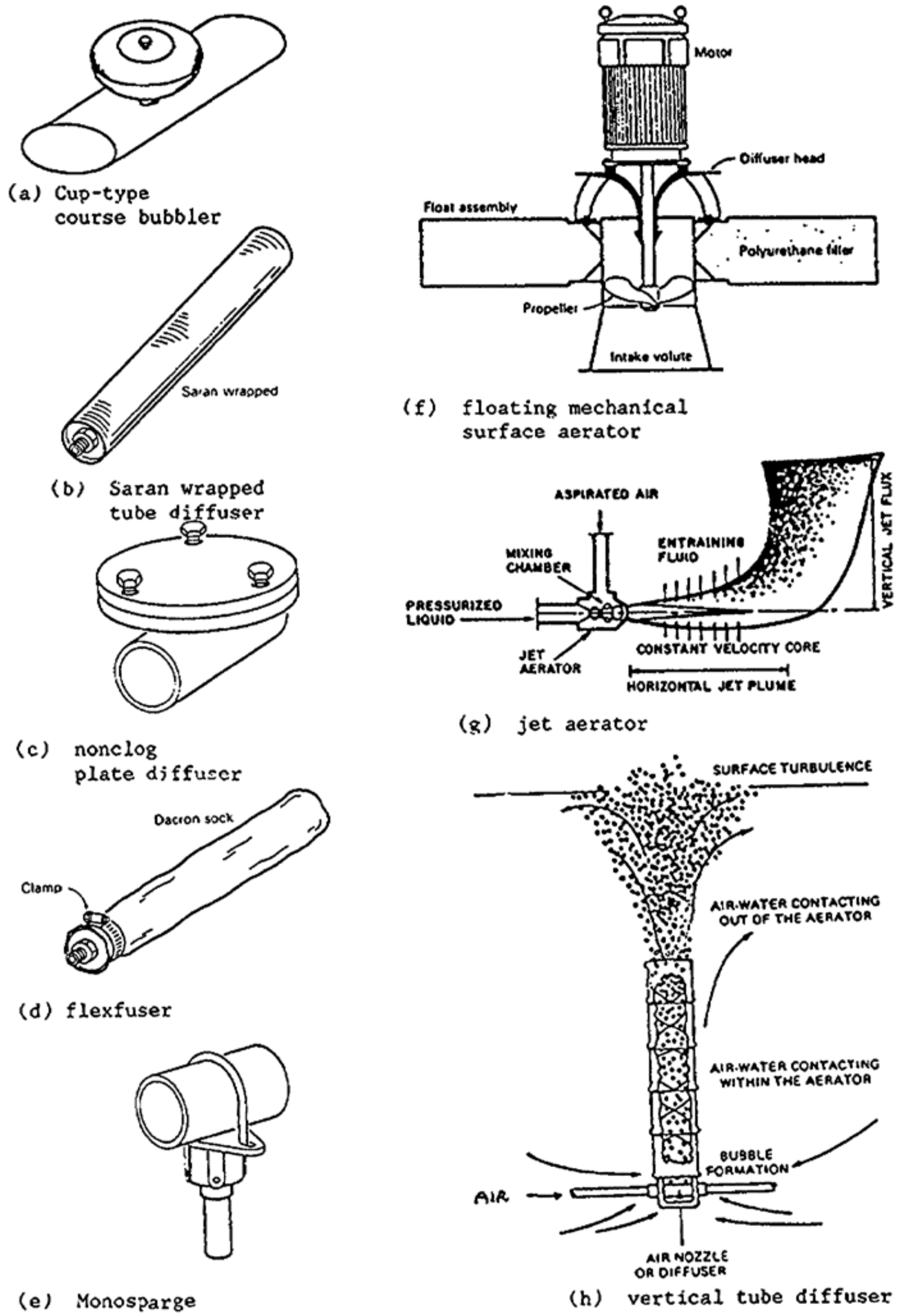


Figure 9

Aerators

3.3.3.4 DIFFUSED AERATION PLUS SLOW MIXER. This type of aeration is more suitable for deep channels. Air bubbles are introduced into the mixed liquor through a pipe grid system with diffusers to provide oxygenation while a slow propeller mixer provides the flow circulation and mixing.

3.3.3.5 AERATOR SIZING. Aerators should be sized to provide adequate mixing and oxygenation. However, the same size rotor provides different levels of mixing and oxygenation depending on the degree of its submergence. First, the oxygen requirement must be calculated for a level that will satisfy the carbonaceous biochemical oxygen demand removal as well as nitrification-denitrification (if needed). Oxidation ditch equipment manufacturers provide tables or charts for selecting the aerator size for any given speed and submergence (immersion) based on the calculated oxygen requirement. The aerator size should also be checked against the mixing requirement set by the manufacturers. Preferably, more than one aerator should be used per channel; they should be placed at different locations so that if one breaks down, the channel will still function. The procedure for selecting the jet aerator size is similar except there is no submergence factor. The sizing of the induction aerator and the diffused air plus slow mixer units is not precise. Design data for these new aeration systems are not yet available. One reason for this is that the amount of energy required for mixing relative to the energy required for oxygenation is uncertain since it depends a great deal on the channel geometry, which varies among plants. More testing data must be collected before a design criterion can be established.

3.3.4 SLUDGE DEWATERING AND DISPOSAL. Sludge from oxidation ditch plants operating in the extended aeration mode (sludge retention time of 20 to 30 days) can be wasted directly to open drying beds. It can also be wasted directly to tank trucks which spread the liquid sludge on the plant grounds or on adjacent land. The degree of sludge stabilization in the oxidation ditch is equivalent to that of a conventional activated sludge plant operated at a 10-day sludge retention time followed by aerobic digestion of the sludge for 7 to 15 days. In most climates, 1 square foot of drying bed surface area per population equivalent (0.17 pound biochemical oxygen demand per capita per day) should be used. This capacity can accept 2.2 cubic feet of wasted sludge per 100 capita per day, which is typical for domestic wastewater treatment. Double units of drying beds should be used so that half of them can be taken out of service for maintenance.

3.3.5 COLD CLIMATE. In moderately cold areas, ice buildup on clarifier scum collection boxes can cause problems and eventually jam the skimmer mechanisms. Therefore, final clarifiers should be covered. In cold areas, the spray from surface aerators will freeze on adjacent structures, bearings, gear reducers, etc., making maintenance difficult. Drive components and walkways near the aerators should be covered to shield them from spray, or mounted in isolated compartments. In very cold areas, heated covers for surface aerators should be provided. Ice fences should be installed across the channel upstream of brush-type aerators to prevent chunks of ice from breaking the brushes.

4. WASTEWATER TREATMENT PONDS.

4.1 BACKGROUND. A wastewater stabilization pond is a relatively shallow body of wastewater contained in an earthen basin which is designed to treat wastewater. (“Oxidation pond" is a synonymous term.) They are used to treat a variety of wastewaters, from domestic wastewater to complex industrial waters, and they function under a wide range of weather conditions, i.e., tropical to arctic. Ponds can be used alone or in combination with other treatment processes. If sufficient land is available, ponds are a cost-effective means to provide wastewater treatment. In addition, their operation is easy and their maintenance requirements are minimal. They are usually the most preferred system in hot climate zones. This section presents some information about ponds. Additional design information and detailed sample design calculations are provided in the *EPA Manual 625/1-83-015.*

4.2 TYPES OF PONDS. Table 6 presents the many different ways that stabilization ponds may be classified. The bases for the classifications are type of influent, method of effluent flow management, oxygenation method, and type of biological activity. This last classification scheme is the best because it describes the dominant feature, i.e., the type(s) of biological activity occurring in a pond. However; to fully describe the different types of ponds, the effluent flow management method should also be noted.

Basis	Classification
Type of Influent	Untreated Wastewater
	Screened Wastewater
	Settled Wastewater
	Activated Sludge Effluent
Effluent Flow Management	Intermittent
	Continuous
Oxygenation Method	Photosynthesis
	Surface Transfer
	Mechanical Aerator
	Complete Mix
	Partial Mix
Biological Activity	Aerobic
	Aerobic-Anaerobic (Facultative)
	Anaerobic

Table 6

Wastewater treatment ponds classifications

4.2.1 AEROBIC PONDS. An aerobic stabilization pond contains bacteria and algae in suspension; aerobic conditions (the presence of dissolved oxygen) prevail throughout its depth. There are two types of aerobic ponds: shallow ponds and aerated ponds.

4.2.1.1 SHALLOW PONDS. Shallow oxidation ponds obtain their dissolved oxygen via two phenomena: oxygen transfer between air and water surface, and oxygen produced by photosynthetic algae. Although the efficiency of soluble biochemical oxygen demand removal can be as high as 95 percent, the pond effluent will contain a large amount of algae which will contribute to the measured total biochemical oxygen demand of the effluent. To achieve removal of both soluble and insoluble biochemical oxygen demand, the suspended algae and microorganisms have to be separated from the pond effluent.

4.2.1.2 AERATED PONDS. An aerated pond is similar to an oxidation pond except that it is deeper and mechanical aeration devices are used to transfer oxygen into the wastewater. The aeration devices also mix the wastewater and bacteria. Figure 9 illustrates various aerators which can be used in aerated ponds. The main advantage of aerated ponds is that they require less area than oxidation ponds. The disadvantage is that the mechanical aeration devices require maintenance and use energy. Aerated ponds can be further classified as either complete-mix or partial-mix systems. A complete-mix pond has enough mixing energy (horsepower) input to keep all of the bacterial solids in the pond in suspension. On the other hand, a partial-mix pond contains a lesser amount of horsepower which is sufficient only to provide the oxygen required to oxidize the biochemical oxygen demand entering the pond.

4.2.2 AEROBIC-ANAEROBIC (FACULTATIVE) PONDS. Three zones exist in an aerobic-anaerobic pond. They are the following:

4.2.2.1 A surface zone where aerobic bacteria and algae exist in a symbiotic relationship.

4.2.2.2 An anaerobic bottom zone in which accumulated solids are actively decomposed by anaerobic bacteria.

4.2.2.3 An intermediate zone that is partly aerobic and partly anaerobic in which the decomposition of organic wastes is carried out by facultative bacteria. Because of this, these ponds are often referred to as facultative ponds. In these ponds, the suspended solids in the wastewater are allowed to settle to the bottom. As a result, the presence of algae is not required. The maintenance of the aerobic zone serves to minimize odor problems because many of the liquid and gaseous anaerobic decomposition products, carried to the surface by mixing currents, are utilized by the aerobic organisms.

4.2.3 CONTROLLED DISCHARGE PONDS. Controlled discharge ponds have long hydraulic detention times and effluent is discharged when receiving water quality will not be adversely affected by the discharge. Controlled discharge ponds are designed to hold the wastewater until the effluent and receiving water quality are compatible.

4.2.4 COMPLETE RETENTION PONDS. Complete retention ponds rely on evaporation and/or percolation to reduce the liquid volume at a rate equal to or greater than the influent accumulation. Favorable geologic or climatic conditions are prerequisite.

4.3 DESIGN CONSIDERATIONS.

4.3.1 APPURTENANCES. In general, the only appurtenances required for wastewater treatment ponds are flow measurement devices, sampling systems, and pumps.

4.3.2 SHALLOW AEROBIC PONDS. Shallow aerobic ponds are limited to a depth of 6 to 18 inches so that light can penetrate the pond to allow algae to grow throughout the pond. This type of pond produces large amounts of algae which must be separated from the wastewater so that biochemical oxygen demand and suspended solids effluent limitations can be met. The separation is typically performed by filtration. The requirement for shallow construction means that this type of pond necessitates a very large amount of land. This land requirement and the need to filter algae are such significant disadvantages that shallow aerobic ponds are not recommended.

4.3.3 AERATED PONDS.

4.3.3.1 COMPLETE-MIX AERATED PONDS. Complete-mix aerated ponds are designed and operated as flowthrough ponds with or without solids recycle. Most systems are operated without solids recycle; however, many systems are built with the option to recycle effluent and solids. Even though the recycle option may not be exercised, it is desirable to include it in the design to provide for flexibility in the operation of the system. If the solids are returned to the pond, the process becomes a modified activated sludge process. Solids in the complete-mix aerated pond are kept suspended at all times. The effluent from the aeration tank will contain from one-third to one-half the concentration of the influent biochemical oxygen demand in the form of solids. These solids must be removed by settling before discharging the effluent. Settling is an integral part of the aerated pond system. Either a settling basin or a quiescent portion of one of the cells separated by baffles is used for solids removal. Seven factors are considered in the design of an aerated pond:

- Biochemical oxygen demand removal;
- Effluent characteristics;
- Oxygen requirements;
- Mixing requirements;
- Temperature effects;
- Solids separation; and
- Hydraulic retention time.

Biochemical oxygen demand removal and the effluent characteristics are generally estimated using a complete-mix hydraulic model and first order reaction kinetics. The complete-mix hydraulic model and first order reaction kinetics will be used by the designer of U.S. Army wastewater treatment facilities. Oxygen requirements will be estimated using equations based on mass balances; however, in a complete-mix system, the power input necessary to keep the solids suspended is much greater than that required to transfer adequate oxygen. Temperature effects are incorporated into the biochemical oxygen demand removal equations. Solids removal will be accomplished by installing a settling pond. If a higher quality effluent is required, then intermittent sand filtrations should be used to produce an acceptable effluent quality.

4.3.3.2 PARTIAL-MIX AERATED PONDS. In the partial-mix aerated pond system, no attempt is made to keep all of the solids in the aerated ponds suspended. Aeration serves only to provide oxygen transfer adequate to oxidize the biochemical oxygen demand entering the pond. Some mixing obviously occurs and keeps portions of the solids suspended; however, in the partial-mix aerated pond, anaerobic degradation of the organic matter that settles does occur. The system is frequently referred to as a facultative aerated pond system. Other than the difference in mixing requirements, the same factors considered in the complete-mix aerated pond system are applicable to the design of a partial-mix system, i.e., biochemical oxygen demand removal, effluent characteristics, oxygen requirements, temperature effects and solids separation. Biochemical oxygen demand removal is normally estimated using the complete-mix hydraulic model and first order reaction kinetics. The only difference in applying this model to partial-mix systems is the selection of a reaction rate coefficient applicable to partial-mix systems.

4.3.4 FACULTATIVE PONDS. Facultative pond design is based upon biochemical oxygen demand removal; however, the majority of the suspended solids will be removed in the primary cell of a pond system. The solids which settle out in a pond undergo digestion and provide a source of organic compounds to the water, which is significant and has an effect on the performance. During the spring and fall, overturn of the pond contents can result in significant quantities of solids being resuspended. The rate of sludge accumulation is affected by the liquid temperature, and additional pond volume is provided for sludge accumulation in cold climates. Although suspended solids have a profound influence on the performance of pond systems, most design equations simplify the incorporation of the influence of suspended solids by using an overall reaction rate constant. Effluent suspended solids generally consist of suspended organism biomass and do not include suspended waste organic matter.

4.3.5 CONTROLLED DISCHARGE PONDS. No rational or empirical design model exists specifically for the design of controlled discharge wastewater ponds. However, rational and empirical design models applied to facultative pond design may also be applied to the design of controlled discharge ponds, provided allowance is made for the required larger storage volumes. These larger volumes result from the long storage periods relative to the very short discharge periods. The unique features of controlled discharge ponds are long-term retention and periodic control discharge, usually once or twice a year. Ponds of this type have operated satisfactorily in the north-central U.S. using the following design criteria:

- Overall organic loading: 20-25 pounds biochemical oxygen demand per acre per day.
- Liquid depth: not more than 6 feet for the first cell, not more than 8 feet for subsequent cells.
- Hydraulic detention: at least 6 months of storage above the 2 feet liquid level (including precipitation), but not less than the period of ice cover.
- Number of cells: at least 3 for reliability, with piping flexibility for parallel or series operation.

4.3.6 COMPLETE RETENTION PONDS. In areas of the U.S. where the moisture deficit, evaporation minus rainfall, exceeds 30 inches annually, a complete retention wastewater pond may prove to be the most economical method of disposal. Complete retention ponds must be sized to provide the necessary surface area to evaporate the total annual wastewater volume plus the precipitation that would fall on the pond. The system should be designed for the maximum wet year and minimum evaporation year of record if overflow is not permissible under any circumstances. Less stringent design standards may be appropriate in situations where occasional overflow is acceptable or an alternative disposal area is available under emergency circumstances. Monthly evaporation and precipitation rates must be known to properly size the system. Complete retention ponds usually require large land areas, and these areas are not productive once they have been committed to this type of system. Land for this system must be naturally flat or be shaped to provide ponds that are uniform in depth and have large surface areas.

4.4 DISINFECTION.

Wastewater contains bacteria which can produce diseases in humans. Disinfection is the selective destruction of these disease-causing organisms. Since chlorine, at present, is less expensive and offers more flexibility than other means of disinfection, chlorination is the most practical method of disinfection. The chlorination of pond effluents requires consideration of some wastewater characteristics which are unique to pond effluents. A list of these considerations is presented below; additional information, design criteria and design examples may be found in *EPA Manual 625/1-83-015.*

4.4.1 SULFIDE. Sulfide, produced as a result of anaerobic conditions in the ponds during winter months when the ponds are frozen over, exerts a significant chlorine demand. For sulfide concentrations of 1.0-1.8 milligrams per liter, a chlorine dose of 6-7 milligrams per liter is required to produce the same residual as a chlorine dose of about 1 milligram per liter for conditions without sulfide.

4.4.2 CHEMICAL OXYGEN DEMAND (COD). Total chemical oxygen demand concentration in a pond effluent is virtually unaffected by chlorination. Soluble oxygen demand, however, increases with increasing concentrations of free chlorine. This increase is attributed to the oxidation of suspended solids by free chlorine.

4.4.3 SUSPENDED SOLIDS. Some reduction in suspended solids, due to the breakdown and oxidation of suspended particulates and resulting increases in turbidity, are attributed to chlorination. However, this reduction is less than that resulting from settling. Suspended solids can be reduced by 10 to 50 percent from settling in chlorine contact tanks.

4.4.4 ALGAE. Filtered pond effluent exerts a lower chlorine demand than unfiltered pond effluent due to the removal of algae. Chlorine demand is directly related to chlorine dose and total chemical oxygen demand.

4.4.5 TEMPERATURE. Disinfection efficiency is temperature dependent. At colder temperatures, the reduction in the rate of disinfection was partially offset by reductions in the exertion of chlorine demand; however, the net effect was a reduction in the chlorine residual necessary to achieve adequate disinfection with increasing temperature for a specific contact period.

4.4.6 CHLORINE RESIDUAL. Adequate disinfection can be obtained with combined chlorine residuals of between 0.5 and 1.0 milligrams per liter after a contact period of approximately 50 minutes, i.e., disinfection can be achieved without discharging excessive concentrations of toxic chlorine residuals into receiving waters.

5. SEWAGE TREATMENT IN HOT CLIMATES

5.1 GENERAL CONSIDERATIONS. Although this discussion is intended to apply to U. S. plants, in areas which may be hotter; drier or wetter than conditions faced in the U.S., certain factors generally found in hot climates bear special consideration.

5.2 ESTABLISHMENT OF FLOW RATES. Calculation of wastewater flow may be based, as in temperate climates, upon fresh water use. However, sewage flow may be either much larger or much smaller than water use. In areas of high rainfall and water abundance, people will bathe more often, use water for cooling and will tend to be less water conscious. Wastewater flow may be greater than expected for a given population. Although brackish water may be used for washing, cooling or cleaning, if it is allowed to enter the wastestream, the increased salinity will lower biological process efficiencies. High dissolved solids concentrations have an impact on the treatment process efficiency. This condition should be considered in designing these systems. On the other hand, greywater may be separated from the wastestream and recycled for purification, or used directly onsite for lawns, plants, washing or cooling. Under these circumstances, wastewater flow will be low and much more concentrated. Loss of water by evaporation and from pipelines into the ground may further decrease flow to the treatment plant.

5.2.1 Typical low flow locations which utilize a standpipe, practice water conservation and recycle water may require only 5-20 gallons per day per person of stored fresh water and only 2-10 gallons per day per person may arrive at the treatment plant.

5.2.2 Typical high flow regimes in the humid tropics are subject to considerable infiltration, use of warm rooftop or cistern stored water. High shower utilization requires 100-125 gallons per day per person of fresh water and 130-150 gallons per day per person may appear at the treatment facility.

5.2.3 The engineer must, therefore, assess the water usage, storage and transport patterns of the site in order to assign reasonable sewage flows.

5.3 HIGH TEMPERATURE PARAMETERS. A major design parameter will be water temperature. Use of rooftop rain storage, cistern water; brackish water; and the ambient conditions will result in very warm sewage. The engineer shall expect high salt content, including sulfate, chloride, phosphate, borate and nitrate anions, and both alkali and alkaline earth cations. Oxygen levels will be very low and chalcogenides as well as dissolved hydrogen sulfide should be anticipated. The most dramatic effect of high temperature will be upon biochemical reaction rates. The general formula relating temperature to rate constants is as follows:

$$K_t = K_{20}\ (1.047)^{(T-20)}$$

Where:

K_t = the rate constant for the sewage treatment reactions involved

K_{20} = the rate constant for that same reaction at 20 degrees Celsius

Using this equation, the rate constants can be calculated at 10 degrees Celsius and 35 degrees Celsius. The result indicates a 3-fold increase in the rate coefficient. It is this high rate of biological reaction which results in unexpectedly high sulfide levels, very low dissolved oxygen concentrations and large biomass accumulation. All chemical moieties found in the sewage will arrive in the reduced state in a much more microbiologically rich liquor.

5.4 UNIT OPERATIONS IN THE TROPICS. Although activated sludge, trickling filter or rotating biological filter processes may be used in hot climates, strong sunlight and adequate space will often dictate the use of oxidation ponds. Temperature and sunlight intensity will control algal growth, which will be intense. The most useful type of pond will be the facultative pond, which is aerobic at the surface and anaerobic at the bottom. Pond retention time may be over 30 days; depth is usually between 5 and 10 feet.

5.4.1 Not only are photosynthetic and microbiological processes accelerated, but gas formation is also increased as temperature rises. Sludge rising is often a problem since sludge accumulates at a rapid rate and much gas is evolved in the material. Daily desludging is normally required rather than the usual weekly desludging. Settlement rate is controlled by viscosity so that the temperature increase does not dramatically change retention time in primaries, which is usually 1-2 hours in a correctly designed tank.

5.4.2 The effect of increased temperature reduces the saturation concentration of oxygen in any process, such as a trickling filter or packaged activated sludge plant, but, fortunately, the mass transport coefficient is increased. In any system involving plug flow, initial oxygen demands will be very high. Flow to the plant will usually be anaerobic. The engineer should, therefore, anticipate 5-15 percent larger blower or bubbler air demands than required in the U.S. At high altitudes, the oxygen saturation value will again be reduced, requiring further increased air capacity at about 5 percent per 1,000 feet. Dissolved oxygen electrodes should be mandatory in hot climate wastewater treatment plant processes because both under and over-aeration will result in process disturbance. In package treatment plants where gravity return of settled activated sludge is common, the sludge will usually turn anaerobic, making positive sludge return usually advisable. Aerobic stabilization of activated sludge is most applicable in hot climates.

5.4.3 Trickling filters and rotating biological disc filters show great promise in hot climates. Since filter media volume requirements are proportional as temperature increases, the volume decreases.

5.4.4 Sludges dry much more rapidly in hot climates; but in the humid tropics, covers will be required. Odor problems have been common in the sludges produced in hot climates, indicating that aerobic digestion or aerobic composting is potentially useful. Anaerobic digestion and gas production should be investigated since a hot climate encourages microbiological fermentation reactions.

5.4.5 The engineer should examine each unit operation in a proposed system for potential problems caused by high temperature, torrential tropical rain, and local sewage characteristics variations.

6. SPECIAL CONSIDERATIONS FOR COLD CLIMATES

6.1 GENERAL CONSIDERATIONS. Arctic and subarctic conditions which exist at either pole present unique problems for design, construction and maintenance of wastewater treatment systems. Fortunately, some U.S. engineers have gained valuable experience in Alaska, Greenland, Canada, Antarctica and Iceland. Further; there exists a body of Scandinavian, Canadian and Russian literature on the special challenges of these harsh climates. For a view of Canadian and Scandinavian engineering, utilize the University of Alberta seminar report (Smith, DW, and Hrudey, SE, *Design of Water and Wastewater Services for Cold Climate Communities,* Pergamon Press, Toronto). These technical reports address the problems of extreme cold, wind and snow, high cost, remote location, thermal stress on structures, frost heaving, permafrost, and the limited availability of construction materials, skilled labor and time for construction and/or maintenance. Extreme low temperature is common: as low as -75 degrees Fahrenheit in interior locations in northern Canada; below -100 degrees Fahrenheit in Antarctica; and a month or more of sub-zero air temperature in the Arctic. Water, sewer, electric utilities and steam lines are all run in utilidors above ground to conserve their heat, allow easy access and conserve materials. Utilidors are kept insulated from the ground because the permafrost can be alternately melted and frozen if trenches are used. Construction on permafrost or seasonal frost soils requires a number of special considerations.

6.2 WIND PROTECTION. Wind in the arctic zone produces a great heat loss problem which is reflected in wind chill factors. Precipitation in northern climates is actually quite low, but the snow produces drifts and can cause severe problems in transportation and operation should the engineer fail to consider wind. Obviously, snow and wind loads on structures require careful consideration. Rotating biological equipment and other covered equipment must not only be well insulated, but must be designed to withstand thermal extremes, buffeting wind loads and wet spring snow.

6.3 CONSERVATION PRACTICES. Wastewater from cold region activities that practice water conservation is high strength since water consumption is normally low, infiltration is nil and stormwater is excluded. Since wastewater is transported above the ground surface or in well-insulated, well constructed tunnels, fresh water use is almost the same as wastewater return. Design conditions should be expected to be about 300 milligrams per liter at 60 to 80 gallons per capita per day. Wastewater will be delivered to the plant at around 50 degrees Fahrenheit.

6.4 MODIFICATIONS FOR VISCOSITY AND DISSOLVED OXYGEN VARIATIONS. All processes where operation is viscosity dependent must be corrected for increased viscosity. This would include sedimentation tanks, filters and oxidation ponds. All processes which involve oxygen transfer will be aided by the increased solubility of oxygen at low temperatures; but to overcome the deleterious effect of increased viscosity, more mixing will be required. An absorption process such as oxygen bubble-water transfer is enhanced by the lower temperature. However, the lower viscosity reduces the rate of contact so that neither oxygen transfer nor absorption changes in rate, overall. All chemical reactions, especially those involving partially soluble salts, must be recalculated to reflect the low solubility of chemicals in cold water. Each flocculent or deflocculent, each polymer and each detergent or other organic chemical used must be tested for unanticipated interaction brought about by low temperatures.

6.5 INSULATION OF APPURTENANCES. Trash racks, bar screens, grit chambers, unit-process tanks, biological reactors, aerators, gates, walkways and instrumental sensing devices must be heated, insulated or redesigned to withstand icing and snow pack.

7. REFERENCES

7.1 GOVERNMENT PUBLICATIONS

- PL 92-500 Federal Water Pollution Control Act

7.1.1 DEPARTMENT OF DEFENSE

- 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