4 Introduction to Process Analysis and Selection

Treatment methods in which the application of physical forces predominate are known as physical unit operations. Examples of physical unit operations include screening, mixing, sedimentation, gas transfer, filtration, and adsorption. Treatment methods in which the removal or conversion of constituents is brought about by the addition of chemicals or by other chemical reactions are known as chemical unit processes.

Examples of chemical unit processes include disinfection, oxidation, and precipitation. Treatment methods in which the removal of constituents is brought about by biological activity are known as biological unit processes.

Unit operations and processes occur in a variety of combinations in treatment flow diagrams.

The rate at which reactions and conversions occur, and the degree of their completion, is generally a function of the constituents involved, the temperature, and the type of reactor (i.e., container or tank in which the reactions take place).

The fundamental basis for the analysis of the physical, chemical, and biological unit operations and processes used for wastewater treatment is the materials mass balance principle in which an accounting of mass is made before and after reactions and conversions have taken place.

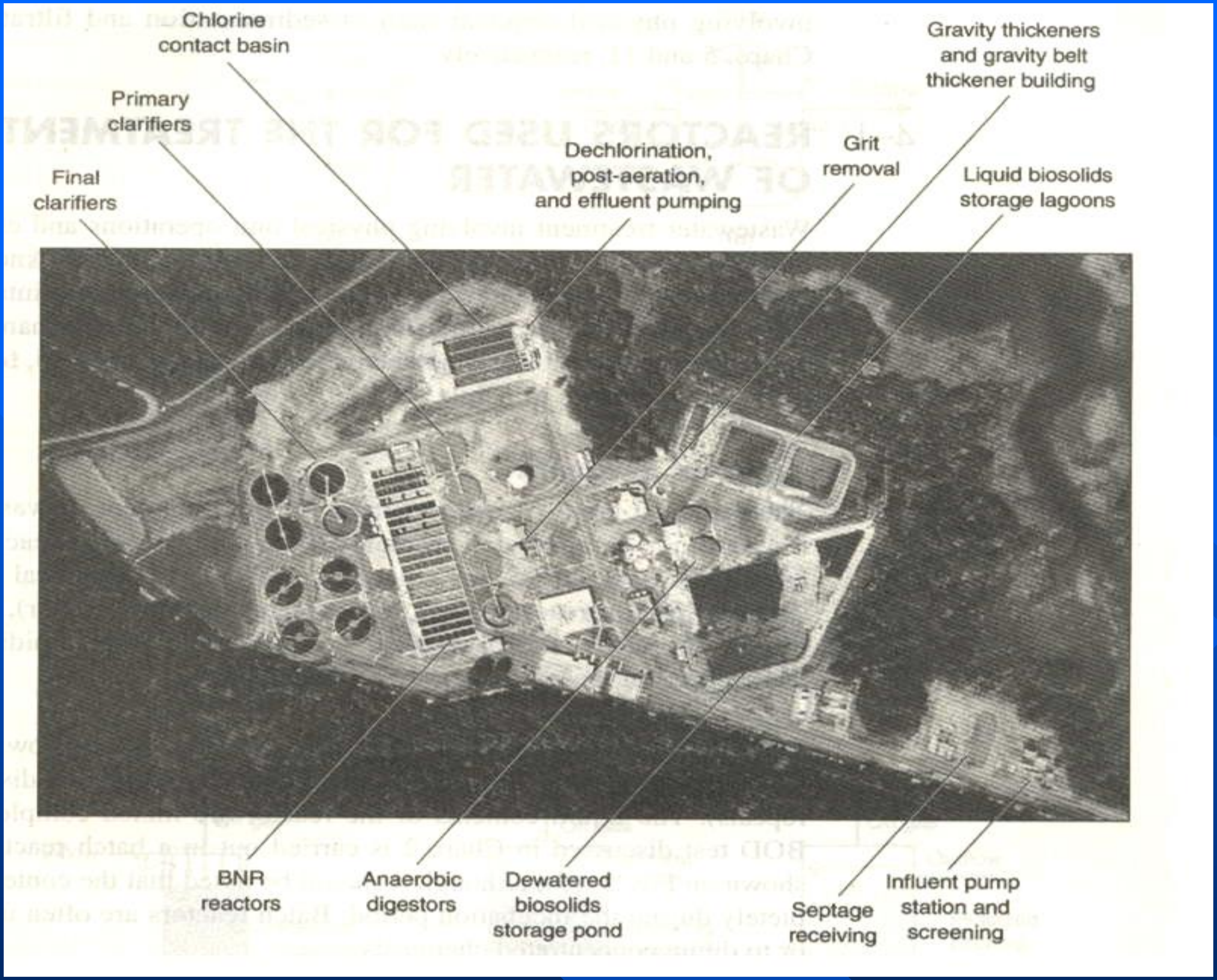


Fig. 4-1 Overview of a biological nutrient removal(BNR) wastewater-treatment plant

4-1 Reactors used for the Treatment of Wastewater

Types of Reactors

Fig. 4-2 Definition sketch for various types of reactors used for wastewater treatment

The principal types of reactors used for the treatment of wastewater, are

(1) the batch reactor,

(2) the complete-mix reactor (also known as the continuous-flow stirred-tank reactor (CFSTR) in the chemical engineering literature),

(3) the plug-flow reactor (also known as a tubular-flow reactor),

(4) complete-mix reactors in series,

(5) the packed-bed reactor,

(6) the fluidized-bed reactor.

Batch Reactor

In the batch reactor, flow is neither entering nor leaving the reactor (i.e, flow enters, is treated, and then is discharged, and the cycle repeats).

The BOD test is carried out in a batch reactor that are often used to blend chemicals or to dilute concentrated chemicals.

Complete-Mix Reactor

Fluid particles leave the reactor in proportion to their statistical population. Complete mixing can be accomplished in round or square reactors if the contents of the reactor are uniformly and continuously redistributed. The actual time required to achieve completely mixed conditions will depend on the reactor geometry and the power input.

Plug-Flow Reactor

Fluid particles pass through the reactor with little or no longitudinal mixing and exit from the reactor in the same sequence in which they entered.

The particles retain their identity and remain in the reactor for a time equal to the theoretical detention time.

Complete-Mix Reactors in Series

The series of complete-mix reactors is used to model the flow regime that exists between the ideal hydraulic flow patterns corresponding to the complete-mix and plug-flow reactors. If the series is composed of one reactor, the complete-mix regime prevails. If the series consists of an infinite number of reactors in series, the plug-flow regime prevails.

Packed-Bed Reactors

Dosing can be continuous or intermittent (e.g., trickling filter). The packing material in packed-bed reactors can be continuous or arranged in multiple stages, with flow from one stage to another.

Fluidized-Bed Reactor

The fluidized-bed reactor is similar to the packed-bed reactor in many respects, but the packing material is expanded by the upward movement of fluid (air or water) through the bed. The expanded porosity of the fluidized-bed packing material can be varied by controlling the flowrate of the fluid.

Application of Reactors

Tab. 4-1 Principal applications of reactor types used for wastewater treatment

Operational factors that must be considered in the selection of the type of reactor or reactors to be used in the treatment process include

(1) the nature of the wastewater to be treated,

(2)the nature of the reaction (i.e., homogeneous or heterogeneous),

(3) the reaction kinetics governing the treatment process,

(4) the process performance requirements,

(5)local environmental conditions. In practice, the construction costs and operation and maintenance costs also affect reactor selection.

Ideal Flow in Complete-Mix and Plug-Flow Reactors

The ideal hydraulic flow characteristics of complete-mix and plug-flow reactors are illustrated on Fig. 4-3 in which dye tracer response craves are presented for pulse (slug-dose) and step inputs (continuous injection).

Fig. 4-3 Output tracer response curves from reactors subject to pulse and step inputs of a tracer

Nonideal Flow in Complete-Mix and Plug-Flow Reactors.

In practice the flow in complete-mix and plug-flow reactors is seldom ideal.

It is the precautions taken to minimize these effects that are important.

4-2 Mass-balance Analysis

The fundamental approach used to study the hydraulic flow characteristics of reactors and to delineate the changes that take place when a reaction is occurring in a reactor (e.g., a container), or in some definable portion of a body of liquid, is the mass-balance analysis.

The Mass-Balance Principle

The mass-balance analysis is based on the principle that mass is neither created nor destroyed, but the form of the mass can be altered (e.g., liquid to a gas). The mass-balance analysis affords a convenient way of defining what occurs within treatment reactors as a function of time.

Fig. 4-4 Definition sketch for the application of materials mass-balance analysis for a complete-mix reactor with inflow and outflow. The presence of a mixer is used to represent symbolically the fact the contents of the reactor are mixed completely. The photo is of a typical complete-mix activated sludge reactor used for the biological treatment of wastewater.

The system boundary is drawn to identify all of the liquid and constituent flows into and out of the system

For a given reactant, the general mass-balance analysis is given by

1. General word statement
2. The corresponding simplified word statement

A positive sign is used for the rate-of-generation term because the necessary sign for the operative process is past of the rate expression (e.g., $r_c = -kC$ for a decrease in the reactant or $r_c = + kC$ for all increase in the reactant).

Preparation of Mass Balances

1. Prepare a simplified schematic or flow diagram of the system or process
2. Draw a system or control volume boundary to define the limits . Proper selection of the system or control volume boundary is extremely important because, in many situations, it may be possible to simplify the mass-balance computations.
3. List all of the pertinent data and assumptions
4. List all of the rate expressions for the biological or chemical reactions
5. Select a convenient basis

It is recommended that the above steps be followed routinely.

Application of the Mass-Balance Analysis

To apply a mass-balance analysis to the liquid contents of the reactor shown on Fig. 4-4, it will be assumed that:

1. The volumetric flowrate into and out of the control volume is constant.
2. The liquid within the control volume is not subject to evaporation (constant volume).
3. The liquid within the control volume is mixed completely.
4. A chemical reaction involving a reactant A is occurring within the reactor.
5. The rate of change in the concentration of the reactant A that is occurring within the control volume is governed by a first-order reaction ($r_c = -kC$).

Using the above assumptions, the mass balance can be formulated as follows

1. Simplified word statement
2. Symbolic representation

Before attempting to solve any mass-balance expression, a unit check should always be made to assure that units of the individual quantities are consistent.

Steady-State Simplification

Fortunately, in most applications in the field of wastewater treatment, the solution of mass-balance equations, such as the one given by the equations, can be simplified by noting that the steady-state(i.e., long-term) concentration is of principal concern. If it is assumed that only the steady-state effluent concentration is desired, then above equation can be simplified by noting that, under steady-state conditions, the rate accumulation is zero ($dC/dt = 0$).

4-3 Analysis of Nonideal Flow in Reactors Using Tracers

Because of a lack of appreciation for the hydraulics of reactors, many of the treatment plants that have been built do not perform hydraulically as designed.

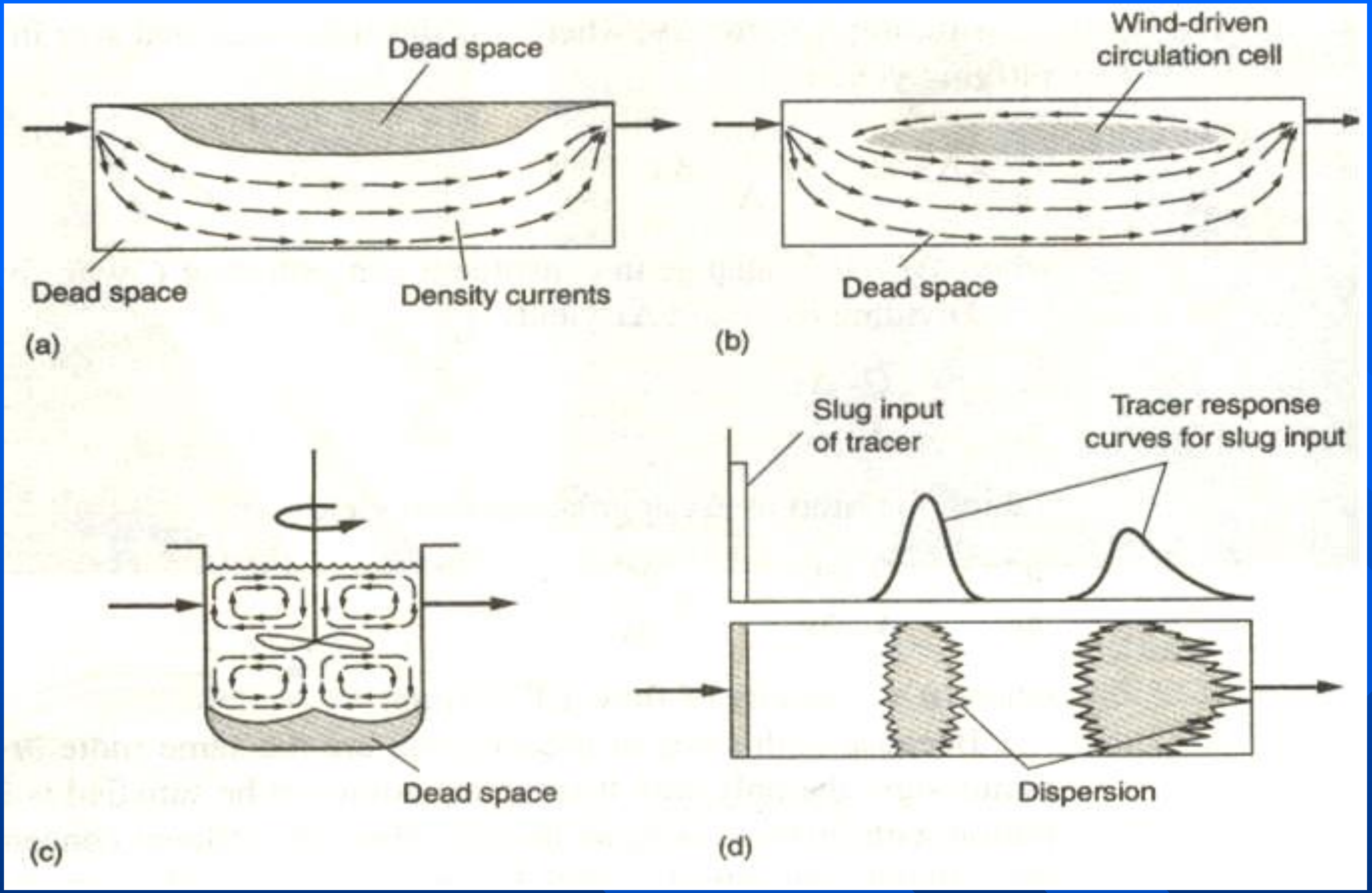


Fig. 4-5 Definition sketch for short circuiting caused by (a)density currents caused by temperature differences; (b)wind circulation patterns; (c)inadequate mixing; (d)fluid advection(平流) and dispersion

Factors leading to nonideal flow in reactors include:

1. Temperature differences. In complete-mix and plug-flow reactors, nonideal flow (short circuiting) can be caused by density currents due to temperature differences. When the water entering the reactor is colder or warmer than the water in the tank, a portion of the water can travel to the outlet along the bottom of or across the top of the reactor without mixing completely (see Fig. 4-5a).
2. Wind-driven circulation patterns. In shallow reactors, wind-circulation patterns can be set up that will transport a portion of the incoming water to the outlet in a fraction of the actual detention time (see Fig. 4-5b).

3. Inadequate mixing. Without sufficient energy input, portions of the reactor contents may not mix with the incoming water (see Fig. 4-5c).

4. Poor design. Depending on the design of the inlet and outlet of the reactor relative to the reactor aspect ratio, dead zones may develop within the reactor that will not mix with the incoming water (see Fig. 4-5d).

5. Axial dispersion in plug-flow reactors. In plug-flow reactors the forward movement of the tracer is due to advection and dispersion. Advection is the term used to describe the movement of dissolved or colloidal material with the current velocity. Dispersion is the term used to describe the axial and longitudinal transport of material brought about by velocity differences, turbulent eddies, and molecular diffusion.

Need for Tracer Analysis

The use of dyes and tracers for measuring the residence time distribution curves is one of the simplest and most successful methods now used to assess the hydraulic performance of full-scale reactors. Important applications of tracer studies include

(1) the assessment of short circuiting in sedimentation tanks and biological reactors,

(2) the assessment of the contact time in chlorine contact basins,

(3) the assessment of the hydraulic approach conditions in UV reactors, and

(4) the assessment of flow patterns in constructed wetlands and other natural treatment systems.

Tracer studies are also of critical importance in assessing the degree of success that has been achieved with corrective measures.

Types of Tracers

Over the years, a number of tracers have been used to evaluate the hydraulic performance of reactors. Important characteristics for a tracer include :

(1)The tracer should not affect the flow (should have essentially the same density as water when diluted).

(2)The tracer must be conservative so that a mass balance can be performed.

(3)It must be possible to inject the tracer over a short time period.

(4)The tracer should be able to be analyzed conveniently.

(5)The molecular diffusivity of the tracer should be low.

(6)The tracer should not be absorbed on or react with the exposed reactor surfaces.

(7)The tracer should not be absorbed on or react with the particles in wastewater.

Dyes and chemicals that have been used successfully in tracer studies include congo-red, fluorescein, fluorosilicic acid (H_2SiF_6), hexafluoride gas (SF_6), lithium chloride (LiCl), Pontacyl Brilliant Pink B, potassium, potassium permanganate, rhodamine WT, and sodium chloride (NaCl). Pontacyl Brilliant Pink B (the acid form of rhodamine WT) is especially useful in the conduct of dispersion studies because it is not readily adsorbed onto surfaces.

- Because fluorescein, rhodamine WT, and Pontacyl Brilliant Pink B can be detected at very low concentrations using a fluorometer , they are the dye tracers used most commonly in the evaluation of wastewater-treatment facilities. Lithium chloride is commonly used for the study of natural systems. Sodium chloride, used commonly in the past, has a tendency to form density currents unless mixed. Hexafluoride gas (SF_6) is used most commonly for tracing the movement of groundwater.

Conduct of Tracer Tests

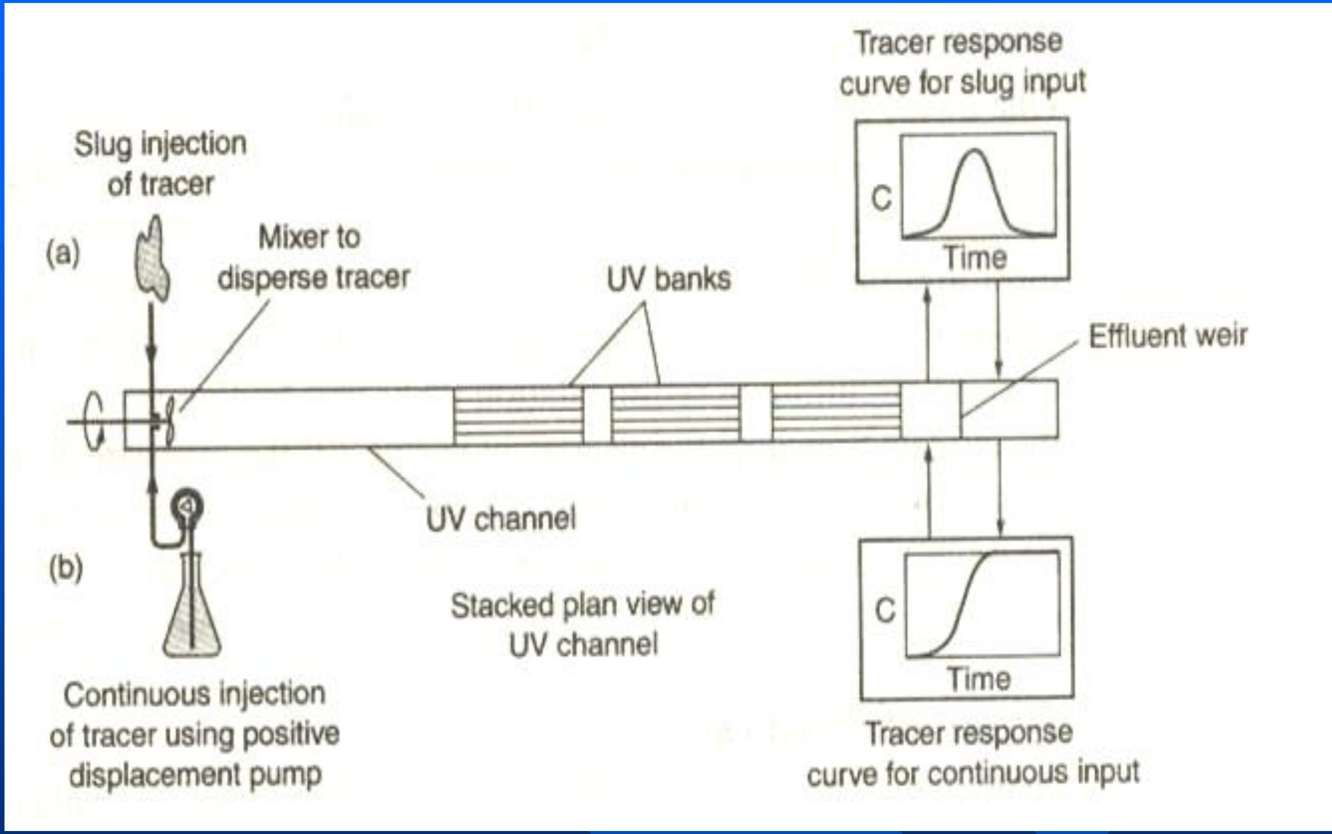


Fig 4-6 Schematic of setup used to control tracer studies of plug-flow reactors

(a)slug of tracers added to flow; (b)continuous input of tracer added to flow. Tracer response curve is measured continuously.

Analysis of Tracer Response Curves

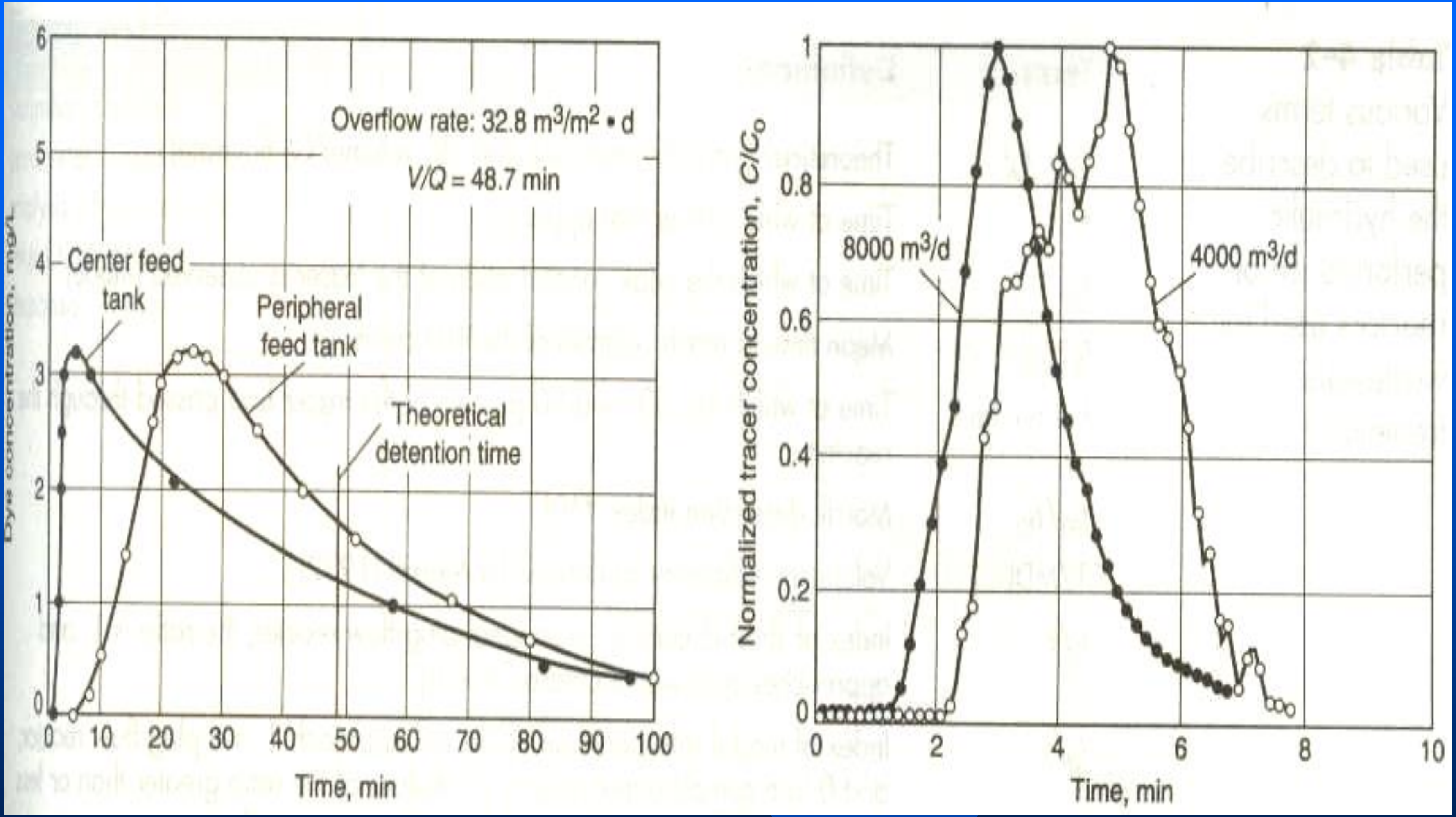


Fig. 4-8 Typical tracer response curves: two different types of circular clarifiers and open channel UV disinfection system

4-4 Reactions, Reaction Rates, and Reaction Rate Coefficients

The stoichiometry of reaction refers to the definition of the quantities of chemical compounds involved in a reaction. The rate expressions discussed in this section will be integrated with the hydraulic characteristics of the reactors, discussed previously, to define treatment kinetics.

Types of Reactions

The two principal types of reactions that occur in wastewater treatment are classified as homogeneous and heterogeneous (non-homogeneous).

Homogeneous Reactions

In homogeneous reactions, the reactants are distributed uniformly throughout the fluid so that the potential for reaction at any point within the fluid is the same, Homogeneous reactions are usually carried out in the batch, complete-mix, and plug-flow reactors .

Examples of irreversible reactions are

a. Simple reactions

$$A \longrightarrow B$$

$$A + A \longrightarrow C$$

$$aA + bB \longrightarrow C$$

b. Parallel reactions

$$A + B \longrightarrow C$$

$$A + B \longrightarrow D$$

c. Consecutive reactions

$$A + B \longrightarrow C$$

$$A + C \longrightarrow D$$

Examples of reversible reactions are

$$A \longleftrightarrow B$$

$$A + B \longleftrightarrow C + D$$

Heterogeneous Reactions

Heterogeneous reactions occur between one or more constituents that can be identified with specific sites, such as those on an ion exchange resin .

These reactions are more difficult to study because a number of interrelated steps may be involved. The typical sequence of these steps is as follows:

1. Transport of reactants from the bulk fluid to the fluid-solid interface (external surface of catalyst particle)

2. Intraparticle transport of reactants into the catalyst particle (if it is porous)
3. Adsorption of reactants at interior sites of the catalyst particle
4. Chemical reaction of adsorbed reactants to adsorbed products (surface reaction)
5. Desorption of adsorbed products
6. Transport of products from the interior sites to the outer surface of the catalyst particle

Rate Expressions Used in Environmental Modeling

Tab. 4-2 Constituent transformation and removal processes(i.e., fate processes) in the environment

Process	Comments	Constituents affected
Adsorption/ desorption	Many chemical constituents tend to attach or sorb onto solids. The implication for wastewater discharges is that a substantial fraction of some toxic chemicals is associated with the suspended solids in the effluent. Adsorption combined with solids settling results in the removal from the water column of constituents that might not otherwise decay	Metal, trace organics, NH_4^+, PO_4^{3-}

Algal synthesis	The synthesis of algal cell tissue using the nutrients found in wastewater	NH_4^+,NO_3^-,PO_4^{3-},pH, etc
Bacterial conversion	Bacterial conversion (both aerobic and anaerobic) is the most important process in the transformation of constituents released to the environment. The exertion of BOD and NOD is the most common example of bacterial conversion encountered in waterquality management. The depletion of oxygen in the aerobic conversion of organic wastes is also known as deoxygenation. Solids discharged with treated wastewater are partly organic. Upon settling to the bottom, they decompose bacterially either anaerobically or aerobically, depending on local conditions. The bacterial transformation of toxic organic compounds is also of great significance.	BOD_5,nitrification, denitrification, sulfate reduction, anaerobic fermentation (in bottom sediments), conversion of priority organic pollutants,etc.

Chemical reactions	Important chemical reactions that occur in the environment include hydrolysis, photochemical, and oxidation-reduction reactions. Hydrolysis reactions occur between contaminants and water.	Chemical disinfection, decomposition of organic compounds, specific ion exchange, element substitution.
Filtration	Removal of suspended and colloidal solids by straining (mechanical and chance contact), sedimentation, interception, impaction, and adsorption.	TSS, colloidal particles
Flocculation	Flocculation is the term used to describe the aggregation of smaller particles into larger particles that can be removed by sedimentation and filtration. Flocculation is brought about by Brownian motion, differential velocity gradients, and differential settling in which large particles overtake smaller particles and form larger particles.	Colloidal and small particles

Gas absorption/desorption	The process whereby a gas is taken up by a liquid is known as absorption. For example, when the dissolved oxygen concentration in a body of water with a free surface is below the saturation concentration in the water, a net transfer of oxygen occurs from the atmosphere to the water. The rate of transfer (mass per unit time per unit surface area) is proportional to the amount by which the dissolved oxygen is below saturation. The addition of oxygen to water is also known as reaeration. Desorption occurs when the concentration of the gas in the liquid exceeds the saturation value, and there is a transfer from the liquid to the atmosphere.	O_2,CO_2,CH_4,NH_3,H_2S

4-5 Treatment Processes Involving Mass Transfer

Unlike mechanical separations, the driving force for the transfer of material is a pressure or concentration gradient). The separation operations are sometimes identified as equilibrium phase separations or equilibrium contact separations, because the transfer of a component will cease when equilibrium conditions prevail.

Tab. 4-4 Principal applications of mass transfer operations and processes in wastewater treatment

The most important mass transfer operations in wastewater treatment involve

(1) the transfer of material across gas-liquid interfaces as in aeration and in the removal of unwanted gaseous constituents found in wastewater by air stripping,

(2) the removal of unwanted constituents from wastewater by adsorption onto solid surfaces such as activated carbon and ion exchange.

Gas-Liquid Mass Transfer

The simplest and most commonly used is the two-film theory proposed by Lewis and Whitman (1924).

The two-film theory remains popular because, in more than 95 percent of the situations encountered, the results obtained are essentially the same as those obtained with the more complex theories.

The Two-Film Theory

The two-film theory is based on a physical model in which two films exist at the gas-liquid interface, as shown on Fig. 4-9.

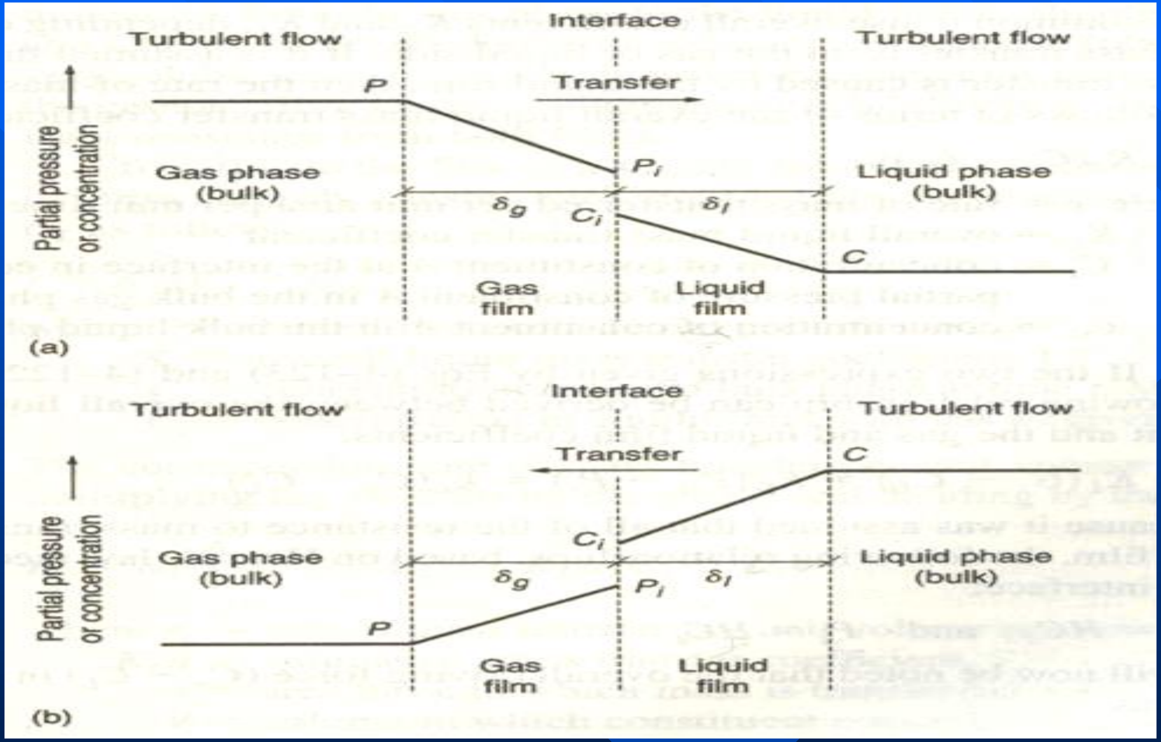


Fig. 4-9 Definition sketch for the two-film theory of gas transfer: (a)absorption;(b)desorption

(a) "absorption," in which a gas is transferred from the gas phase to the liquid phase,

(b) "desorption," in which a gas is transferred out of the liquid phase into the gas phase. The two films, one liquid and one gas, provide the resistance to the passage of gas molecules between the bulk-liquid and the bulk-gaseous phases.

It is assumed that the concentration and partial pressure in both the bulk liquid and bulk-gas phase are uniform (i.e., mixed completely)

Using Fick's first law, the mass flux for each phase for absorption (gas addition) is written as follows:

$$r = k_G(P_G - P_i) = k_L(C_i - C_L)$$

where r=rate of mass transferred per unit area per unit time

k_G =gas film mass transfer coefficient

P_G =partial pressure of constituent *A* in the bulk of the gas phase

P_i =partial pressure of constituent *A* at the interface in equilibrium with concentration *Ci* of constituent *A* in liquid

It should be noted that the gas and liquid film mass transfer coefficients depend on the conditions at the interface. The terms (P_G - P_i) and (C_i-C_L) represent the driving force causing transfer in the gas and liquid phase, respectively.

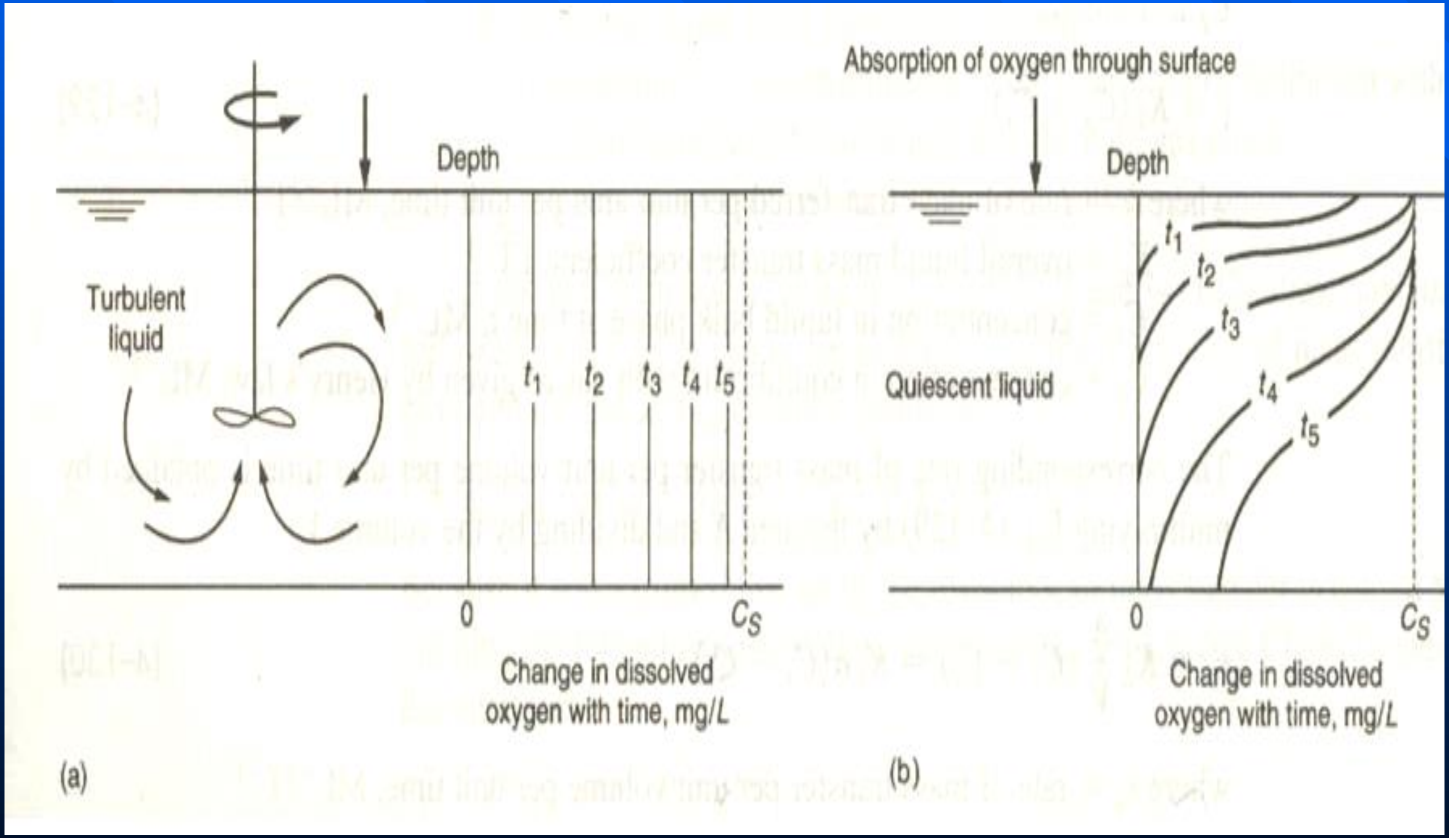
Thus, the degree of mass transport can be enhanced by reducing the thickness of the film, depending on which is the controlling film.

If it is assumed that all of the resistance to mass transfer is caused by the liquid film, then the rate of mass transfer can be defined as follows in terms of the overall liquid mass transfer coefficient:

$$r = K_L(C_S - C_L)$$

Absorption of Gases

Fig. 4-10 Definition sketch for the absorption of a gas: (1)under turbulent conditions of gas in the gaseous and liquid phases is uniform; (b)under quiescent conditions.



Liquid-Solid Mass Transfer

Adsorption

The adsorbate is the substance that is being removed from liquid phase at the interface. The adsorbent is the solid, liquid, or gas phase onto which the adsorbate accumulates. The adsorption process takes place in three steps: macrotransport, microtransport, and sorption.

Although adsorption also occurs on the surface of the solid adsorbent and in the macropores and mesopores, the surface area of these parts of most solid adsorbents is so extremely small compared with the surface area of the micropores .

Two important characteristics of the solid adsorbent are

(1) its extremely large surface area to volume ratio

(2) its preferential affinity for certain constituents in the liquid phase.

Granular or powdered activated carbon (GAC or PAC) is used most commonly for the removal of selected constituents from wastewater.

A common adsorption isotherm is the Freundlich isotherm.

4-6 Introduction to Process Selection

The purpose of process analysis is to select the most suitable unit operations and processes and the optimum operational criteria.

Important Factors in Process Selection

The first factor, 'process applicability,' stands out above all others and reflects directly upon the skill and experience of the design engineer.

Available resources include performance data from operating installations, published information in technical journals, manuals of practice published by the Water Environment Federation, process design manuals published by EPA, and the results of pilot-plant studies.

Tab. 4-5 Important factors that must be considered when evaluating and selecting unit operations and processes

Factor	Comment
1.Process applicability	The applicability of a process is evaluated on the basis of past experience, data from full-scale plants, published data, and from pilot-plant studies. If new or unusual conditions are encountered, pilot-plant studies are essential.
2.Applicable flow range	The process should be matched to the expected range of flowrate. For example, stabilization ponds are not suitable for extremely large flowrates in highly populated areas.
3.Applicable flow variation	Most unit operations and processes have to be designed to operate over a wide range of flowrates. Most processes work best at a relatively constant flowrate. If the flow variation is too great, flow equalization may be necessary.

4.Influent wastewater characteristics	The characteristics of the influent wastewater affect the types of processes to be used (e.g.,chemical or biological) and the requirements for their proper operation.
5.Inhibiting and unaffected constituents	What constituents are present and may be inhibitory to the treatment processes? What constituents are not affected during treatment?
6.Climatic constraints	Temperature affects the rate of reaction of most chemical and biological processes. Temperature may also affect the physical operation of the facilities. Temperatures may accelerate odor generation and also limit atmospheric dispersion.
7.Process sizing based on reaction kinetics or process loading criteria	Reactor sizing is based on the governing reaction kinetics and kinetic coefficients. If kinetic expressions are not available, process loading criteria are used. Data for kinetic expressions and process loading criteria usually are derived from experience, published literature, and the results of pilot-plant studies

8.Process sizing based on mass transfer rates or process loading criteria	Reactor sizing is based on mass transfer coefficients, If mass transfer rates are not available, process loading criteria are used. Data for mass transfer coefficients and process loading criteria usually are derived from experience, published literature, and the results of pilot-plant studies.
9.Performance	Performance is usually measured in terms of effluent quality and its variability, which must be consistent with the effluent discharge requirements
10.Treatment residuals	The types and amounts of solid, liquid, and gaseous residuals produced must be known or estimated. Often, pilot-plant studies are used to identify and quantify residuals.
11.Sludge processing	Are there any constraints that would make sludge processing and disposal infeasible or expensive? How might recycle loads from sludge processing affect the liquid unit operation or processes? The selection of the sludge processing system should go hand in hand with the selection of the liquid treatment system

12.Environmental constraints	Environment factors, such as prevailing wind directions and proximity to residential areas, may restrict or affect the use of certain processes, especially where odors may be produced. Noise and traffic may affect selection of a plant site. Receiving waters may have special limitations, requiring the removal of specific constituents such as nutrients.
13.Chemical requirements	What resources and what amounts must be committed for a long period of time for the successful operation of the unit operation or process? What effects might the addition of chemicals have on the characteristics of the treatment residuals and the cost of treatment?
14.Energy requirements	The energy requirements, as well as probable future energy cost, must be known if cost-effective treatment systems are to be designed.

Selection of Reactor Types

A complete-mix reactor might be selected over a plug-flow reactor, because of its dilution capacity, if the influent wastewater is known to contain toxic constituents that cannot be removed by pretreatment. Alternatively, a plug-flow or multistage reactor might be selected over a complete-mix reactor to control the growth of filamentous microorganisms.

Process Selection Based on Mass Transfer

The principal operations in wastewater treatment involving mass transfer are aeration, especially the addition of oxygen to water; the drying of biosolids and sludge; the removal of volatile organics from wastewater; the stripping of dissolved constituents such as ammonia from digested supernatant; and the exchange of dissolved constituents as in ion exchange.

Process Design Based on Loading Criteria

If appropriate reaction rate expressions and/or mass transfer coefficients cannot be developed, generalized loading criteria are frequently used. Early design loading criteria for activated sludge biological treatment systems were based on aeration tank capacity [e.g., kg of BOD/m^3 (lb BOD/10^3 ft^3)].

Bench Tests and Pilot-Plant Studies

The purpose of conducting pilot-plant studies is to establish the suitability of the process in the treatment of a specific wastewater under specific environmental conditions and to obtain the necessary data on which to base a full-scale design.

Tab. 4-6 Considerations in setting up pilot-plant testing programs

For example, testing of UV disinfection systems is typically done:

(1) to verify manufacturers' performance claims,

(2) to quantify effects of effluent water quality constituents on UV performance,

(3) to assess the effect(s) of system and reactor hydraulics on UV performance,

(4) to assess the effect(s) of effluent filtration on UV performance,

(5) to investigate photo reactivation and impacts.

Bench-scale tests are conducted in the laboratory with small quantities of the wastewater in question. Pilot-scale tests are typically conducted with flows that are 5 to 10 percent of the design flows.

Reliability Considerations in Process Selection

Because waste water treatment effluent quality is variable for a number of reasons (varying organic loads, changing environmental conditions, etc.), it is necessary to ensure that the treatment system is designed to produce effluent concentrations equal to or less than the permit limits.

5 Physical Unit Operation

Because physical unit operations were derived originally from observations of the physical world, they were the first treatment methods to be used.

The unit operations most commonly used in wastewater treatment include (1) screening, (2) coarse solids reduction (comminution, maceration, and screenings grinding), (3) flow equalization, (4) mixing and flocculation, (5) grit removal, (6) sedimentation, (7) high-rate clarification, (8) accelerated gravity separation (vortex separators), (9) flotation, (10) oxygen transfer, (11)packed-bed filtration, membrane separation, (12) aeration, (13)biosolid dewatering, and (14) volatilization and stripping of volatile organic compounds (VOCs).

5-1 Screening

A screen is a device with openings, generally of uniform size, that is used to retain solids found in the influent wastewater

The coarse materials could

(1) damage subsequent process equipment,

(2) reduce overall treatment process reliability and effectiveness,

(3) contaminate waterways.

All aspects of screenings removal, transport, and disposal must be considered in the application of screening devices, including

(1) the degree of screenings removal required because of potential effects on downstream processes,

(2) health and safety of the operators as screenings contain pathogenic organisms and attract insects,

(3) odor potential

(4) requirements for handling, transport, and disposal,

(5) disposal options.

Classification of Screens

Coarse screens have clear openings ranging from 6 to 150 mm; fine screens have clear openings less than 6 mm. Micro screens generally have screen openings less than 50 μm.

The screening element may consist of parallel bars, rods or wires, grating, wire mesh, or perforated plate, and the openings may be of any shape but generally are circular or rectangular slots.

Coarse Screens (Bar Racks)

In wastewater treatment, coarse screens are used to protect pumps, valves, pipelines and other appurtenances from damage or clogging by rags and large objects.

Hand-Cleaned Coarse Screens

Hand-cleaned coarse screens are used frequently ahead of pumps in small wastewater pumping stations and sometimes used at the headworks of small- to medium-sized wastewater-treatment plants. Often they are used for standby screening in bypass channels for service during high-flow periods, when mechanically cleaned screens are being repaired, or in the event of a power failure.

A perforated drainage plate should be provided at the top of the rack where the raking may be stored temporarily for drainage.

The screen channel should be designed to prevent the accumulation of grit and other heavy materials in the channel ahead of the screen and following it. The channel floor should be level or should slope downward through the screen without pockets to trap solids.

Mechanically Cleaned Bar Screens

The design of mechanically cleaned bar screens has evolved over the years to reduce the operating and maintenance problems and to improve the screenings removal capabilities. Many of the newer designs include extensive use of corrosion-resistant materials including stainless steel and plastics(ABS, etc).

Reciprocating Rake (Climber) Screen

The reciprocating-rake-type bar screen (see Fig. 5-3b) imitates the movements of a person raking the screen.

A major advantage is that all parts requiring maintenance are above the waterline and can be easily inspected and maintained without dewatering the channel. The front cleaned, front return feature minimizes solids carryover.

As a result, the reciprocating rake screen may have limited capacity in handling heavy screenings loads, particularly in deep channels where a long 'reach' is necessary.

Fig 5-3 Typical mechanically cleaned coarse screens: (a)front clean, front return chain-driven; (b)reciprocating rake, (c)catenary, (d)continuous belt

Catenary Screen

In the catenary screen (see Fig. 5-3c), the rake is held against the rack by the weight of the chain. If heavy objects become jammed in the bars, the rakes pass over them instead of jamming. The screen, however, has a relatively large 'footprint' and thus requires greater space for installation.

Continuous Belt Screen

The continuous belt screen is a relatively new development for use in screening applications. A large number of screening elements (rakes) are attached to the drive chains.

Hooks protruding from the belt elements are provided to capture large solids such as cans, sticks, and rags.

Design of Coarse Screen Installations

Considerations in the design of screening installations include

(1) location;

(2)approach velocity;

(3)clear openings between bars or mesh size;

(4) headloss through the screens;

(5) screenings handling processing, and disposal;

(6) controls.

In nearly all cases, coarse screen should be installed ahead of the grit chambers. If grit chambers are placed before screens, rags and other stringy material could foul the grit chamber collector mechanisms, wrap around air piping, and settle with the grit.

In hand-cleaned installations, it is essential that the velocity of approach be limited to approximately 0.45 m/s at average flow to provide adequate screen area for accumulation of screenings between raking operations. Additional area to limit the velocity may be obtained by widening the channel at the screen and by placing the screen at a flatter angle to increase the submerged area. As screenings accumulate, partially plugging the screen, the upstream head will increase, submerging new areas for the flow to pass through.

Two or more units should be installed so that one unit may be taken out of service for maintenance.

The unit can be dewatered for screen maintenance and repair. If only one unit is installed, it is absolutely essential that a bypass channel with a manually cleaned bar screen be provided for emergency use.

An approach velocity of at least 0.4 m/s is recommended to minimize solids deposition in the channel. To prevent the pass-through of debris at peak flowrates, the velocity through the bar screen should not exceed 0.9 m/s. Headloss through mechanically cleaned coarse screens is typically limited to about 150 mm.

Hydraulic losses through bar screens are a function of approach velocity and the velocity through the bars.

For installations with multiple units, the screenings may be discharged onto a conveyor or into a pneumatic ejector system and transported to a common screenings storage hopper. As an alterative, screenings grinders may be used to grind and shred the screenings. Ground screenings are then returned to the wastewater, however, ground screenings may adversely affect operation and maintenance of down stream equipment such as clogging weir openings on sedimentation tanks or wrapping around air diffusers.

Fine Screens

The applications for fine screens range over a broad spectrum; uses include preliminary treatment (following coarse bar screens), primary treatment (as a substitute for primary clarifiers), and treatment of combined sewer overflows. Fine screens can also be used to remove solids from primary effluent that could cause clogging problems in trickling filters.

Screens for Preliminary and Primary Treatment

Fine screens used for preliminary treatment are of the

(l) static (fixed),

(2) rotary drum,

(3) step type.

Typically, the openings vary from 0.2 to 6 mm. Examples of line screens are illustrated on Fig. 5-4.

Fig. 5-4 Typical fine screens: (a)static wedge-wire, (b)drum, (c)step. In step screens, screenings are moved up the screen by means of movable and fixed vertical plates.

Stainless-steel mesh or special wedge-shaped bars are used as the screening medium. Provision is made for the continuous removal of the collected solids, supplemented by water sprays to keep the screening medium clean.

Drum Screens

The wastewater flows either into one end of the drum and outward through the screen with the solids collection on the interior surface, or into the top of the unit and passing through to the interior with solids collection on the exterior. Internally fed screens with applicable for flow ranges of 0.03 to 0.8 m^3/s per screen, while externally fed screens are applicable for flowrates less than 0.13 m^3/s. Drum screens are available n various sizes from 0.9 to 2 m in diameter and from 1.2 to 4 m in length.

Step Screens

The design consists of two step-shaped sets of thin vertical plates, one fixed and one movable .

The fixed and movable step plates alternate across the width of an open channel and together form a single screen face. The movable plates rotate in a vertical motion. Through this motion solids captured on the screen face are automatically lifted up to the next fixed step landing, and are eventually transported to the top of the screen where they are discharged to a collection hopper. The circular pattern of the moving plates provides a self-cleaning feature for each step.

Solids trapped on the screen also create a "filter mat" that enhances solids removal performance.

Design of Fine-Screen Installations

An installation should have a minimum of two screens, each with the capability of handling peak flowrates. In colder climates, hot water or steam is more effective for grease removal.

Headloss depends on the size and amount of solids in the wastewater, the size of the apertures, and the method and frequency of cleaning.

Microscreens

Microscreening involves the use of variable low-speed (up to 4 r/min), continuously backwashed, rotating-drum screens operating under gravity-flow conditions.

The wastewater enters the open end of the drum and flows outward through the rotating-drum screening cloth. The collected solids are backwashed by high-pressure jets into a trough located within the drum at the highest point of the drum.

Reducing the rotating speed of the drum and less frequent flushing of the screen have resulted in increased removal efficiencies but reduced capacity.

Screenings Retained on Coarse Screens

Coarse screenings, collected on coarse screens of about 12 mm or greater spacing, consist of debris such as rocks, branches, pieces of lumber, leaves, paper, tree roots, plastics, and rags.

Tab. 5-4 Typical information on the characteristics and quantities of screenings removed from wastewater with coarse screens

Combined storm and sanitary collection systems may produce volumes of screenings several times the amounts produced by separate systems.

Screenings Retained on Fine Screens

The materials retained on fine screens include small rags, paper, plastic materials of various types razor blades, grit, undecomposed food waste, feces, etc. Compared to coarse screenings, the specific weight of the fine screenings is slightly lower and the moisture content is slightly higher.

Fine screenings contain substantial grease and scum, which require similar care, especially if odors are to be avoided.

Screenings Handling, Processing, and Disposal

Screenings are discharged from the screening unit directly into a screenings grinder, a pneumatic ejector, or a container for disposal; or onto a conveyor for transport to a screenings compactor or collection hopper.

Screenings compactors can be used to dewater and reduce the volume of screenings.

Fig. 5-5 Typical device used for compacting screenings

Compactors can reduce the water content of the screenings by up to 50 percent and the volume by up to 75 percent. As with pneumatic ejectors, large objects can cause jamming, but automatic controls can sense jams, automatically reverse the mechanism, and actuate alarms and shut down equipment.

Means of disposal of screenings include (1) removal by hauling to disposal areas (landfill) including co-disposal with municipal solid wastes, (2) disposal by burial on the plant site (small installations only), (3) incineration either alone or in combination with sludge and grit (large installations only), and (4) discharge to grinders or macerators where they are ground and returned to the wastewater.

In some cases, screenings are required to be lime stabilized for the control of pathogenic organisms before disposal in landfills.

5-2 Coarse Solids Reduction

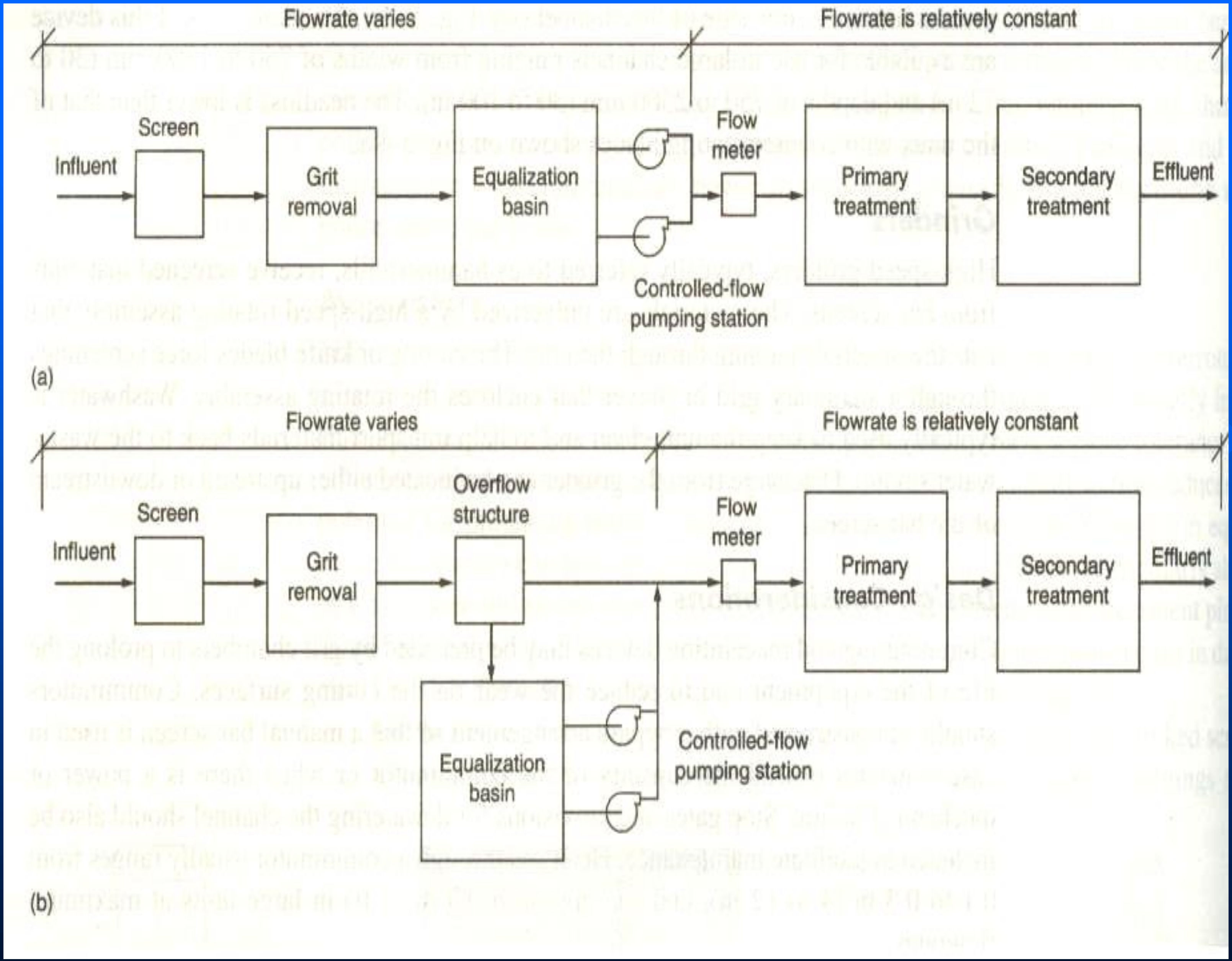
There is a wide divergence of views, however, on the suitability of using devices that grind and shred screenings at wastewater-treatment plants. One school of thought maintains that once coarse solids have been removed from wastewater, they should not be returned, regardless of the form. The other school of thought maintains that once cut up, the solids are more easily handled in the downstream processes. Shredded solids often present downstream problems, particularly with rags and plastic bags, as they tend to form ropelike strands. Rag and plastic strands can have a number of adverse impacts, such as clogging pump impellers, sludge pipelines, and heat exchangers, and accumulating on air diffusers and clarifier mechanisms. Plastics and other non-biodegradable material may also adversely affect the quality of bio-solids that are to be beneficially reused.

5-3 Flow Equalization

Flow equalization is a method used to overcome the operational problems caused by flowrate variations, to improve the performance of the downstream processes, and to reduce the size and cost of down- stream treatment facilities.

Description/Application

Fig. 5-8 Typical wastewater treatment plant flow diagram incorporating flow equalization: (a)in-line equalization ;(b)off-line equalization. Flow equalization can be applied after grit removal, after primary sedimentation ,and after secondary treatment where advanced treatment is used


Flowrate varies
Flowrate is relatively constant
Screen
Influent
Grit removal
Equalization basin
Flow meter
Primary treatment
Secondary treatment
Effluent
Controlled-flow pumping station
(a)
Flowrate varies
Flowrate is relatively constant
Overflow structure
Screen
Influent
Grit removal
Flow meter
Primary treatment
Secondary treatment
Effluent
Equalization basin
Controlled-flow pumping station
(b)

Off-line equalization is sometimes used to capture the 'first flush' from combined collection systems.

The principal benefits are:

(1) biological treatment is enhanced, because shock loadings are eliminated or can be minimized, inhibiting substances can be diluted and pH can be stabilized;

(2) the effluent quality and thickening performance of secondly sedimentation tanks is improved through improved consistency in solids loading;

(3) effluent filtration surface area requirements are reduced, and more uniform filter-backwash cycles are possible;

(4) in chemical treatment, damping of mass loading improves chemical feed control and process reliability.

Disadvantages of flow equalization include:

(1) relatively large land areas or sites are needed;

(2) equalization facilities may have to be covered for odor control near residential areas;

(3) additional operation and maintenance is required;

(4) capital cost is increased.

Location of Equalization Facilities

In some cases, equalization after primary treatment and before biological treatment may be appropriate. Equalization after primary treatment causes fewer problems with solids deposits and scum accumulation. If flow-equalization systems are to be located ahead of primary settling and biological systems, the design must provide for sufficient mixing to prevent solids deposition and concentration variations, and aeration to prevent odor problems.

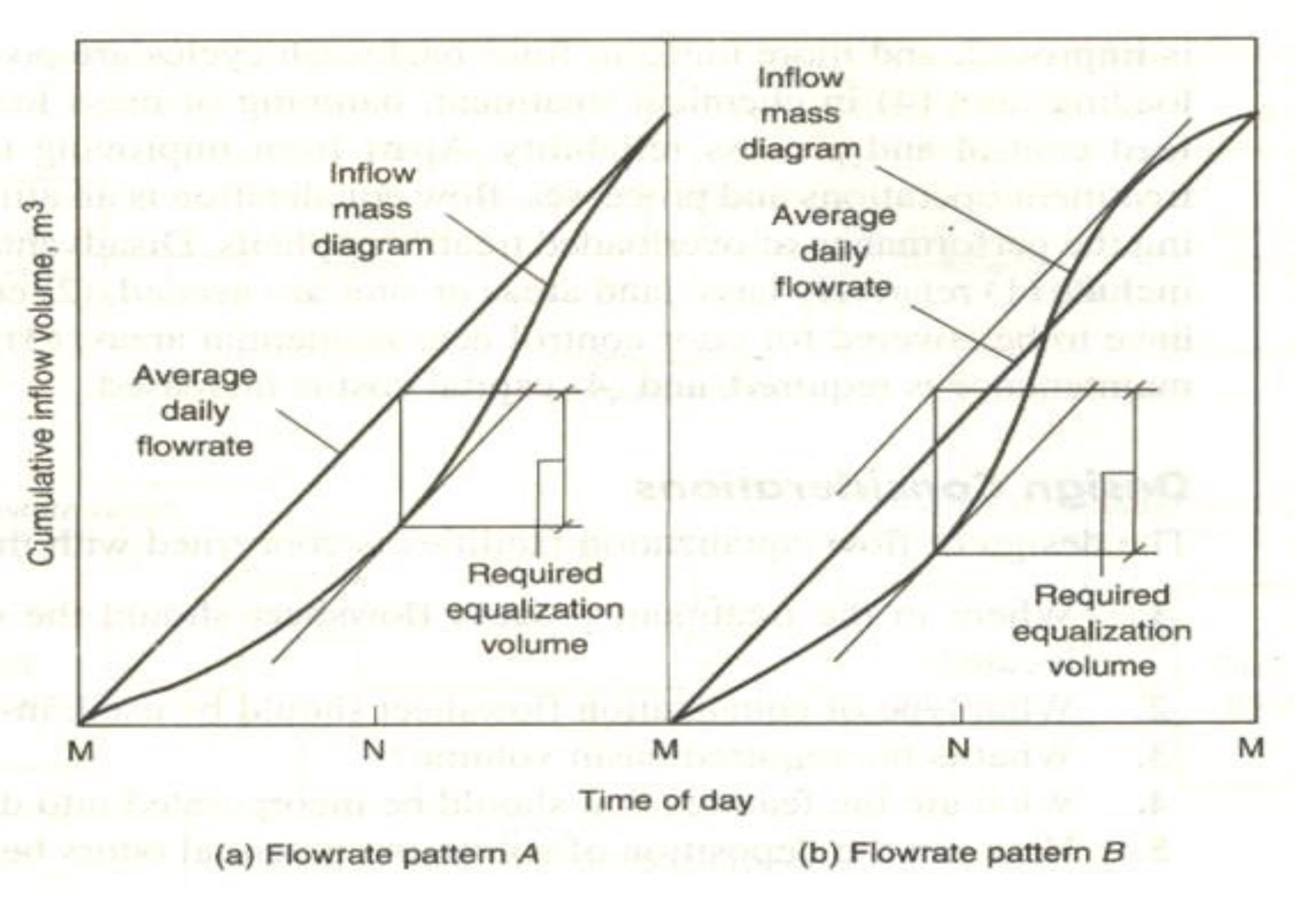
In-Line or Off-Line Equalization

As shown on Fig. 5-8, it is possible to achieve considerable damping of constituent mass loadings to the downstream processes with in-line equalization, but only slight damping is achieved with off-line equalization.

Volume Requirements for the Equalization Basin

The volume required for flowrate equalization is determined by using an inflow cumulative volume diagram in which the cumulative inflow volume is plotted versus the time of day. The average daily flowrate, also plotted on the same diagram, is the straight line drawn from the origin to the endpoint of the diagram.

Fig. 5-9 Schematic mass diagrams for the determination of the required equalization basin storage volume for two typical flowrate patterns



The required volume is then equal to the vertical distance from the point of tangency to the straight line representing the average flowrate .

The required volume is then equal to the vertical distance between the two lines.

In practice, the volume of the equalization basin will be larger than that theoretically determined to account for the following factors:

(1)continuous operation of aeration and mixing equipment will not allow complete drawdown.

(2) volume must be provided to accommodate the concentrated plant recycle streams that are expected, if such flows are returned to the equalization basin

Basin Geometry

If in-line equalization is used to dampen both the flow and the mass loadings, it is important to use a geometry that allows the basin to function as a continuous-flow stirred-tank reactor insofar as possible.

Therefore, elongated designs should be avoided, and the inlet and outlet configurationally should be arranged to minimize short circuiting.

Basin Construction

New basins may be of earthen, concrete, or steel construction; earthen basins are generally the least expensive.

In most installations, a liner is required to prevent ground-water contamination. Basin depths will vary depending on land availability, ground-water level, and topography, if a liner is used in areas of high groundwater, the effects of hydraulic uplift on the liner must be considered.

If a floating aerator is used to provide mixing and prevent septicity and odor formation, a minimum operating level is needed to protect the aerator.

To prevent wind-induced erosion in the upper portions of the basin, it may be necessary to protect the slopes with riprap, soil cement, or a partial concrete layer. Fencing should also be provided to prevent public access to the basins.

Mixing and Air Requirements

To minimize mixing requirements, grit-removal facilities should precede equalization basins where possible. Mixing requirements for blending a medium-strength municipal wastewater, having a suspended solids concentration of approximately 210 mg/L, range from 0.004 to 0.008 kW/m^3 of storage. In equalization basins that follow primary sedimentation and have short detention times (less than 2 h), aeration may not be required.

To protect the aerators in the event of excessive level drawdown, low-level shutoff controls should be provided. Various types of diffused air systems may also be used for mixing and aeration including static tube, jet, and aspirating aerators.

Operational Appurtenances

Among the appurtenances that should be included in the design of equalization basins are (1) facilities for flushing any solids and grease that may tend o accumulate on the basin walls; (2) a high water takeoff for the removal of floating material and foam; (3) water sprays to prevent the accumulation of foam on the sides of the basin and to aid in scum removal; and (4) separate odor control facilities where covered equalization basins must be used.

Pumps and Pump Control

An automatically controlled flow-regulating device will be required where gravity discharge from the basin is used.

5-4 Mixing and Flocculation

Mixing is an important unit operation in many phases of wastewater treatment including:

(1) mixing of one substance completely with another,

(2) blending of miscible liquids,

(3) flocculation of wastewater particles,

(4) continuous mixing of liquid suspensions,

(5) heat transfer.

Continuous Rapid Mixing in Wastewater Treatment

Continuous rapid mixing is used, most often, where one substance is to be mixed with another. The principal applications of continuous rapid mixing are in

(1) the blending of chemicals with wastewater (e.g., the addition of alum or iron salts prior to flocculation and settling or for dispersing chlorine and hypochlorite into wastewater for disinfection),

(2) the blending of miscible liquids,

(3) the addition of chemicals to sludge and biosolids to improve their dewatering characteristics.

Continuous Mixing in Wastewater Treatment

Continuous mixing is used where the contents of a reactor or holding tank or basin must be kept in suspension such as in equalization basins, flocculation basins, suspended-growth biological treatment processes, aerated lagoons, and aerobic digesters.

Flocculation in Wastewater Treatment

The purpose of wastewater flocculation is to form aggregates or flocs from finely divided particles and from chemically destabilized particles. Flocculation is a transport step that brings about the collisions between the destabilized particles needed to form larger particles that can be removed readily by settling or filtration.

Maintaining Material in Suspension

In biological treatment systems the mixing device is also used to provide the oxygen needed for the process. Thus, the aeration equipment must be able to provide the oxygen needed for the process and must be able to deliver the energy needed to maintain mixed conditions within the reactor.

In both aerobic and anaerobic digestion, mixing is used to homogenize the contents of the digester to accelerate the biological conversion process, and to distribute uniformly the heat generated from biological conversion reactions.

Types of Mixers Used for Rapid Mixing in Wastewater Treatment

The principal devices used for rapid mixing in wastewater-treatment applications include static in-line mixers, high-speed induction mixers, pressurized water jets, and propeller and turbine mixers. Mixing can also be accomplished in pumps and with the aid of hydraulic devices such as hydraulic jumps, Parshall flumes, or weirs.

Static Mixers

Static in-line mixers contain internal vanes or orifice plates that bring about sudden changes in the velocity patterns as well as momentum reversals. Static mixers are principally identified by their lack of moving parts.

In-line mixers are available in sizes varying from about 12 mm to 3 m × 3 m open channels. Low-pressure-drop round, square, and rectangular in-line static mixers have been developed for chlorine mixing in open channels and tunnels

For static in-line mixers with vanes, the longer the mixing elements, the better the mixing; however, the pressure loss increases.

In-line mixers are similar to static mixers but contain a rotating mixing element to enhance the mixing process.

In the in-line mixer shown on Fig. 5-12c, the power required for mixing is supplied by an external source. For the mixer shown on Fig. 5-12d, the power for mixing is supplied by the energy dissipation caused by the orifice plate and by the power input to the propeller mixer.

High-Speed Induction Mixer

A proprietary device, consists of a motor-driven open propeller that creates a vacuum in the chamber directly above the propeller.

Pressurized Water Jets

With pressurized water jet mixers, the power for mixing is provided by an external source (i.e., the solution feed pump).

Turbine and Propeller Mixers

Turbine or propeller mixers are usually constructed with a vertical shaft driven by a speed reducer and electric motor. Two types of impellers are used for mixing: (1) radial-flow impellers and (2) axial-flow impellers. Radial-flow impellers generally have flat or curved blades located parallel to the axis of the shaft. The vertical flat-blade turbine impeller is a typical example of a radial-flow impeller. Axial-flow impellers make an angle of less than 90° with the drive shaft.

Types of Mixers Used for Flocculation in Wastewater Treatment

Static Mixers

Static mixers can be comprised of over and under narrow flow channels, such as shown on Fig. 5-12a, or the narrow flow channels can be laid out horizontally.

In some designs, the channel spacing is varied to provide a decreasing energy gradient so that the large floc particles formed toward the end of the flocculation basin will not be broken apart.

Paddle Mixers

Paddle mixers are used as flocculation devices when coagulants, such as aluminum or ferric sulfate, and coagulant aids, such as polyelectrolytes and lime, are added to wastewater or solids (sludge).

Increased particle contact promotes floc growth, but, if the mixing is too vigorous, the increased shear forces will break up the floc into smaller particles.

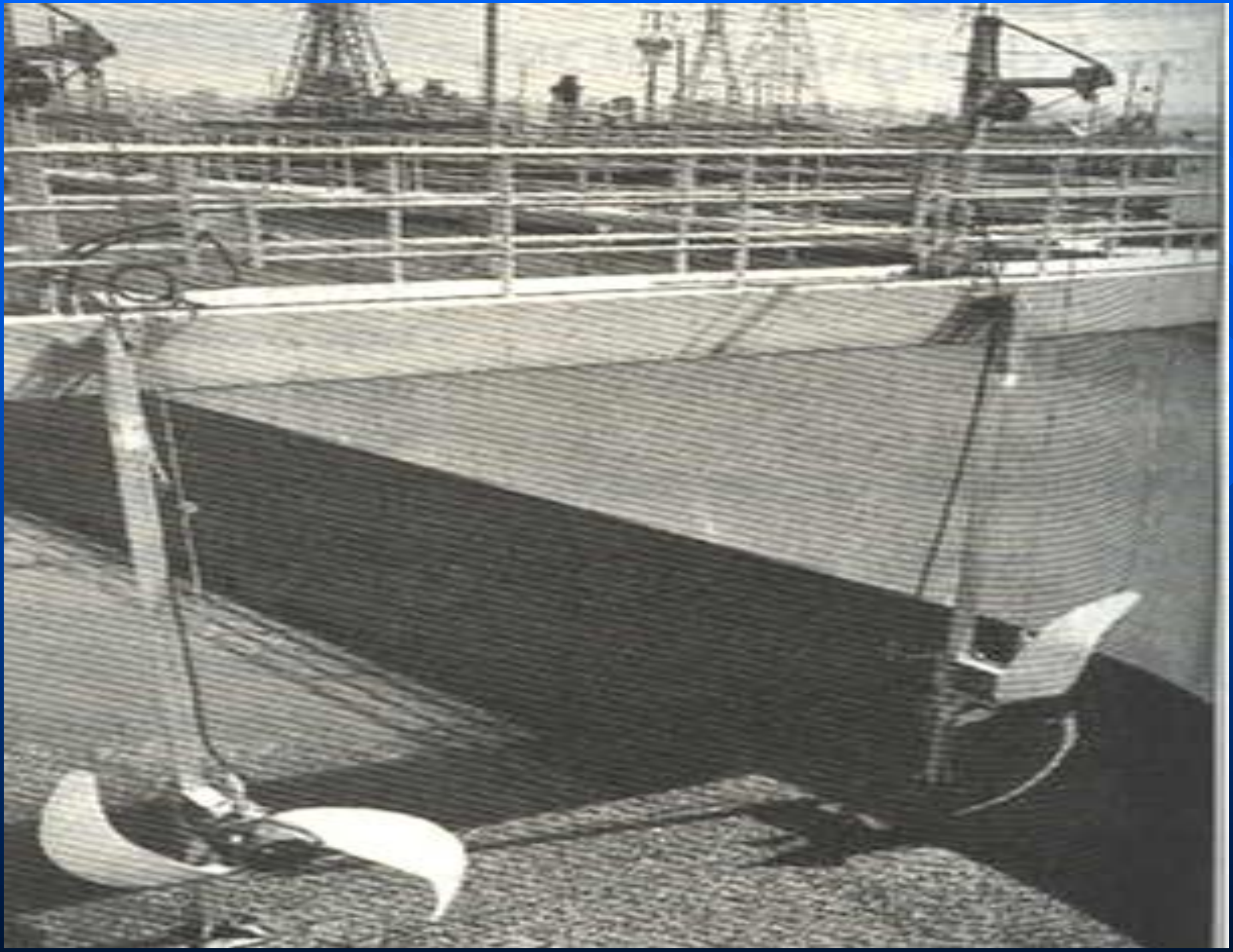
Types of Mixers Used for Continuous Mixing in Wastewater Treatment

Horizontal, submersible propeller mixers are often used to maintain channel velocities in oxidation ditches, mix the contents of anoxic reactors (see Fig. 5-15) , and aid in the destratification of reclaimed water storage reservoirs.

Pneumatic Mixing

In pneumatic mixing, a gas (usually air or oxygen) is injected into the bottom of mixing or activated-sludge tanks, and the turbulence caused by the rising gas bubbles serves to mix the fluid contents of the tank.

Fig. 5-15 Submerged propeller mixers used to mix the contents of an anoxic reactor



5-5 Gravity Separation Theory

The terms sedimentation and settling are used interchangeably.

Sedimentation is also used for solids concentration in sludge thickeners.

Particle Settling Theory

The settling of discrete, nonflocculating particles can be analyzed by means of the classic laws of sedimentation formed by Newton and Stokes. Newton's law yields the terminal particle velocity by equating the gravitational force of the particle to the frictional resistance, or drag.

Settling in the Laminar Region

For Reynolds numbers less than about 1.0, viscosity is the predominant force governing the settling process.

Flocculent Particle Settling

The extent to which flocculation occurs is dependent on the opportunity for contact, which varies with overflow rate, depth of the basin, velocity gradients in the system, concentration of particles, and range of particle sizes. The effects of these variables can be determined only by sedimentation tests.

The settling characteristics of a suspension of flocculent particles can be obtained by using a settling column test. Such a column can be of any diameter but should be equal in height to the depth of the proposed tank.

Settling should take place under quiescent conditions. The duration of the test should be equivalent to the settling time in the proposed tank.

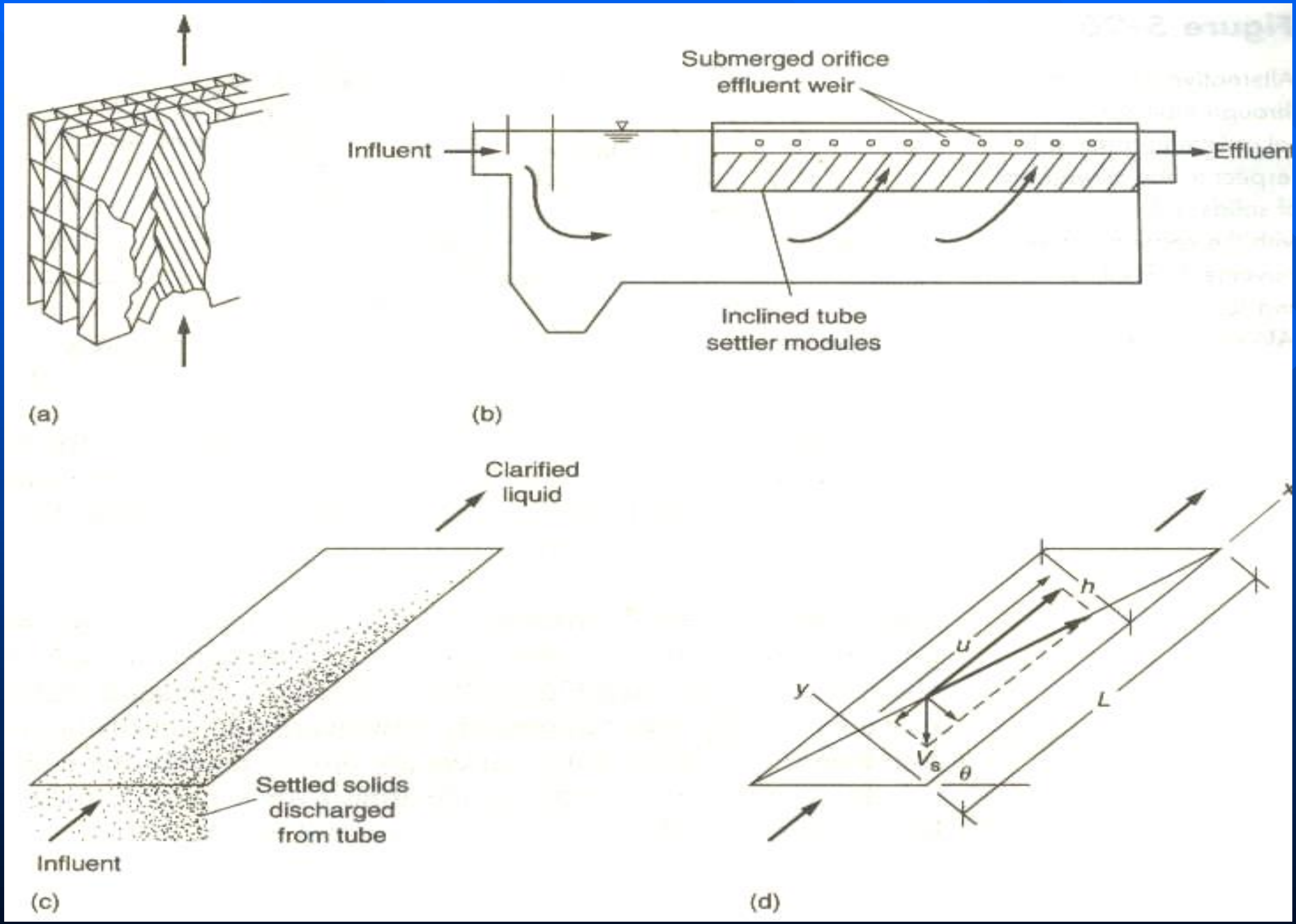
The more traditional method of determining settling characteristics of a suspension is to use a column similar to the one described above but with sampling ports inserted at approximately 0.5 m intervals. At various time intervals, samples are withdrawn from the ports and analyzed for suspended solids. The percent removal is computed for each sample analyzed and is plotted as a number against time and depth.

Inclined Plate and Tube Settling

Inclined plate and tube settlers are shallow settling devices consisting of stacked offset trays or bundles of small plastic tubes of various geometries .

They are based on the theory that settling depends on the settling area rather than detention time. Although they are used predominantly in water-treatment applications, plate and tube settlers are used in wastewater-treatment for primary, secondary, and tertiary sedimentation.

Fig. 5-17 Plate and tube settlers: (a)module of inclined tubes, (b)tubes installed in a rectangular sedimentation tank, (c)operation, (d)definition sketch for the analysis of settling in a tube settler



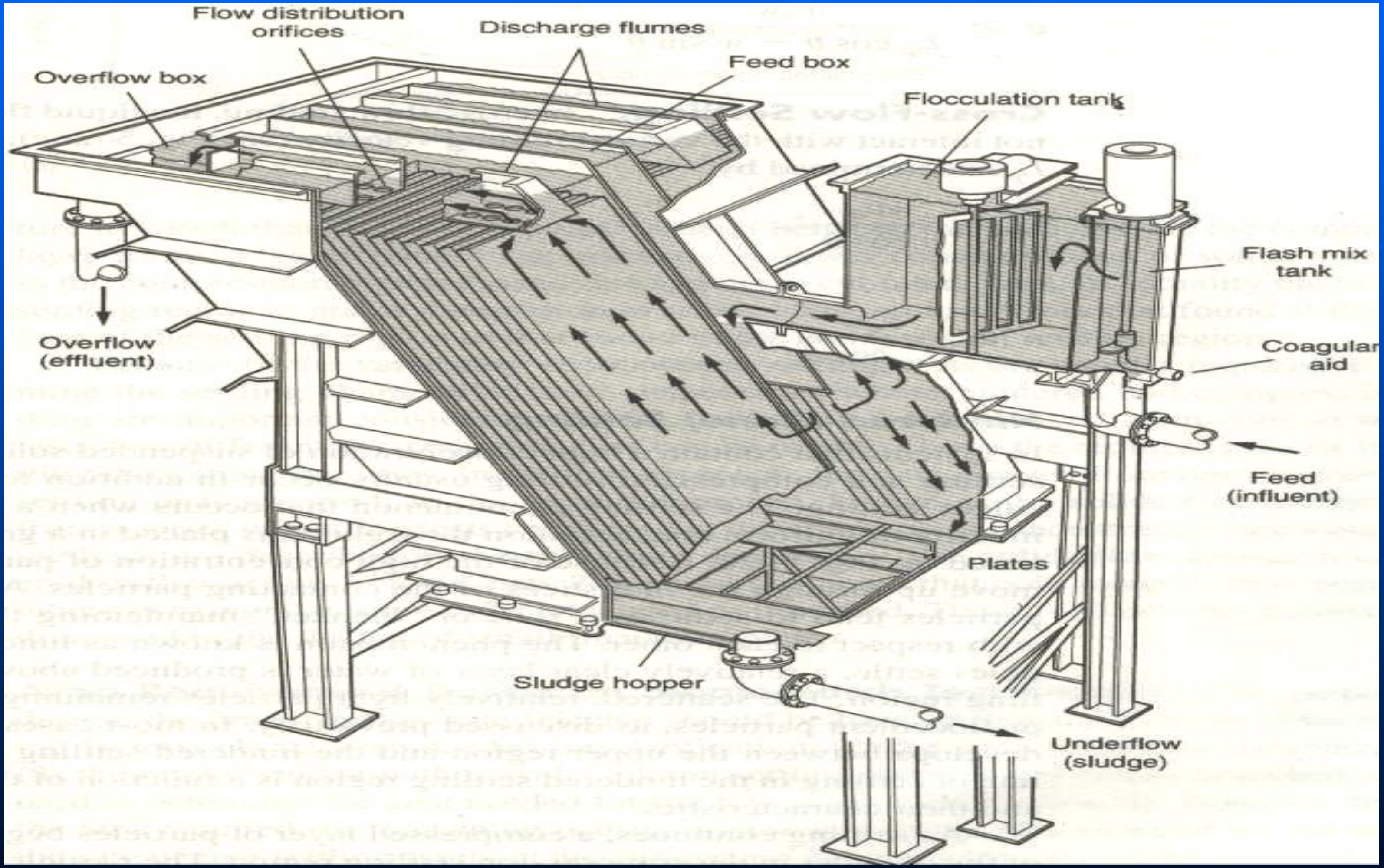
To be self-cleaning, plate ox tube settlers are usually set at an angle between 45 and 60^{o} above the horizontal. When the angle is increased above 60^{o}, the efficiency decreases. If the plates and tubes are inclined at angles less than 45% solids will tend to accumulate within the plates or tubes. Nominal spacing between plates is 50 mm, with an inclined length of 1 to 2 m. To control biological growths and the production of odors (the principal problems encountered with their use), the accumulated solids must be flushed out periodically

Inclined settling systems are generally constructed for use in one of three ways with respect to the direction of liquid flow relative to the direction of particle settlement:

(1) countercurrent, (2) co-current, and (3) cross-flow.

Countercurrent Settling.

Fig. 5-18 Lamella plate settler



Further thickening of the solids occurs in the hopper due to compression in the quiescent zone made possible by feeding the plates from the side rather than from the bottom.

5-6 Grit Removal

Primary sedimentation tanks function for the removal of the heavy organic solids.

Grit chambers are provided to (1) protect moving mechanical equipment from abrasion and accompanying abnormal wear; (2) reduce formation of heavy deposits in pipelines, channels, and conduits; and (3) reduce the frequency of digester cleaning caused by excessive accumulations of grit.

There are three general types of grit chambers: horizontal flow, of either a rectangular or a square configuration; aerated; or vortex type.

The aerated type consists of a spiral-flow aeration tank where the spiral velocity is induced and controlled by the tank dimensions and quantity of air supplied to the unit. The vortex type consists of a cylindrical tank in which the flow enters tangentially creating a vortex flow pattern; centrifugal and gravitational forces cause the grit to separate.

Rectangular Horizontal-Flow Grit Chambers

The design velocity will carry most organic particles through the chamber and will tend to resuspend any organic particles that settle but will permit the heavier grit to settle out.

The cross-sectional area will be governed by the rate of flow and by the number of channels. Allowance should be made for inlet and outlet turbulence.

Grit removal from horizontal- flow grit chambers is accomplished usually by a conveyor with scrapers, buckets, or plows. Screw conveyors or bucket elevators are used to elevate the removed grit for washing or disposal.

Square Horizontal-Flow Grit Chambers

They are nominally designed to remove 95 percent of the 0.15-mm-diameter (100- mesh) particles at peak flow.

In square grit chambers, the solids are removed by a rotating raking mechanism to a sump at the side of the tank.

The concentrated grit then may be washed again in a classifier using a submerged reciprocating rake or an inclined-screw conveyor. By either method, organic solids are separated from the grit and flow back into the basin, resulting in a cleaner, dryer grit.

Aerated Grit Chambers

In aerated grit chambers, air is introduced along one side of a rectangular tank to create a spiral flow pattern perpendicular to the flow through the tank.

If the velocity is too great, grit will be carried out of the chamber; if it is too small, organic material will be removed with the grit.

Aerated grit chambers are nominally designed to remove 0.21-mm-diameter (65-mesh) or larger, with 2- to 5-minute detention periods at the peak hourly rate of flow. The cross section of the tank is similar to that provided for spiral circulation in activated-sludge aeration tanks, except that a grit hopper about 0.9 m deep.

Influent and effluent baffles are used frequently for hydraulic control.

Wastewater should be introduced in the direction of the roll. To determine the required headloss through the chamber, the expansion in volume caused by the air must be considered.

Vortex-Type Grit Chambers

Effluent exits the center of the top of the unit from a rotating cylinder, or "eye" of the fluid. Centrifugal and gravitational forces within this cylinder minimize the release of particles with densities greater than water.

Grit settles by gravity to the bottom of the unit, while organics, including those separated from grit particles by centrifugal forces, exit principally with the effluent.

Grit Characteristics, Quantities, Processing, and Disposal

In addition to these materials, grit includes eggshells, bone chips, seeds, coffee grounds, and large organic particles.

Characteristics of Grit

Generally, what is removed as grit is predominantly inert and relatively dry material. However, grit composition can be highly variable, with moisture content ranging from 13 to 65 percent, and volatile content from 1 to 56 percent. A bulk density of 1600 kg/m^3 is commonly used for grit.

Unwashed grit may contain 50 percent or more of organic material.

Quantities of Grit

The quantities of grit will vary greatly from one location to another, depending on the type of sewer system, the characteristics of the drainage area, the condition of the sewers, the frequency of street sanding to counteract icing conditions, the types of industrial wastes, the number of household garbage grinders served, and in areas with sandy soils.

Disposal of Grit

The most common method of grit disposal is transport to a landfill. In some large plants, grit is incinerated with solids. As with screenings, some states require grit to be lime stabilized before disposal in a landfill. Disposal in all cases should be done in conformance with the appropriate environmental regulations.

5-7 Primary Sedimentation

Efficiently designed and operated primary sedimentation tanks should remove from 50 to 70 percent of the suspended solids and from 25 to 40 percent of the BOD.

Description

The selection of the type of sedimentation unit for a given application is governed by the size of the installation, by rules and regulations of local control authorities, by local site conditions, and by the experience and judgment of the engineer. Two or more tanks should be provided so that the process may remain in operation while one tank is out of service for maintenance and repair work. At large plants, the number of tanks is determined largely by size limitations.

Rectangular Tanks

Rectangular sedimentation tanks may use either chain-and-flight solids collectors or traveling-bridge-type collectors.

Equipment for settled solids removal generally consists of a pair of endless conveyor chains, manufactured of alloy steel, cast iron, or thermoplastic. Attached to the chains at approximately 3-m intervals are scraper flights made of wood or fiberglass, extending the full width of the tank or bay. The solids settling in the tank are scraped to solids hoppers in small tanks and to transverse troughs in large tanks.

Rectangular tanks may also be cleaned by a bridge-type mechanism that travels up and down the tank on rubber wheels or on rails supported on the sidewalls. One or more scraper blades are suspended from the bridge. Some of the bridge mechanisms are designed so that the scraper blades can be lifted clear of the solids blanket on the return travel.

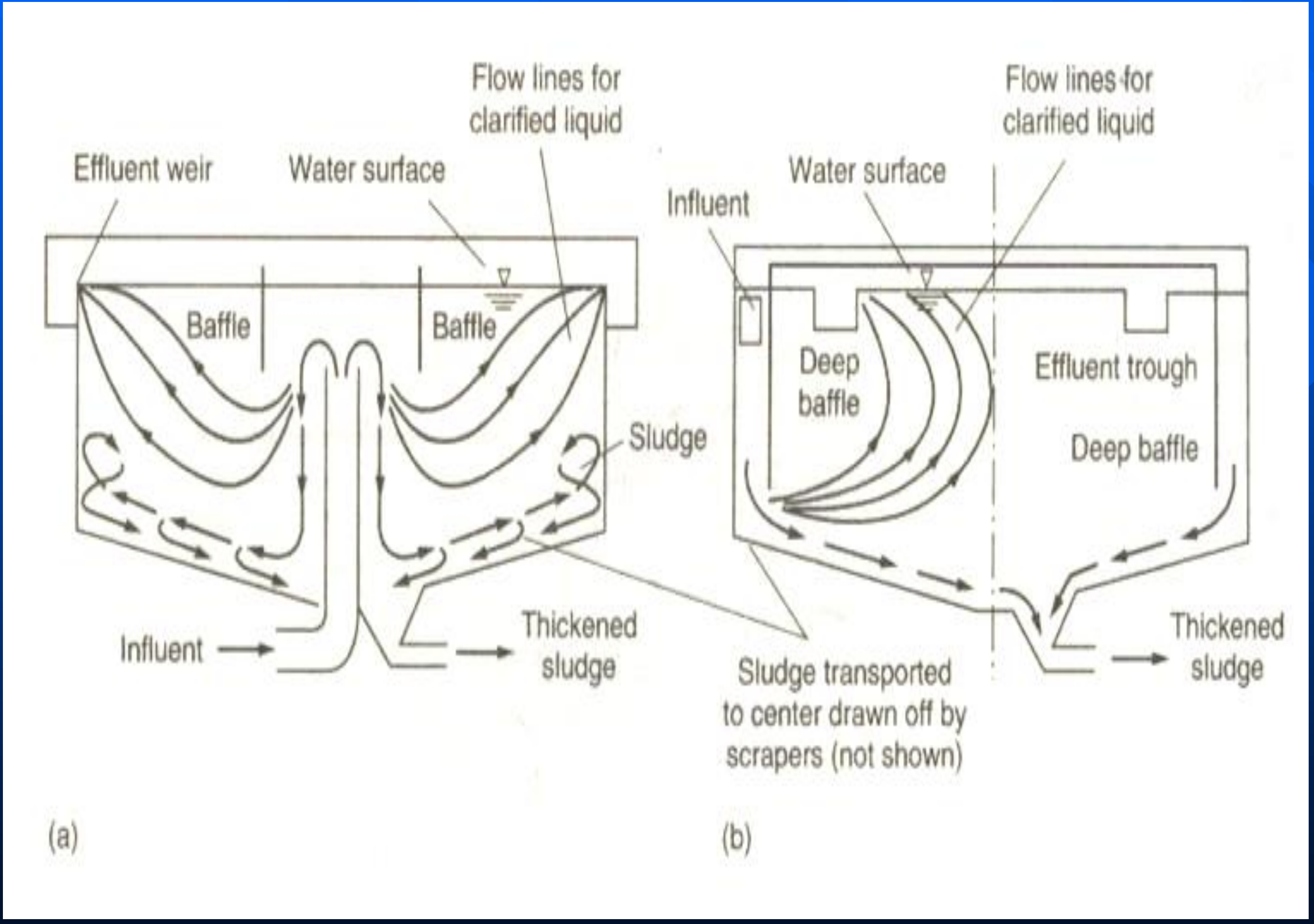
Because flow distribution in rectangular tanks is critical, one of the following inlet designs is used: (1) full-width inlet channels with inlet weirs, (2) inlet channels with submerged ports or orifices, (3) or inlet channels with wide gates and slotted baffles. Inlet weirs are effective in spreading flow across the tank width. Inlet ports can provide good distribution across the tank width if the velocities are maintained in the 3 to 9 m/min range, inlet baffles are effective in reducing the high initial velocities and distribute flow over the widest possible cross-sectional area. Where full-width baffles are used, they should extend from 150 mm below the surface to 300 mm below the entrance opening.

For installations of multiple rectangular tanks, below-grade pipe and equipment galleries can be constructed integrally with the tank structure and along the influent end. The galleries are used to house the sludge pumps and sludge drawoff piping. Galleries can also be connected to service tunnels for access to other plant units.

Scum is usually collected at the effluent end of rectangular tanks with the flights returning at the liquid surface. Water sprays can also move the scum.

Multiple rectangular tanks require less land area than multiple circular tanks. Rectangular tanks also lend themselves to nesting with preaeration tanks and aeration tanks in activated-sludge plants, thus permitting common wall construction and reducing construction costs.

Fig. 5-26 Typical circular primary sedimentation tanks: (a)center feed; (b)peripheral feed



In circular tanks the flow pattern is radial .To achieve a radial flow pattern, the wastewater to be settled can be introduced in the center or around the periphery of the tank.

The wastewater is transported to the center of the tank in a pipe suspended from the bridge, or encased in concrete beneath the tank floor.

The center well has a diameter typically between 15 and 20 percent often total tank diameter and ranges from 1 to 2.5 m in depth and should have a tangential energy-dissipating inlet within the feedwell.

The energy-dissipating device functions to collect influent from the center column and discharge it tangentially into the upper 0.5 to 0.7 m of the feedwell. The discharge ports are sized to produce a velocity of $\leq$ 0.75 m/s at maximum flow and 0.30 to 0.45 m/s at average flow.

The depth of the feedwell should extend about 1 meter below the energy-dissipating inlet ports.

The clarified liquid is skimmed off over weirs on both sides of a centrally located weir trough.

Circular tanks 3.6 to 9 m in diameter have the solids-removal equipment supported on beams spanning the tank. Tanks 10.5 m in diameter and larger have a central pier that supports the mechanism and is reached by a walkway or bridge. The bottom of the tank is sloped at about 1 in 12 (vertical: horizontal) to form an inverted cone, and the solids are scraped to a relatively small hopper located near the center of the tank.

Multiple tanks are customarily arranged in groups of two or four. The flow is divided among the tanks by a flow-split structure, commonly located between the tanks.

Stacked (Multilevel) Clarifiers

Stacked clarifiers originated in Japan in the 1960s where limited land area is available for the construction of wastewater-treatment facilities.

In addition to saving space, advantages claimed for stacked clarifiers include less piping and pumping requirements. Because the facilities are more compact and have less exposed surface area, better control of odors and volatile organic compound emissions is possible. Disadvantages include higher construction cost than conventional clarifiers and more complex structural design.

Sedimentation Tank Performance

The efficiency of sedimentation basins with respect to the removal of BOD and TSS is reduced by

(1) eddy currents formed by the inertia of the incoming fluid,

(2) wind-induced circulation cells formed in uncovered tanks,

(3) thermal convection currents,

(4) cold or warm water causing the formation of density currents that move along the bottom of the basin and warm water rising and flowing across the top of the tank,

(5) thermal stratification in hot arid climates.

Temperature Effects

Temperature effects can be significant in sedimentation basins. It has been shown that a 1° Celsius temperature differential between the incoming wastewater and the wastewater in the sedimentation tank will cause a density current to form .

Design Considerations

If all solids in wastewater were discrete particles of uniform size, uniform density, uniform specific gravity, and uniform shape, the removal efficiency of these solids would be dependent on the surface area of the tank and time of detention.

Detention Time

Normally, primary sedimentation tanks are designed to provide 1.5 to 2.5 h of detention based on the average rate of wastewater flow. In cold climates, increases in water viscosity at lower temperatures retard particle settling in clarifiers and reduce performance at wastewater temperatures below 20°C.

Surface Loading Rates

Sedimentation tanks are normally designed on the basis of a surface loading rate.

Scour Velocity

To avoid the resuspension (scouring) of settled particles, horizontal velocities through the tank should be kept sufficiently low.

Characteristics and Quantities of Solids (Sludge) and Scum

The solids volume will depend on (1) the characteristics of the untreated wastewater, including strength and freshness; (2) the period of sedimentation and the degree of purification to be effected in the tanks; (3) the condition of the deposited solids, including specific gravity, water content, and changes in volume under the influence of tank depth or mechanical solids-removal devices; and (4) the period between solids-removal operations.

5-8 High-rate Clarification

High-rate clarification employs physical/chemical treatment and utilizes special flocculation and sedimentation systems to achieve rapid settling.

Advantages of high-rate clarification are

(1) units are compact and thus reduce space requirements,

(2) start-up times are rapid (usually less than 30 min) to achieve peak efficiency,

(3) a highly clarified effluent is produced.

Enhanced Particle Flocculation

Enhanced particle flocculation involves the addition of an inert ballasting agent (usually silica sand or recycled chemically conditioned sludge) .

The polymer appears to coat the ballasting particles and forms the "glue' that binds the chemical floc to the ballasted particles

The particles grow as the larger, faster-settling particles overtake and collide with slower-settling particles. The velocity gradient G for flocculation is important as a high gradient will cause a breakdown in the floc particles, and insufficient agitation will inhibit floc formation.

Applications for high-rate clarification include

(1) providing advanced primary treatment,

(2) treating wet-weather flows and combined sewer overflows,

(3) treating waste filter backwash water,

(4) treating return flows from solids-processing facilities.

5-9 Large-scale Swirl and Vortex Separators for Combined Wastewater and Stormwater

These devices are compact solids-separation units with no moving parts. Concentrated foul matter is intercepted for treatment while the cleaner, treated flow discharges to receiving waters.

5-10 Flotation

Separation is brought about by introducing fine gas (usually air) bubbles into the liquid phase. The bubbles attach to the particulate matter, and the buoyant force of the combined particle and gas bubbles is great enough to cause the particle to rise to the surface. Particles that have a higher density than the liquid can thus be made to rise. The rising of particles with lower density than the liquid can also be facilitated .

In wastewater treatment, flotation is used principally to remove suspended matter and to concentrate biosolids.

The principal advantages of flotation over sedimentation are that very small or light particles that settle slowly can be removed more completely and in a shorter time.

Description

Air bubbles are added or caused to form by (1) injection of air while the liquid is under pressure, followed by release of the pressure (dissolved-air flotation), and (2) aeration at atmospheric pressure (dispersed-air flotation).

Dissolved-Air Flotation

In dissolved-air flotation (DAF) systems, air is dissolved in the wastewater under a pressure of several atmospheres, followed by release of the pressure to the atmospheric level.

Dispersed-Air Flotation

It is used in industrial applications for the removal of emulsified oil and suspended solids , air bubbles are formed by introducing the gas phase directly into the liquid phase through a revolving impeller.

The advantages of a dispersed-air flotation system are (1) compact size, (2) lower capital cost, and (3) capacity to remove relatively free oil and suspended solids.

The quantities of float skimmings are significantly higher than the pressurized unit: 3 to 7 percent of the incoming flow as compared to less that 1 percent for dissolved-air systems.

Chemical Additives

Chemicals are commonly used to aid the flotation process. These chemicals, for the most part, function to create a surface or a structure that can easily absorb or entrap air bubbles.

Various organic polymers can be used to change the nature of either the air-liquid interface or the solid-liquid interface, or both.

Design Considerations for Dissolved-Air Flotation Systems

Factors that must be considered in the design of flotation traits include the concentration of particulate matter, quantity of air used, the particle-rise velocity, and the solids loading rate.

The performance of a dissolved-air flotation system depends primarily on the ratio of the volume of air to the mass of solids (A/S) required to achieve a given degree of clarification.

5-11 Oxygen Transfer

The functioning of aerobic processes, such as activated sludge, biological filtration, and aerobic digestion, depends on the availability of sufficient quantities of oxygen.

Description

The low solubility of oxygen and the consequent low rate of oxygen transfer.

Either air or oxygen can be introduced into the liquid, or the liquid in the form of droplets can be exposed to the atmosphere.

In wastewater-treatment plants, submerged-bubble aeration is most frequently accomplished by dispersing air bubbles in the liquid at depths up to 10 m; depths up to 30 m have been used in some European designs.

Turbine mixers may be used to disperse air bubbles, they are designed both to mix the liquid in the basin and to expose it to the atmosphere in the form of small liquid droplets.

Evaluation of Oxygen Transfer Coefficient

Oxygen Transfer in Clean Water.

The accepted test method involves the removal of dissolved oxygen (DO) from a known volume of water by the addition of sodium sulfite followed by re-oxygenation to near the saturation level. The DO of the water volume is monitored during the reaeration period by measuring DO concentrations at several different points.

Oxygen Transfer in Wastewater

Typically, oxygen is maintained at a level of 1 to 3 mg/L . The mass transfer coefficient *KLa* is also a function of temperature, intensity of mixing and hence of the type of aeration device used and the geometry of the mixing chamber, and constituents in the water.

Effects of Mixing Intensity and Tank Geometry

In most cases an aeration device is rated for a range of operating conditions using tap water having a low TDS concentration.

Effects of Wastewater Characteristics

The correction factor is used to correct the test system oxygen transfer rate for differences in oxygen solubility due to constituents in the water such as salts, particulates, and surface-active substances. Values of β vary from about 0.7 to 0.98.

Application of Correction Factors

The actual amount of oxygen required must be obtained by applying factors to a standard oxygen requirement that reflect the effects of salinity-surface tension (beta factor), temperature, elevation, diffused depth (for diffused aeration systems), the desired oxygen operating level, and the effects of mixing intensity and basin configuration.

The fouling factor F is used to account for both internal and external fouling of air diffusers. Internal fouling is caused by impurities in the compressed air, whereas external fouling is caused by the formation of biological slimes and inorganic precipitants.

5-12 Aeration Systems

The systems used depend on the function to be performed, type and geometry of the reactor, and cost to install and operate the system.

Diffused-Air Aeration

A diffused-air system consists of diffusers that are submerged in the wastewater, header pipes, air mains, and the blowers and appurtenances through which the air passes.

Porous Diffusers

Domes, disks, or tube diffusers are mounted on or screwed into air manifolds.

Dome and disk diffusers may also be installed in a grid pattern on the bottom of the aeration tank to provide uniform aeration throughout the tank.

These materials generally fall into the categories of rigid ceramic and plastic materials and flexible plastic, rubber, or cloth sheaths.

When the air is turned on, the sheath expands and each slot acts as a variable aperture opening; the higher the air flowrate, the greater the opening.

Advantages cited for aeration panels are (1) ultra-fine bubbles are produced that significantly improve oxygen transfer and system energy efficiency, (2) large areas of the tank floor can be covered, which facilitates mixing and oxygen transfer, and (3) foulants can be dislodged by "bumping," i.e., increasing the airflow to flex the membrane.

Disadvantages are (1) the panel is a proprietary design and thus lacks competitive bidding, (2) the membrane has a higher headloss, which may affect blower performance in retrofit applications, and (3) increased blower air filtration is required to prevent internal fouling.

Nonporous Diffusers

The advantages of lower cost, less maintenance, and the absence of stringent air-purity requirements may offset the lower oxygen transfer efficiency and energy cost.

Diffuser Performance

Aeration devices are conventionally evaluated in clean water and the results adjusted to process operating conditions through widely used conversion factors.

Factors commonly used to convert the oxygen transfer required for clean water to wastewater are the alpha, beta, and theta factors.

The presence of constituents such as detergents, dissolved solids, and suspended solids can affect the bubble shape and size and result in diminished oxygen transfer capability.

Blowers

There are three types of blowers commonly used for aeration: centrifugal, rotary lobe positive displacement, and inlet guide vane-variable diffuser. Centrifugal blowers are almost universally used where the unit capacity is greater than 425 m^3/min of free air. Rated discharge pressures range normally from 48 to 62 kN/m^2.

The operating point of the blower is determined, similar to a centrifugal pump, by the intersection of the head-capacity curve and the system curve.

Because it is necessary to meet a wide range of airflows and pressures at a wastewater-treatment plant, provisions have to be included in the blower system design to regulate or turn down the blowers. Methods to achieve regulation or turndown are (1) flow blowoff or bypassing, (2) inlet throttling, (3) adjustable discharge diffuser, (4) variable-speed driver, and (5) parallel operation of multiple units.

For higher discharge pressure applications (> 55 kN/m^2) and for capacities smaller than 425 m^3/min of free air per unit, rotary-lobe positive-displacement blowers are commonly used. The positive-displacement blower is a machine of constant capacity with variable pressure.

The performance curve typically is a falling-head curve where the pressure decreases as the inlet volume increases. Blowers are rated at standard air conditions, defined as a temperature of 20ºC, a pressure of 760 mm Hg, and a relative humidity of 36 percent. Standard air has a specific weight of 1.20 kg/m^3.

Air Piping

Air piping consists of mains, valves, meters, and other fittings that transport compressed air from the blowers to the air diffusers. Because the pressures are low(less than 70 kN/m^2), lightweight piping can be used.

The piping should be sized so that losses in air headers and diffuser manifolds are small in comparison to the losses in the diffusers. Typically, if headlosses in the air piping between the last flow-split device and the farthest diffuser are less than 10 percent of the headloss across the diffusers, good air distribution through the aeration basin can be maintained. Valves and control orifices are an important consideration in piping design

The discharge pressure at the blowers will be the sum of the above losses, the depth of water over the air diffusers, and the loss through the diffusers.

The high temperature of the air discharged by blowers 60 to 80ºC. It is essential, however, that provisions be made for pipe expansion and contraction.

Pipe materials are often stainless steel, fiberglass, or plastics suitable for higher temperatures. Other materials used include mild steel or cast iron with external coatings (e.g., coal tar or vinyl). Interior surfaces include cement lining or coal tar or vinyl coatings.

Mechanical Aerators

Aerators with vertical axis and aerators with horizontal axis. Both groups are further subdivided into surface and submerged aerators.

In submerged aerators, oxygen is entrained from the atmosphere and, for some types, from air or pure oxygen introduced in the tank bottom. In either case, the pumping or agitating action of the aerators helps to keep the contents of the aeration tank or basin mixed.

Surface Mechanical Aerators with Vertical Axis

Surface aerators consist of submerged or partially submerged impellers that are attached to motors mounted on floats or on fixed structures. The impellers are fabricated from steel, cast iron, noncorrosive alloys, and fiberglass-reinforced plastic and causing a rapid change in the air-water interface to facilitate solution of the air.

High-speed aerators are almost always mounted on floats. These units were originally developed for use in ponds or lagoons where the water surface elevation fluctuates, or where a rigid support would be impractical. Surface aerators may be obtained in sizes from 0.75 to 100 kW (1 to 150 hp).

Mechanical Aerators with Horizontal Axis

The surface aerator is patterned after the original Kessener brush aerator, a device used to provide both aeration and circulation in oxidation ditches. Angle steel, steel of other shapes, or plastic bars or blades are now used instead of bristles.

The disks are submerged in the wastewater for approximately one-eighth to three-eighths of the diameter . Standard conditions exist when the temperature is 20ºC, the dissolved oxygen is 0.0 mg/L, and the test liquid is tap water.

6 Chemical Unit Processes

6-1 Role Of Chemical Unit Processes In Wastewater Treatment

Application of Chemical Unit Processes

Currently the most important applications of chemical unit processes in wastewater treatment are for (1) the disinfection of wastewater, (2) the precipitation of phosphorus, (3) the coagulation of particulate matter, (4)oxidation and reduction of industrial pollutants.

Tab. 6-1 Applications of chemical unit process in wastewater treatment

Process	Application
Advanced oxidation processes	Removal of refractory organic compounds
Chemical coagulation	The chemical destabilization of particles in wastewater to bring about their aggregation during perikinetic and orthokinetic flocculation
Chemical disinfection	Disinfection with chlorine, chlorine compounds, bromine, and ozone
	Control of slime growths in sewers
	Control of odors
Chemical neutralization	Control of pH
Chemical oxidation	Removal of BOD, grease, etc.
	Removal of ammonia (NH_4^+)
	Destruction of microorganisms
	Control of odors in sewers, pump stations, and treatment plants
	Removal of resistant organic compounds
Chemical precipitation	Enhancement removal of total suspended solids and BOD i primary sedimentation facilities
	Removal of phosphorus
	Removal of heavy metals
	Physical-chemical treatment
	Corrosion control in sewers due to H_2S
Chemical scale control	Control of scaling due to calcium carbonate and related compounds
Chemical stabilization	Stabilization of treated effluents
Ion exchange	Removal of ammonia (NH_4^+), heavy metals, total dissolved solids
	Removal of organic compounds

Considerations in the Use of Chemical Unit Processes

One of the inherent disadvantages associated with most chemical unit processes, as compared with the physical unit operations, is that they are additive processes (i.e., something is added to the wastewater to achieve the removal of something else). As a result, there is usually a net increase in the dissolved constituents in the wastewater. High operation cost and secondary pollution are also their disadvantages.

Similarly, when chlorine is added to wastewater, the TDS of the effluent is increased. If the treated wastewater is to be reused, the increase in dissolved constituents can be a significant factor. This additive aspect is in contrast to the physical unit operations and the biological unit processes, which may be described as being subtractive, in that wastewater constituents are removed from the wastewater.

6-2 Fundamentals Of Chemical Coagulation

Colloidal particles found in wastewater typically have a net negative surface charge. The size of colloids (about 0.01 to 1 μ m and is such that the attractive body forces between particles are considerably less than the repelling forces of the electrical charge. Under these stable conditions, Brownian motion keeps the particles in suspension.

Coagulation is the process of destabilizing colloidal particles so that particle growth can occur as a result of particle collisions.

Basic Definitions

Typical coagulants and flocculants include natural and synthetic organic polymers, metal salts such as alum or ferric sulfate, and prehydrolized metal salts such as poly-aluminum chloride (PACl,PAC) and poly-iron chloride (PIC1,PFC).

Flocculants, especially organic polymers, are also used to enhance the performance of granular medium filters and in the dewatering of digested biosolids. In these applications, the flocculant chemicals are often identified as filter aids.

The purpose of flocculation is to produce particles, by means of aggregation, that can be removed by inexpensive particle-separation procedures such as gravity sedimentation and filtration.

Nature of Particles in Wastewater

Because colloidal particles cannot be removed by sedimentation in a reasonable period of time, chemical methods (i.e., the use of chemical coagulants and flocculant aids) must be used to help bring about the removal of these particles.

Particle Shape and Flexibility.

Particle shapes found in wastewater can be described as spherical, semispherical, ellipsoids of various shapes (e.g., prolate and oblate), rods of various length and diameter (e.g., E. coli), disk and disklike, strings of various lengths, and random coils.

The shape of the particles will affect the electrical properties, the particle-particle interactions, and particle-solvent interactions.

Particle-Solvent Interactions

There are three general types of colloidal particles in liquids: hydrophobic or "water-hating," hydrophilic or "water-loving," and association colloids.

The third type of colloid is known as an association colloidal, typically made up of surface-active agents such as soaps, synthetic detergents, and dyestuffs which form organized aggregates.

Development and Measurement of Surface Charge

Surface charge develops most commonly through
(1) isomorphous replacement,
(2) structural imperfections,
(3) preferential adsorption,
(4) ionization

Isomorphous Replacement

Charge development through isomorphous replacement occurs in clay and other soil particles, in which ions in the lattice structure are replaced with ions from solution (e.g., the replacement of Si^{4+} with Al^{3+}).

Structural Imperfections

In clay and similar particles, charge development can occur because of broken bonds on the crystal edge and imperfections in the formation of the crystal.

Preferential Adsorption

When oil droplets, gas bubbles, or other chemically inert substances are dispersed in water, they will acquire a negative charge through the preferential adsorption of anions (particularly hydroxyl ions).

Ionization

In the case of substances such as proteins or microorganisms, surface charge is acquired through the ionization of carboxyl and amino groups.

Measurement of Surface Potential

The potential at the surface of the cloud (called the surface of shear) is sometimes measured in wastewater-treatment operations. The measured value is often called the zeta potential.

Particle-Particle Interactions

It should be noted that the van der Waals forces of attraction do not come into play until the two plates are brought together in close proximity to each other.

Particle Destabilization with Potential-Determining Ions and Electrolytes

The effect of the charge can be overcome by (1) the addition of potential-determining ions, which will be taken up by or will react with the colloid surface to lessen the surface charge and (2) the addition of electrolytes, which have the effect of reducing the thickness of the diffuse electric layer and, thereby, reduce the zeta potential.

Use of Potential-Determining Ions

The magnitude of the effect will depend on the concentration of potential-determining ions added. It is interesting to note that depending on the concentration and nature of the counter-ions added, it is possible to reverse the charge of the double layer and develop a new stable particle.

Use of Electrolytes

Increased concentration of a given electrolyte will cause a decrease in zeta potential and a corresponding decrease in repulsive forces. The concentration of an electrolyte that is needed to destabilize a colloidal suspension is known as the critical coagulation concentration (CCC).

Particle Destabilization and Aggregation with Polyelectrolytes

Important natural poly-electrolytes include polymers of biological origin and those derived from starch products such as cellulose derivatives and alginates.

Depending on whether their charge, when placed in water, is negative, positive, or neutral, these poly-electrolytes are classified as anionic, cationic, and nonionic, respectively.

Charge Neutralization

Because wastewater particles normally are charged negatively, cationic poly-electrolytes are used for this purpose.

Because of the large number of particles found in wastewater, the mixing intensity must be sufficient to bring about the adsorption of the polymer onto the colloidal particles. With inadequate mixing, the polymer will eventually fold back on itself and its effectiveness in reducing the surface charge will be diminished. Further, if the number of colloidal particles is limited, it will be difficult to remove them with low poly-electrolyte dosages.

Polymer Bridge Formation

A bridge is formed when two or more particles become adsorbed along the length of the polymer. Bridged particles become intertwined with other bridged particles during the flocculation process. The size of the resulting three-dimensional particles grows until they can be removed easily by sedimentation. Where particle removal is to be achieved by the formation of particle-polymer bridges, the initial mixing of the polymer and the wastewater containing the particles to be removed must be accomplished in a matter of seconds.

Charge Neutralization and Polymer Bridge Formation

The third type of poly-electrolyte action may be classified as a charge neutralization and bridging phenomenon, which results from using cationic poly-electrolytes of extremely high molecular weight.

Formation of Hydrolysis Products

In the past, it was thought that free $A1^{3+}$ and Fe^{3+} were responsible for the effects observed during particle aggregation; it is now known, however, that their hydrolysis products are responsible.

It should be noted that the complex compounds are known as coordination compounds, which are defined as a central metal ion (or atom) attached to a group of surrounding molecules or ions by coordinate covalent bonds. The surrounding molecules or ions are known as ligands, and the atoms attached directly to the metal ion are called ligand donor atoms. Ligand compounds of interest in wastewater treatment include carbonate (CO_3^{2-}), chloride ($C1^-$), hydroxide (OH), ammonia (NH_3), and water (H_2O).

Over the past 50 years, it has been observed that the intermediate hydrolysis reactions of Al(III) are much more complex than would be predicted on the basis of a model in which a base is added to the solution.

Further, because the hydrolysis reactions follow a stepwise process, the effectiveness of aluminum and iron will vary with time. For example, an alum slurry that has been prepared and stored will behave differently from a freshly prepared solution when it is added to a wastewater.

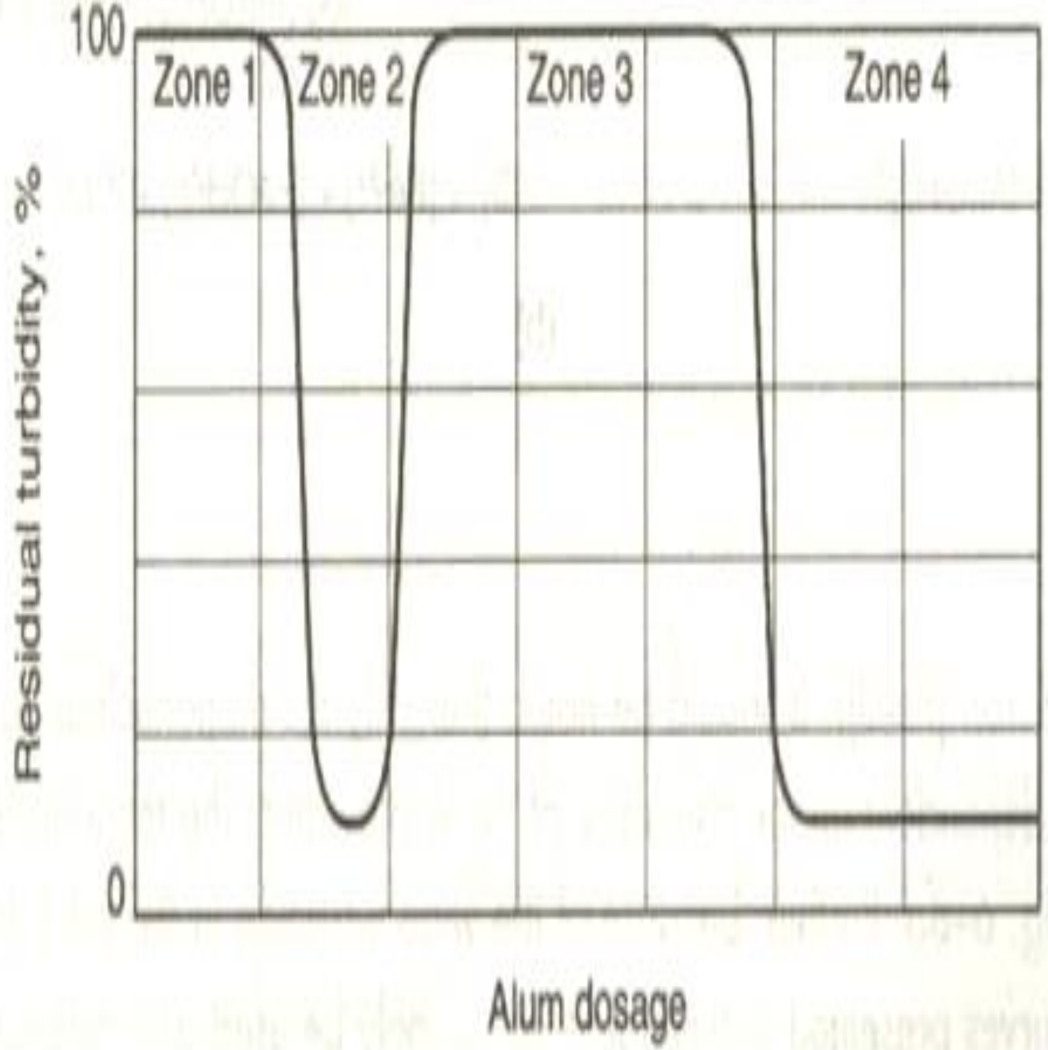
Action of Hydrolyzed Metal Ions

1. Adsorption and charge neutralization
2. Adsorption and interparticle bridging
3. Enmeshment in sweep floc

If a sufficient concentration of metal salt is added, large amounts of metal hydroxide floc will form. In turn, as these floc particles settle, they sweep through the water containing colloidal particles. The colloidal particles that become enmeshed in the floc will thus be removed from the wastewater.

Figure 6–7

Definition sketch for the effects of the continued addition of a coagulant (e.g., alum) on the destabilization and flocculation of colloidal particles.

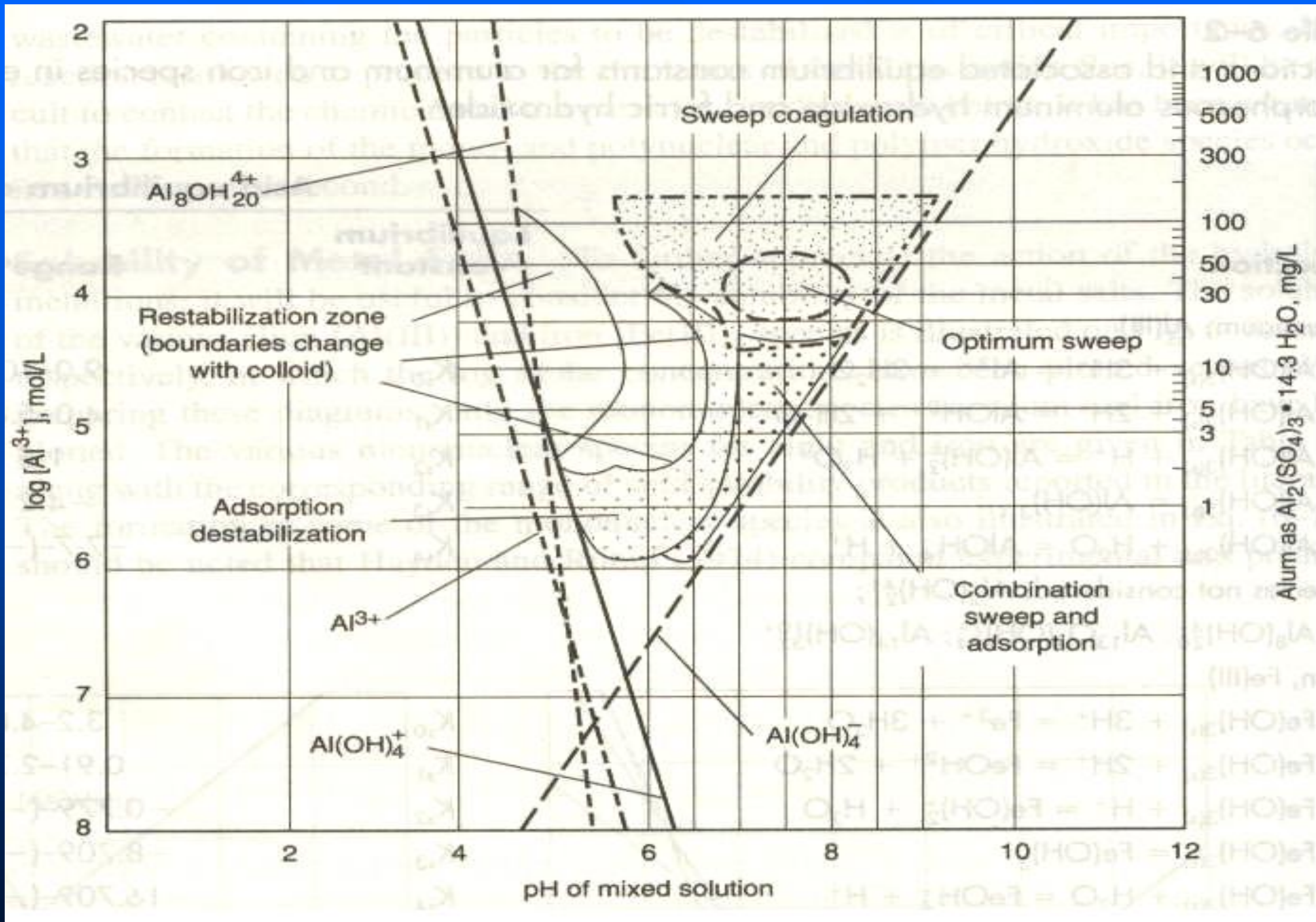


Solubility of Metal Salts

The operating region for alum precipitation is from a pH range of 5 to about 7, with minimum solubility occurring at a pH of 6.0, and from about 7 to 9 for iron precipitation, with minimum solubility occurring at a pH of 8.0.

Operating Regions for Action of Metal Salts

Fig. 6-4 Typical operating ranges for alum coagulation



For example, optimum particle removal by sweep floc occurs in the pH range of 7 to 8 with an alum dose of 20 to 60 mg/L.

Generally, for many wastewater effluents that have high pH values (e.g., 7.3 to 8.5), low alum dosages in the range of 5 to 10 mg/L will not be effective. With proper pH control it is possible to operate with extremely low alum dosages. Because the characteristics of wastewater will vary from treatment plant to treatment plant, bench-scale and pilot-plant tests must be conducted to establish the appropriate chemical dosages.

6-3 Chemical Precipitation For Improved Plant Performance

Chemical precipitation, as noted previously, involves the addition of chemicals to alter the physical state of dissolved and suspended solids and facilitate their removal by sedimentation.

Since about 1970, the need to provide more complete removal of the organic compounds and nutrients (nitrogen and phosphorus) contained in wastewater has brought about renewed interest in chemical precipitation. In current practice, chemical precipitation is used (1) as a means of improving the performance of primary settling facilities, (2) as a basic step in the independent physical-chemical treatment of wastewater, (3) for the removal of phosphorus, and (4) for the removal of heavy metals.

Alum.

The insoluble aluminum hydroxide is a gelatinous floc that settles slowly through the wastewater, sweeping out suspended material and producing other changes. The reaction is exactly analogous when magnesium bicarbonate is substituted for the calcium salt.

If less than this amount of alkalinity is available, it must be added. Lime is commonly used for this purpose when necessary, but it is seldom required in the treatment of wastewater.

Lime.

Much more lime is generally required when it is used alone than when sulfate of iron is also used where industrial wastes introduce mineral acids or acid salts into the wastewater.

Enhanced Removal of Suspended Solids in Primary Sedimentation

With chemical precipitation, it is possible to remove 80 to 90 percent of the total suspended solids (TSS) including some colloidal particles, 50 to 80 percent of the BOD, and 80 to 90 percent of the bacteria. Comparable removal values for well-designed and well-operated primary sedimentation tanks without the addition of chemicals are 50 to 70 percent of the TSS, 25 to 40 percent of the BOD, and 25 to 75 percent of the bacteria.

Independent Physical-Chemical Treatment

In some localities, industrial wastes have rendered municipal wastewater difficult to treat by biological means.

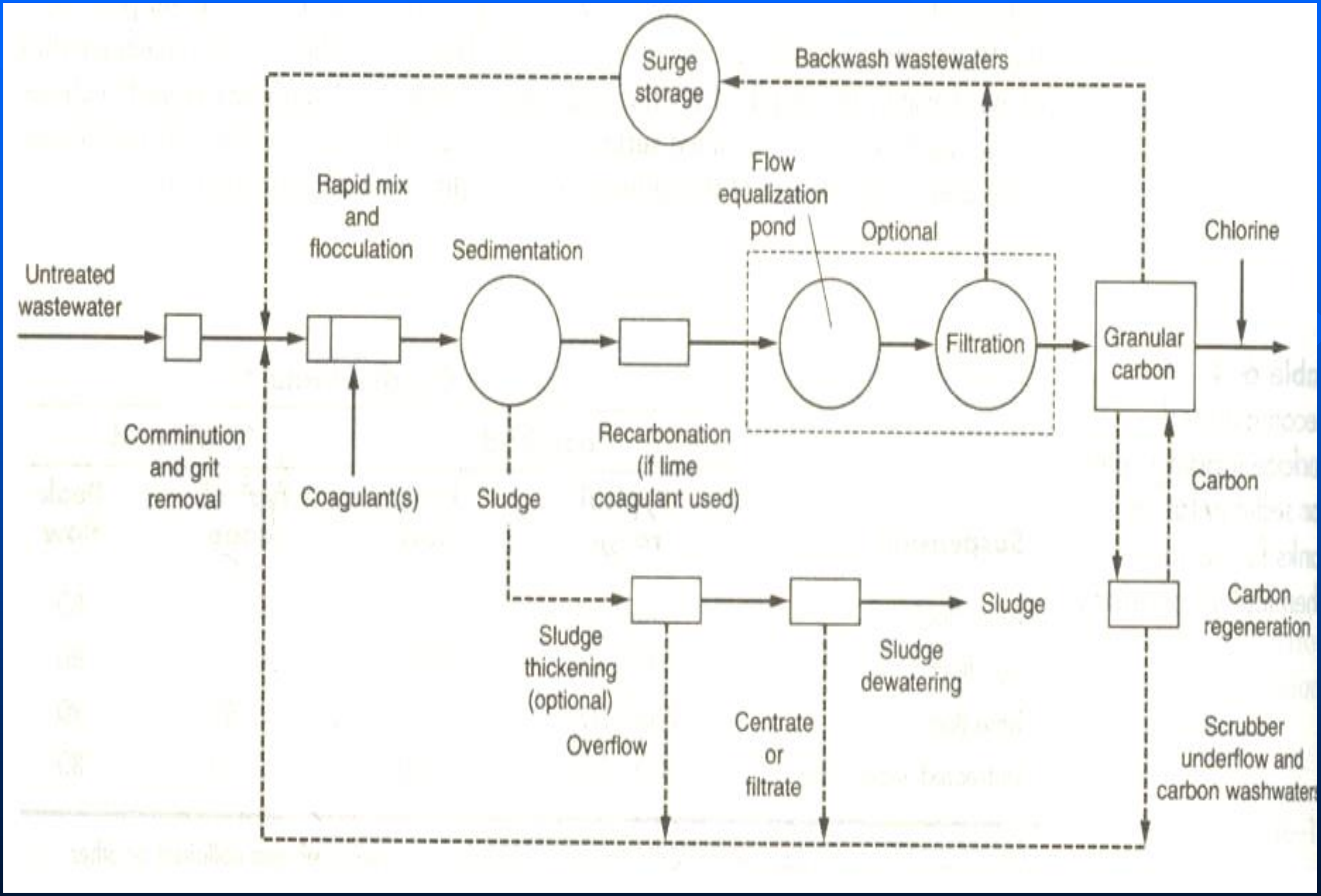
In such situations, physical-chemical treatment may be an alternative approach. This method of treatment has met with limited success because of its lack of consistency in meeting discharge requirements, high costs for chemicals, handling and disposal of the great volumes of sludge resulting from the addition of chemicals, and numerous operating problems.

Because of these reasons, new applications of physical-chemical treatment for municipal wastewater are rare. Physical-chemical treatment is used more extensively for the treatment of industrial wastewater.

The filter is shown as optional, but its use is recommended to reduce the blinding and headloss buildup in the carbon columns.

The handling and disposal of the sludge resulting from chemical precipitation is one of the greatest difficulties associated with chemical treatment. Sludge is produced in great volume from most chemical precipitation operations, often reaching 0.5 percent of the volume of wastewater treated when lime is used.

Fig. 6-5 Typical flow diagram of an independent physical-chemical treatment plant



6-4 Chemical Precipitation For Phosphorus Removal

The removal of phosphorus from wastewater involves the incorporation of phosphate into TSS and the subsequent removal of those solids. Phosphorus can be incorporated into either biological solids (e.g., microorganisms) or chemical precipitates.

The topics to be considered include

(1) the chemistry of phosphate precipitation,

(2) strategies for phosphorous removal,

(3) phosphorus removal using metal salts and polymers

(4) phosphorus removal using lime.

Chemistry of Phosphate Precipitation

The chemical precipitation of phosphorus is brought about by the addition of the salts of multivalent metal ions that form precipitates of sparingly soluble phosphates. The multivalent metal ions used most commonly are calcium [Ca(II)], aluminum [Al(III)], and iron [Fe(III)].

Because the chemistry of phosphate precipitation with calcium is quite different than with aluminum and iron, the two different types of precipitation are considered separately in the following discussion.

Phosphate Precipitation with Calcium.

When lime is added to water it reacts with the natural bicarbonate alkalinity to precipitate $CaCO_3$. As the pH value of the wastewater increases beyond about 10, excess calcium ions will then react with the phosphate to precipitate hydroxylapatite $Ca_{10}(PO_4)_6(OH)_2$.

Because of the reaction of lime with the alkalinity of the wastewater, the quantity of lime required will, in general, be independent of the amount of phosphate present and will depend primarily on the alkalinity of the wastewater. The quantity of lime required to precipitate the phosphorus in wastewater is typically about 1.4 to 1.5 times the total alkalinity expressed as $CaCO_3$.

Because a high pH value is required to precipitate phosphate, coprecipitation is usually not feasible. When lime is added to raw wastewater or to secondary effluent, pH adjustment is usually required before subsequent treatment or disposal. Recarbonation with carbon dioxide (CO_2) is used to lower the pH value

Phosphate Precipitation with Aluminum and Iron.

These reactions are deceptively simple and must be considered in light of the many competing reactions and their associated equilibrium constants, and the effects of alkalinity, pH, trace elements, and ligands found in wastewater. Therefore, dosages are generally established on the basis of bench-scale tests and occasionally by full-scale tests .

Strategies for Phosphorus Removal

The general locations where phosphorus can be removed may be classified as (1) pre-precipitation, (2) coprecipitation, and (3) postprecipitation.

Pre-precipitation.

Factors affecting the choice of chemical for phosphorus removal

1. Influent phosphorus level
2. Wastewater suspended solids
3. Alkalinity
4. Chemical cost(including transportation)
5. Reliability of chemical supply
6. Sludge handling facilities
7. Ultimate disposal methods
8. Compatibility with other treatment processes

Coprecipitation.

The addition of chemicals to form precipitates that are removed along with waste biological sludge is defined as "coprecipitation." Chemicals can be added to (1) the effluent from primary sedimentation facilities, (2) the mixed liquor (in the activated-sludge process), or (3) the effluent from a biological treatment process before secondary sedimentation.

Phosphorus Removal Using Metal Salts and Polymers

Because polyphosphates and organic phosphorus are less easily removed than orthophosphorus, adding aluminum or iron salts after secondary treatment (where organic phosphorus and polyphosphorus are transformed into orthophosphorus) usually results in the best removal. Some additional nitrogen removal occurs because of better settling, but essentially no ammonia is removed unless chemical additions to primary treatment reduce BOD loadings to the point where nitrification can occur. A number of the important features of adding metal salts and polymers at different points in the treatment process are discussed in this section.

Metal Salt Addition to Primary Sedimentation Tanks.

Organic phosphorus and polyphosphate are removed by more complex reactions and by adsorption onto floc particles. Adequate initial mixing and flocculation are necessary upstream of primary facilities, whether separate basins are provided or existing facilities are modified to provide these functions.

In low-alkalinity waters, the addition of a base is sometimes necessary to keep pH in the 5 to 7 range. Alum generally is applied in a molar ratio in the range of a 1.4 to 2.5 mole Al/mole P.

Metal Salt Addition to Secondary Treatment.

In trickling filter systems, the salts are added to the untreated wastewater or to the filter effluent. Phosphorus is removed from the liquid phase through a combination of precipitation, adsorption, exchange, and agglomeration, and removed from the process with either the primary or secondary sludges, or both.

Theoretically, the minimum solubility of $AlPO_4$ occurs at about pH 6.3, and that of $FePO_4$ occurs at about pH 5.3; however, practical applications have yielded good phosphorus removal anywhere in the range of pH 6.5 to 7.0, which is compatible with most biological treatment processes.

The use of ferrous salts is limited because they produce low phosphorus levels only at high pH values. In low-alkalinity waters, either sodium aluminate and alum or ferric plus lime, or both, can be used to maintain the pH higher than 5.5.

Dosages generally fall in the range of a 1 to 3 metal ion-phosphorus molar ratio.

Metal Salt and Polymer Addition to Secondary Clarifiers.

In certain cases, such as trickling filtration and extended aeration activated-sludge processes, solids may not flocculate and settle well in the secondary clarifier. This settling problem may become acute in plants that are overloaded.

Aluminum and iron salts, along with certain organic polymers, can also be used to coagulate colloidal particles and to improve removals on filters.

Dosages of aluminum and iron salts usually fall in the range of 1 to 3 metal ion/phosphorus on a molar ratio basis if the residual phosphorus in the secondary effluent is greater than 0.5 mg/L. To achieve phosphorus levels below 0.5 mg/L, significantly higher metal salt dosages and filtration will be required.

Polymers may be added (1) to the mixing zone of a highly mixed or internally recirculated clarifier, (2) preceding a static or dynamic mixer, or (3) to an aerated channel.

Although mixing times of 10 to 30 seconds have been used for polymers, shorter mixing times are favored .

Phosphorus Removal Using Lime

The use of lime for phosphorus removal is declining because of (1) the substantial increase in the mass of sludge to be handled compared to metal salts and (2) the operation and maintenance problems associated with the handling, storage, and feeding of lime.

Although lime recalcination lowers chemical costs, it is a feasible alternative only for large plants.

The carbon dioxide from this process or other onsite stack gas (containing 10 to 15 percent carbon dioxide) is generally used as the source of recarbonation for pH adjustment of the wastewater.

Lime Addition to Primary Sedimentation Tanks.

In the trickling filter process, the carbon dioxide generated during treatment is usually sufficient to lower the pH without recarbonation.

The dosage for low lime treatment is usually in the range of 75 to 250 mg/L as $Ca(OH)_2$ at pH values of 8.5 to 9.5. In low lime systems, however, the conditions required for precipitation are more specialized; the Ca^{2+}/Mg^{2+} mole ratio is $\leq 5/1$.

Lime Addition Following Secondary Treatment.

Generally, there is a second injection of carbon dioxide to the second-stage effluent to reduce the formation of scale. To remove the residual levels of TSS and phosphorus, the secondary clarifier effluent is passed through a multimedia filter or a membrane filter. Care should be taken to limit excess calcium in the filter feed to ensure cementing of the filter media will not occur.

Phosphorus Removal with Effluent Filtration

The removal of phosphorus by chemical addition to the contact filtration process is used in many parts of the country to remove phosphorus from wastewater treatment plant effluents which are discharged to sensitive water bodies. A two-stage filtration process has proved to be very effective for the removal of phosphorus. Based on the performance data from full-scale installations, phosphorus levels equal to or less than 0.02 mg/L have been achieved in the filtered effluent.

Comparison of Chemical Phosphorus Removal Processes

Tab. 6-4 Advantages and disadvantages of chemical addition in various sections of a treatment plant for phosphorus removal

Level of treatment	Advantages	Disadvantages
Primary	Applicable to most plants; increased BOD and suspended solids removal; lowest degree of metal leakage; lime recovery demonstrated	Least efficient use of metal; polymer may be required for flocculation; sludge more difficult to dewater than primary sludge
Secondary	Lowest cost; lower chemical dosage than primary; improved stability of activated sludge; polymer not required	Overdose of metal may cause low pH toxicity; with low-alkalinity wastewaters, a pH control system may be necessary; cannot use lime because of excessive pH; inert solids added to activated-sludge mixed liquor, reducing the percentage of volatile solids
Advanced—precipitation	Lowest phosphorus effluent; most efficient metal use; lime recovery demonstrated	Highest capital cost; highest metal leakage

Estimation of Sludge Quantities from Phosphorus Precipitation

The additional BOD and TSS removals afforded by chemical addition to primary treatment may also solve overloading problems on downstream biological systems, or may allow seasonal or year-round nitrification, depending on biological system designs. The BOD removal in the primary sedimentation operation is on the order of 50 to 60 percent at a pH of 9.5. The amount of primary sludge will also increase significantly.

6-5 Chemical Precipitation For Removal Of Heavy Metals And Dissolved Inorganic Substances

The technologies available for the removal of heavy metals from wastewater include chemical precipitation, carbon adsorption, ion exchange, and reverse osmosis. Of these technologies, chemical precipitation is most commonly employed for most of the metals.

Common precipitants include hydroxide (OH) and sulfide (S^{2-}). Carbonate (CO_3^{2-}) has also been used in some special cases. Metal may be removed separately or coprecipitated with phosphorus.

Precipitation Reactions

Metals of interest include arsenic (As), barium (Ba), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), selenium (Se), and zinc (Zn).

In wastewater treatment facilities, metals are precipitated most commonly as metal hydroxides through the addition of lime or caustic to a pH of minimum solubility.

In practice, the minimum achievable residual metal concentrations will also depend on the nature and concentration of the organic matter in the wastewater as well as the temperature.

Tab. 6-5 Solubility products for free metal ion concentrations in equilibrium with hydroxides and sulfides

Disinfectant	Half reaction	pK_{sp}
Cadmium hydroxide	$Cd(OH)_2 \leftrightarrow Cd^{2+} + 2OH^-$	13.93
Cadmium sulfide	$CdS \leftrightarrow Cd^{2+} + S^{2-}$	28
Chromium hydroxide	$Cr(OH)_3 \leftrightarrow Cr^{3+} + 3OH^-$	30.2
Copper hydroxide	$Cu(OH)_2 \leftrightarrow Cu^{2+} + 2OH^-$	19.66
Copper sulfide	$CuS \leftrightarrow Cu^{2+} + S^{2-}$	35.2
Iron (II) hydroxide	$Fe(OH)_2 \leftrightarrow Fe^{2+} + 2OH^-$	14.66
Iron (II) sulfide	$FeS \leftrightarrow Fe^{2+} + S^{2-}$	17.2
Lead hydroxide	$Pb(OH)_2 \leftrightarrow Pb^{2+} + 2OH^-$	14.93
Lead sulfide	$PbS \leftrightarrow Pb^{2+} + S^{2-}$	28.15
Mercury hydroxide	$Hg(OH)_2 \leftrightarrow Hg^{2+} + 2OH^-$	23
Mercury sulfide	$HgS \leftrightarrow Hg^{2+} + S^{2-}$	52
Nickel hydroxide	$Ni(OH)_2 \leftrightarrow Ni^{2+} + 2OH^-$	15
Nickel sulfide	$NiS \leftrightarrow Ni^{2+} + S^{2-}$	24
Silver hydroxide	$AgOH \leftrightarrow Ag^+ + OH^-$	14.93
Silver sulfide	$(Ag)_2S \leftrightarrow 2Ag^+ + S^{2-}$	28.15
Zinc hydroxide	$Zn(OH)_2 \leftrightarrow Zn^{2+} + 2OH^-$	16.7
Zinc sulfide	$ZnS \leftrightarrow 2Ag^+ + S^{2-}$	22.8

Tab. 6-6 Practical effluent concentration levels achievable in heavy metals removal by precipitation

Metal	Achievable effluent concentration, mg/L	Type of precipitation and technology
Arsenic	0.05	Sulfide precipitation with filtration
	0.005	Ferric hydroxide coprecipitation
Barium	0.5	Sulfate precipitation
Cadmium	0.05	Hydroxide precipitation at pH 10–
	0.05	Coprecipitation with ferric hydroxic
	0.008	Sulfide precipitation
Copper	0.02–0.07	Hydroxide precipitation
	0.01–0.02	Sulfide precipitation
Mercury	0.01–0.02	Sulfide precipitation
	0.001–0.01	Alum coprecipitation
	0.0005–0.005	Ferric hydroxide coprecipitation
	0.001–0.005	Ion exchange
Nickel	0.12	Hydroxide precipitation at pH 10
Selenium	0.05	Sulfide precipitation
Zinc	0.1	Hydroxide precipitation at pH 11

Coprecipitation with Phosphorus

When chemical precipitation is used, anaerobic digestion for sludge stabilization may not be possible because of the toxicity of the precipitated heavy metals. As noted previously, one of the disadvantages of chemical precipitation is that it usually results in a net increase in the total dissolved solids of the wastewater that is being treated.

6-6 Chemical Oxidation

Chemical oxidation in wastewater treatment typically involves the use of oxidizing agents such as ozone (O_3), hydrogen peroxide (H_20_2), permanganate (MnO_4), chloride dioxide (ClO_2), chlorine ($C1_2$) or (HOC1), and oxygen (O_2)

Advanced oxidation process (AOPs) in which the free hydroxyl radical ($HO\cdot$) is used as a strong oxidant to destroy specific organic constituents and compounds that cannot be oxidized by conventional oxidants such as ozone and chlorine are discussed in later chapters.

Oxidation-Reduction Reactions.

While an oxidizing agent causes the oxidation to occur, it is reduced in the process.

Half-Reaction Potentials.

Of the many properties that can be used to characterize oxidation-reduction reactions, the electrical potential (i.e., voltage) or emf of the half reaction is used most commonly.

The half-reaction potential is a measure of the tendency of a reaction to proceed to the right. Half reactions with large positive potential, E° , tend to proceed to the right as written. Conversely, half reactions with large negative potential, E° , tend to proceed to the left.

Tab. 6-7 Standard electrode potentials for oxidation half reactions for chemical disinfection

Disinfectant	Half reaction	Oxidation potential,[b] V
Ozone	$O_3 + 2e^- \leftrightarrow O_2 + H_2O$	+2.07
Hydrogen peroxide	$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$	+1.78
Permanganate	$MnO_4^- + 4H^+ + 3e^- \leftrightarrow MnO_2 + 2H_2O$	+1.67
Chlorine dioxide	$ClO_2 + e^- \leftrightarrow ClO_2^-$	+1.50
Hypochlorous acid	$HOCl + H^+ + 2e^- \leftrightarrow Cl^- + H_2O$	+1.49
Hypoiodous acid	$HOI + H^+ + e^- \leftrightarrow 1/2I_2 + H_2O$	+1.45
Chlorine gas	$Cl_2 + 2e^- \leftrightarrow 2Cl^-$	+1.36
Oxygen	$O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O$	+1.23
Bromine	$Br_2 + 2e^- \leftrightarrow 2Br^-$	+1.09
Hypochlorite	$OCl^- + H_2O + 2e^- \leftrightarrow Cl^- + 2OH^-$	+0.90
Chlorite	$ClO_2^- + 2H_2O + 4e^- \leftrightarrow Cl^- + 4OH^-$	+0.76
Iodine	$I_2 + 2e^- \leftrightarrow 2I^-$	+0.54

Tab. 6-8 Typical applications of chemical oxidation in wastewater collection, treatment, and disposal

Application	Chemicals used[a]	Remarks
Collection		
Slime-growth control	Cl_2, H_2O_2	Control of fungi and slime-producing bacteria
Corrosion control (H_2S)	Cl_2, H_2O_2, O_3	Control brought about by oxidation of H_2S
Odor control	Cl_2, H_2O_2, O_3	Especially in pumping stations and long, flat sewers
Treatment		
Grease removal	Cl_2	Added before preaeration
BOD reduction	Cl_2, O_3	Oxidation of organic substances
Ferrous sulfate oxidation	Cl_2[b]	Production of ferric sulfate and ferric chloride
Filter-ponding control	Cl_2	Maintaining residual at filter nozzles
Filter-fly control	Cl_2	Maintaining residual at filter nozzles during fly season
Sludge-bulking control	Cl_2, H_2O_2, O_3	Temporary control measure
Control of filamentous microorganisms	Cl_2	Dilute chlorine solution sprayed on foam caused by filamentous organisms
Digester supernatant oxidation	Cl_2	
Digester foaming control	Cl_2	
Ammonia oxidation	Cl_2	Conversion of ammonia to nitrogen gas
Odor contol	Cl_2, H_2O_2, O_3	
Oxidation of refractory organic compounds	O_3	
Dispersal		
Bacterial reduction	Cl_2, H_2O_2, O_3	Plant effluent, overflows, and stormwater
Odor control	Cl_2, H_2O_2, O_3	

Chemical Oxidation of Ammonia

The chemical process in which chlorine is used to oxidize the ammonia nitrogen in solution to nitrogen gas and other stable compounds is known as breakpoint chlorination. Perhaps the most important advantage of this process is that, with proper control, all the ammonia nitrogen in the wastewater can be oxidized.

However, because the process has a number of disadvantages including the buildup of acid (HCl) which will react with the alkalinity, the buildup of total dissolved solids, and the formation of unwanted chloro-organic compounds, ammonia oxidation is seldom used today.

6-7 Chemical Neutralization, Scale Control, And Stabilization

Scaling control is required for nanofiltration and reverse osmosis treatment to control the formation of scale .

pH Adjustment

Lime can be purchased as quicklime or slaked hydrated lime, high-calcium or dolomitic lime, and in several physical forms. Limestone and dolomitic limestone are cheaper but less convenient to use and slower in reaction rate. Because they can become coated in certain waste-treatment applications, their use is limited. Depending on the sensitivity of the environment, two-stage neutralization may be required. The reagent chemicals can be fed automatically, in the form of solutions, slurries, or dry materials.

Analysis of Scaling Potential

With the increasing use that is being made of nanofiltration, reverse osmosis, and electrodialysis in wastewater reuse applications, adjustment of the scaling characteristics of the effluent to be treated is important to avoid calcium carbonate and sulfate scale formation. Depending on the recovery rate, the concentration of salts can increase by a factor of up to 10 within the treatment module. When such a salt concentration increase occurs, it is often possible to exceed the solubility product of calcium carbonate and other scale-forming compounds. The formation of scale within the treatment module will cause a deterioration in the performance, ultimately leading to the failure of the membrane module.

Scaling Control

Usually, $CaCO_3$ scale control can be achieved using one or more of the following methods:

. Acidifying to reduce pH and alkalinity

. Reducing calcium concentration by ion exchange or lime softening

. Adding a scale inhibitor chemical (antiscalant) to increase the apparent solubility of $CaCO_3$ in the concentrate stream

. Lowering the product recovery rate

Stabilization

Wastewater effluent that is demineralized with reverse osmosis will generally require pH and calcium carbonate adjustment (stabilization) to prevent metallic corrosion, due to the contact of the demineralized water with metallic pipes and equipment.

Corrosion occurs because material from the solid is removed (solubilized) to satisfy the various solubility products. Demineralized water typically is stabilized by adding lime to adjust the LSI, using the procedure outlined above.

6-8 Chemical Storage, Feeding, Piping, And Control Systems

Coagulants in the dry solid form generally are converted to solution or slurry form prior to introduction into the wastewater. Coagulants in the liquid form are usually delivered to the plant in a concentrated form and have to be diluted prior to introduction into the wastewater. Chemicals in the gas form (generally stored as a liquid), typically used for disinfection purposes, are either dissolved in water before injection or are injected directly into the wastewater.

Chemical feeders are generally designed to be (1) proportioning, feeding chemical in proportion to the influent wastewater flowrate, and (2) constant feed, designed to deliver chemical at a fixed rate regardless of the influent flowrate.

Dry Chemical-Feed Systems

The units are sized according to the volume of wastewater, treatment rate, and optimum length of time for chemical feeding and dissolving. Hoppers used with powdered chemicals that are compressible and can form an arch such as lime are equipped with positive agitators and a dust-collection system.

Liquid Chemical-Feed Systems

The storage tank is sized based upon the stability of the chemical, feed rate requirements, delivery constraints (cost, size of tank truck, etc.), and availability of the supply.