

7 Suspended Growth Biological Treatment Processes

7-1 Introduction to the Activated-Sludge Process

Historical Development

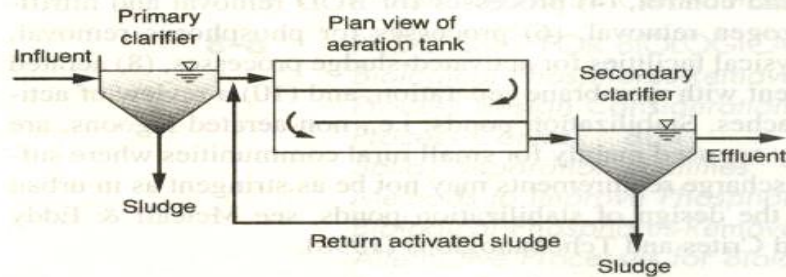
Experiments conducted at the Lawrence Experiment Station during 1912 and 1913 by Clark and Gage

With air input into wastewater, growths of organisms could be cultivated in bottles and in tanks partially filled with roofing slate spaced about 25 mm (1 in) apart and would greatly increase the degree of purification.

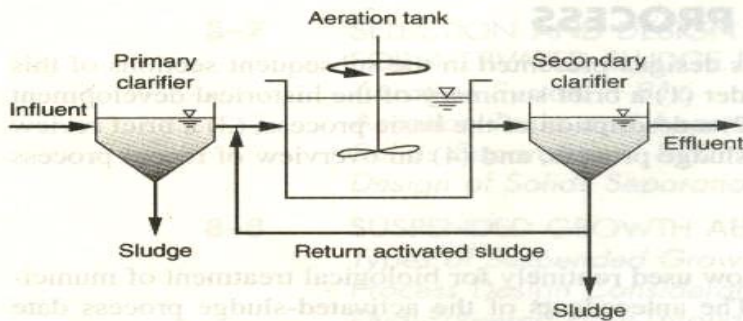
Lockett found that the sludge played an important part.

The basic activated-sludge treatment process, as illustrated on Fig. 7-1a and b, consists of the following three basic components: (1) a reactor in which the microorganisms responsible for treatment are kept in suspension and aerated; (2) liquid-solids separation, usually in a sedimentation tank; and (3) a recycle system for returning solids removed from the liquid-solids separation unit back to the reactor.

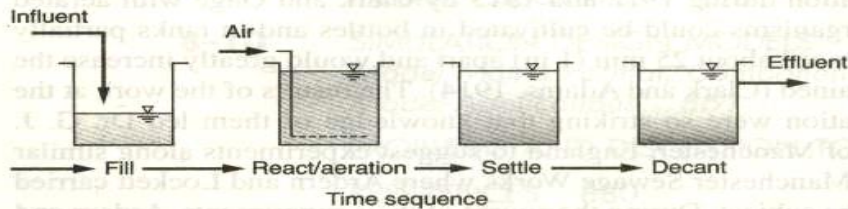
Fig. 7-1 Description of Basic Process



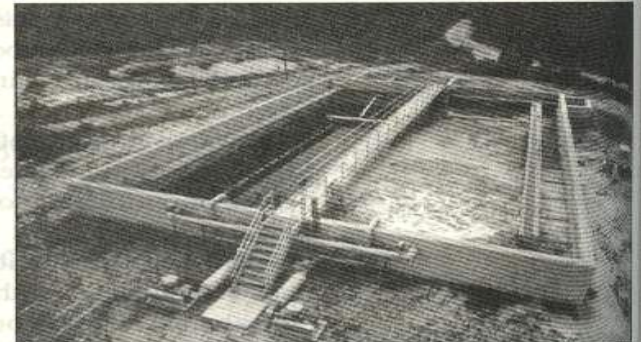
(a)



(b)



(c)



An important feature of the activated-sludge process is the **formation of flocculent settleable solids** .

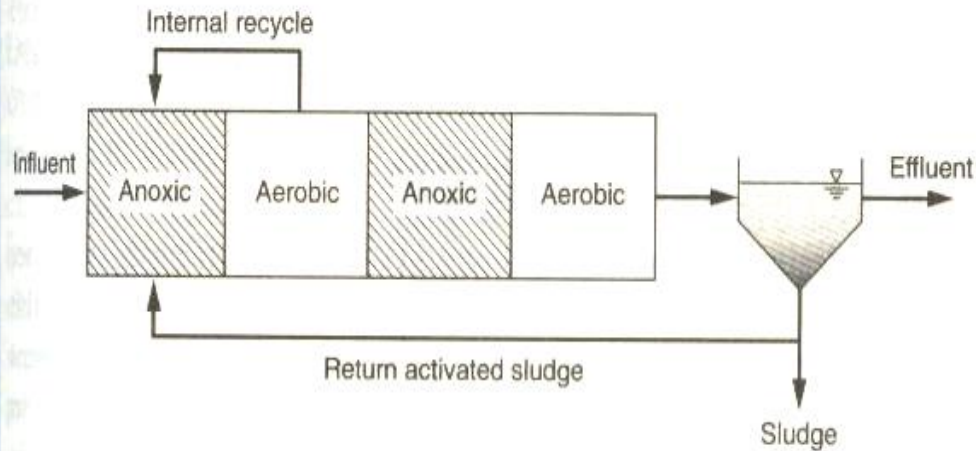
For these applications, **various modifications of conventional activated-sludge processes are used, including sequencing batch reactors, oxidation ditch systems, aerated lagoons, or stabilization ponds.**

Evolution of the Activated-Sludge Process

A number of activated-sludge processes and design configurations have evolved since its early conception as a result of (1) engineering innovation in response to the need for higher-quality effluents from wastewater treatment plants; (2) technological advances in equipment, electronics, and process control; (3) increased understanding of microbial processes and fundamentals; and (4) the continual need to reduce capital and operating costs.

The use of a plug-flow process became problematic when industrial wastes were introduced because of the toxic effects of some of the discharges.

With the development of simple inexpensive program logic controllers (PLCs) and the availability of level sensors and automatically operated valves, the sequencing batch reactor (SBR) process (see Fig. 7-1c) became more widely used by the late 1970s, especially for smaller communities. Some of the stages are not aerated (anaerobic or anoxic stages) and internal recycle flows may be used.



(a)

Figure 8-2

Bardenpho process with staged reactors for biological nitrogen removal: (a) schematic diagram of staged process and (b) view of a staged Bardenpho treatment plant in Palmetto, FL, the first of its type in the United States. (From H. D. Stensel.)



(b)

Recent Process Developments

As noted above, numerous modifications of the activated-sludge process have evolved in the last 10 to 20 years, aimed principally at **effective and efficient removal of nitrogen and phosphorus.**

7-2 Wastewater Characterization

Activated-sludge process design requires determining (1) the aeration basin volume, (2) the amount of sludge production, (3) the amount of oxygen needed, and (4) the effluent concentration of important parameters.

7-3 Fundamentals of Process Analysis and Control

Selection of Reactor Type

Important factors that must be considered in the selection of reactor types for the activated-sludge process include (1) the effects of reaction kinetics, (2) oxygen transfer requirements, (3) nature of the wastewater, (4) local environmental conditions, (5) presence of toxic or inhibitory substances in the influent wastewater, (6) costs, and (7) expansion to meet future treatment needs.

Selection of Solids Retention Time and Loading Criteria

The common parameters used are the solids retention time (**SRT**), the food to biomass (**F/M**) ratio (also known as food to microorganism ratio), and the volumetric organic loading rate(**L_v**).

Solids Retention Time

The SRT, in effect, represents the average period of time during which the sludge has remained in the system. SRT is the most critical parameter for activated-sludge design as **SRT affects the treatment process performance, aeration tank volume, sludge production, and oxygen requirements.**

Treatment goal	SRT range, d	Factors affecting SRT
Removal of soluble BOD in domestic wastewater	1–2	Temperature
Conversion of particulate organics in domestic wastewater	2–4	Temperature
Develop flocculent biomass for treating domestic wastewater	1–3	Temperature
Develop flocculent biomass for treating industrial wastewater	3–5	Temperature/compounds
Provide complete nitrification	3–18	Temperature/compounds
Biological phosphorus removal	2–4	Temperature
Stabilization of activated sludge	20–40	Temperature
Degradation of xenobiotic compounds	5–50	Temperature/specific bacteria/compounds

Sludge Production

Sludge will accumulate in the activated-sludge process if it cannot be processed fast enough by an undersized sludge-handling facility.

The observed yield decreases as the SRT is increased due to **biomass loss by more endogenous respiration**. The yield is higher when no primary treatment is used, as more nbVSS remains in the influent wastewater(**A-B**).

Oxygen Requirements

As an approximation, for BOD removal only, the oxygen requirement will vary from 0.90 to 1.3 kg O₂/kg BOD removed for SRTs of 5 to 20 d .

Nutrient Requirements

Using the formula C₅H₇NO₂, for the composition of cell biomass, about 12.4 percent by weight of nitrogen will be required. The phosphorus requirement is usually assumed to be about one-fifth of the nitrogen value. As a general rule, for SRT values greater than 7 d, about 5 g nitrogen and 1 g phosphorus will be required per 100 g of BOD to provide an excess of nutrients.

Other Chemical Requirements

The amount of **alkalinity** required for nitrification, taking into account cell growth, is about $7.07 \text{ g CaCO}_3/\text{g NH}_4\text{-N}$. In addition to the alkalinity required for nitrification, additional alkalinity must be available to maintain the pH in the range from 6.8 to 7.4. Typically the amount of residual alkalinity required to maintain pH near a neutral point (i.e., $\text{pH} \approx 7$) is between 70 and 80 mg/L as CaCO_3 .

Mixed-Liquor Settling Characteristics

Clarifier design must provide **adequate clarification of the effluent and solids thickening for the activated-sludge solids.**

Two commonly used measures developed to quantify the settling characteristics of activated sludge are the sludge volume index (SVI) and the zone settling rate .

The **SVI** is determined by placing a mixed-liquor sample in a 1- to 2-L cylinder and measuring the settled volume after 30 min and the corresponding sample MLSS concentration. For example, a mixed-liquor sample with a 3000 mg/L TSS concentration that settles to a volume of 300 mL in 30 min in a 1-L cylinder would have an SVI of 100 mL/g. A value of 100 mL/g is considered a good settling sludge (SVI values below 100 are desired). SVI values above 150 are typically associated with **filamentous growth.**

Use of Selectors

Because solids separation is one of the most important aspects of biological wastewater treatment, a biological selector (a small contact tank) is often incorporated in the design to limit the growth of organisms that do not settle well. An appropriate selector design can be added before the activated-sludge aeration basin.

Process Control

To maintain high levels of treatment performance
The principal approaches to process control are (1) maintaining dissolved oxygen levels in the aeration tanks, (2) regulating the amount of return activated sludge (RAS), and (3) controlling the waste-activated sludge (WAS).

The parameter used most commonly for controlling the activated-sludge process is SRT.

Dissolved Oxygen Control.

When oxygen limits the growth of microorganisms, filamentous organisms may predominate and the settleability and quality of the activated sludge may be poor.

In general, the dissolved oxygen concentration in the aeration tank should be maintained at about 1.5 to 2 mg/L in all areas of the aeration tank.

Return Activated-Sludge Control

Return sludge concentrations from secondary clarifiers range typically from 4000 to 12,000 mg/L .

Settleability

If the settleable solids occupied a volume of 275 mL after 30 min of settling, the percentage volume would be equal to 38 percent $[(275 \text{ mL} / 725 \text{ mL}) * 100]$. If the plant flow were $2 \text{ m}^3/\text{s}$, the return sludge rate should be $0.38 \times 2 \text{ m}^3/\text{s} = 0.76 \text{ m}^3/\text{s}$.

Sludge Blanket Level

The optimum level is determined by experience and is a balance between settling depth and sludge storage. The optimum depth of the sludge blanket usually ranges between 0.3 and 0.9 m.

Considerations:

- (1) diurnal flow variations
- (2) sludge production variations
- (3) changes in the settling characteristics of the sludge.

Sludge Wasting

An alternative method of wasting sometimes used is withdrawing mixed liquor directly from the aeration tank or the aeration tank effluent pipe .

Oxygen Uptake Rates

OUR or respiration rate used to assess the presence of toxic or inhibitory substances in the influent wastewater.

Microscopic Observations

Specific information gathered includes

- changes in floc size and density
- status of filamentous organism growth in the floc
- presence of *Nocardia* bacteria,
- type and abundance of higher life-forms such as protozoans and rotifers.

A decrease in the protozoan population may be indicative of DO limitations, operation at a lower SRT inhibitory substances in the wastewater.

Operational Problems

The **most common problems** encountered in the operation of an activated-sludge plant are **bulking sludge**, **rising sludge**, and *Nocardia* foam.

Bulking Sludge

In a bulking sludge condition, the MLSS **floc does not compact or settle well**, and **floc particles are discharged in the clarifier effluent**.

The other type of bulking, viscous bulking, is caused by an excessive amount of extracellular biopolymer. Viscous bulking is usually found with nutrient-limited systems or in a very high loading condition with wastewater having a high amount of rbCOD.

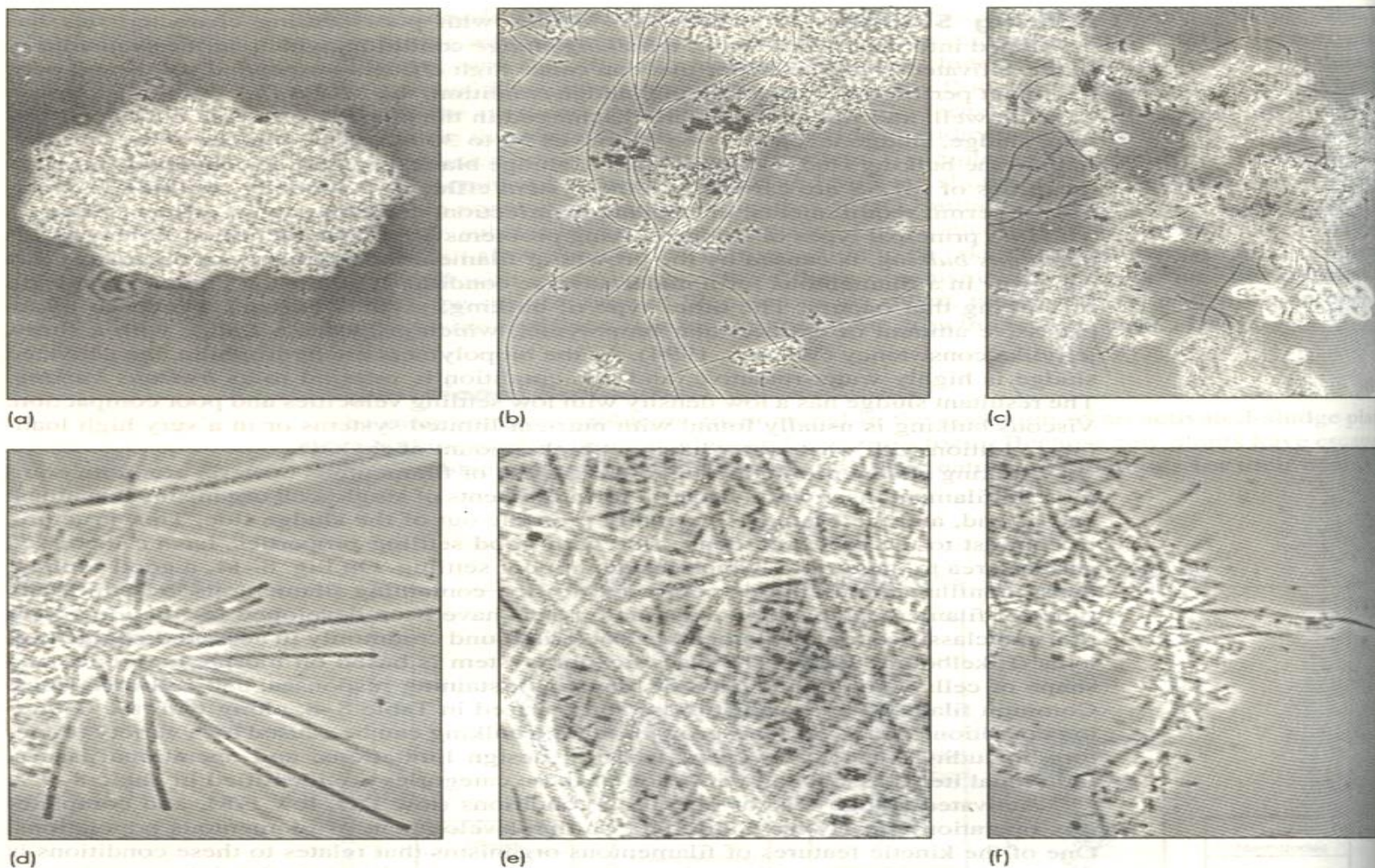


Figure 8-11

Examples of good and poor settling floc particles: (a) nonfilamentous good settling floc, (b) floc particles bridged by filamentous microorganisms, (c) floc particles with limited filamentous microorganisms and secondary form, (d) filaments extending from floc causing poor settling, (e) *Thiothrix* filaments with sulfur granules, and (f) type 1701 filamentous microorganism observed under low dissolved oxygen conditions. (Courtesy Dr. David Jenkins, University of California, Berkeley.)

This structure, in contrast to the preferred dense floc with good settling properties, has an increased surface area to mass ratio, which results in poor settling.

The classification system is based on morphology (size and shape of cells, length and shape of filaments), staining responses, and cell inclusions.

Filament type identified

Sphaerotilus natans, *Halsicomenobacter hydrossis*,
Microthrix parvicella, type 1701

M. parvicella, types 0041, 0092, 0675, 1851

H. hydrossis, *Nocardia* spp., *Nostocoida limicola*,
S. natans, *Thiothrix* spp., types 021N, 0914

Beggiatoa, *Thiothrix* spp., types 021N, 0914

S. natans, *Thiothrix* spp., type 021N, possible
H. hydrossis, types 0041, 0675

Fungi

Cause of filament growth

Low dissolved oxygen concentration

Low F/M

Complete-mix reactor conditions

Septic wastewater/sulfide available

Nutrient deficiency

Low pH, nutrient deficiency

Factor	Description
Wastewater characteristics	Variations in flowrate Variations in composition pH Temperature Septicity Nutrient content
Design limitations	Nature of waste components Limited air supply Poor mixing Short circuiting (aeration tanks and clarifiers) Clarifier design (sludge collection and removal) Limited return sludge pumping capacity
Operational issues	Low dissolved oxygen Insufficient nutrients Low F/M Insufficient soluble BOD

One of the kinetic features of filamentous organisms that relates to these conditions is that they are **very competitive** at **low substrate concentrations** whether it be organic substrates, DO, or nutrients. Thus, lightly loaded complete-mix activated-sludge systems or low DO (<0.5 mg/L) operating conditions provide an environment more favorable to filamentous bacteria than to the desired floc-forming bacteria.

When the influent wastewater contains fermentation products such as volatile fatty acids(VFA) and reduced sulfur compounds (sulfides and thiosulfate), *Thiothrix* can proliferate.

View the mixed liquor under the microscope. A reasonable quality phase-contrast microscope with magnification up to 1000 times (oil immersion) is necessary to view the filamentous bacteria or fungi structure and size.

Process Loading/Reactor Configuration

In many cases, complete-mix systems with long SRTs and subsequent low F/M ratios experience filamentous growths. In such systems, the filamentous organisms are more competitive for substrate.

We can use selector processes to solve these problems because they provide conditions that cause selection of floc-forming bacteria in lieu of filamentous organisms as the dominant population.

Temporary Control Measures

In an emergency situation or while the aforementioned factors are being investigated, **chlorine and hydrogen peroxide may be used to provide temporary help.**

Chlorination of return sludge has been practiced quite extensively as a means of controlling bulking.

Rising Sludge

The most common cause of this phenomenon is **denitrification**, in which nitrites and nitrates in the wastewater are converted to nitrogen gas. If enough gas is formed, the sludge mass becomes buoyant and rises or floats to the surface.

***Nocardia* Foam.**

Two bacteria genera, *Nocardia* and *Microthrix parvicella*, are associated with extensive **foaming** in activated-sludge processes. These organisms have **hydrophobic cell surfaces** and **attach to air bubbles**, where they **stabilize the bubbles to cause foam**.

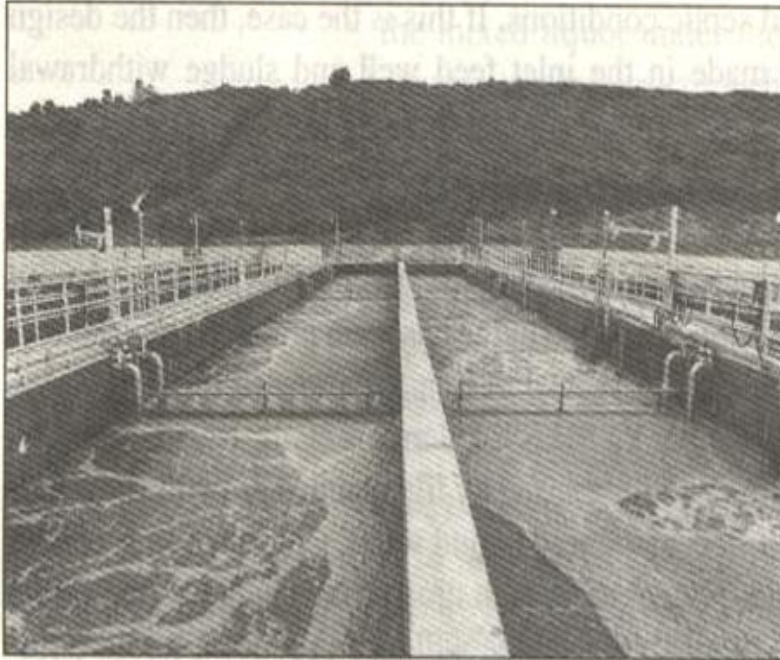
Nocardia has a filamentous structure, and the filaments are very short and are contained within the floc particles.

Microthrix parvicella has thin filaments extending from the floc particles.

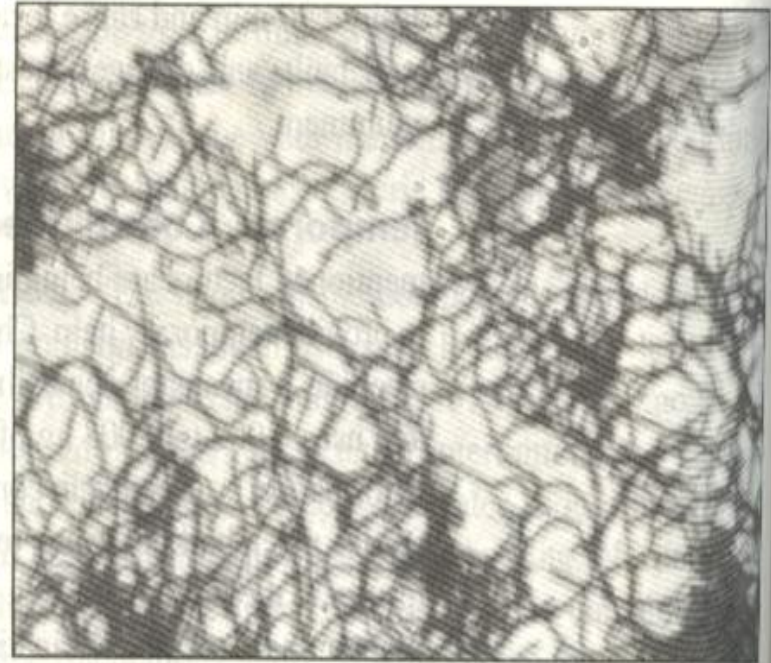
The foam is thick, has a brown color, and can build up in thickness of 0.5 to 1 m, but is more pronounced with diffused aeration and with higher air flowrates.

Methods that can be used to control *Nocardia* include (1) avoiding trapping foam in the secondary treatment process, (2) avoiding the recycle of skimmings into the secondary treatment process, and (3) using chlorine spray on the surface of the *Nocardia* foam.

The addition of a small concentration of cationic polymer has been used with some success for controlling *Nocardia* foaming . Reducing the oil and grease content from discharges to the collection system from restaurants, truck stops, and meatpacking facilities by effective degreasing processes can help control potential *Nocardia* problems.



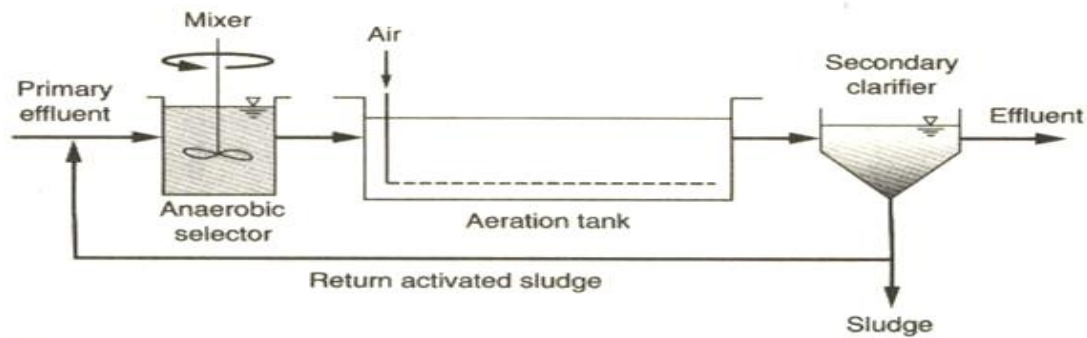
(a)



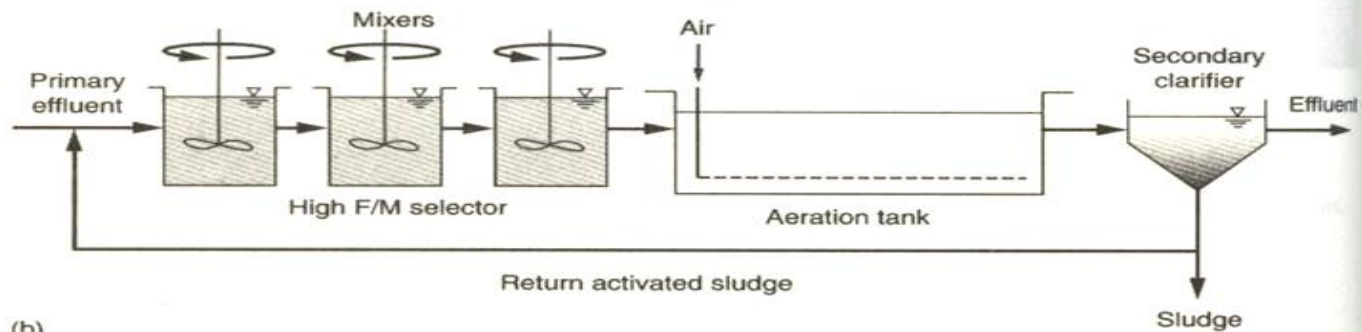
(b)

Figure 8-12

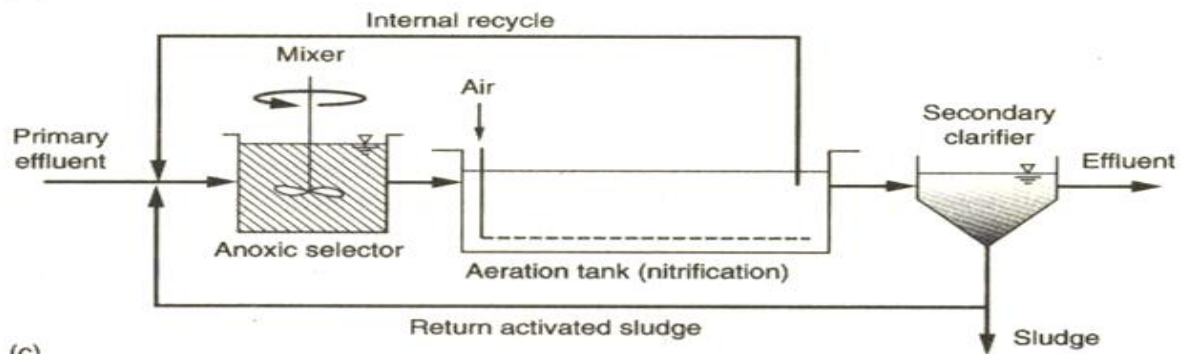
Nocardia foam: (a) example of foam on an aeration tank and (b) microscopic observation of gram-stained *Nocardia* filaments.
(Courtesy Dr. David Jenkins, University of California, Berkeley.)



(a)



(b)



(c)

Activated-Sludge Selector Processes

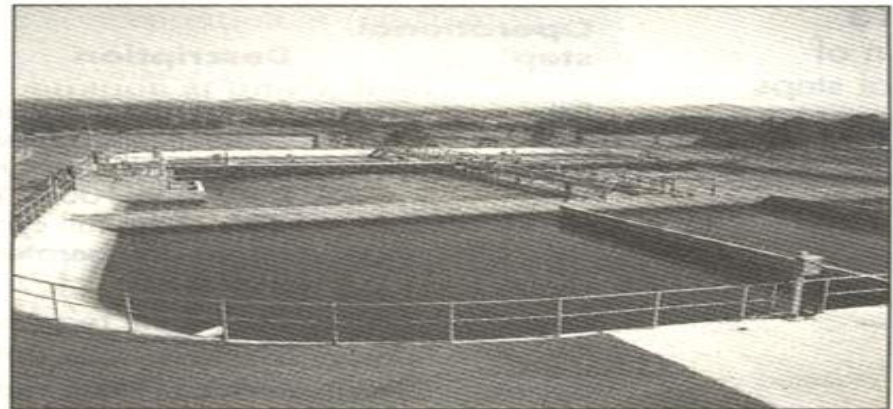
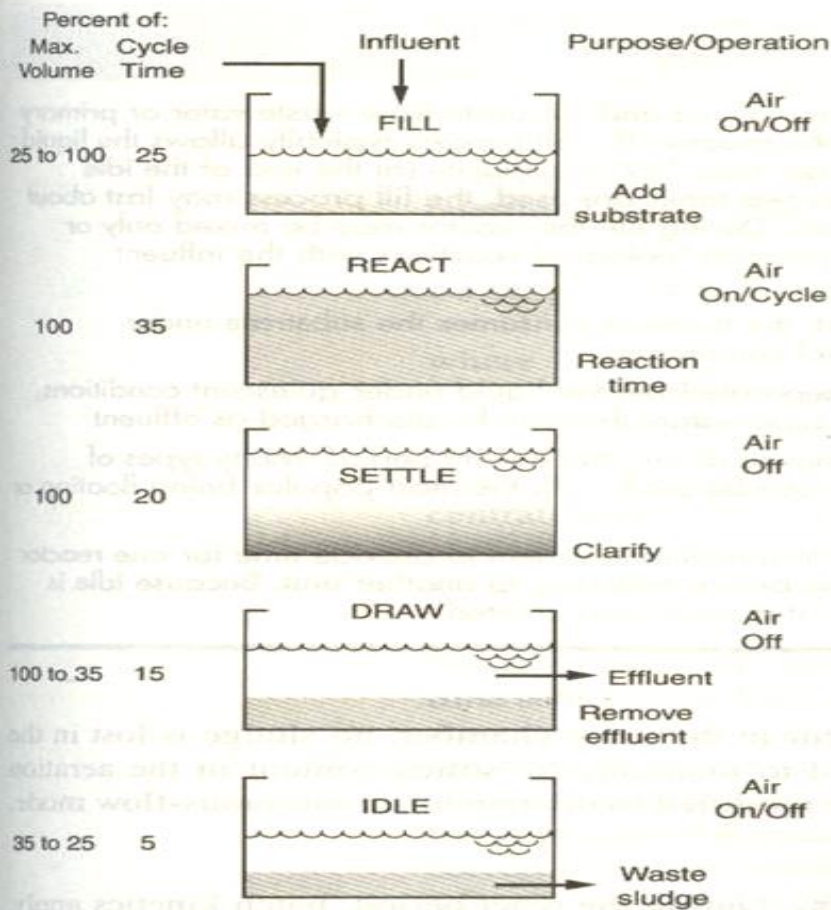
The high substrate concentration in the selector favors the growth of nonfilamentous organisms.

A selector is a small tank (20 to 60 min contact time) or a series of tanks in which the incoming wastewater is mixed with return sludge under aerobic, anoxic, and anaerobic conditions.

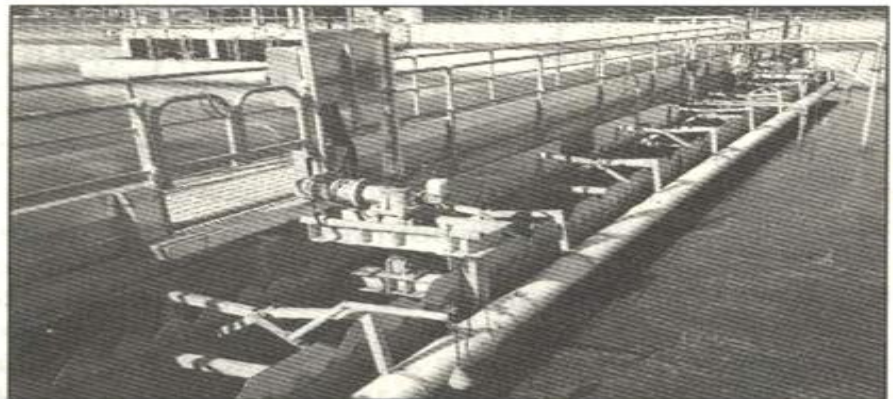
The goal in the selector is to have most of the rbCOD consumed by the floc-forming bacteria.

With biological nutrient-removal processes(脱氮除磷), improved sludge-settling characteristics, and, in many cases, minimal filamentous bacteria growth has been observed. The anoxic or anaerobic metabolic conditions used in these processes favor growth of the floc-forming bacteria. The filamentous bacteria cannot use nitrate or nitrite for an electron acceptor.

Sequencing Batch Reactor Process



(b)



(c)

Figure 8-16

Sequencing batch reactor (SBR) activated-sludge process: (a) schematic diagram and (b) view of a typical SBR reactor and (c) view of movable weir used to decant contents of SBR reactor. Weir is located on the far side of the second dividing wall shown in (b). Photographs were taken in Australia.

For continuous-flow applications, at least two SBR tanks must be provided so that one tank receives flow while the other completes its treatment cycle.

Sludge Wasting in SBRs

A unique feature of the SBR system is that there is no need for a return activated-sludge (RAS) system.

Because of the substrate concentration changes with time, the substrate utilization and oxygen demand rates change, progressing from high to low levels.

Tab. 7-6 Computation approach for the design of a SBR

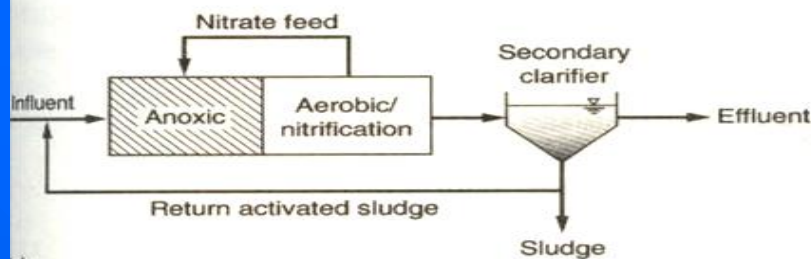
1. Obtain influent wastewater characterization data, define effluent requirements, and define safety factors
2. Select the number of SBR tanks
3. Select the react/aeration, settling, and decant times. Determine the fill time and total time per cycle. Determine the number of cycles per day
4. From the total number of cycles per day, determine the fill volume per cycle
5. Select the MLSS concentration and determine the fill volume fraction relative to the total tank volume. Determine the decant depth. Using the computed depths, determine the SBR tank volume
6. Determine the SRT for the SBR process design developed
7. Determine the amount of TKN added that is nitrified
8. Calculate the nitrifier biomass concentration and determine if the aeration time selected is sufficient for the nitrification efficiency needed
9. *Adjust the design as needed—additional iterations may be done*
10. Determine the decant pumping rate
11. Determine the oxygen required and average transfer rate
12. Determine the amount of sludge production
13. Calculate the F/M and BOD volumetric loading
14. Evaluate alkalinity needs
15. Prepare design summary

7-5 Process for Biological Nitrogen Removal

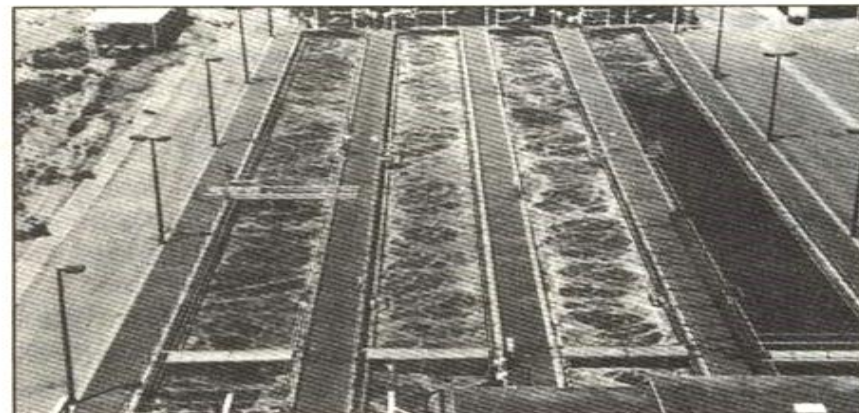
Nitrogen removal is needed to prevent **eutrophication**), or for **groundwater recharge** or other **reuse applications**.

Nitrogen removal can be either an integral part of the biological treatment system or an add-on process to an existing treatment plant.

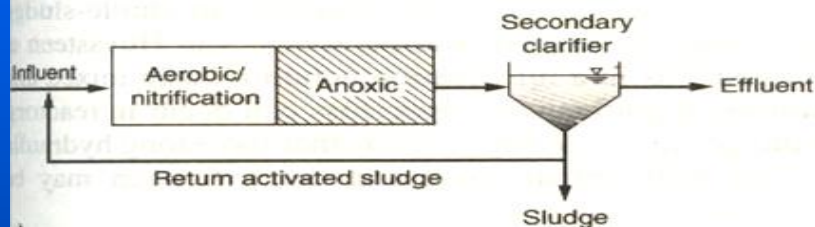
Following the discussion of design issues, design examples are provided for (1) the **anoxic/aerobic process**, (2) **step-feed anoxic/aerobic process**, (3) **intermittent aeration**, (4) a **sequencing batch reactor**, and (5) **postanoxic denitrification with methanol addition**.



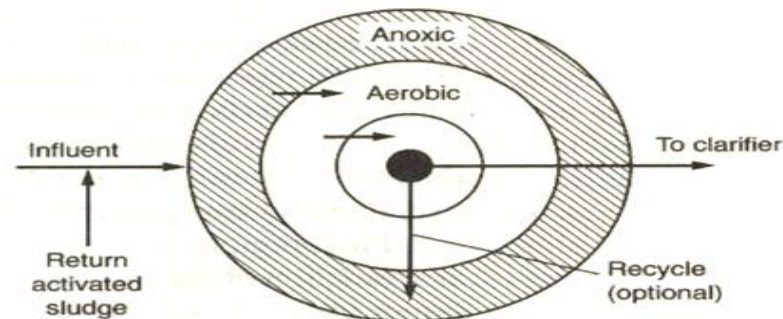
(a)



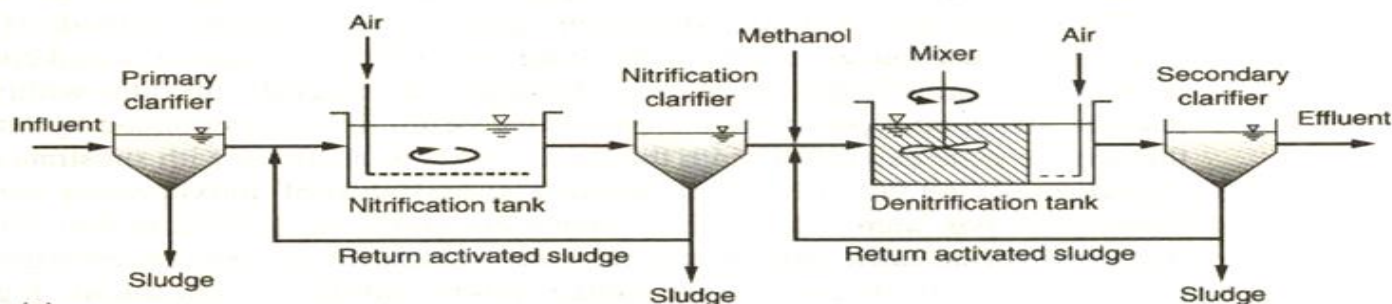
(b)



(c)



(d)



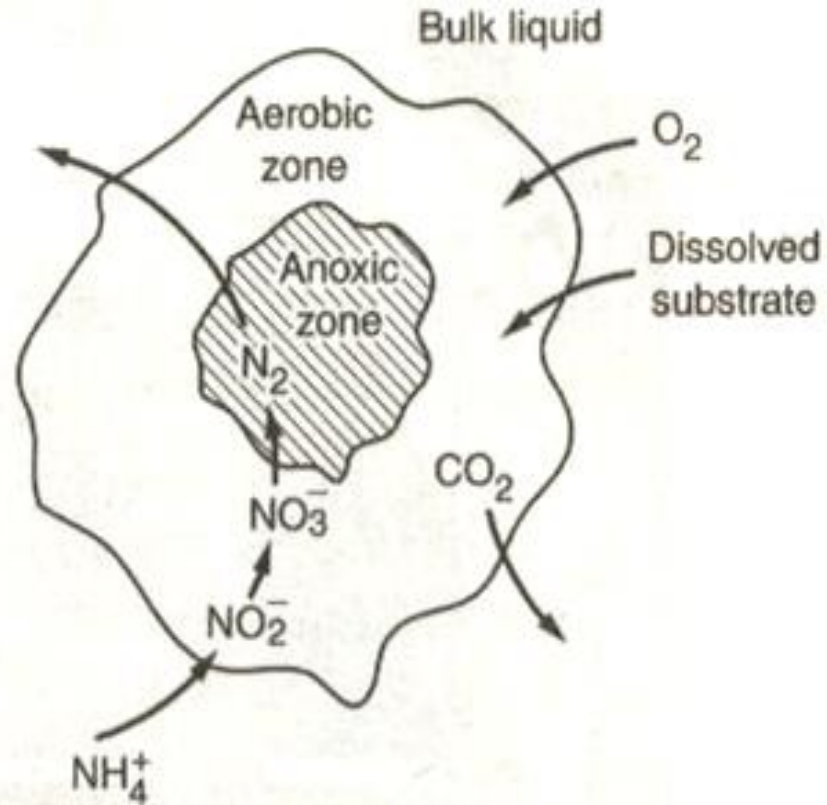
(e)

Figure 8-21

Schematic diagrams of four basic nitrogen-removal process configurations and a view of a typical reactor: (a) preanoxic, (b) view of plug-flow activated-sludge reactor used for nitrogen removal (the right-hand channel without aeration is the preanoxic section), (c) postanoxic, (d) simultaneous nitrification/denitrification, and (e) two stage nitrification-denitrification (also known as two-sludge).

Figure 8-22

Diagram of an activated-sludge particle showing aerobic and anoxic zones.



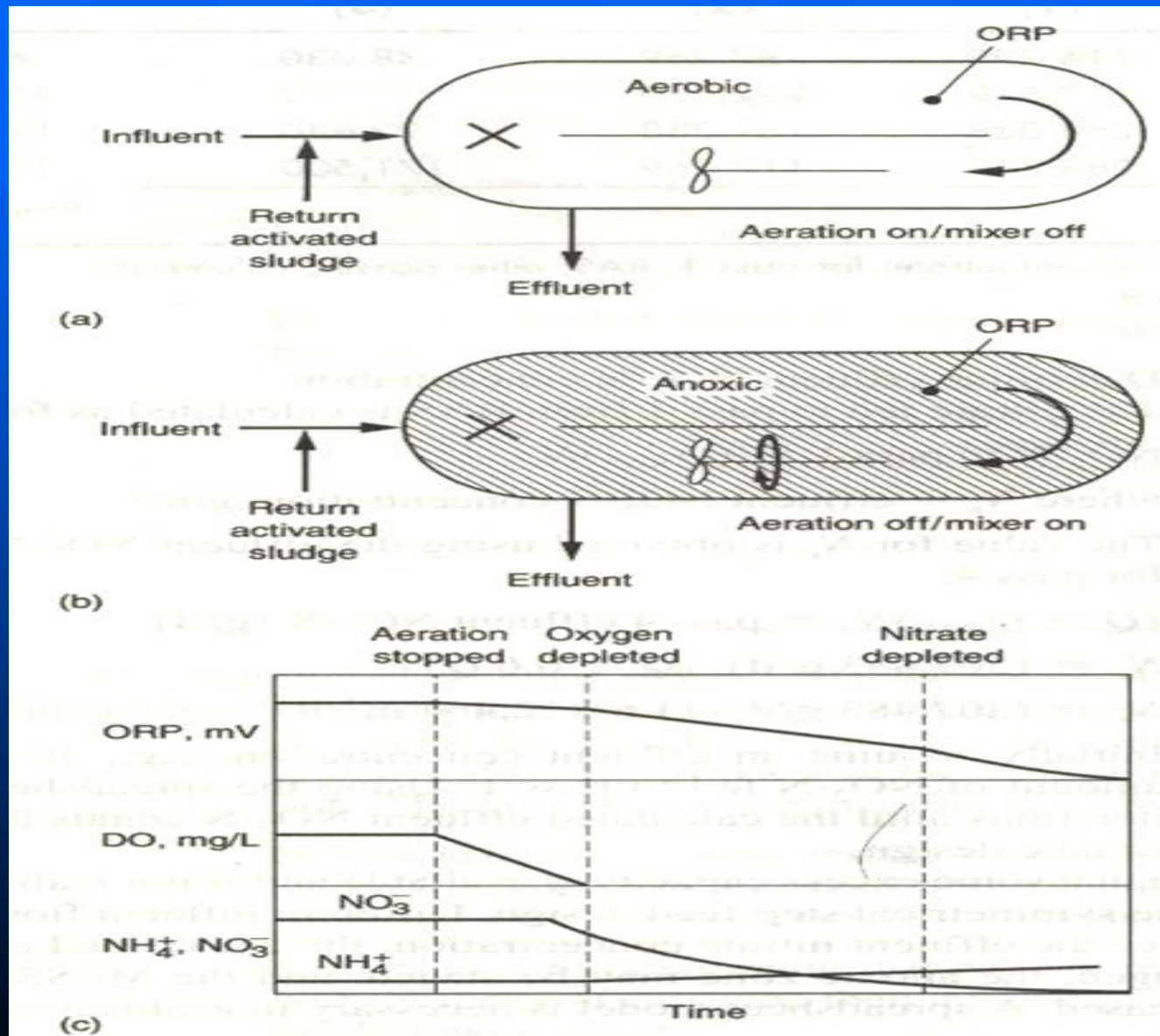
First, regions of low DO or zero DO concentration may be present within the basin as a function of the mixing regime.

Second, activated-sludge floc can contain both aerobic and anoxic zones.

Single-Sludge Simultaneous Nitrification Denitrification (SNdN) Processes

The nitrification and denitrification rates are a function of the reaction kinetics, floc size, floc density, floc structure, rbCOD loading, and bulk liquid DO concentration.

Fig. 7-16 Operation of a Nitrox oxidation ditch process using intermittent aeration: (a)aerobic conditions; (b)anoxic conditions; (c)variations in ORP,DO,ammonia and nitrate



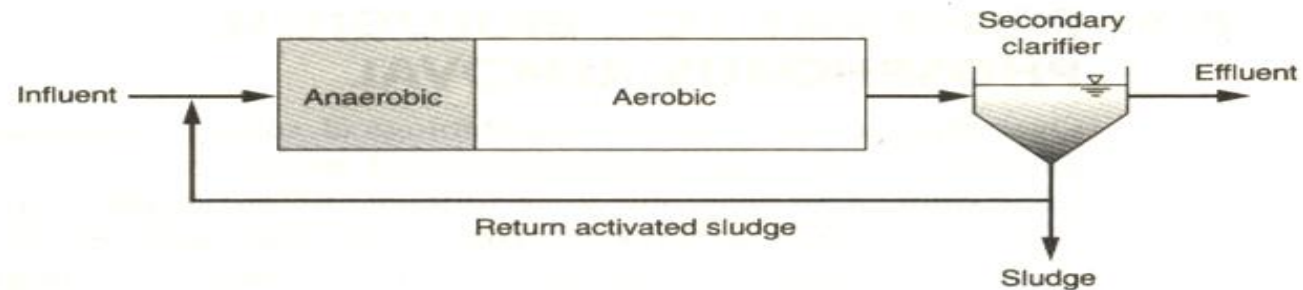
7-6 Processes for Biological Phosphorus Removal

Barnard (1974) was the first to clarify the need for **anaerobic contacting between activated sludge and influent wastewater before aerobic degradation** to accomplish biological phosphorus removal.

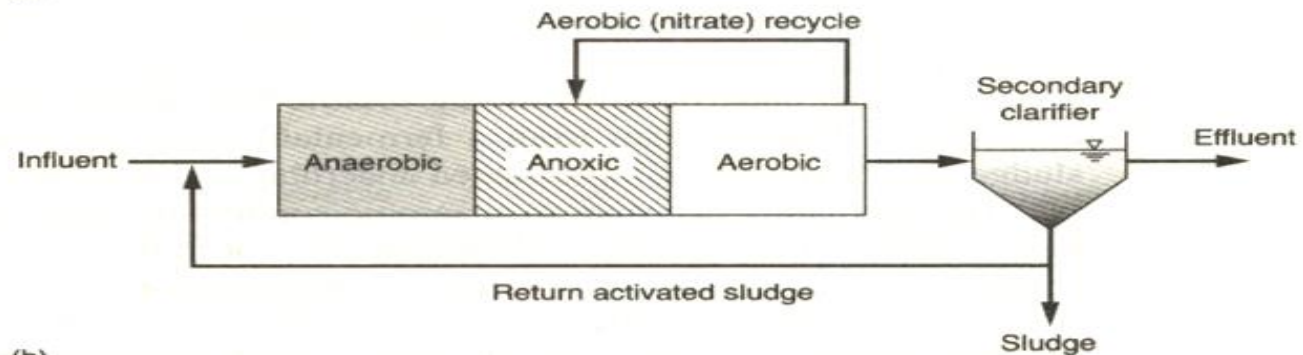
Biological Phosphorus-Removal Processes

The main difference between the Phoredox (A/O) process and the A²O processes shown on Fig. 7-17a and b is that **nitrification does not occur in the Phoredox (A/O) process**. Low operating SRTs are used to prevent the initiation of nitrification.

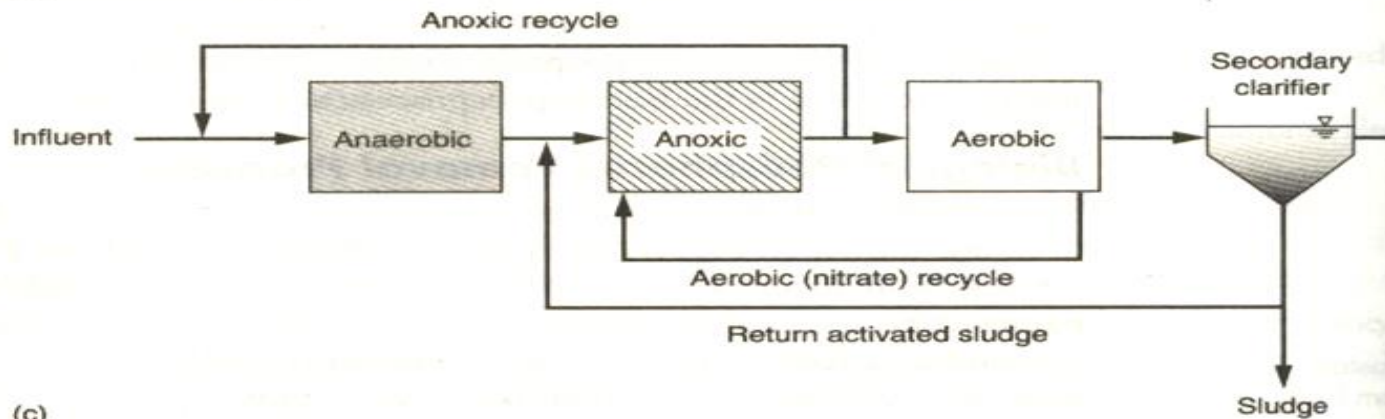
Fig. 7-17 Typical biological phosphorus removal process



(a)



(b)



(c)

Process Design Considerations

The process design considerations for BPR(biological phosphorus removal) processes include (1) wastewater characteristics, (2) anaerobic contact time, (3) SRT, (4) waste sludge processing method, and (5) chemical addition capability.

The conversion of rbCOD to VFAs (including acetate) occurs quickly through fermentation in the anaerobic zone and 7 to 10 mg of acetate results in about 1.0 mg P removal. The more acetate, the more cell growth, and, thus, more phosphorus removal.

During wet-weather conditions, especially in the winter, BPR may be difficult to achieve due to cold, low strength wastewater that does not readily become anaerobic.

With continuous VFA addition, the effluent soluble phosphorus concentration decreased from 2.5 to 0.3 mg/L.

Anaerobic Contact Time

Detention times of 0.25 to 1.0 h are adequate for fermentation of rbCOD. Polyhydroxybutyrate(PHB) provides energy for phosphorus uptake and storage.

Solids Retention Time

First, the final amount of phosphorus removed is proportional to the amount of biological phosphorus-storing bacteria wasted.

Second, at long SRTs the biological phosphorus bacteria are in a more extended endogenous phase, which will deplete more of their intracellular storage products. If the intracellular glycogen(糖元) is depleted, less efficient acetate uptake and PHB storage will occur in the anaerobic contact zone, thus making the overall BPR process less efficient.

Waste Sludge Processing

Phosphorus is released when the bacteria that contain stored phosphorus are subject to anaerobic conditions.

Anaerobic conditions in thickening and/or digestion can thus result in the release of significant amounts of phosphorus.

Thickening of waste sludge by dissolved air flotation, gravity belt thickeners, or rotary-drum thickeners is preferred over gravity thickening of waste sludge to minimize phosphorus release.

Chemical Addition Capability

Phosphorus can be removed biologically to dissolved concentrations as low as 0.20 to 0.30 mg/L, provided sufficient rbCOD is available.

Where there are insufficient amounts of rbCOD in the influent wastewater, chemical addition is necessary to provide enough phosphorus removal to meet the effluent discharge concentration needed. Alum or iron salts may be used and may be applied at a number of locations in the liquid stream treatment process.

Iron salts may be preferred in some cases over alum salts for primary treatment applications, because they have the additional advantage of removing sulfide to help reduce odors.

Process Control

Filter backwash recycle flows should be sent to the aerobic zone instead of the anaerobic or anoxic zones. Recycle streams with significant concentrations of DO and nitrate can have an adverse impact on process performance.

Effluent Suspended Solids

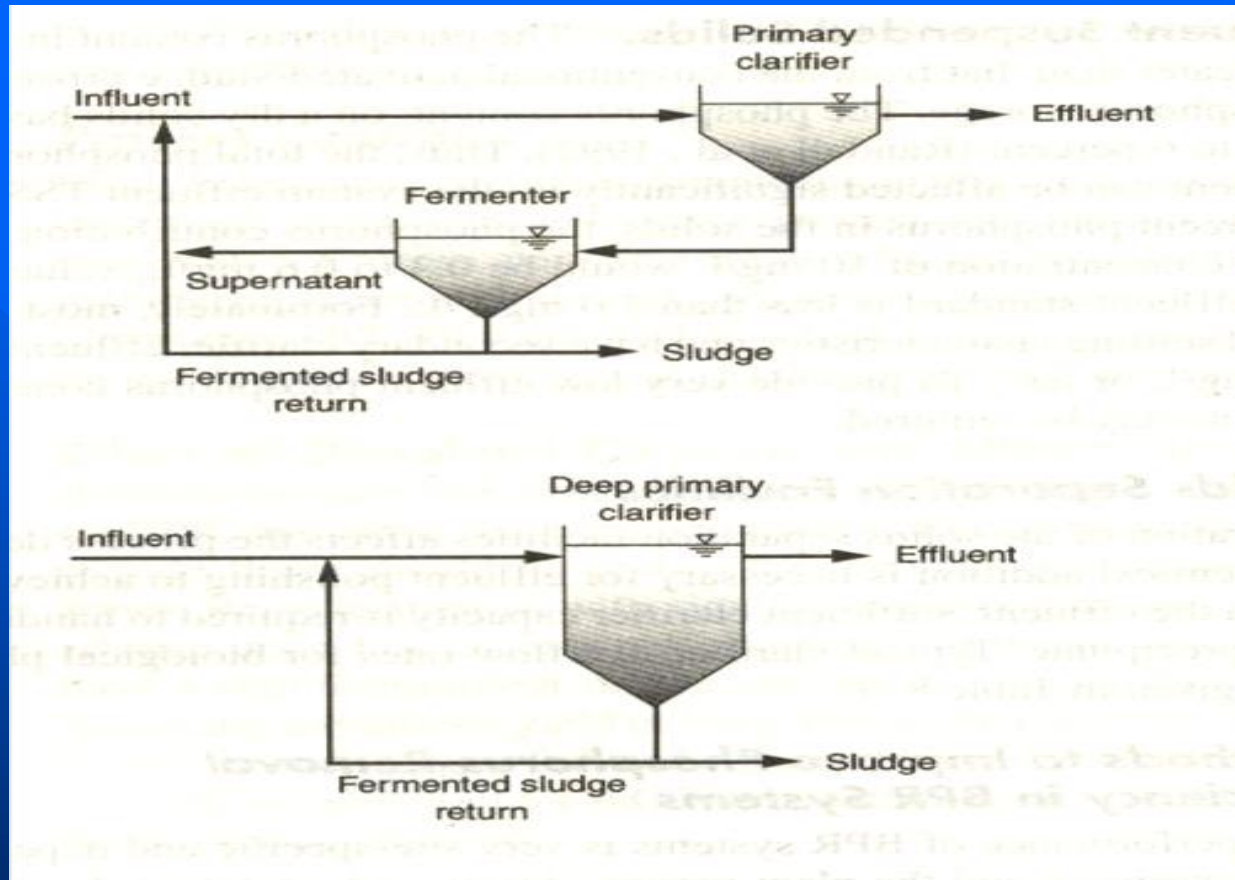
The phosphorus content in the mixed-liquor solids is greater than that from the conventional activated-sludge process due to the biological phosphorus storage.

At 3 to 6 percent phosphorus in the solids, the phosphorus contribution in an effluent having a TSS concentration of 10 mg/L would be 0.3 to 0.6 mg/L, values that are significant if the effluent standard is less than 1.0 mg P/L. To provide very low effluent phosphorus concentrations, effluent filtration may be required.

Methods to Improve Phosphorus-Removal Efficiency in BPR Systems

1. Provide supplemental acetate by direct purchase or by primary sludge fermentation.
2. Reduce the process SRT.
3. Add alum or iron salts in primary treatment or for effluent polishing.
4. Reduce the amount of nitrate and/or oxygen entering the anaerobic zone.

Fig. 7-18 Examples of fermentation reactors for producing volatile fatty acids(VFAs) used for phosphorus removal



A deeper depth primary clarifier design has also been proposed to provide sufficient holding time for the settled primary sludge for hydrolysis and acid fermentation .

The additional VFA supply to the BPR process decreased the average effluent phosphorus concentration from about 1.5 to 0.5 mg/L. Alum was later added before the secondary clarifiers at a dosage of about 8 mg/L (as alum) to further reduce the effluent phosphorus concentration.

With both **prefermentation and alum addition**, the effluent phosphorus concentration averaged less than 0.20 mg/L.

Fig. 7-19 Typical non-Nocardia froth on activated-sludge aeration tank sludge return channels

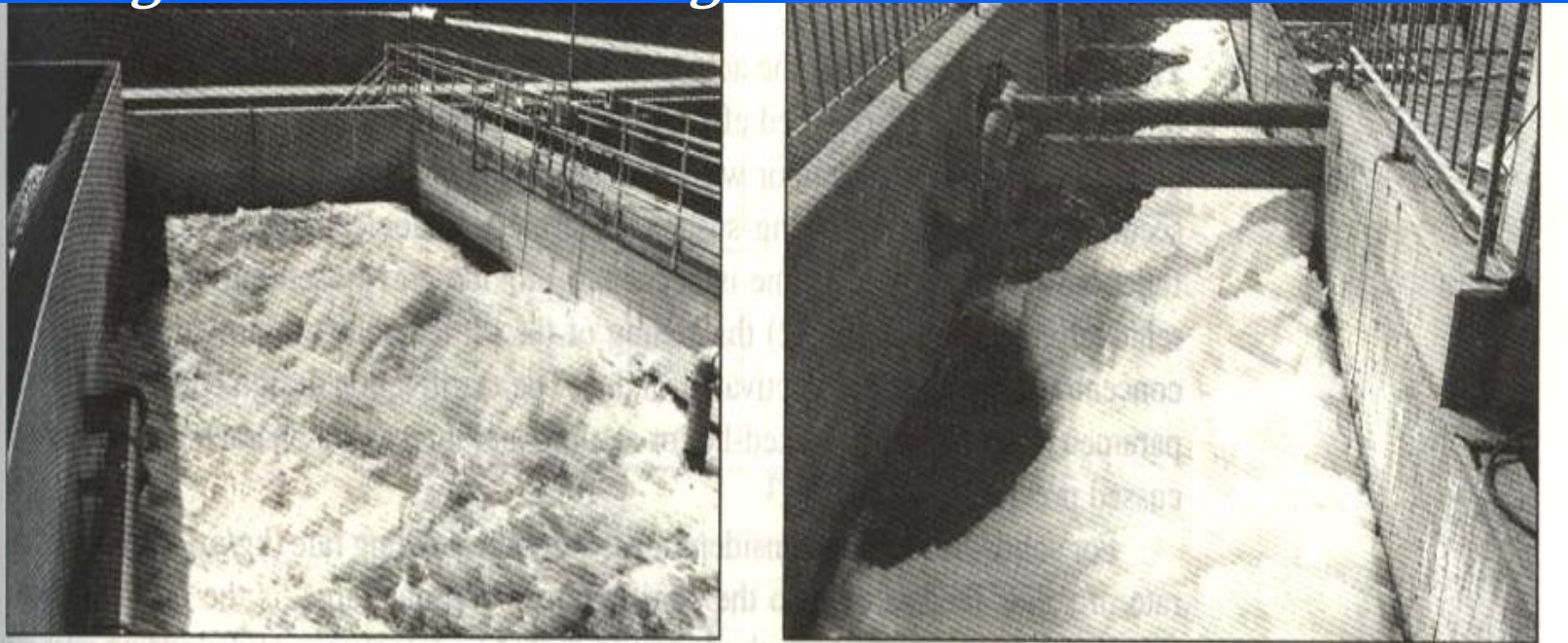


Figure 8-33

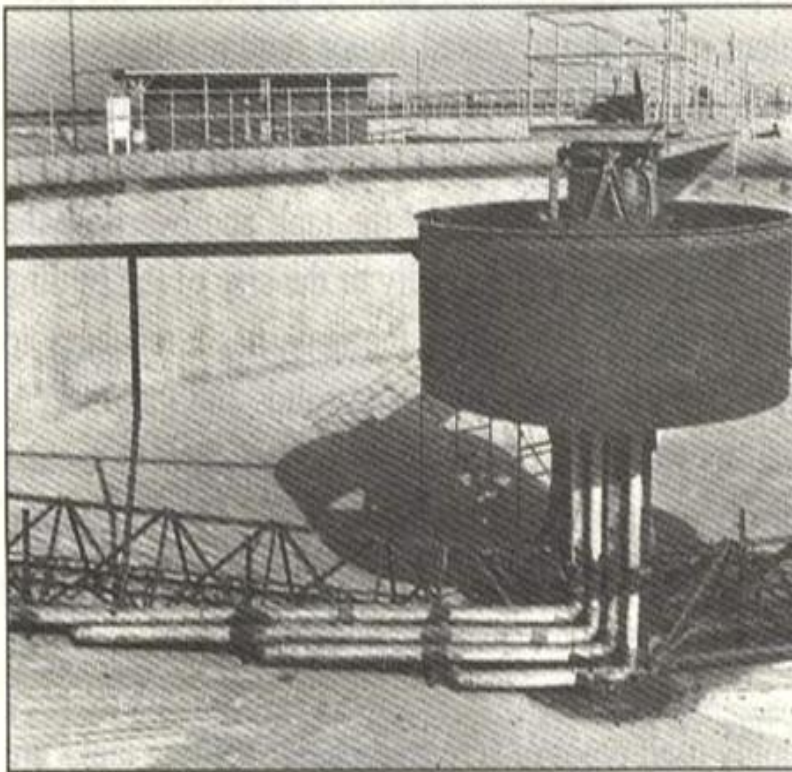
Typical non-Nocardia froth on activated-sludge aeration tank sludge return channels.

Wastewater normally contains soap, detergents, and other surfactants that produce foam when the wastewater is aerated.

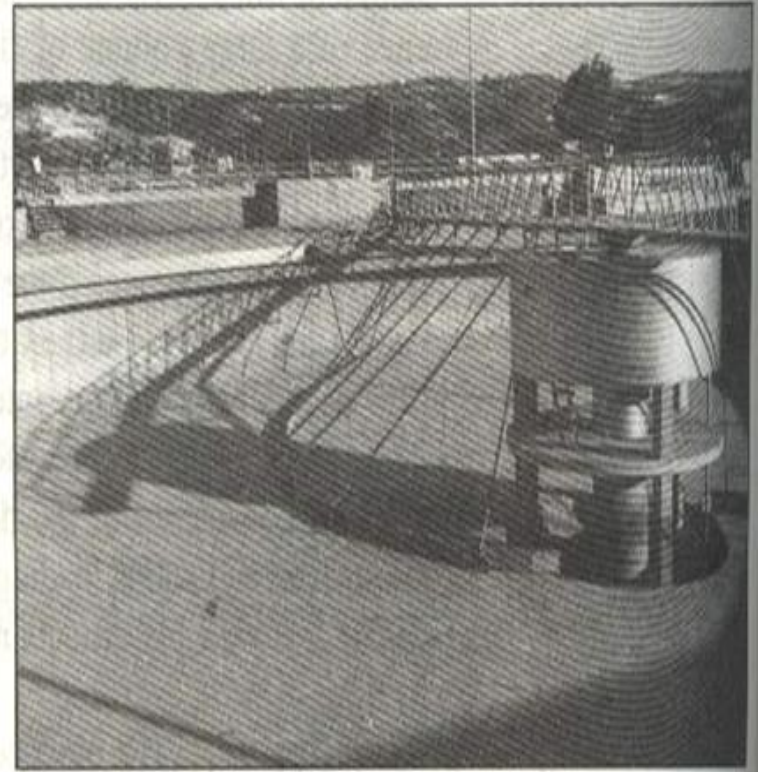
The wind may lift the froth off the tank surface and blow it about, contaminating whatever it touches. The froth, besides being **unsightly**, is a **hazard to those working with it** because it is very **slippery**, even after it collapses. In addition, **once the froth has dried, it is difficult to remove.**

A commonly used system for spiral-roll tanks consists of a series of **spray nozzles** mounted above the surface in areas where the froth collects. Screened effluent or clear water is sprayed through these nozzles and physically breaks down the froth as it forms. Another approach is to meter a small quantity of **antifoaming chemical additive** into the spray water.

*Fig. 7-20 Typical circular sludge collection mechanisms:
(a)suction type; (b)spiral type scrapper*



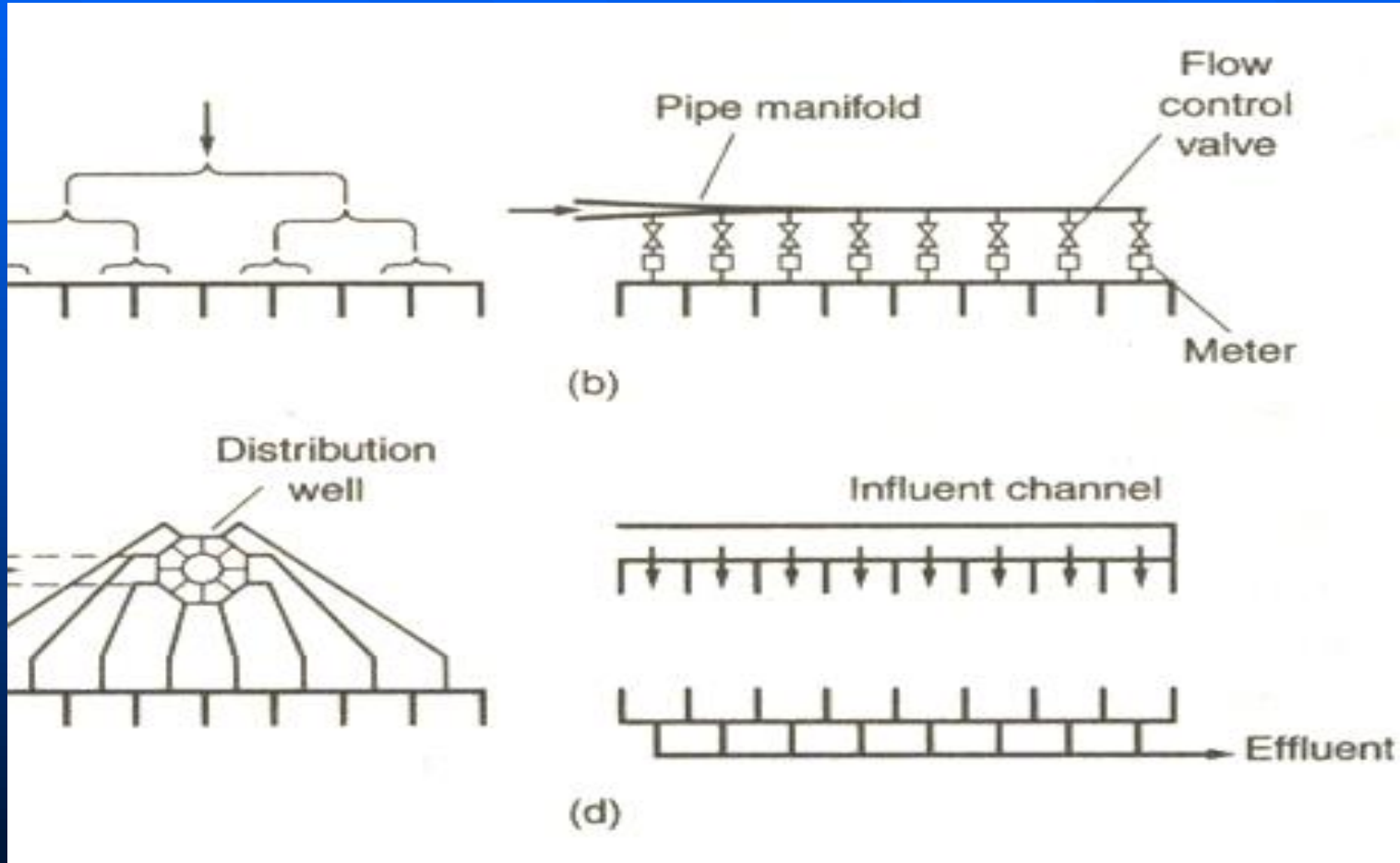
(a)



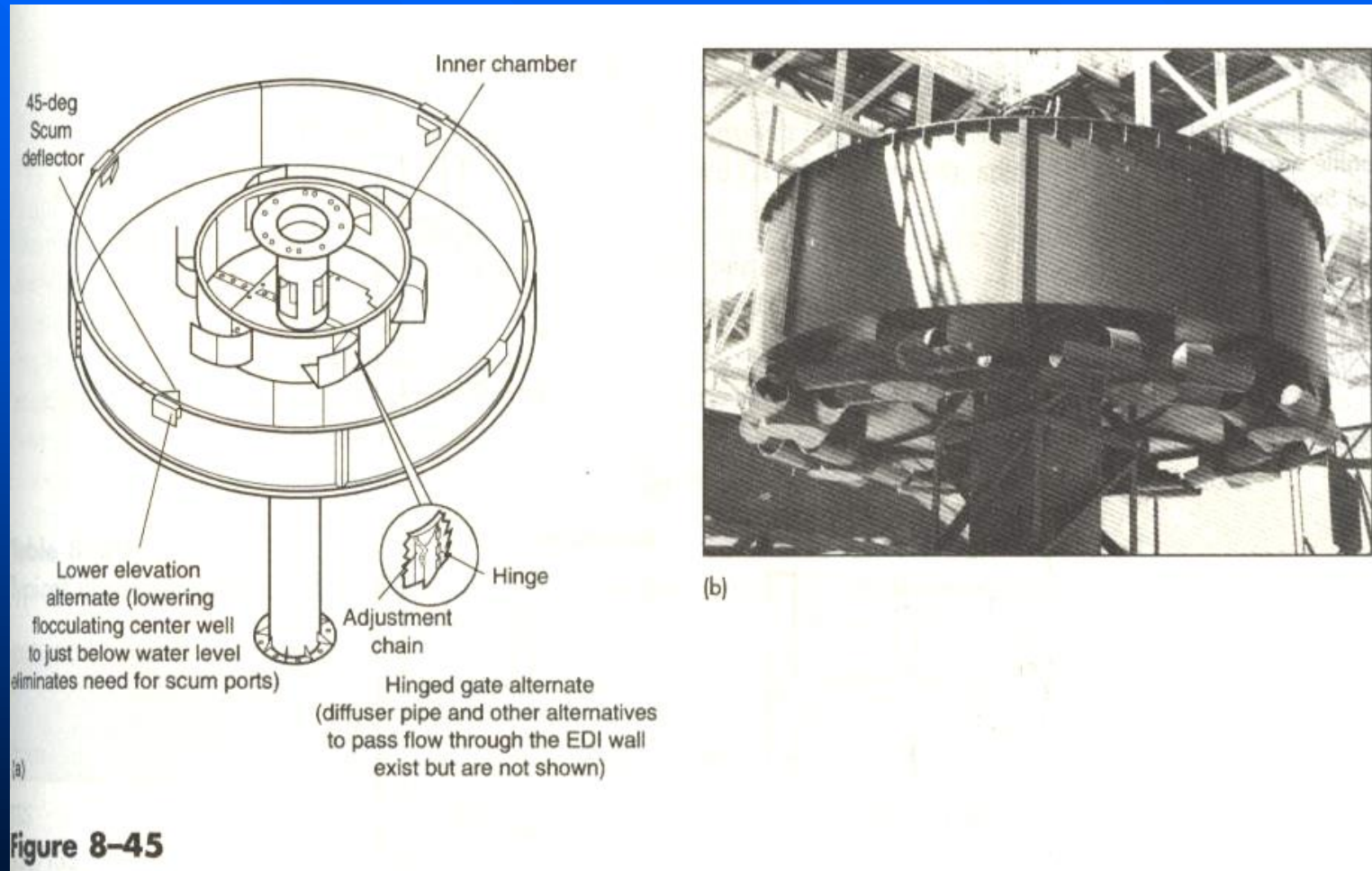
(b)

Figure 8-40

***Fig. 7-22 Alternative methods of flow splitting:
(a)hydraulic symmetry; (b)flow measurement and
feedback control; (c)hydraulic split with Weirs; (d)inlet
feed gate control***



***Fig. 7-23 Energy-dissipating inlet devices used in circular clarifiers:
(a)schematic of a center column energy-dissipating inlet and
flocculation feed well; (b)view of an energy-dissipating feed well***

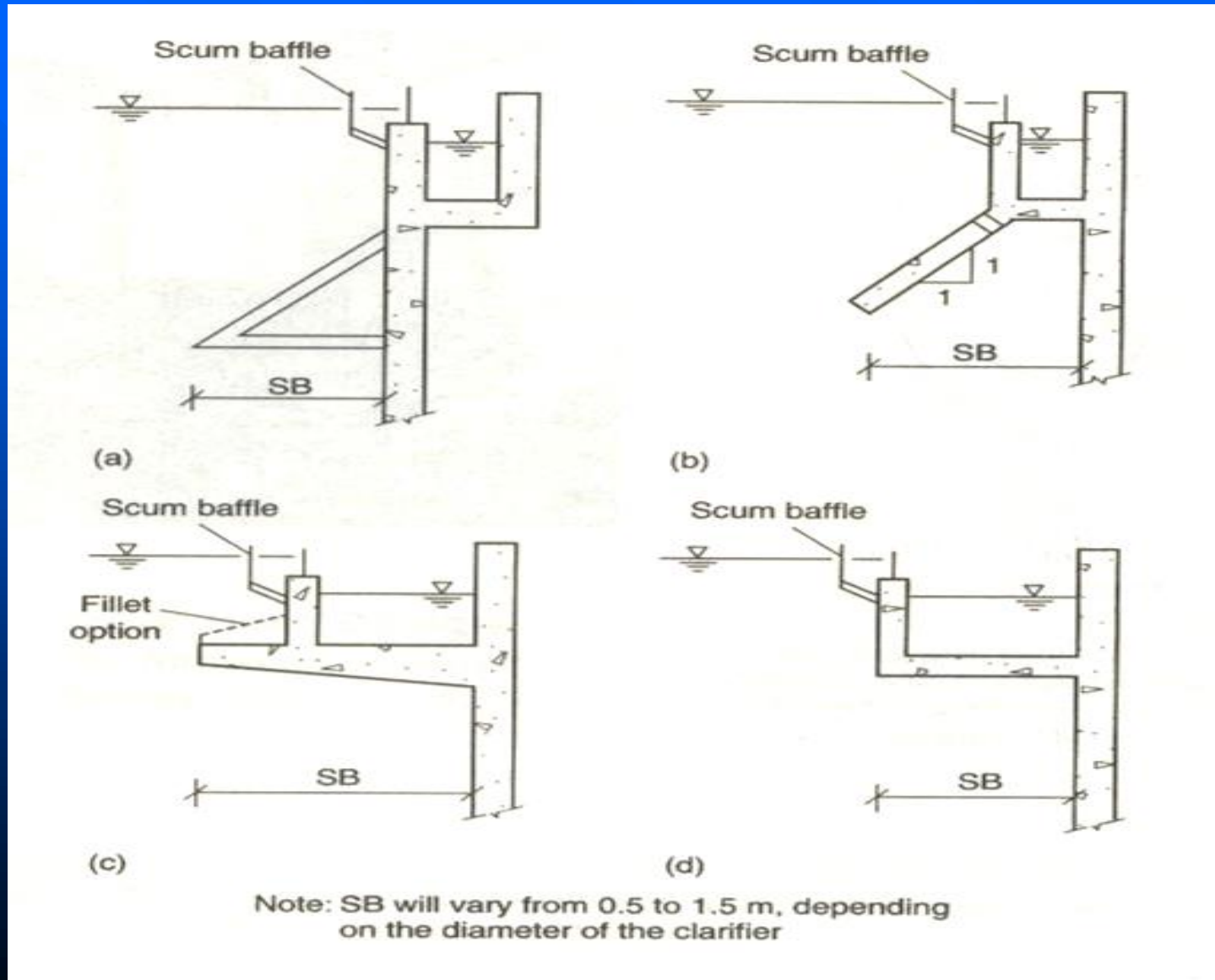


Tank Inlet Design

Poor distribution or jetting of the tank influent can increase the formation of density currents and scouring of settled sludge, etc.

Tank inlets should dissipate influent energy, distribute the flow evenly in horizontal and vertical directions, mitigate density currents, minimize sludge blanket disturbance, and promote flocculation.

***Fig. 7-24 Alternative peripheral baffle arrangements:
(a)Stamford; (b)unnamed; (c)Mckinney; (d)interior trough***



Scum Removal

Typical scum-removal equipment includes beach and scraper type, rotating pipe-through skimmer, and slotted pipes.

Scum should not be returned to the plant headworks because microorganisms responsible for foaming (typically *Nocardia*) will be recycled, causing foaming problems to persist because of continuous seeding of the unwanted microorganisms.

7-8 Suspended Growth Aerated Lagoons

Types of Suspended Growth Aerated Lagoons

Classified based on the manner in which the solids are handled are:

1. Facultative partially mixed
2. Aerobic flow through with partial mixing
3. Aerobic with solids recycle and nominal complete mixing

Facultative Partially Mixed Lagoon

The energy input is only sufficient to transfer the amount of oxygen required for biological treatment, but is not sufficient to maintain the solids in suspension.

Because the energy input will not maintain the solids in suspension, a portion of the incoming solids will settle along with a portion of the biological solids produced from the conversion of the soluble organic substrate.

Temperature

Because suspended growth aerobic flow-through lagoons are often installed and operated in locations with **widely varying climatic conditions**, the effects of temperature change must be considered in their design. The two most important effects of temperature are (1) **reduced biological activity and treatment efficiency** and (2) **the formation of ice**.

Surface aerators tend to further cool lagoons in cold weather, but **submerged diffused air systems** add heat to some extent.

In multiple lagoon systems, cold-weather effects can be mitigated by seasonal changes in the method of operation. During the warmer months, the lagoons would be **operated in parallel**; in the winter, they would be **operated in series**. In the winter operating mode, the **downstream aerators could be turned off and removed**, and the lagoon surface is allowed to freeze.

With this method of operation it is possible to achieve a 60 to 70 percent removal of BOD even during the coldest winter months. Still another method that can be used to improve performance during the winter months is to **recycle a portion of the solids** removed by settling.

Mixing Requirements

The **threshold energy input value** for the suspension of biosolids is about 1.5 to 1.75 kW/10³ m³. For depths greater than 3.7m, aerators with draft tubes may be considered to prevent solids deposition.

The **hydraulic detention time** for the complete-mix lagoon will typically vary from 1.5 to 3 d. The total retention time for the facultative lagoons is on the order of 3d.

7-9 Biological Treatment with Membrane Separation

Membrane biological reactors (**MBRs**), consisting of a biological reactor (bioreactor with suspended biomass and solids separation by **microfiltration membranes** with nominal pore sizes ranging from 0.1 to 0.4 μm , are finding many applications in wastewater treatment.

The ability of MBR to eliminate secondary clarification and operate at higher MLSS concentration provides the following **advantages**: (1) higher volumetric loading rates and thus shorter reactor hydraulic retention times; (2) **longer SRTs resulting in less sludge production**; (3) operation at low DO concentrations with potential for simultaneous nitrification-denitrification in long SRT designs; (4) **high-quality effluent in terms of low turbidity bacteria, TSS, and BOD**; **and**; (5) less space required for wastewater treatment.

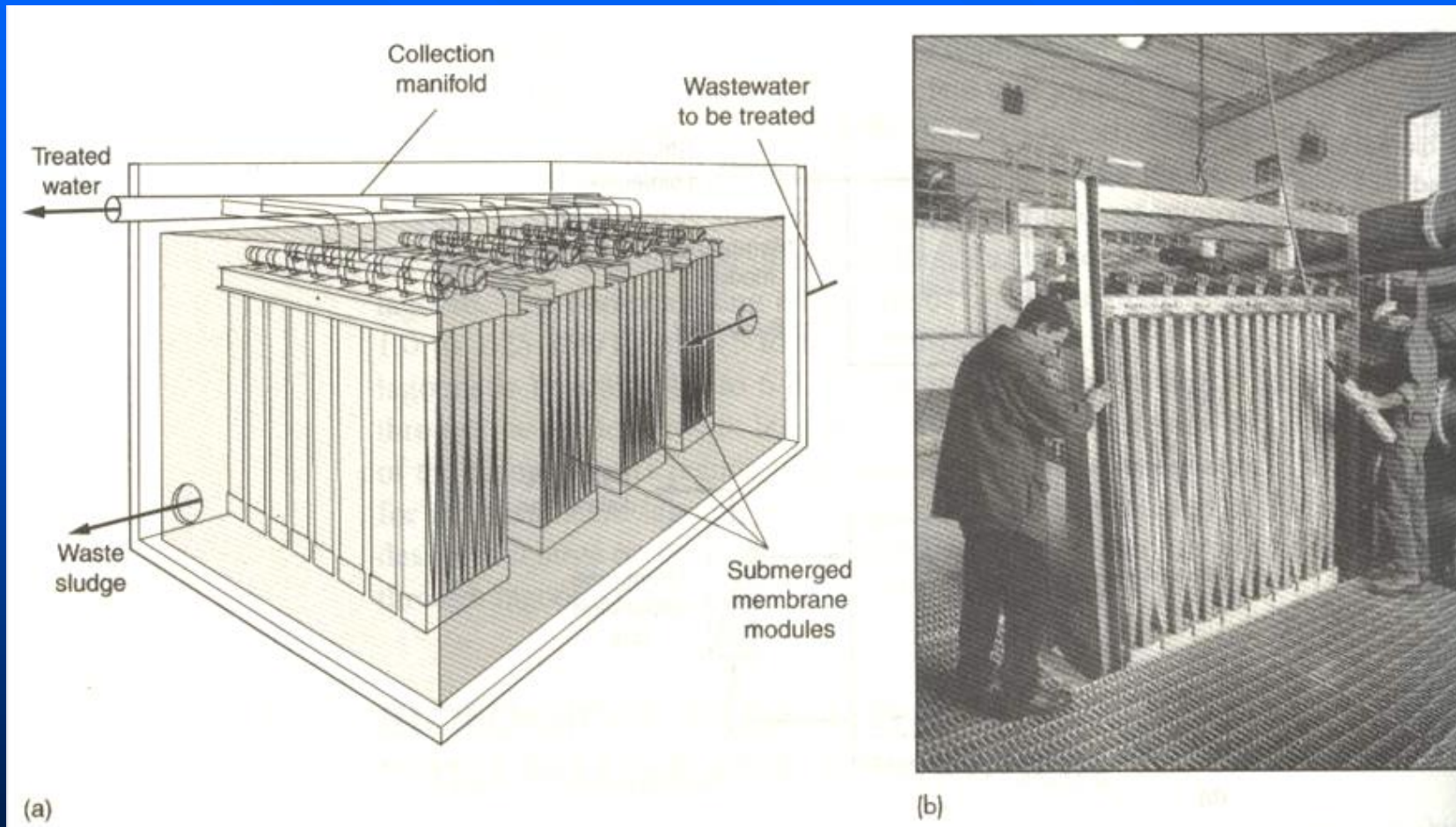
Disadvantages of MBRs include high capital costs, limited data on membrane life, potential high cost of periodic membrane replacement or scouring, higher energy costs, and the need to control membrane fouling.

Membrane bioreactor systems have **two basic configurations**: (1) the **integrated bioreactor** that uses membranes immersed in the bioreactor and (2) the recirculated MBR in which the mixed liquor circulates through a **membrane module situated outside the bioreactor**.

The membranes are mounted in modules (sometimes called cassettes) that can be lowered into the bioreactor. The modules are comprised of the membranes, support structure for the membranes, feed inlet and outlet connections, and an overall support structure.

The membranes are subjected to a vacuum (less than 50 kPa) that draws water (permeate) through the membrane while retaining solids in the reactor. To maintain TSS within the bioreactor and to clean the exterior of the membranes, compressed air is introduced through a distribution manifold at the base of the membrane module. As the air bubbles rise to the surface, scouring of the membrane surface occurs; the air also provides oxygen to maintain aerobic conditions.

Fig. 7-25 Typical membrane bioreactors: (a) schematic of placement of membrane bundles in an activated Sludge reactor ; (b) membrane bundle in position to be placed in a membrane bioreactor



In the MBR system, MLSS concentrations in the range of 8000 to 10,000 mg/L appear to be most cost-effective when all factors are considered.

The membrane flux rate, defined as the mass or volume rate of transfer through the membrane surface [in terms of $\text{L}/\text{m}^2\cdot\text{h}$] is an important design and operating parameter that affects the process economics.

Membrane Fouling Control

In the activated-sludge reactor, **biomass coats** the outer layer of the membranes used in an integrated MBR during effluent withdrawal. **Finer particles may penetrate** the inner pores of the membrane, causing an increase in pressure loss.

First, coarse bubble aeration is provided at the bottom of the membrane tank directly below the membrane fibers. The air bubbles flow upward between the vertically oriented fibers, **causing the fibers to agitate against one another** to provide mechanical scouring.

Second, filtration is interrupted about every 15 to 30 min and the membrane fibers are **backwashed** for 30 to 45 s.

Typically, a low concentration of **chlorine** (<5 mg/L) is maintained in the backflush water to inactivate and remove microbes. Third, about three times per week a strong **sodium hypochlorite** solution (about 100 mg/L) or citric acid is used in the backflush mode for 45 min .

The cassettes can be removed easily from the aeration basin by an overhead hoist system for a periodic chemical-bath cleaning.

When removed for cleaning, the cassettes are submerged in a high-concentration chlorine solution bath in a separate small tank or basin. **External cleaning** occurs about every 3 to 6 months.

The combination of air scour, backflushing, and maintenance cleaning is **not completely effective** in controlling membrane fouling, and the pressure drop across the membrane increases with time. At a maximum operating pressure drop of ≈ 60 kPa, the membranes are removed from the aeration basin for a recovery cleaning .