Excerpt from "Water Supply & Pollution Control" by Viessman & Hammer

Ch. 12

ACTIVATED SLUDGE

Activated-sludge processes are used for both secondary treatment and complete aerobic treatment without primary sedimentation. Wastewater is fed continuously into an aerated tank, where the microorganisms metabolize and biologically flocculate the organics (Fig. 12.8). Microorganisms (activated sludge) are settled from the aerated mixed liquor under quiescent conditions in the final clarifier and returned to the aeration tank. Clear supernatant from the final settling tank is the plant effluent.

The primary feeders in activated sludge are bacteria; secondary feeders are holozoic protozoans (Fig. 12.11). Microbial growth in the mixed liquor is maintained in the declining or endogenous growth phase to ensure good settling characteristics (Fig. 12.9). Synthesis of the waste organics results in a buildup of the microbial mass in the system. Excess activated sludge is wasted from the system to maintain the proper food/microorganism ratio (F/M) and sludge age to ensure optimum operation.

Activated sludge is truly an aerobic treatment process because the biological floc are suspended in a liquid medium containing dissolved oxygen. Aerobic conditions must be maintained in the aeration tank; however, in the final clarifier, the dissolved-oxygen concentration can become extremely low. Dissolved oxygen extracted from the mixed liquor is replenished by air supplied to the aeration tank.

12.19 BOD Loadings and Aeration Periods

General loading and operational parameters for the activated-sludge processes used in treatment of municipal wastewater are listed in Table 12.3.

The BOD load on an aeration tank is calculated using the BOD in the influent wastewater without regard to that in the return sludge flow. BOD loadings are expressed in terms of pounds of BOD applied per day per 1000 ft^3 of liquid volume in the aeration tank and in terms of pounds of BOD applied/day/lb of mixed-liquor suspended solids (MLSS) in the aeration tank. The latter, the F/M ratio, is expressed by some authors in terms of lb of BOD applied/day/lb of volatile mixed-liquor suspended solids (MLVSS).

The aeration period is the detention time of the raw-wastewater flow in the aeration tank expressed in hours. It is calculated by dividing the tank volume by the daily average flow without regard to return sludge. The activated sludge returned is expressed as a percentage of the raw-wastewater influent. For example, if the return sludge rate is 20% and the raw-wastewater flow into the plant is 10 mgd, the return sludge is 2.0 mgd.

BOD loadings per unit volume of aeration tank vary from greater than 100 to less than 10 lb of BOD/1000 ft^3/day, while the aeration periods correspondingly vary from 2.5 to 24 hr. The relationship between volumetric BOD loading and aeration period is directly related to BOD concentration in the wastewater. For example, converting the average BOD concentration of 200 mg/l into units of pounds per 1000 ft^3 yields a concentration of

$$200 \text{ mg/l} \times \frac{62.4 \text{ lb/1000 ft}^3}{1000 \text{ mg/l}} = 12.5 \text{ lb/1000 ft}^3$$

Therefore, 200 mg/l wastewater applied to an extended aeration system with a 24-hr (1-day) aeration period results in a BOD loading of 12.5 lb/1000 ft^3/day. If a high-rate aeration period of 6.0 hr is considered, the BOD loading becomes

$$12.5 \text{ lb/1000 ft}^3\text{/day} \times \frac{24 \text{ hr}}{6.0 \text{ hr}} = 50 \text{ lb/1000 ft}^3\text{/day}$$

Sludge age (mean cell residence time) relates the quantity of microbial solids in an activated-sludge process to the quantity of solids lost in the effluent and excess solids withdrawn in the waste sludge. Equation (12.60) establishes the sludge age in days on

Table 12.3 General Loading and Operational Parameters for Activated-Sludge Processes

PROCESS	BOD LOADING: lb BOD 1000ft³/day[a]	BOD LOADING: lb BOD/day/lb of MLSS	SLUDGE AGE (days)	AERATION PERIOD (hr)	AVERAGE RETURN SLUDGE RATES (%)
Step aeration	30–50	0.2–0.5	5–15	5.0–7.0	50
Conventional (tapered aeration)	30–40	0.2–0.5	5–15	6.0–7.5	30
Contact stabilization	30–50	0.2–0.5	5–15	6.0–9.0	100
Extended aeration	10–30	0.05–0.2	20+	20–30	100
High-purity oxygen	120+	0.6–1.5	5–10	1.0–3.0	30

[a] 1.0 lb/1000 ft^3/day = 16 $g/m^3 \cdot d$.

the basis of MLSS in the aeration tank relative to SS discharged in the effluent and SS in the waste sludge withdrawn daily:

$$\text{Sludge age} = \frac{\text{MLSS} \times V}{\text{SS}_e \times Q_e + \text{SS}_w \times Q_w} \quad \textbf{(12.60)}$$

where

sludge age = mean cell residence time, days
MLSS = mixed-liquor suspended solids, mg/l
V = volume of the aeration tank, mil gal (m^3/d)
SS_e = suspended solids in effluent, mg/l
SS_w = suspended solids in waste sludge, mg/l
Q_e = quantity of effluent wastewater, mgd (m^3/d)
Q_w = quantity of waste sludge, mgd (m^3/d)

Sludge age is also calculated using the MLVSS (volatile portion of the MLSS) and the VSS (volatile suspended solids) in the effluent and waste sludge. The argument is that the volatile portion of the suspended solids is more representative of the microbial masses, and thus the sludge age expresses the residence time of the microbial cells in the system more realistically.

The suspended-solids concentration maintained in the MLSS of conventional and step-aeration processes ranges from 1500 to 3000 mg/l. The concentration held in the operation of a particular system depends on the desired F/M and sludge age for the applied BOD load. High-rate completely mixed processes generally operate with higher MLSS concentrations of 3000–4000 mg/l. Because of the variety of extended aeration processes, MLSS values encompass the entire range of 1000 to greater than 5000 mg/l.

Solids retention in an activated-sludge system is measured in days, whereas the liquid aeration period is in hours. For example, a conventional activated-sludge process with an MLSS of 2500 mg/l in the aeration tank, treating an average domestic wastewater and operating at a 6-hr aeration period, has a sludge age of approximately 7 days. The suspended solids are cycled in the system from final clarifier back to aeration tank, while the liquid flows through the aeration tank and clarifier.

Effluent quality from well-operated activated-sludge processes in the BOD loading range of 30–50 lb BOD/1000 ft^3/day can reliably meet the secondary standards of average maximum BOD of 30 mg/l and suspended solids of 30 mg/l with the temperature of mixed liquor at 10°–20°C (50°–68°F). At loadings lower in the listed range, or mixed-liquor temperature in the upper range, the effluent quality is more likely to be nearer 20 mg/l BOD and 20 mg/l suspended solids. Biological activity doubles (or halves) for every 10°–15°C temperature change. Therefore, for processes in the loading range of 30–50 lb BOD/1000 ft^3/day, reducing the mixed-liquor temperature to 5°–10°C can adversely affect effluent quality. Conversely, in the range of 15°–25°C, the quality of the effluent is likely to improve, or the loading can be increased with no detriment to effluent quality. Because extended aeration systems operate in a lower range of 10–30 lb BOD/1000 ft^3/day, a decrease or an increase in mixed-liquor temperature has less influence on effluent quality. Selection of aeration equipment is to some extent dictated by this relationship between allowable BOD loading and operating temperature. In a cool climate, submerged diffused aeration is common to reduce cooling of the mixed liquor in winter operation. In a warm climate, surface aerators that spray the mixed liquor in the air to absorb oxygen can be used since cooling is not a major consideration.

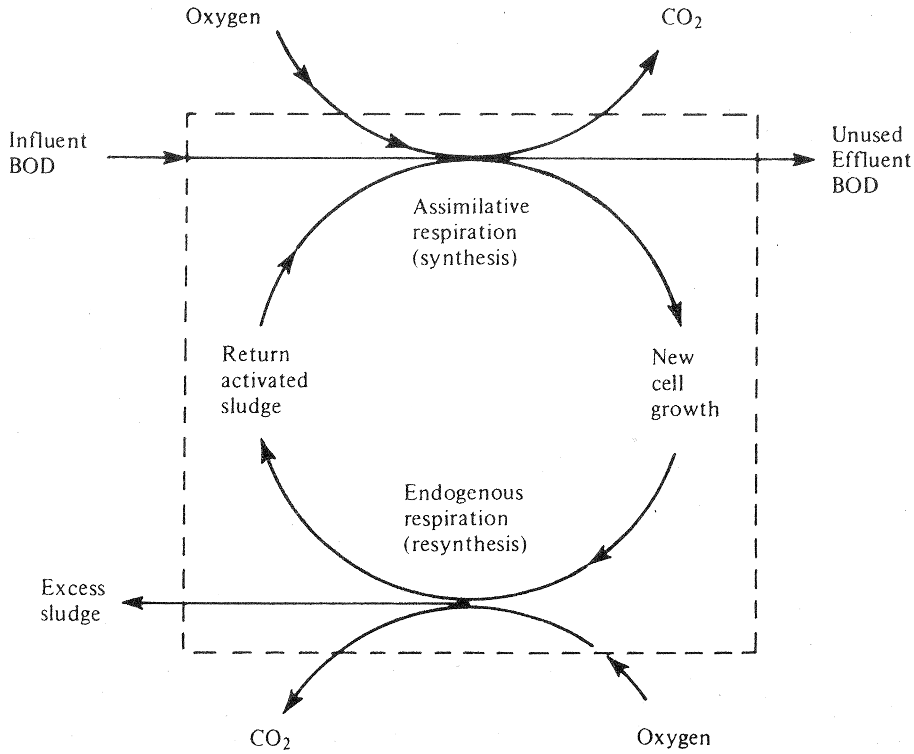


Figure 12.31 Generalized biological process reactions in the activated-sludge process.

The wide range of aeration periods and BOD loadings used in activated-sludge processes tends to contrast one process with another. Also, the variety of physical features, such as the aeration tank size and shape, used in the various processes tends to accent the differences. Actually all activated-sludge processes are biologically similar, as seen in the generalized activated-sludge diagram of Fig. 12.31. BOD is removed in the process by assimilative respiration of microorganisms, and the new cell growth is reduced by endogenous respiration. Excess microbial growth is withdrawn from the system by wasting activated sludge. Oxygen is added to the process to maintain aerobic biological activity.

■ **EXAMPLE 12.9** Data from a field study on a step-aeration activated-sludge secondary are as follows:

$$\text{aeration tank volume} = 120{,}000\ \text{ft}^3 = 0.898\ \text{mil gal}$$

$$\text{settled wastewater flow} = 3.67\ \text{mgd}$$

$$\text{return sludge flow} = 1.27\ \text{mgd}$$

$$\text{waste sludge flow} = 18{,}900\ \text{gpd} = 0.0189\ \text{mgd}$$

$$\text{MLSS in aeration tank} = 2350\ \text{mg/l}$$

$$\text{SS in waste sludge} = 11{,}000\ \text{mg/l}$$

$$\text{influent wastewater BOD} = 128\ \text{mg/l}$$

$$\text{effluent wastewater BOD} = 22\ \text{mg/l}$$

$$\text{effluent SS} = 26\ \text{mg/l}$$

Using these data, calculate the loading and operational parameters listed in Table 12.3 and the excess sludge production in pounds of excess suspended solids per pound of BOD applied.

Solution:

$$\text{BOD load} = 3.67 \text{ mgd} \times 128 \text{ mg/l} \times 8.34 = 3920 \text{ lb/day}$$

$$\text{MLSS in aeration tank} = 0.898 \text{ mil gal} \times 2350 \text{ mg/l} \times 8.34 = 17{,}600 \text{ lb}$$

$$\text{BOD loading} = 3920/120 = 32.7 \text{ lb/day/1000 ft}^3$$

$$\text{BOD loading} = 3920/17{,}600 = 0.22 \text{ lb/day/lb of MLSS}$$

Using Eq. (12.60),

$$\text{sludge age} = \frac{2350 \times 0.898}{26 \times 3.67 + 11{,}000 \times 0.0189} = 7.0 \text{ days}$$

$$\text{aeration period} = \frac{0.898 \times 24}{3.67} = 5.9 \text{ hr}$$

$$\text{return sludge rate} = \frac{1.27 \times 100}{3.67} = 35\%$$

$$\text{BOD efficiency} = \frac{(128 - 22)100}{128} = 83\%$$

$$\text{sludge production} = \frac{0.0189 \text{ mgd} \times 11{,}000 \text{ mg/l} \times 8.34}{3920}$$

$$= 0.44 \text{ lb SS wasted/lb BOD applied}$$

■

12.20 Operation of Activated-Sludge Processes

Operation of an activated-sludge treatment plant is regulated by (1) the quantity of air supplied to the aeration basin, (2) the rate of activated-sludge recirculation, and (3) the amount of excess sludge withdrawn from the system. Sludge wasting is used to establish the desired concentration of MLSS, food/microorganism ratio, and sludge age.

Field observations for monitoring an aeration system are the rates of wastewater influent, excess sludge wasting, and sludge recirculation; the dissolved-oxygen concentration in the mixed liquor; and the depth of the sludge blanket in the final clarifier. Laboratory tests are used to determine influent and effluent BOD, the concentration of suspended solids in the return sludge, and the concentration of MLSS in the aeration tank. From these data, BOD loadings, the aeration period, the return sludge rate, and the BOD removal efficiency can be calculated. The final clarifier operation is observed by testing for the concentration of suspended solids in the effluent and calculating the overflow rate and solids loading.

The degree of treatment achieved in an activated-sludge process depends directly on the settleability of the suspended solids in the final clarifier. If the biological floc agglomerate and settle rapidly by gravity, the overflow is a clear supernatant. Conversely, poorly flocculated particles (pin floc) and buoyant filamentous growths that do not separate by gravity contribute to BOD and suspended solids in the system effluent.

Table 12.4 Factors That Can Adversely Affect Settleability of Activated Sludge

BIOLOGICAL FACTORS	
Species of dominant microorganisms (filamentous)	
Ineffective biological flocculation	
Denitrification in final clarifier (floating solids)	
Excessive volumetric and food/microorganism loadings	
Mixed-liquor suspended-solids concentration	
Unsteady-state conditions (nonuniform feed rate and discontinuous wasting of excess activated sludge)	
CHEMICAL FACTORS	
Lack of nutrients	Insufficient aeration
Presence of toxins	Low temperature
Kinds of organic matter	
PHYSICAL FACTORS	
Excessive agitation during aeration resulting in shearing of floc	
Ineffective final clarification: inadequate rate of return sludge, excessive overflow rate or solids loading, or hydraulic turbulence	

Excessive carryover of floc resulting in inefficient operation is referred to as sludge bulking. This can be caused by any one or a combination of the biological, chemical, and physical factors listed in Table 12.4. If an activated-sludge process is not functioning properly, the loadings on the aeration tank and final clarifier are calculated and compared to established design criteria. Next, operational procedures are reviewed to ensure proper aeration, sludge recirculation, and sludge wasting. Special laboratory tests can be performed to determine detrimental chemical characteristics of the wastewater, such as a lack of nutrients or the presence of toxins. Microscopic examination of the activated sludge can reveal excessive filamentous growth [14].

12.21 Activated-Sludge Treatment Systems

Conventional Activated-Sludge Process

The conventional process diagrammed in Fig. 12.32(a) is an outgrowth of the earliest activated-sludge systems constructed, used for secondary treatment of domestic wastewater. The aeration basin is a long rectangular tank with air diffusers on one side of the tank bottom to provide aeration and mixing. Settled raw wastewater and return activated sludge enter the head of the tank and flow down its length in a spiral flow pattern. An air supply is tapered along the length of the tank to provide a greater amount of diffused air near the head where the rate of biological metabolism and resultant oxygen demand are the greatest. A conventional activated-sludge aeration tank is shown in Fig. 12.33.

The conventional activated-sludge process uses bubble air diffusers set at a depth of 8 ft or more to provide adequate oxygen transfer and deep mixing. Several different bubble diffusers are manufactured; common kinds are stainless-steel or hollow-cylinder

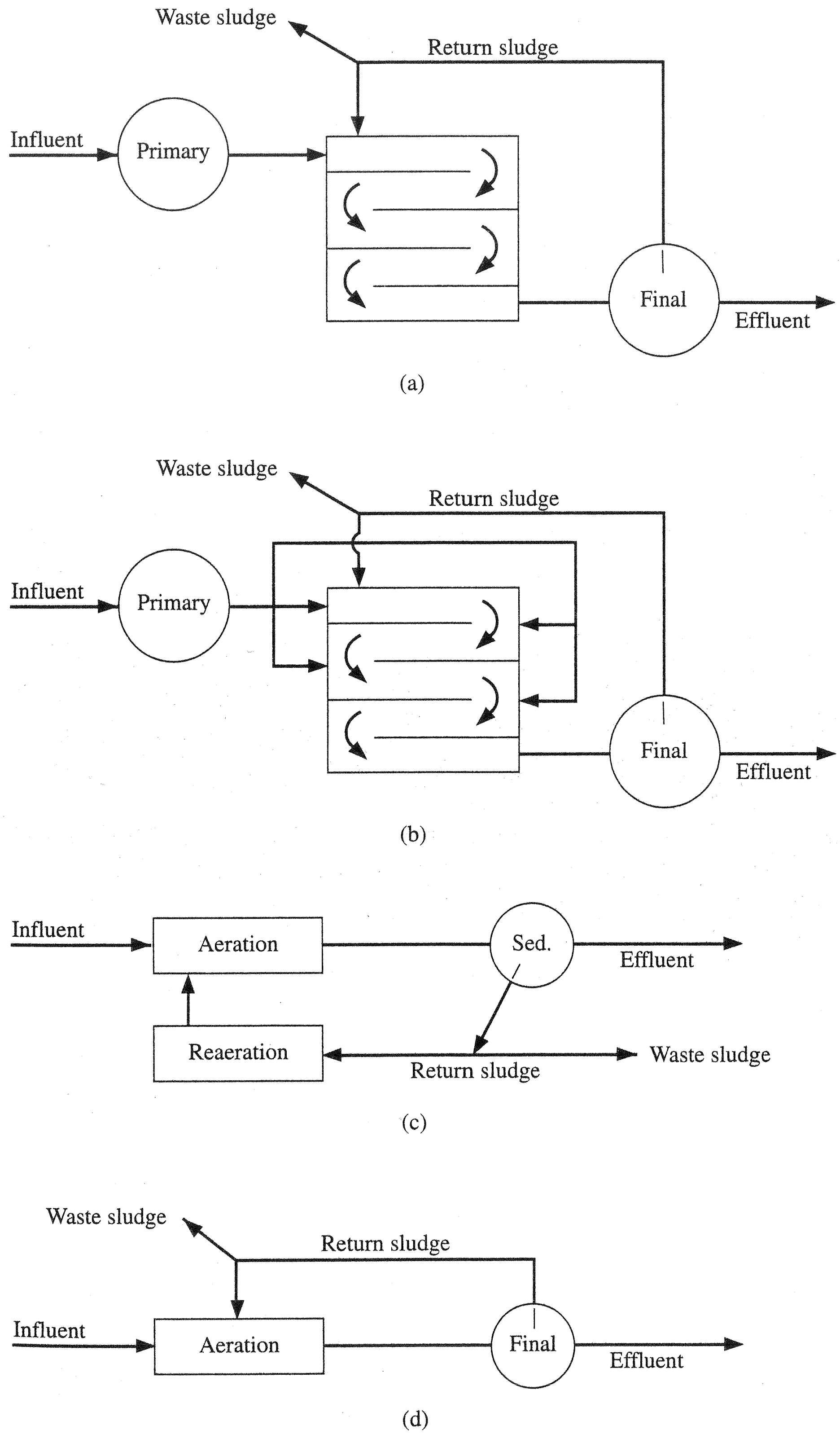
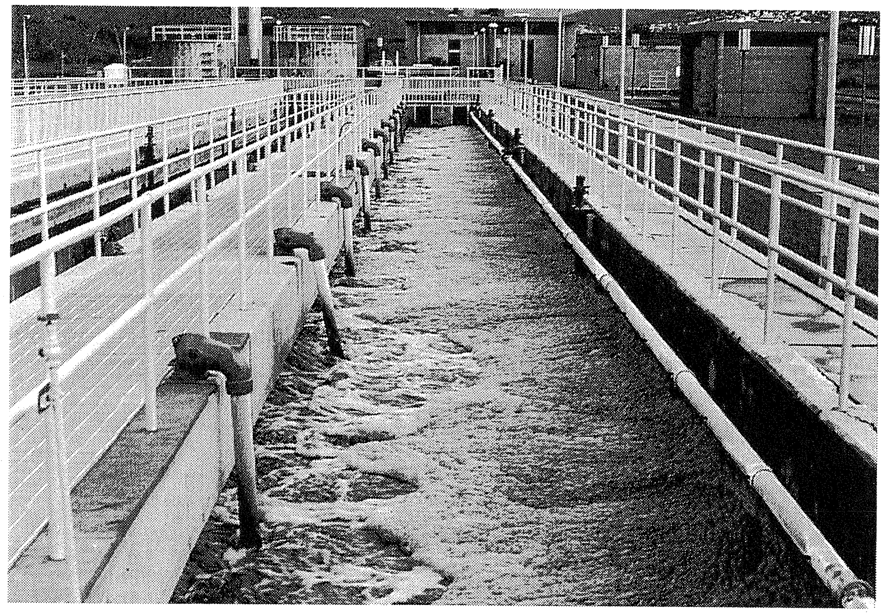
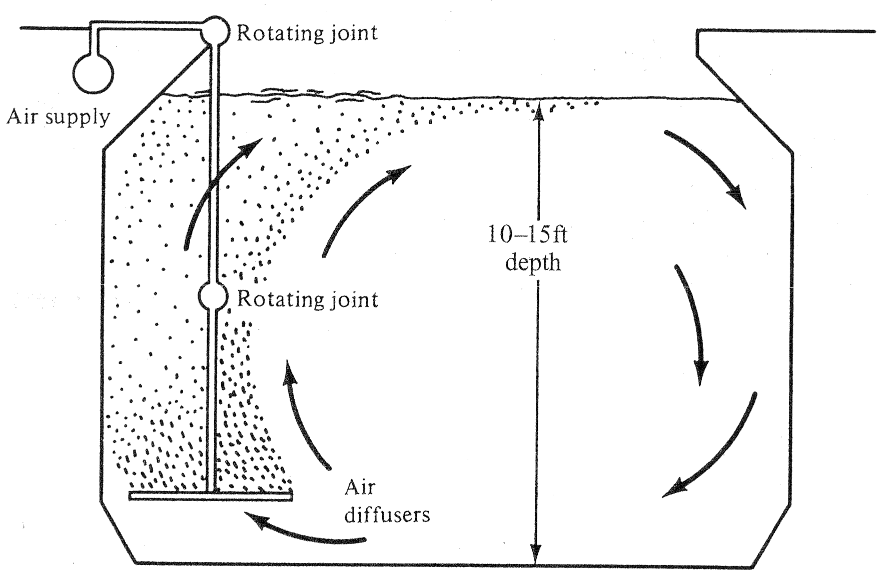


Figure 12.32 Flow diagrams for common activated-sludge processes. (a) Conventional activated-sludge process. (b) Step-aeration activated-sludge process. (c) Contact stabilization without primary sedimentation. (d) Extended aeration without primary sedimentation.



(a)



(b)

Figure 12.33 Conventional activated-sludge process. (a) Long rectangular aeration tank with submerged coarse-bubble diffusers along one side (Santee, CA). (b) Cross section of a typical aeration tank illustrating the spiral flow pattern created by aeration along one side.

porous tubes 1–2 ft in length or porous disks about 6 in. in diameter. These individual diffusers are attached along a submerged air header about 10 ft in length attached to an air-supply hanger pipe. For maintenance of the diffusers, the hanger pipe can be designed with rotating joints (a swing-diffuser arm) so the header can be retracted using a portable jack. The tops of swing-diffuser hanger arms can be seen in Fig. 12.33(a) along the aeration tank.

Step-Aeration Activated-Sludge Process

The *step-aeration process* [Fig. 12.32(b)] is a modification of the conventional process. Instead of introducing all raw wastewater at the tank head, raw flow is introduced at several points along the tank length. Stepping the influent load along the tank produces a more uniform oxygen demand throughout. While tapered aeration attempts to supply air to match oxygen demand along the length of the tank, step loading provides a more uniform oxygen demand for an evenly distributed air supply.

Both step-aeration and conventional processes can use fine-bubble aeration. Fine-bubble diffusers produce bubbles with a diameter of approximately 2–5 mm (0.08–0.20 in.) in clean water. The three general categories of fine-pore media are ceramics, porous plastics, and perforated membranes. As illustrated in Fig. 12.34, individual diffusers are mounted on holders attached to air piping on the tank bottom. Each membrane or ceramic disc, either 9 in. or 7 in. in diameter, is sealed to a holder by a screw-on retainer ring with an O-ring seal. With the diffusers over the entire floor area, the rising streams of fine bubbles mix and aerate the mixed liquor uniformly, keeping the microbial floc in suspension. The benefit of fine-bubble aeration is a power savings of 40%–60% when compared to coarse-bubble or mechanically aerated activated-sludge processes [14]. As a result of cost savings and system performance, use of fine-bubble aeration is now common in activated-sludge processes, particularly with automated control. Automated aeration control is the manipulation of the aeration rate by computer to match the dynamic oxygen demand and maintain the desired residual dissolved-oxygen concentration in the mixed liquor.

■ **EXAMPLE 12.10** A step-aeration activated-sludge process is being sized for a settled wastewater flow of 7.40 mgd (989,000 ft^3/d) containing 7900 lb of BOD. The design maximum BOD loading is 40 lb/1000 ft^3/day, and the design minimum aeration period is 6.0 hr. (a) Calculate the dimensions for 4 identical aeration tanks. (b) Calculate the dimensions for 4 circular final clarifiers. (c) If the proposed minimum operating MLSS is 2000 mg/l, what is the calculated F/M at design loading?

Solution:

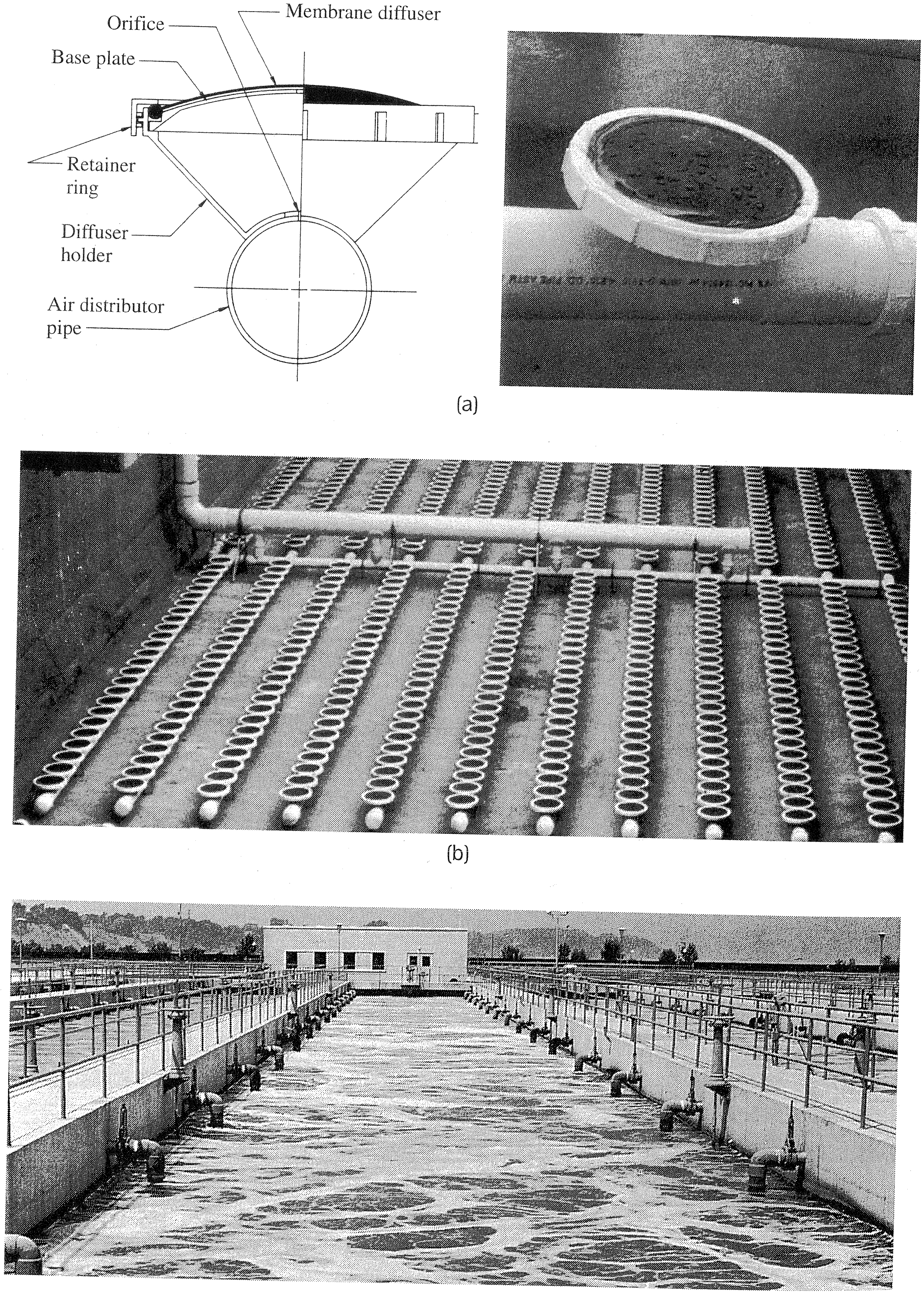
1.

$$V \text{ (based on BOD loading)} = \frac{7900 \times 1000}{40} = 198{,}000 \text{ ft}^3$$

$$V \text{ (based on aeration period)} = \frac{7{,}400{,}000 \times 6.0}{24 \times 7.48} = 247{,}000 \text{ ft}^3$$

Use 247,000 ft^3 with an aeration period of 6.0 min, which results in a BOD loading of 31 lb/1000 ft^3/day. Install 4 aeration tanks with 13 ft liquid depth and 24 ft width for fine-bubble aeration.

$$\text{length of each tank} = \frac{247{,}000}{4 \times 13 \times 24} = 198 \text{ ft}$$



(c)

Figure 12.34 Fine-bubble diffuser for wastewater aeration. (a) A disc diffuser mounted on top of an air distributor pipe. (b) A grid of diffusers attached to air pipes mounted on the floor of an aeration tank. (c) Long rectangular aeration tank with uniform mixing and oxygenation by a grid of fine-bubble diffusers. (Courtesy of SANITAIRE, Water Pollution Control Corp.)

2. From Section 10.16, use an overflow rate of 800 gpd/ft^2 and side-water depth of 11 ft to size 4 circular clarifiers.

$$\text{surface area} = \frac{7{,}400{,}000}{4 \times 800} = 2310 \text{ ft}^2 \quad (\text{diameter} = 54 \text{ ft})$$

$$\text{detention time} = \frac{2300 \times 11 \times 24}{989{,}000/4} = 2.5 \text{ hr}$$

3. $$\text{F/M} = \frac{7900}{2000 \times 1.85 \times 8.34} = 0.26 \text{ lb BOD/day/lb of MLSS}$$

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