

# 8

## SUSPENDED GROWTH BIOLOGICAL TREATMENT PROCESSES

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**Instructors Note:** In many of the problems where constituent concentrations are used, the units mg/L and g/m<sup>3</sup> are used interchangeably to facilitate computations without introducing additional conversion factors.

### PROBLEM 8-1

**Problem Statement** – see text, page 919

**Solution**

1. Use Eq. (8-4) in page 711 to obtain the bCOD concentration:

$$\frac{bCOD}{UBOD} = \frac{1}{1.0 - 1.42 f_d(Y_H)}$$

$$\frac{bCOD}{UBOD} = \frac{1}{1.0 - 1.42(0.15\text{g/g})(0.40\text{g/g})} = 1.093$$

$$bCOD = 1.093(180 \text{ mg/L}) = 196.8 \text{ mg/L}$$

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### PROBLEM 8-2

**Problem Statement** – see text page 920

**Solution (Wastewater 1)**

1. Develop a diagram illustrating the three phases of oxygen consumption.

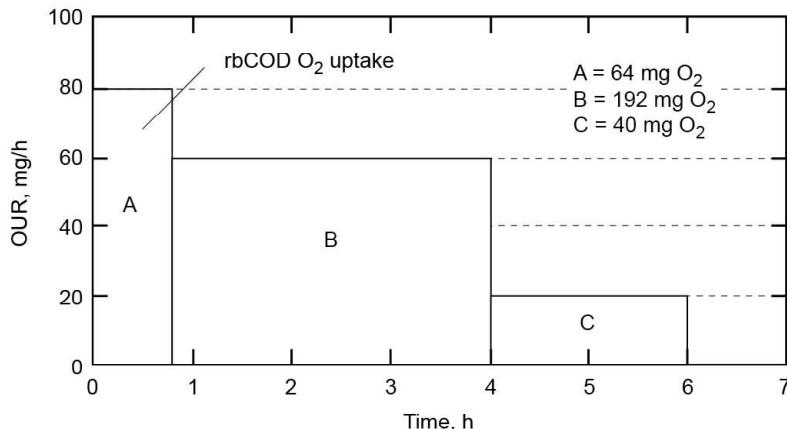
- a. Compute the oxygen consumption for each phase.

$$\text{Phase A OUR} = 64 \text{ mg}/0.8 \text{ h} = 80 \text{ mg/h}$$

$$\text{Phase B OUR} = 192 \text{ mg}/3.2 \text{ h} = 60 \text{ mg/h}$$

$$\text{Phase C OUR} = 40 \text{ mg}/2 \text{ h} = 20 \text{ mg/h}$$

- b. Plot oxygen consumption versus time as illustrated below.



2. Compute the oxygen consumption for rbCOD and the rbCOD concentration in the wastewater.

- a. Compute the rbCOD oxygen consumption. The oxygen consumed for biological uptake of the rbCOD is illustrated as the upper section of Area A in the above graph between 60 and 80 mg/h. Determine that area by subtracting the uptake rate due to the activity associated with area B.

$$\text{rbCOD area OUR} = (80 - 60) \text{ mg/h} = 20 \text{ mg/h}$$

$$O_A = \text{oxygen used for rbCOD uptake} = 20 \text{ mg/h} (0.8 \text{ h}) = 16.0 \text{ mg}$$

The total test volume was 1.0 L so the uptake concentration is 16.0 mg/L

- b. Compute the rbCOD concentration in the wastewater.

The rbCOD of the wastewater sample is calculated using the equation below to account for the sample and mixed liquor volumes and the fraction of rbCOD oxidized.

- i. Determine the rbCOD measured in the test from the oxygen consumed.

$$O_A \text{ used} = \text{rbCOD} - \text{COD}_{\text{cells}} = (1 - Y_{H,\text{COD}})\text{rbCOD}$$

$$\text{rbCOD} = \frac{O_A}{(1 - Y_{H,\text{COD}})}$$

$$Y_{H,\text{COD}} = 0.45 \frac{\text{gVSS}}{\text{gCOD}} \left( 1.42 \frac{\text{gCOD}}{\text{gVSS}} \right) = \frac{0.64 \text{ gCOD}_{\text{cells}}}{\text{gCOD}}$$

$$\text{rbCOD} = \frac{16.0 \text{ mg}}{(1.0 - 0.64)} = 44.44 \text{ mg}$$

- ii. Determine the rbCOD concentration in the sample

The sample volume for the rbCOD used was 0.50 L

$$\text{rbCOD concentration} = \frac{44.44 \text{ mg}}{0.50 \text{ L}} = 88.9 \text{ mg/L}$$

### **PROBLEM 8-3**

**Problem Statement** – see text, page 920

**Solution (Wastewater 1)**

1. Subtract the treated effluent ffCOD from the primary effluent ffCOD.

$$\text{rbCOD} = (90 - 30) \text{ mg/L} = 60 \text{ mg/L}$$

### **PROBLEM 8-4**

**Problem Statement** – see text, page 920

**Solution (Wastewater 1)**

1. Determine the biodegradable COD (bCOD) concentration. The bCOD/BOD ratio is given as 1.6.

$$\text{bCOD} = 1.6 \text{ (BOD)} = 1.6 (200 \text{ mg/L}) = 320 \text{ mg/L}$$

2. Determine the slowly biodegradable COD (sbCOD). The sbCOD is defined as the bCOD minus the readily biodegradable COD (rbCOD).

$$\text{sbCOD} = \text{bCOD} - \text{rbCOD} = (320 - 100) \text{ mg/L} = 220 \text{ mg}$$

3. Determine the nonbiodegradable COD (nbCOD).

$$\text{nbCOD} = \text{COD} - \text{bCOD} = (500 - 320) \text{ mg/L} = 180 \text{ mg/L}$$

4. Determine the nonbiodegradable soluble COD (nbsCOD). The nonbiodegradable soluble COD is equal to the activated sludge system sCOD = 30 mg/L

5. Determine the nonbiodegradable volatile suspended solids (nbVSS) concentration.

- a. Determine the particulate nonbiodegradable COD (nbpCOD). The nbpCOD equals the nbCOD minus the nbsCOD.

The nbPCOD equals the nonbiodegradable COD minus the nbsCOD

$$\text{nbpCOD} = \text{nbCOD} - \text{nbsCOD} = (180 - 30) \text{ mg/L} = 150 \text{ mg/L}$$

- b. Determine the nbVSS concentration.

From Eq. (8-8)

$$\text{VSS}_{\text{COD}} = \frac{\text{TCOD} - \text{sCOD}}{\text{VSS}} = \frac{[(500 - 160) \text{ mg/L}]}{(200 \text{ mg/L})} = 1.7 \text{ mg COD/mg VSS}$$

$$\text{nbVSS} = 150 / 1.7 = 88.2 \text{ mg/L}$$

6. Determine the inert TSS (iTSS) concentration.

$$\text{iTSS} = \text{TSS} - \text{VSS} = 220 - 200 = 20 \text{ mg/L}$$

### PROBLEM 8-5

**Problem Statement** – see text, page 921

#### Solution (wastewater 1)

1. Determine the organic nitrogen for **Wastewater 1** using Eq. (8-16).

$$\text{ON} = \text{TKN} - \text{NH}_4\text{-N}$$

$$\text{ON} = (40 - 25) \text{ mg/L} = 15 \text{ mg/L}$$

2. Determine the nonbiodegradable particulate organic nitrogen (nbpON).

- a. Calculate the organic nitrogen content of VSS using Eq. (8-10)

$$f_N = \frac{\text{TKN} - \text{sON} - (\text{NH}_4\text{-N})}{\text{VSS}}$$

$$f_N = \frac{[(40 - 5.0 - 25) \text{ mg/L}]}{(180 \text{ mg/L})} = 0.056$$

- b. Calculate nbVSS

$$\text{nbVSS} = \text{VSS} \text{ (nbVSS fraction)}$$

$$\text{nbVSS} = 180 \text{ mg/L} (0.40) = 72 \text{ mg/L}$$

- c. Determine nbpON using Eq. (8-11) and the results from part (a) and (b).

$$\text{nbpON} = f_N \text{ (nbVSS)}$$

$$\text{nbpON} = 0.056 (72 \text{ mg/L}) = 4.03 \text{ mg/L}$$

3. Determine the biodegradable organic nitrogen (bON)

- a. Calculate nbON using Eq. (8-18)

$$nbON = nbsON + nbpON$$

nbsON value is given, and nbpON was calculated in part 2

$$nbON = (1.0 + 4.03) \text{ mg/L} = 5.03 \text{ mg/L}$$

- b. Calculate biodegradable organic nitrogen (bON) using Eq. (8-17)

$$bON = ON - nbON$$

$$bON = (15 - 5.03) \text{ mg/L} = 9.97 \text{ mg/L}$$

## PROBLEM 8-6

**Problem Statement** – see text, page 921

### Solution

1. Determine the aeration tank volume ( $\text{m}^3$ ) for Influent BOD concentration of **120 mg/L**.

- a. Determine the net waste sludge daily in kgVSS/d

From Figure 8-7, at SRT = 6 d, T = 10°C, the observed yield  $Y_{\text{obs}} = 0.7$  kg VSS/kg BOD

Calculate  $P_{X,\text{VSS}}$  using Eq. (8-19) in page 720

Assuming  $S_o - S \approx S_o$  (S is usually small compared to  $S_o$  at SRT = 6 d)

$$P_{X,\text{VSS}} = Y_{\text{obs}} Q (S_o - S) \approx Y_{\text{obs}} Q S_o$$

$$\begin{aligned} P_{X,\text{VSS}} &= (0.7 \text{ kgVSS / kg BOD}) (6000 \text{ m}^3/\text{d}) (120 \text{ g/m}^3 \text{ BOD}) (1 \text{ kg}/10^3 \text{ g}) \\ &= 504 \text{ kg/d} \end{aligned}$$

- b. Calculate the aeration tank volume from Eq. (7-48) in Chap. 7

$$P_{X,\text{VSS}} = \frac{X_T V}{SRT}$$

$$V = \frac{P_{X,\text{VSS}} (\text{SRT})}{X_T}$$

$$V = \frac{(504 \text{ kg/d})(6 \text{ d})(10^3 \text{ g/kg})}{(2500 \text{ g/m}^3)} = 1210 \text{ m}^3$$

2. Determine the amount of sludge wasted daily in kg TSS/d using Eq. (7-48).

$$P_{X,\text{VSS}} = \frac{X_T V}{SRT}$$

$$P_{X,TSS} = \frac{(3000 \text{ g/m}^3)(1210 \text{ m}^3)(1 \text{ kg}/10^3\text{g})}{(6 \text{ d})} = 605 \text{ kg/d}$$

3. Determine the tank volume and daily waste sludge for SRT = 12 d
  - a. Determine the aeration tank volume. Calculate the amount of wasted sludge daily from Fig. 8-7, at SRT = 12 d and T = 10°C, the observed yield  $Y_{obs} = 0.6 \text{ kg VSS/kg BOD removed}$

$$P_{X,VSS} = Y_{obs} (Q) S_0$$

$$\begin{aligned} P_{X,VSS} &= (0.6 \text{ g VSS/g BOD})(6000 \text{ m}^3/\text{d}) (120 \text{ g/m}^3 \text{ BOD})(1 \text{ kg}/10^3 \text{ g}) \\ &= 432 \text{ kg/d} \end{aligned}$$

Calculate the tank volume from Eq. (7-48)

$$P_{X,VSS} = \frac{X_T V}{SRT}$$

$$V = \frac{(432 \text{ kg/d})(12 \text{ d})(10^3 \text{ g/kg})}{(2500 \text{ g/m}^3)} = 2074 \text{ m}^3$$

- b. Calculate the wasted sludge daily in TSS kg/d from Eq. (7-48).

$$P_{X,VSS} = \frac{X_T V}{SRT}$$

$$P_{X,TSS} = \frac{(3000 \text{ g/m}^3)(2074 \text{ m}^3)(1 \text{ kg}/10^3\text{g})}{(12 \text{ d})} = 518.5 \text{ kg/d}$$

## PROBLEM 8-7

**Problem Statement – see text, page 921**

### Solution

1. Develop the wastewater characteristics needed for design

Find bCOD using Eq. (8-13) in page 714

$$bCOD = 1.6 \text{ (BOD)}$$

$$bCOD_{inf} = 1.6 (150 \text{ mg/L}) = 240 \text{ mg/L}$$

$$bCOD_{eff} = 1.6 (2 \text{ mg/L}) = 3.2 \text{ mg/L}$$

2. Design an activated-sludge system for BOD removal only for **wastewater 1**

- a. Determine biomass production using parts A and B of Eq. (8-20) in page 721.

$$P_{X,VSS} = \frac{Q Y_H (S_o - S)}{1 + b_H (SRT)} + \frac{(f_d)(b_H) Q Y_H (S_o - S) SRT}{1 + b_H (SRT)}$$

Define input data for above equation

$$Q = 10,000 \text{ m}^3/\text{d}$$

$$Y_H = 0.4 \text{ g VSS/g bCOD}$$

$$S_o = 240 \text{ mg/L}$$

$$f_d = 0.15$$

$$b_H = 0.08$$

$$SRT = 6 \text{ d}$$

$$S = 3.2 \text{ mg/L}$$

$$\begin{aligned} P_{X,VSS} &= \frac{(10,000 \text{ m}^3 / \text{d})(0.4)[(240 - 3.2) \text{ g/m}^3](1 \text{ kg} / 10^3 \text{ g})}{[1 + (0.08 \text{ d}^{-1})(6 \text{ d})]} \\ &\quad + \frac{(0.15)(0.08)(10,000 \text{ m}^3 / \text{d})(0.4)(240 - 3.2) \text{ g/m}^3 (6 \text{ d})(1 \text{ kg} / 10^3 \text{ g})}{[1 + (0.08 \text{ d}^{-1})(6 \text{ d})]} \\ &= (640 \text{ kg/d}) + (46.08 \text{ kg/d}) \\ &= 686.08 \text{ kg/d} \end{aligned}$$

- b. Calculate the O<sub>2</sub> demand using Eq. (7-61) in Chap. 7.

$$R_o = Q(S_o - S) - 1.42 P_{X,bio}$$

$$R_o = (10,000 \text{ m}^3/\text{d})[(240 - 3.2) \text{ g/m}^3](1 \text{ kg}/10^3 \text{ g}) - 1.42 (686.08 \text{ kg/d})$$

$$R_o = (2368 - 974.2) \text{ kg/d} = 1393.8 \text{ kg/d}$$

- c. Determine the aeration tank OUR in mg/L•h

$$OUR = \frac{R_o}{V}$$

$$V = Q \tau$$

Define input data for above equation

$$R_o = 1393.8 \text{ kg/d} = 58.1 \text{ kg/h}$$

$$Q = 10,000 \text{ m}^3/\text{d}$$

$$\tau = 4 \text{ h}$$

$$\text{OUR} = \frac{R_o}{Q\tau} = \frac{(158.1 \text{ kg/h})(10^6 \text{ mg/kg})}{(10,000 \text{ m}^3/\text{d})(1 \text{ d}/24 \text{ h})(4 \text{ h})(10^3 \text{ L/m}^3)}$$

$$\text{OUR} = 34.9 \text{ mg/L}\cdot\text{h}$$

- d. Determine the aeration tank biomass concentration (mg/L) using Eq. (7-56) in Table 8-10

$$X_{VSS} = \frac{P_{X,VSS}(\text{SRT})}{V} = \frac{P_{X,VSS}(\text{SRT})}{Q\tau}$$

$$X_{bio} = \frac{(686.08 \text{ kg/d})(6 \text{ d})}{(10,000 \text{ m}^3/\text{d})(4 \text{ h})(1 \text{ d}/24 \text{ h})}$$

$$X_{bio} = 2.470 \text{ kg/m}^3 = 2470 \text{ mg/L}$$

### PROBLEM 8-8

**Problem Statement** – see text, page 922

#### Solution

1. Develop the wastewater characteristics needed for design for **wastewater 1**.

Determine bCOD using Eq. (8-13)

$$\text{bCOD} = 1.6 \text{ (BOD)}$$

$$\text{bCOD}_{inf} = 1.6 \text{ (150 mg/L)} = 240 \text{ mg/L}$$

$$\text{bCOD}_{eff} = 1.6 \text{ (2.0 mg/L)} = 3.2 \text{ mg/L}$$

2. Design an activated sludge system for BOD removal and nitrification

- a. Determine the aeration tank O<sub>2</sub> demand

Calculate P<sub>X,VSS</sub> using Eq (8-20), parts A, B, and C

$$P_{X,VSS} = \frac{QY_H(S_o - S)(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})} + \frac{(f_d)(b_H)Q Y_H(S_o - S)\text{SRT}(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})} + \frac{QY_n(\text{NO}_x)(1 \text{ kg}/10^3 \text{ g})}{1 + b_n(\text{SRT})}$$

- b. Define data input for above equation

$$Q = 10,000 \text{ m}^3/\text{d}$$

$$Y_H = 0.4 \text{ g VSS/g bCOD}$$

$$S_0 = 240 \text{ mg/L bCOD}$$

$$S = 3.2 \text{ mg/L bCOD}$$

$$b_H = 0.08 \text{ g VSS/gVSS} \cdot d$$

$$SRT = 15 \text{ d}$$

$$f_d = 0.1 \text{ g VSS/g VSS}$$

$$Y_n = 0.18 \text{ g VSS/g NH}_4\text{-N}$$

$$b_n = 0.12$$

Assume all of the influent TKN is biodegradable

Assume 20 percent of the TKN is used for cell synthesis

$$NO_x = (100\% - 20\%)(TKN) - NH_4\text{-N}_{eff} = (0.80)(35) - 1.0 = 27.0 \text{ mg/L}$$

c. Solve above equation

$$\begin{aligned} P_{X,VSS} &= \frac{(10,000 \text{ m}^3/d)(0.4 \text{ g/g})[(240 - 3.2) \text{ g/m}^3](1 \text{ kg}/10^3 \text{ g})}{[1 + (0.08 \text{ d}^{-1})(15 \text{ d})]} \\ &+ \frac{(0.1 \text{ g/g})(0.08 \text{ d}^{-1})(10,000 \text{ m}^3/d)(0.4 \text{ g/g})[(240 - 3.2) \text{ g/m}^3](15 \text{ d})(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.08 \text{ d}^{-1})(15 \text{ d})]} \\ &+ \frac{(10,000 \text{ m}^3/d)(0.18)(27.0 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.12 \text{ d}^{-1})(15 \text{ d})]} \end{aligned}$$

$$P_{X,VSS} = (430.5 + 51.7 + 17.4) \text{ kg/d} = 499.6 \text{ kg/d}$$

Re-calculate  $NO_x$  using Eq (8-24)

$$NO_x = TKN - N_e - 0.12 P_{X,bio} / Q$$

$$NO_x = 35 \text{ g/m}^3 - 1.0 \text{ g/m}^3 - 0.12(499.6 \text{ kg/d})(10^3 \text{ g}/1 \text{ kg})10,000 \text{ m}^3/\text{d})$$

$$NO_x = (34.0 - 6.0) \text{ g/m}^3 = 28.0 \text{ g/m}^3$$

Re-calculate  $P_{X,VSS}$  using  $NO_x = 28.0 \text{ mg/L}$

$$P_{X,VSS} = (430.5 + 51.7 + 18.0) \text{ kg/d} = 500.2 \text{ kg/d}$$

$$\text{Re-calculate } NO_x = 35.0 - 1.0 - 6.0 \text{ g/m}^3 = 28.0 \text{ mg/L}$$

$$(NO_x = 28.0 \text{ g/m}^3)$$

Calculate  $O_2$  demand using Eq. (8-23)

$$R_o = Q (S_0 - S) - 1.42 P_{X,bio} + 4.57 Q (NO_x)$$

$$P_{x,\text{bio}} \text{ (heterotrophs)} = (430.5 + 51.7) \text{ kg/d} = 482.2 \text{ kg/d}$$

$$R_o = (10,000 \text{ m}^3/\text{d})[(240 - 3.2)\text{g/m}^3](1 \text{ kg}/10^3\text{g}) - 1.42 (482.2 \text{ kg/d}) +$$

$$4.57 (10,000 \text{ m}^3/\text{d})(28.0 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})$$

$$R_o = 2368 \text{ kg/d} - 684.7 \text{ kg/d} + 1279.6 \text{ kg/d} = 2962.9 \text{ kg/d}$$

$$R_o = 122.9 \text{ kg/h}$$

- b. Determine the OUR in mg/L • h

$$\text{OUR} = \frac{R_o}{Q\tau}$$

Define the input data for above equation

$$R_o = 123.5 \text{ kg/h}$$

$$Q = 10,000 \text{ m}^3/\text{d}$$

$$\tau = 8 \text{ h}$$

$$\text{OUR} = \frac{(123.5 \text{ kg/h})(10^6 \text{ mg/kg})}{(10,000 \text{ m}^3/\text{d})(1\text{d}/24\text{h})(8\text{h})(10^3 \text{ L/m}^3)}$$

$$\text{OUR} = 37.05 \text{ mg/L}\cdot\text{h}$$

- c. Determine the tank biomass concentration (mg/L) using Eq. (7-56) in Table 8-10

$$X_{\text{bio}} = \frac{P_{x,\text{VSS}}(\text{SRT})}{V} = \frac{P_{x,\text{VSS}}(\text{SRT})}{Q\tau}$$

$$X_{\text{bio}} = \frac{(500.2 \text{ kg/d})(15 \text{ d})}{(10,000 \text{ m}^3/\text{d})(8\text{h})(1\text{d}/24\text{h})}$$

$$X_{\text{bio}} = 2.251 \text{ kg/m}^3 = 2251 \text{ mg/L}$$

- c. Determine the portion of the O<sub>2</sub> required that is for nitrification

$$f_n = \frac{R_{on}}{R_o} = \frac{(1279.6 \text{ kg/d})}{(2962.9 \text{ kg/d})} = 0.43$$

### PROBLEM 8-9

**Problem Statement** – see text, page 922

**Solution**

1. Develop the wastewater characteristics needed for design

$$bCOD = 1.6 \text{ (BOD)} [\text{Eq. (8-13)}]$$

$$bCOD_{inf} = 1.6 \text{ (200 mg/L)} = 320 \text{ mg/L}$$

$$bCOD_{eff} = 1.6(2 \text{ mg/L}) = 3.2 \text{ mg/L}$$

2. Determine sludge wasted daily using Eqs. (8-20) and (8-21)

$$\frac{QY_H(S_o - S)(1 \text{ kg}/10^3\text{g})}{1 + b_H(\text{SRT})} + \frac{(f_d)(b_H)QY_H(S_o - S)\text{SRT}(1 \text{ kg}/10^3\text{g})}{1 + b_H(\text{SRT})}$$

(A)

(B)

$$+ \frac{QY_n(NO_x)(1 \text{ kg}/10^3\text{g})}{1 + (b_n)\text{SRT}} + Q(nbVSS)(1 \text{ kg}/10^3\text{g})$$

(C)

(D)

- a. Define the input data for above equation. For SRT = 10d:

$$Q = 15,000 \text{ m}^3/\text{d}$$

$$Y_H = 0.4 \text{ g VSS/g bCOD}$$

$$S_o = 320 \text{ mg/L bCOD}$$

$$S = 3.2 \text{ mg/L}$$

$$b_H = 0.1 \text{ g VSS/gVSS}\cdot\text{d}$$

$$\text{SRT} = 10 \text{ d}$$

$$f_d = 0.15 \text{ g VSS/g VSS}$$

$$Y_n = 0.18 \text{ g VSS/g NH}_4\text{-N}$$

Assume all of influent TKN is biodegradable

$$NO_x \text{ is assumed to be 80% of TKN: } NO_x = (0.8)(35) = 28 \text{ mg/L}$$

$$b_n = 0.12 \text{ g VSS/g VSS}\cdot\text{d}$$

For **Wastewater 1**, nbVSS = 100 mg/L

- b. Determine  $P_{X,VSS}$

$$P_{X,VSS} = \frac{(15,000 \text{ m}^3 / \text{d})(0.4 \text{ g/g})[(320 - 3.2) \text{ g/m}^3](1\text{kg}/10^3\text{g})}{[1 + (0.1 \text{ g/g}\cdot\text{d})(10 \text{ d})]} \quad (\text{A})$$

$$+ \frac{(0.15 \text{ g/g})(0.1 \text{ g/g})(15,000 \text{ m}^3 / \text{d})(0.4 \text{ g/g})[(320 - 3.2) \text{ mg/L}](10 \text{ d})(1\text{kg}/10^3\text{g})}{[1 + (0.1 \text{ g/g}\cdot\text{d})(10 \text{ d})]} \quad (\text{B})$$

$$+ \frac{(15,000 \text{ m}^3 / \text{d})(0.18 \text{ g})(28 \text{ g/m}^3)(1\text{kg}/10^3\text{g})}{[1 + (0.12 \text{ g/g}\cdot\text{d})(10 \text{ d})]} \quad (\text{C})$$

$$+ (15,000 \text{ m}^3 / \text{d})(100 \text{ g/m}^3)(1\text{kg}/10^3\text{g}) \quad (\text{D})$$

$$P_{X,VSS} = (950.4 + 142.6 + 34.4 + 1500) \text{ kg/d} = 2627.4 \text{ kg/d}$$

$$P_{X,Bio} = (950.4 + 142.6 + 34.4) \text{ kg/d} = 1127.4 \text{ kg/d}$$

3. Use the above  $P_{X,VSS}$  to re-calculate  $NO_x$

$$NO_x = TKN - N_e - 0.12 P_{X,bio}/Q$$

$$NO_x = (35 - 0.5) \text{ g/m}^3 - [0.12(1127.4 \text{ kg/d})/(15,000 \text{ m}^3/\text{d})](10^3 \text{ g/1 kg})$$

$$NO_x = 25.5 \text{ g/m}^3$$

4. Re-calculate the VSS sludge production rate ( $P_{X,VSS}$ ) using  $NO_x = 25.6 \text{ g/m}^3$

$$(\text{C}) \quad \frac{(15,000 \text{ m}^3 / \text{d})(0.18 \text{ g})(25.5 \text{ g/m}^3)(1\text{kg}/10^3\text{g})}{[1 + (0.12 \text{ g/g}\cdot\text{d})(10 \text{ d})]} = 31.3 \text{ kg/d}$$

$$P_{X,VSS} = (950.4 + 142.6 + 31.3 + 1500) \text{ kg/d} = 2624.3 \text{ kg/d}$$

5. Determine sludge production rate in TSS using Eq (8-21).

$$P_{X,TSS} = \frac{A}{0.85} + \frac{B}{0.85} + \frac{C}{0.85} + D$$

$$P_{X,TSS} = \left( \frac{950.4}{0.85} + \frac{142.6}{0.85} + \frac{31.3}{0.85} + 1500 \right) \text{ kg TSS/d} = 2822.7 \text{ kg TSS/d} \text{ kg/d}$$

6. Determine biomass production rate using Eq (8-20), part A, B, and C.

$$P_{X,Bio} = (950.4 + 142.6 + 31.3) \text{ kg/d} = 1124.3 \text{ kg/d} \text{ (note: it is close to the value in step 3, so further iteration for } NO_x \text{ was not needed.)}$$

7. Determine the TSS, VSS, and biomass production rates without accounting for cell debris production (B) and the resulting error.

$$\text{a. } P_{X,VSS} = A + C + D$$

$$P_{X,VSS} = (950.4 + 31.3 + 1500) \text{ kg/d} = 2481.7 \text{ kg/d}$$

$$\% \text{ Error} = \frac{(2624.3 - 2481.7)100}{2624.3} = 5.4 \%$$

b.  $P_{X,\text{Bio}} = A + C$

$$P_{X,\text{Bio}} = (950.4 + 31.3) \text{ kg/d} = 981.7 \text{ kg/d}$$

$$\% \text{ Error} = \frac{(1124.3 - 981.7)100}{1124.3} = 12.7 \%$$

c.  $P_{X,\text{TSS}} = [(950.4 + 31.3)/0.85] + 1500 = 2654.9 \text{ kg/d}$

$$\% \text{ Error} = \frac{(2822.7 - 2654.9)100}{2822.7} = 5.9 \%$$

8. For 20 d SRT, repeat the above steps with SRT = 20 d instead of 10 d. The following table summarizes and compares the results.

SRT, d	10	20
$P_{X,\text{VSS}}$ , kg/d	2624.3	2353.7
$P_{X,\text{Bio}}$ , kg/d	1124.3	853.7
$P_{X,\text{TSS}}$ , kg/d	2822.7	2504.4
Without debris term		
$P_{X,\text{VSS}}$ , kg/d	2481.7	5.4
$P_{X,\text{Bio}}$ , kg/d	981.7	12.7
$P_{X,\text{TSS}}$ , kg/d	2654.9	5.9
	% Error	% Error

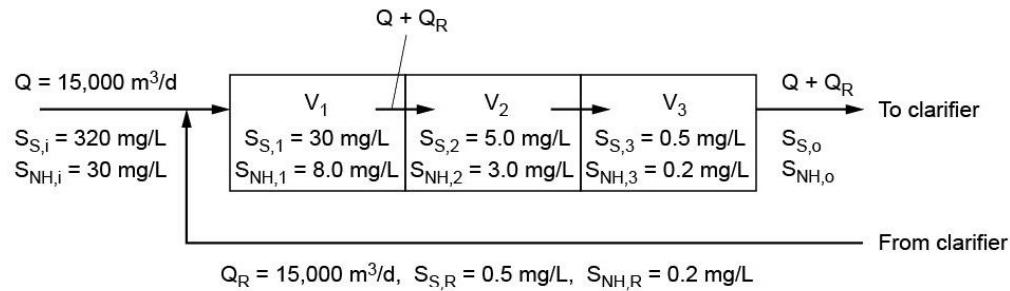
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### PROBLEM 8-10

**Problem Statement** – see text, page 923

**Solution – for wastewater #1**

1. Sketch system and show information provided for 3-stage activated sludge system.



$$S_S = bCOD, X_H = \text{biomass} = 1500 \text{ mg/L}$$

$$S_{NH} = NH_4-N$$

$$V_1 = V_2 = V_3 = 2300 \text{ m}^3$$

2. Determine the total oxygen transfer rate required for bCOD removal, nitrification, and endogenous decay using Eq. (8-25) in Table 8-10.

$$R_o = Q_1(1 - Y_H)(S_{S,1} - S_{S,2}) + Q_1(4.57)(NO_2 - NO_1) + 1.42b_H(X_H)V_2$$

Note:  $Y_H = \text{g COD cell/g COD used}$

$$= (0.45 \text{ g VSS/g COD})(1.42 \text{ g COD/g VSS}) = 0.639$$

$$NO_2 - NO_1 = S_{NH,1} - S_{NH,2}$$

- a. Determine flow and concentration of bCOD and NH<sub>4</sub>-N entering stage 1 from combining influent and recycle flow.

$$Q_1 = Q + Q_R = 30,000 \text{ m}^3/\text{d}$$

$$Q(S_{S,i}) + Q_R(S_{SR}) = (Q + Q_R)(S_{S,o})$$

$$(15,000 \text{ m}^3/\text{d})(320 \text{ g/m}^3) + (15,000 \text{ m}^3/\text{d})(0.5 \text{ g/m}^3) \\ = (30,000 \text{ m}^3/\text{d})(S_{S,o})$$

$$S_{S,o} = 160.25 \text{ g/m}^3$$

$$Q(S_{NH,i}) + Q_R(S_{NH,R}) = (Q + Q_R)(S_{NH,o})$$

$$(15,000 \text{ m}^3/\text{d})(30 \text{ g/m}^3) + (15,000 \text{ m}^3/\text{d})(0.2 \text{ g/m}^3) \\ = (30,000 \text{ m}^3/\text{d})(S_{NH,o})$$

$$S_{NH,o} = 15.1 \text{ g/m}^3$$

- b. Determine the oxygen transfer rate for State 1, using Eq. (8-25).  $Q_1 = 30,000 \text{ m}^3/\text{d}$ .

$$\begin{aligned}
 R_{o,1} &= (30,000 \text{ m}^3 / \text{d})(1 - 0.639)[(160.25 - 30.0)\text{g} / \text{m}^3] \\
 &\quad + (30,000 \text{ m}^3 / \text{d})(4.57)[(15.1 - 8.0)\text{g} / \text{m}^3] \\
 &\quad + 1.42(0.10 \text{ g} / \text{g} \cdot \text{d})(1500 \text{ g} / \text{m}^3)(2300 \text{ m}^3) \\
 &= 1,410,607.5 \text{ g O}_2 / \text{d} + 973,410 \text{ g O}_2 / \text{d} + 489,900 \text{ g O}_2 / \text{d} \\
 &= (1,410,607.5 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad + (973,410 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad + (489,900 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &= 58.8 \text{ kg O}_2 / \text{h} + 40.6 \text{ kg O}_2 / \text{h} + 20.4 \text{ kg O}_2 / \text{h}
 \end{aligned}$$

$$R_{o,1} = 119.8 \text{ kg O}_2 / \text{h}$$

- c. Determine the oxygen transfer rate for Stage 2.

$$\begin{aligned}
 R_{o,2} &= (30,000 \text{ m}^3 / \text{d})(1 - 0.639)[(30.0 - 5.0)\text{g} / \text{m}^3] \\
 &\quad + (30,000 \text{ m}^3 / \text{d})(4.57)[(8.0 - 3.0)\text{g} / \text{m}^3] \\
 &\quad + 1.42(0.10 \text{ g} / \text{g} \cdot \text{d})(1500 \text{ g} / \text{m}^3)(2300 \text{ m}^3) \\
 &= 270,750 \text{ g O}_2 / \text{d} + 685,500 \text{ g O}_2 / \text{d} + 489,900 \text{ g O}_2 / \text{d} \\
 &= (270,750 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad + (685,500 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad + (489,900 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &= 11.3 \text{ kg O}_2 / \text{h} + 28.6 \text{ kg O}_2 / \text{h} + 20.4 \text{ kg O}_2 / \text{h}
 \end{aligned}$$

$$R_{o,2} = 60.3 \text{ kg O}_2 / \text{h}$$

- d. Determine the oxygen transfer rate for Stage 3.

$$\begin{aligned}
 R_{O_3} &= (30,000 \text{ m}^3 / \text{d})(1 - 0.639)[(5.0 - 0.5)\text{g} / \text{m}^3] \\
 &\quad +(30,000 \text{ m}^3 / \text{d})(4.57)[(3.0 - 0.2)\text{g} / \text{m}^3] \\
 &\quad +1.42(0.10 \text{ g/g} \cdot \text{d})(1500 \text{ g/m}^3)(2300 \text{ m}^3) \\
 &= 48,735 \text{ g O}_2 / \text{d} + 383,880 \text{ g O}_2 / \text{d} + 489,900 \text{ g O}_2 / \text{d} \\
 &= (48,735 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad +(383,880 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &\quad +(489,900 \text{ g O}_2 / \text{d})(1 \text{ d} / 24 \text{ h})(1 \text{ kg} / 10^3 \text{ g}) \\
 &= 2.0 \text{ kg O}_2 / \text{h} + 16.0 \text{ kg O}_2 / \text{h} + 20.4 \text{ kg O}_2 / \text{h}
 \end{aligned}$$

$$R_{O_3} = 38.4 \text{ kg O}_2 / \text{h}$$

e. Prepare a summary table.

Oxygen transfer rate (kg O<sub>2</sub>/h)

Stage	bCOD removal	Nitrification	Endogenous	Total	% of total
1	58.8	40.6	20.4	119.8	55
2	11.3	28.6	20.4	60.3	28
3	2.0	16.0	20.4	38.4	17
Total	72.1	85.2	61.2	218.5	100

### PROBLEM 8-11

**Problem Statement** – see text, pages 923-924

**Solution**

- Determine the biomass production in kg/d using Eq (8-20), parts A and B, and assume the process is designed for BOD removal only for **wastewater**
- 

$$P_{X,\text{bio}} = \frac{QY_H(S_o - S)(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})} + \frac{(f_d)(b_H)QY_H(S_o - S)\text{SRT}(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})}$$

- Define input data for above equation

$$Q = 3000 \text{ m}^3/\text{d}$$

$$S_o = 2000 \text{ mg/L bCOD}$$

$$S = 5 \text{ mg/L bCOD}$$

$$Y_H = 0.4 \text{ g VSS/g COD}$$

$$b_H = 0.1 \text{ g VSS/g VSS} \cdot d$$

$$f_d = 0.1 \text{ g VSS/g VSS}$$

$$SRT = 10 \text{ d}$$

- b. Solve for  $P_{X,\text{bio}}$

$$\begin{aligned} P_{X,\text{bio}} &= \frac{(3000 \text{ m}^3/d)(0.4 \text{ g/g})[(2000 - 5) \text{ g/m}^3](1 \text{ kg}/10^3 \text{ g})}{[1 + (0.1 \text{ g/g} \cdot d)(10 \text{ d})]} \\ &\quad + \frac{(0.1 \text{ g/g})(0.1 \text{ g/g} \cdot d)(3000 \text{ m}^3/d)(0.4 \text{ g/g})[(2000 - 5) \text{ g/m}^3](10 \text{ d})(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.1 \text{ g/g} \cdot d)(10 \text{ d})]} \end{aligned}$$

$$P_{X,\text{bio}} = (1197 + 119.7) = 1316.7 \text{ kg/d}$$

2. Determine the amount of N and P needed for biogrowth in kg/d

Assume 12 percent by weight of N will be required and assume P required is about 20 percent of N required (see page 686).

- a. Determine the amount of N needed for biogrowth

$$N \text{ needed} = (P_{X,\text{bio}})(12\%) = (1316.7 \text{ kg/d})(0.12) = 158 \text{ kg/d}$$

- b. Determine the amount of P needed for bio-growth

$$P \text{ needed} = (N \text{ needed})(20\%) = (158 \text{ kg/d})(0.2) = 31.6 \text{ kg/d}$$

3. Determine the amount of N and P that must be added to the influent

- a. Prepare a mass balance for N and P

$$N \text{ in the influent} + N_{\text{added}} = N \text{ in biomass} + N \text{ in effluent}$$

$$Q(N_i) + Q(N_{\text{added}}) = P_{X,\text{bio}}(12\%) + Q(N_e)$$

$$N_{\text{added}} = \frac{P_{X,\text{bio}}(12\%)}{Q} + N_e - N_i \quad (i)$$

$$P \text{ in the influent} + P_{\text{added}} = P \text{ in biomass} + P \text{ in effluent}$$

$$Q(P_i) + Q(P_{\text{added}}) = P_{X,\text{bio}}(12\%)(20\%) + Q(P_e)$$

$$P_{\text{added}} = \frac{P_{X,\text{bio}}(0.12)(0.20)}{Q} + P_e - P_i \quad (ii)$$

- b. Define input data for above equation (i) and (ii)

$$Q = 3000 \text{ m}^3/d$$

$$P_{X,\text{bio}} = 1316.7 \text{ kg/d from part 1}$$

$$N_i = 20 \text{ mg/L NH}_4\text{-N} \quad \text{influent N}$$

$$N_e = 0.1 \text{ mg/L NH}_4\text{-N} \quad \text{effluent N}$$

$$P_i = 5 \text{ mg/L} \quad \text{influent P}$$

$$P_e = 0.1 \text{ mg/L} \quad \text{effluent P}$$

c. Solve Eq. (i).

$$\begin{aligned} N_{\text{added}} &= (1316.7 \text{ kg/d})(0.12)/(3000 \text{ m}^3/\text{d})(10^3 \text{ g}/1 \text{ kg}) + 0.1 \text{ g/m}^3 - 20 \\ &\quad \text{g/m}^3 \end{aligned}$$

$$= (52.67 + 0.1 - 20) \text{ g/m}^3 = 32.77 \text{ g/m}^3$$

$$N_{\text{added}} \text{ in kg/d} = N_{\text{added}} (Q) = (32.77 \text{ g/m}^3)(3000 \text{ m}^3/\text{d})(1 \text{ kg}/10^3 \text{ g})$$

$$= 98.3 \text{ kg/d}$$

d. Solve Eq. (ii).

$$\begin{aligned} P_{\text{added}} &= (1376.7 \text{ kg/d})(0.12)(0.2) / (3000 \text{ m}^3/\text{d})(10^3 \text{ g}/1 \text{ kg}) \\ &\quad + 0.1 \text{ g/m}^3 - 5 \text{ g/m}^3 \end{aligned}$$

$$P_{\text{added}} = (10.53 + 0.1 - 5) = 5.63 \text{ g/m}^3$$

$$\begin{aligned} P_{\text{added}} \text{ in kg/d} &= P_{\text{added}} (Q) = (5.63 \text{ g/m}^3)(3000 \text{ m}^3/\text{d})(1 \text{ kg}/10^3 \text{ g}) \\ &= 16.9 \text{ kg/d} \end{aligned}$$

## PROBLEM 8-12

**Problem Statement** – see text, page 924

**Solution (Activated sludge system 1)**

- Determine the average daily waste sludge rate in m<sup>3</sup>/d from the return activated sludge line for a 10 d SRT. Solve for Q<sub>w</sub> in Eq. (8-27) in Table 8-10.

$$\text{SRT} = \frac{V(X)}{(Q - Q_w)X_e + Q_w X_R}$$

Rearranging:

$$Q_w = \frac{(VX / \text{SRT}) - Q_w X_e}{X_R - X_e}$$

From data in table,

$$Q_w = \frac{\left[ \frac{(2000 \text{ m}^3)(3000 \text{ g/m}^3)}{10 \text{ d}} \right] - (4000 \text{ m}^3/\text{d})(10 \text{ g/m}^3)}{[(9000 - 10)\text{g/m}^3]}$$

$$Q_w = 62.3 \text{ m}^3/\text{d}$$

2. Determine the actual SRT when 1/10th of the aeration volume is wasted. In this case the wasting rate,  $Q_w$ , equals  $V/10$  at a solids concentration =  $X$ .

Substitute  $Q_w$  with  $V/10$  into Eq. (8-27).

$$\text{SRT} = \frac{V(X)}{\left( Q - \frac{V}{10} \right) X_e + \left( \frac{V}{10} \right) X_R}$$

$$\text{SRT} = \frac{(2000 \text{ m}^3)(3000 \text{ g/m}^3)}{\left[ (4000 \text{ m}^3/\text{d}) - \frac{(2000 \text{ m}^3/\text{d})}{10} \right] (10 \text{ g/m}^3) + \left[ \frac{(2000 \text{ m}^3/\text{d})}{10} \right] (3000 \text{ g/m}^3)}$$

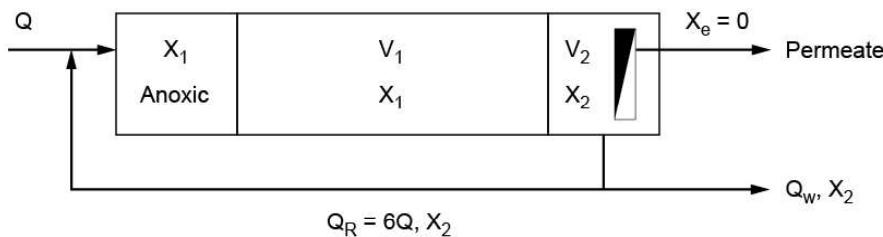
$$\text{SRT} = 9.4 \text{ d}$$

### PROBLEM 8-13

**Problem Statement** – see text, page 924

#### Solution

1. Provide a sketch of the membrane bioreactor and show problem information.



$$V_1 = 0.75(V_T) = 0.75(4000 \text{ m}^3) = 3000 \text{ m}^3$$

$$V_2 = 0.25(V_T) = 0.25(4000 \text{ m}^3) = 1000 \text{ m}^3$$

2. Define the aerobic SRT from Eq. (8-27) in Table 8-10 for the MBR process.

$$SRT = \frac{V(X)}{(Q - Q_w)X_e + Q_w X_R}, \quad X_e = 0$$

$$SRT = \frac{[V_1(X_1) + V_2(X_2)]}{Q_w(X_2)}$$

$$SRT = 10 \text{ d}, X_2 = 12,000 \text{ mg/L}$$

3. Determine  $X_1$  by mass balance on volume,  $V_1$ .

$$Q_R X_2 + Q(0) = (Q + Q_R) X_1$$

$$6Q(X_2) = (Q + 6Q) X_1$$

$$X_1 = \left(\frac{6}{7}\right) X_2 = \left(\frac{6}{7}\right)(12,000 \text{ mg/L})$$

$$X_1 = 10,285.7 \text{ mg/L}$$

4. Solve for  $Q_w$  from Step 2.

$$Q_w X_2 = \frac{[V_1(X_1) + V_2(X_2)]}{SRT}$$

$$Q_w = \frac{[V_1(X_1 / X_2) + V_2]}{SRT}$$

$$Q_w = \frac{(3000 \text{ m}^3) \left( \frac{10,285.7}{12,000} \right) + 1000 \text{ m}^3}{10 \text{ d}}$$

$$Q_w = 357.1 \text{ m}^3 / \text{d}$$

5. Alternative solution based on  $Q$ ,  $Q_R$ , volumes from Step 3.

$$\frac{X_1}{X_2} = \frac{Q_R}{Q + Q_R} = \frac{(Q_R / Q)}{(1 + Q_R / Q)}$$

$$R = Q_R / Q = 6.0$$

$$\frac{X_1}{X_2} = \frac{R}{1+R}$$

From Step 4,

$$Q_w = \frac{[V_1(X_1 / X_2) + V_2]}{SRT}$$

$$Q_w = \frac{\left[ V_1 \left( \frac{R}{1+R} \right) + V_2 \right]}{SRT}$$

$$Q_w = \frac{\left[ (3000 \text{ m}^3) \left( \frac{6}{1+6} \right) + 1000 \text{ m}^3 \right]}{10 \text{ d}}$$

$$Q_w = 357.1 \text{ m}^3 / \text{d}$$

Note: The SRT can be controlled without any MLSS measurements as a function of recycle ratio and volumes.

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### PROBLEM 8-14

**Problem Statement** – see text, page 924

**Solution**

- From discussion on page 729 and page 892, determine the SVI value using Eq. (8-83)

$$SVI = \frac{(\text{settled volume of sludge, mL/L})(10^3 \text{ mg/g})}{(\text{suspended solids, mg/L})} = \text{mL/g}$$

$$SVI = \frac{(840 \text{ mL/2 L})(10^3 \text{ mg/g})}{(3500 \text{ mg/L})} = 120 \text{ mL/g}$$

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### PROBLEM 8-15

**Problem Statement** – see text, pages 924-925

**Solution (for (1) heterotrophic bacteria under aerobic conditions)**

- Assume flow into 2nd stage equal influent flow, Q, plus return activated sludge flow  $Q_R$ .
- Volume for 2nd stage equal  $V_2$  and heterotrophic bacteria concentration equal  $X_{Ha}$ .
- Perform mass balance and use component stoichiometric terms for  $X_{Ha}$  shown in Table 8-13 with corresponding processes in Table 8-12.

a. Prepare mass balance

Rate of change = rate in – rate out + rate of production + rate of depletion

b. Express each term with stoichiometric terms

$$V_2 \frac{dX_{H,2}}{dt} = (Q + Q_R)X_{H,1} - (Q + Q_R)X_{H,2} + R_4 V_2 + R_5 V_2 + R_9 V_2$$

$$R_4 = (1)\mu_H \left( \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \right) \left( \frac{S_F}{K_F + S_F} \right) \left( \frac{S_F}{S_A + S_F} \right) (\text{Growth}_{\text{Lim}})(X_{H,2})$$

$$R_5 = (1)\mu_H \left( \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \right) \left( \frac{S_A}{K_A + S_A} \right) \left( \frac{S_A}{S_A + S_F} \right) (\text{Growth}_{\text{Lim}})(X_{H,2})$$

where:

$$(\text{Growth}_{\text{Lim}}) = \left( \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \right) \left( \frac{S_{PO_4}}{K_{PO_4} + S_{PO_4}} \right) \left( \frac{S_{alk}}{K_{alk} + S_{alk}} \right)$$

$$R_9 = (-1)b_H X_{H,2}$$

$$V_2 \frac{dX_{H,2}}{dt} = (Q + Q_R)X_{H,1} - (Q + Q_R)X_{H,2}$$

$$+ V_2 \mu_H \left( \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \right) \left( \frac{S_F}{K_F + S_F} \right) \left( \frac{S_F}{S_A + S_F} \right) \left( \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \right) \left( \frac{S_{PO_4}}{K_{PO_4} + S_{PO_4}} \right) \left( \frac{S_{alk}}{K_{alk} + S_{alk}} \right)$$

$$+ V_2 \mu_H \left( \frac{S_{O_2}}{K_{O_2} + S_{O_2}} \right) \left( \frac{S_A}{K_A + S_A} \right) \left( \frac{S_A}{S_A + S_F} \right) \left( \frac{S_{NH_4}}{K_{NH_4} + S_{NH_4}} \right) \left( \frac{S_{PO_4}}{K_{PO_4} + S_{PO_4}} \right) \left( \frac{S_{alk}}{K_{alk} + S_{alk}} \right)$$

$$- V_2 b_H X_{H,2}$$

### PROBLEM 8-16

**Problem Statement** – see text, page 925

#### Solution

- Determine the specific steps needed to investigate the cause of bulking sludge condition. The following steps should be taken to investigate possible causes of bulking sludge:

- View the mixed liquor under a microscope with phase contrast to determine if bulking is related to a filamentous growth population or perhaps to hydrous bulking due to a large polysaccharide growth around the cells. The latter can be determined by staining with India ink. If filamentous growth is present, further investigation can be done microscopically to identify the type of filament, which may lead to an understanding of the cause, such as low DO, sulfide, insufficient nutrients, or low F/M.
- Evaluate the wastewater characteristics. The characteristics of wastewater that may relate to bulking are the soluble BOD or rbCOD concentration, BOD/N/P ratio, pH, sulfides, and total dissolved solids. High influent sulfide concentrations may lead to thiothrix or beggiatoa growth (filamentous bacteria). A high soluble BOD fraction or high rbCOD concentration may encourage filamentous growth if there are no selective pressures in the system design to encourage uptake of most of the readily available soluble substrate by non-filamentous bacteria.
- Evaluate the system operation. What is the DO concentration in the aeration basin at various times of the day? Are there conditions that encourage low DO filaments? Operation with a DO concentration in the range of 0.5 mg/L and availability of rbCOD can encourage growth of low DO filamentous bacteria. It was stated that full nitrification was occurring so determine if significant denitrification is occurring in the secondary clarifier that affects the sludge blanket. Evidence of denitrification is the presence of rising gas bubbles in the clarifier and the presence of some floating sludge. Indications can also be found by observing the behavior of the sludge during an SVI test.

Note that the information given was that it is a complete-mix activated sludge process with full nitrification so DO is likely not a problem. If there is a significant rbCOD concentration in the wastewater influent, sufficient nutrients are present, sulfides are low, and the pH and total dissolved solids

concentration are not abnormal, there is a good chance that the bulking is due to low F/M filamentous bacteria growth.

2. The possible short-term immediate actions that can be taken to reduce the effluent TSS concentration include the following and the choice depends on the initial investigation:
  - Add chlorine or hydrogen peroxide to the return sludge at a dose that will damage the filamentous bacteria extending from the floc but not damage the nitrifying bacteria in the floc. The addition of chlorine or hydrogen peroxide will be effective if bulking is caused by filamentous growth.
  - Add nutrients if needed
  - Chlorinate the influent if a high sulfide concentration is present
  - Control pH if needed
  - Increase the aeration DO concentration if needed.
  - Add alum to final clarifier to improve effluent TSS capture.
3. What selector type can be considered for bulking sludge control? The selector alternatives that can be considered for bulking sludge control include:
  - High F/M selector in series (usually up to 3 reactors)
  - Anaerobic selector
  - Anoxic selector

Because nitrification is occurring, an anoxic selector, whether in a single stage or multiple stage (high F/M mode), is a logical choice. The design should evaluate the amount of rbCOD in the influent and the amount of nitrate produced in the system. For an anoxic selector sufficient nitrate must be provided to consume the rbCOD, and thus internal recycle to the anoxic selector may be needed to provide more nitrate in excess of that from the return activated sludge. If there is not sufficient nitrate, consideration should be given to a staged high F/M selector.

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**PROBLEM 8-17****Problem Statement** – see text, page 925**Solution (Wastewater #1)**

1. Develop the wastewater characteristics needed for design using the kinetic values in Table 8-14.

- a. Compute bCOD using Eq. (8-13) for **wastewater 1**.

$$bCOD = 1.6 \text{ (BOD)}$$

$$bCOD = 1.6 (220) = 352 \text{ mg/L}$$

- b. Compute kinetic coefficients for  $T = 15^{\circ}\text{C}$  with Eq. (1-44) in Table 8-10

$$\mu_{max,H,15^{\circ}\text{C}} = 6.0(1.07)^{15-20} = 4.3 \text{ g/g} \cdot \text{d}$$

$$K_s, 15^{\circ}\text{C} = 8.0(1.0)^{15-20} = 8.0 \text{ g/m}^3$$

$$b_{H,15^{\circ}\text{C}} = 0.12(1.04)^{15-20} = 0.10 \text{ g/g} \cdot \text{d}$$

$$\mu_{max,AOB,15^{\circ}\text{C}} = 0.90(1.072)^{15-20} = 0.636 \text{ g/g} \cdot \text{d}$$

$$K_{NH,15^{\circ}\text{C}} = 0.50(1.0)^{15-20} = 0.50 \text{ g NH}_4\text{-N/m}^3$$

$$b_{AOB,15^{\circ}\text{C}} = 0.17(1.029)^{15-20} = 0.147 \text{ g/g} \cdot \text{d}$$

2. Determine the effluent sbCOD and ammonia-N concentration as a function of SRT.

- a. Determine S as a function SRT using Eq. (7-46) where  $\mu_m = Yk$ , and kinetic coefficients computed in step 1b.

$$Y_H = 0.45 \text{ g VSS/g COD}, f_d = 0.15 \text{ g VSS/g VSS}$$

$$S = \frac{K_S[1 + (b_H)SRT]}{SRT(\mu_m - b_H) - 1}$$

$$S = \frac{(8.0 \text{ g/m}^3)[1 + (0.1 \text{ g/g} \cdot \text{d})SRT]}{SRT[(4.3 - 0.1) \text{ g/g} \cdot \text{d}] - 1}$$

$$S = \frac{8(1 + 0.1SRT)}{4.2SRT - 1} \text{ g/m}^3$$

$$\text{At SRT} = 3.0 \text{ d}, S = 0.90 \text{ g/m}^3$$

S as a function of SRT is summarized in table below.

- b. Determine effluent  $\text{NH}_3\text{-N}$  ( $N_e$ ) concentrations as a function of SRT by combining Eq. (7-94) and Eq. (7-98) in Table 10. Let  $S_o = \text{DO}$ .

$$\frac{1}{\text{SRT}} = \left( \frac{\mu_{\max, \text{AOB}} S_{\text{NH}_4}}{K_{\text{NH}_4} + S_{\text{NH}_4}} \right) \left( \frac{\text{DO}}{K_o + \text{DO}} \right) - b_{\text{AOB}}$$

Solving for  $S_{\text{NH}_4}$  (let  $S_{\text{NH}_4} = N_e$ ):

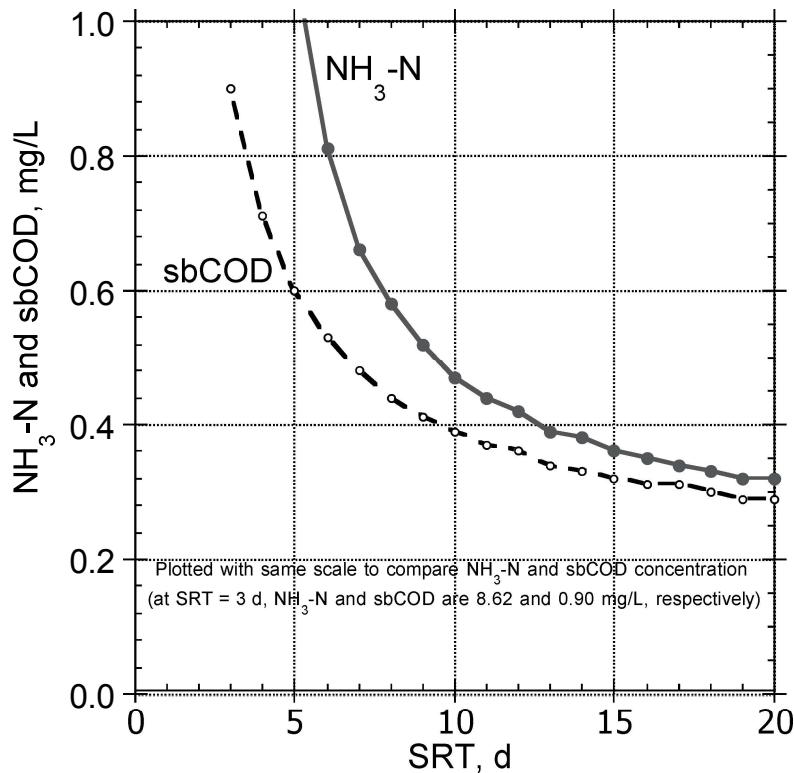
$$N_e = \frac{K_{\text{NH}_4} (1 + b_{\text{AOB}} \text{SRT})}{[\mu_{\max, \text{AOB}} \left( \frac{\text{DO}}{K_o + \text{DO}} \right) - b_{\text{AOB}}] \text{SRT} - 1}$$

$$N_e = \frac{0.50 \text{ g/m}^3 [1 + (0.147 \text{ g/g-d}) \text{SRT}]}{\text{SRT} \left\{ 0.636 \text{ g/g-d} \left[ \frac{(2.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3 + 2.0 \text{ g/m}^3)} \right] - 0.147 \text{ g/g-d} \right\} - 1}$$

At SRT = 3.0 days,  $N_e = 8.62 \text{ g/m}^3$

Table showing Effluent  $\text{NH}_3\text{-N}$  ( $N_e$ ) and effluent sbCOD (S) concentration as a function of SRT:

SRT, d	Effl. sbCOD mg/L	Effl. $\text{NH}_3\text{-N}$ mg/L	SRT, d	Effl. sbCOD mg/L	Effl. $\text{NH}_3\text{-N}$ mg/L
3	0.90	8.62	12	0.36	0.42
4	0.71	1.79	13	0.34	0.39
5	0.60	1.08	14	0.33	0.38
6	0.53	0.81	15	0.32	0.36
7	0.48	0.66	16	0.31	0.35
8	0.44	0.58	17	0.31	0.34
9	0.41	0.52	18	0.75	0.24
10	0.39	0.47	19	0.73	0.23
11	0.37	0.44	20	0.72	0.22

Figure 1. Effluent  $\text{NH}_3\text{-N}$  and sbCOD concentration vs SRT

3. Determine solids wasted as kg TSS/d as a function of SRT. At steady state solids wasted is equal to the solids production rate, which can be calculated using Eq. (8-20) and Eq. (8-21) in Table 8-10.

$$P_{X,TSS} = \frac{A}{0.85} + \frac{B}{0.85} + \frac{C}{0.85} + D + E$$

where  $E = Q(TSS_o - VSS_o)$

- a. Calculate the terms in Eq. 8-21; For first calculation assume  $NO_X \approx 80\%$  of influent TKN

- i. Active biomass:

$$A = \frac{QY_H(S_o - S)(1 \text{ kg} / 10^3 \text{ g})}{[1 + (b_H)SRT]0.85}$$

$$= \frac{(20,000 \text{ m}^3/\text{d})(0.45 \text{ g VSS/g COD})(352 - S)(\text{g sbCOD/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.10 \text{ g/g}\cdot\text{d})(SRT)]0.85}$$

At SRT = 3.0 d, A = 2869 kg TSS/d

ii. Cell debris:

$$B = \frac{(f_d)(b_H)(Q)(Y_H)(S - S_o)SRT(1 \text{ kg}/10^3 \text{ g})}{[1 + b_H(SRT)]0.85}$$

$$= \frac{(0.15 \text{ g/g})(0.10 \text{ g/g}\cdot\text{d})(20,000 \text{ m}^3/\text{d})(0.45 \text{ g VSS/g COD})(352 - S)(\text{g sbCOD/m}^3)SRT(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.10 \text{ g/g}\cdot\text{d})(SRT)]0.85}$$

At SRT = 3.0 d, B = 127 kg TSS/d

iii. Nitrifying bacteria:

$$C = \frac{QY_n(\text{NO}_x)(1 \text{ kg}/10^3 \text{ g})}{[1 + b_{AOB}(SRT)]0.85}$$

Note  $Y_n = 0.20 \text{ g VSS/g NOx-N}$  to account for growth of both AOB and NOB.

For first calculation assume  $\text{NOx-N} = 0.80$  (Influent TKN)

$$= \frac{(20,000 \text{ m}^3/\text{d})(0.20 \text{ g VSS/g NOx-N})(0.8)(40 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.147 \text{ g/g}\cdot\text{d})(SRT)]0.85}$$

At SRT = 3.0 d, C = 52 kg TSS/d

iv. Nonbiodegradable VSS (VSS = TSS)

$$D = Q(nbVSS)(1 \text{ kg}/10^3 \text{ g})$$

$$D = (20,000 \text{ m}^3/\text{d})(100 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g}) = 2000 \text{ kg VSS/d}$$

v. Inert inorganic TSS

$$E = (20,000 \text{ m}^3/\text{d})[(220 - 200) \text{ g/m}^3](1 \text{ kg}/10^3 \text{ d}) = 400 \text{ kg TSS/d}$$

- b. Iterate for  $\text{NO}_x\text{-N}$  value by calculating  $\text{NO}_x\text{-N}$  from  $P_{X,\text{bio}}$ , using Eq. (8-24), Table 8-10 and replacing the initial assume value.

$$\text{NO}_x\text{-N} = \text{TKN} - 0.12(P_{X,\text{bio}}) - N_e$$

where  $P_{X,\text{bio}} = \text{VSS}/d$  of active heterotrophs, debris, and nitrifiers

Solve for  $\text{NO}_x\text{-N}$  and change value inserted in Eq. C above to iterate

Insert A, B, C, D, and E into Eq. (8-21) to solve  $P_{X,\text{TSS}}$  as a function of SRT. Using a spreadsheet program, the values of  $P_{X,\text{TSS}}$  and  $P_{X,\text{bio},\text{VSS}}$  for SRTs ranging from 3 to 20 d are shown in the following table.

SRT, d	As kg TSS/d, except $P_{X,\text{bio}}$ which is kg VSS/d						
	A	B	C	D	E	$P_{X,\text{TSS}}$	$P_{X,\text{bio}}$
3	2869	127	52	2000	400	5448	2591
4	2667	158	68	2000	400	5293	2459
5	2492	184	68	2000	400	5144	2332
6	2338	208	65	2000	400	5010	2219
7	2202	228	63	2000	400	4892	2119
8	2081	246	58	2000	400	4785	2027
9	1972	263	57	2000	400	4691	1948
10	1874	277	53	2000	400	4605	1874
11	1786	291	52	2000	400	4528	1809
12	1705	303	49	2000	400	4457	1749
13	1632	314	47	2000	400	4392	1693
14	1564	324	46	2000	400	4334	1644
15	1502	333	44	2000	400	4279	1597
16	1444	342	42	2000	400	4228	1554
17	1391	350	42	2000	400	4183	1515
18	1342	357	41	2000	400	4140	1479
19	1296	364	40	2000	400	4100	1445
20	1253	371	38	2000	400	4062	1412

- c. Determine tank volume  $V(\text{m}^3)$  and  $\tau$  (h) as a function of SRT using Eq. (7-57) in Table 8-10.

$$(X_{TSS})(V) = (P_{X,TSS})SRT$$

$$V = \frac{(P_{X,TSS})SRT}{X_{TSS}}$$

$$V = \frac{(P_{X,TSS}, \text{ kg / d})(SRT, \text{ d})}{(2500 \text{ g / m}^3)(1 \text{ kg / } 10^3 \text{ g})} = \frac{P_{X,TSS}(SRT)}{2.5} \text{ m}^3$$

$$\tau = \frac{V}{Q}$$

$$\tau = \frac{[(P_{X,TSS})(SRT)](m^3)(24 \text{ h/d})}{2.5(20,000 \text{ m}^3/\text{d})} = 4.8 \times 10^{-4} [(P_{X,TSS})(SRT)] \text{ h}$$

Using a spreadsheet program, compute the values of V and  $\tau$  for SRTs ranging from 3 to 20 d as shown in the following table and plot below:

SRT d	Volume $\text{m}^3$	$\tau$ h	SRT d	Volume $\text{m}^3$	$\tau$ h
3	6538	7.8	12	21,394	25.7
4	8469	10.2	13	22,839	27.4
5	10,288	12.3	14	24,270	29.1
6	12,025	14.4	15	25,674	30.8
7	13,699	16.4	16	27,061	32.5
8	15,313	18.4	17	28,442	34.1
9	16,889	20.3	18	29,810	35.8
10	18,419	22.1	19	31,157	37.4
11	19,925	23.9	20	32,493	39.0

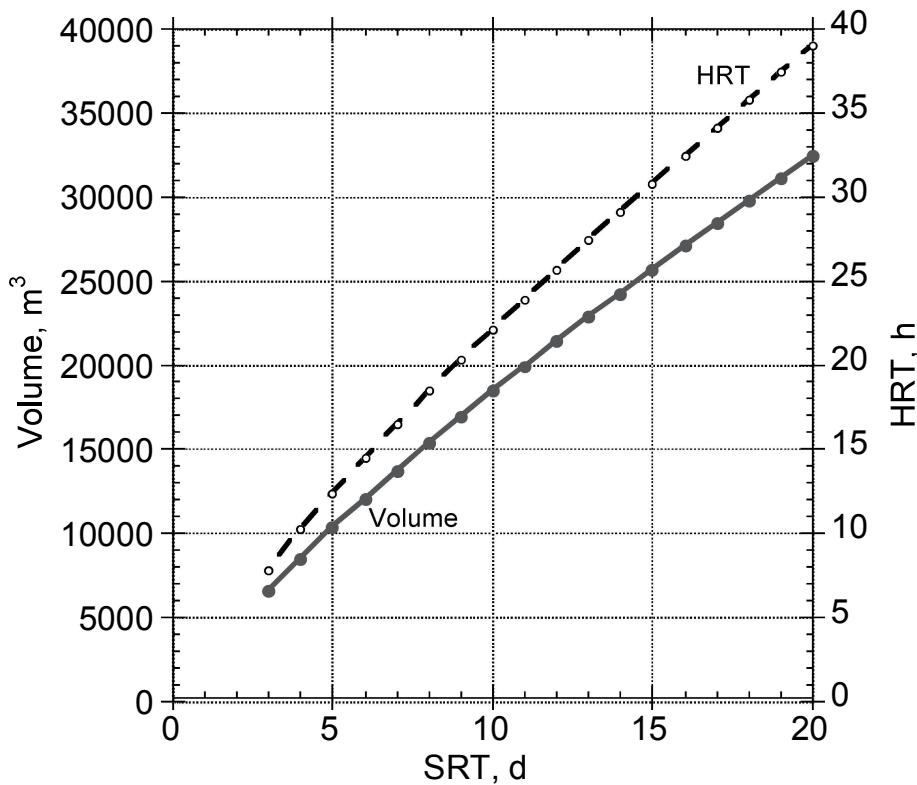


Figure 2. Plot of Volume and hydraulic retention time (HRT) versus SRT.

- d. Determine observed yield as g TSS/g BOD and g TSS/g bCOD  
 $Y_{obs}$  based on g TSS/g BOD  
 Observed yield =  $P_{X,TSS}/g$  BOD removed  
 $P_{X,TSS}$  was determined in Step 3a above.  
 BOD removed =  $Q (S_o - S)$ , S is determined above as function of SRT

$$Y_{obs, TSS/BOD} = \frac{(P_{X,TSS}, \text{ g TSS/d})}{(20,000 \text{ m}^3/\text{d})(220 - S) \text{ g BOD/m}^3}$$

$$Y_{obs, TSS/COD} = (Y_{obs, TSS/BOD}) \left( \frac{\text{BOD}}{1.6\text{BOD}} \right)$$

$$Y_{obs, TSS/COD} = \frac{(Y_{obs, TSS/BOD})}{1.6}$$

Using a spreadsheet program, compute the values of  $Y_{obs}$  for SRTs ranging from 3 to 20 d as shown in the following table and plot.

SRT d	$Y_{obs}$ gTSS/gBOD	$Y_{obs}$ gTSS/gCOD	SRT d	$Y_{obs}$ gTSS/gBOD	$Y_{obs}$ gTSS/gCOD
3	1.24	0.78	12	1.01	0.63
4	1.20	0.75	13	1.00	0.62
5	1.17	0.73	14	0.99	0.62
6	1.14	0.71	15	0.97	0.61
7	1.11	0.70	16	0.96	0.60
8	1.09	0.68	17	0.95	0.59
9	1.07	0.67	18	0.94	0.59
10	1.05	0.66	19	0.93	0.58
11	1.03	0.64	20	0.92	0.58

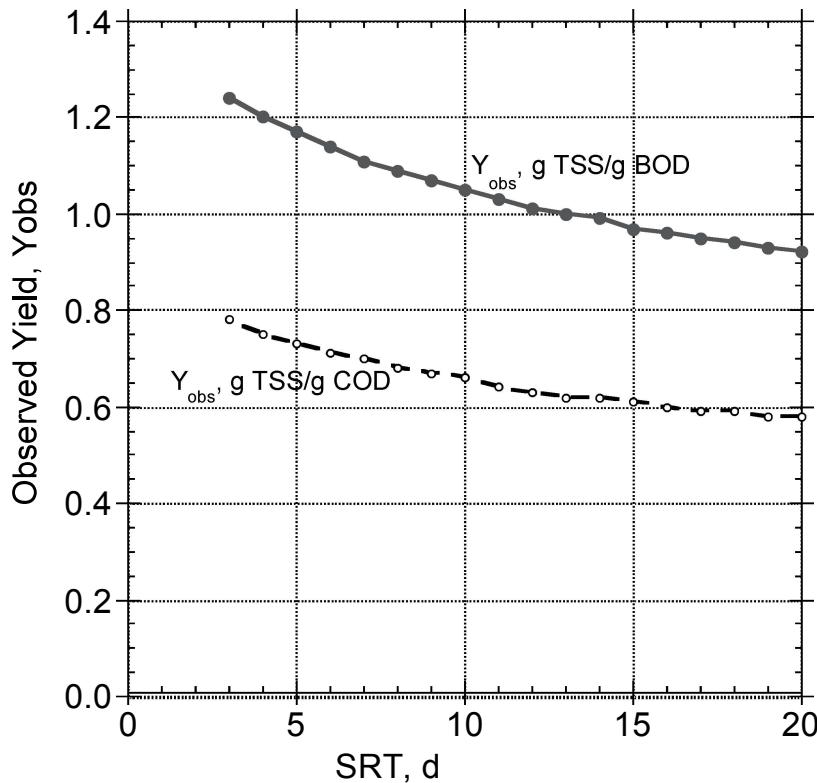


Figure 3. Observed yield vs SRT

- e. Determine oxygen requirement in kg/d as a function of SRT
  - i. Calculate  $NO_x$  using Eq. (8-24)

$$NO_x = TKN - N_e - 0.12 P_{X,bio}/Q$$

$P_{X,\text{bio}}$  is calculated as shown above from A, B, and C

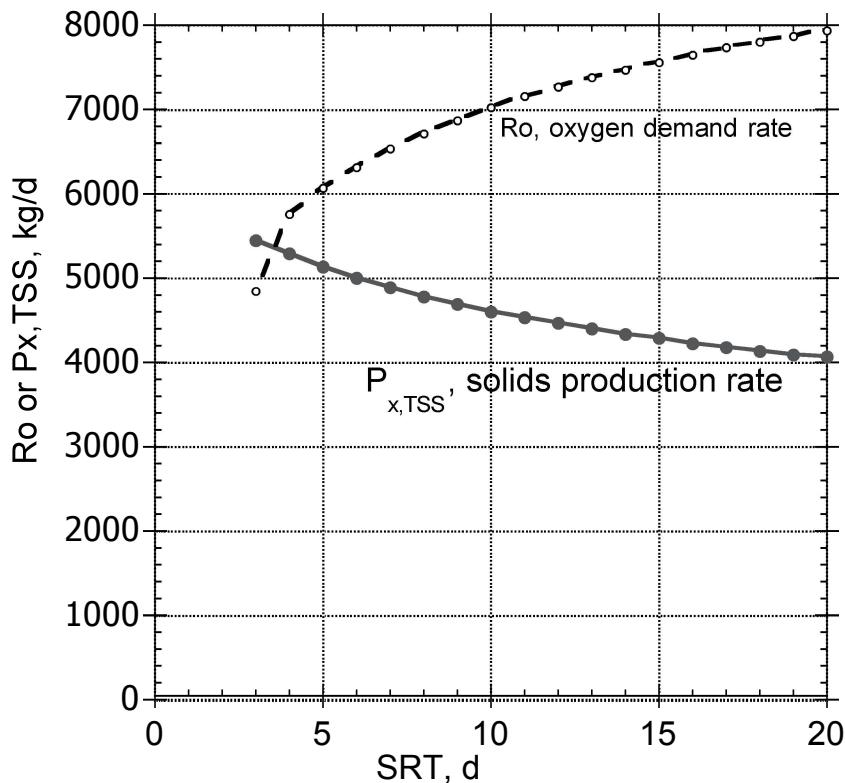
Using a spreadsheet program, compute the values of  $\text{NO}_x$  for SRTs ranging from 3 to 20 d as shown in the table following item ii. below.

- ii. Calculate  $O_2$  demand rate using Eq. (8-23).

$$R_o = Q(S_o - S) - 1.42P_{X,\text{bio}} + 4.57Q(\text{NO}_x\text{-N})$$

- f. Using a spreadsheet program, compute the values of  $R_o$  for SRTs ranging from 3 to 20 d as shown in the following table and plot.  
The plot also includes the sludge production rate (kg TSS/d)

SRT d	NOx-N mg/L	$R_o$ kg/d	SRT d	NOx-N mg/L	$R_o$ kg/d
3	16	4853	12	29	7269
4	23	5760	13	29	7377
5	25	6076	14	30	7475
6	26	6323	15	30	7566
7	27	6531	16	30	7649
8	27	6714	17	31	7726
9	28	6875	18	31	7798
10	28	7020	19	31	7865
11	29	7150	20	31	7927




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### PROBLEM 8-18

**Problem Statement** – see text, page 925

**Solution**

The use of membranes for liquid-solids separation results in two important design changes compared to the single-tank activated sludge system in problem 8-17:

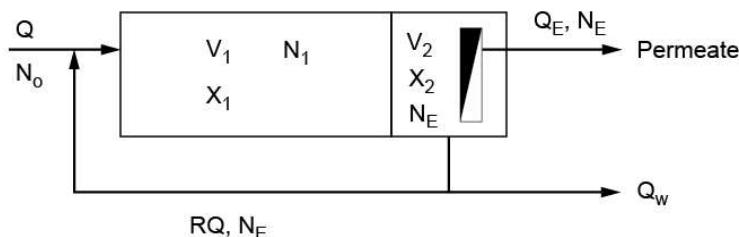
(1) The aeration tank MLSS concentration is much higher with 12,000 mg/L (versus 2500 mg/L) in the membrane compartment and also a much higher MLSS concentration in the first compartment which will be determined here by a mass balance, and (2) the two-stage reactor configuration provides a greater BOD removal and ammonia oxidation efficiency due to removal at a higher concentration in the first compartment. Because the effluent soluble bCOD is already very low for the solution in problem 8-17, the 2-stage effluent concentration will not be calculated here. However, the effluent  $\text{NH}_4\text{-N}$  concentration is calculated in this solution to show the effect of staged kinetics.

Before proceeding with the solution, the effect of the higher MLSS concentration and two-stage reactor configuration are addressed for each process parameter required to be addressed in Problem 8-17.

- (a) The solids wasted will be the same as in Problem 8-17 for a given SRT
- (b) The aeration tank volume and  $\tau$  will be lower for each SRT for the membrane system due to the higher average MLSS concentration
- (c) The observed yields will be the same due to the same solids production rate at each SRT
- (d) The effluent soluble bCOD concentration will be lower for the two-stage membrane system but is not calculated here as it is already at a very low concentration in the Problem 8-17 solution
- (e) The effluent  $\text{NH}_4\text{-N}$  concentration will be lower for the two-stage membrane system and is calculated here because of a greater interest to minimize effluent  $\text{NH}_4\text{-N}$  concentration for water quality concerns and as related to nitrogen removal processes
- (f) The total oxygen demand will be increased by only a small amount due to slight increase in  $\text{NH}_4\text{-N}$  oxidized.

The following solution thus determines  $V$ ,  $\tau$ , effluent  $\text{NH}_4\text{-N}$  and  $R_o$  as a function of SRT.

1. Determine the MLSS concentration in compartment 1 and the total membrane aeration tank volume needed at each SRT.
  - a. Perform a mass balance for MLSS (ignore waste solids flow) in  $V_1$ .



( $N = \text{NH}_4\text{-N}$  concentration,  $V = \text{volume}$ ,  $X = \text{MLSS}$  concentration,  $R = \text{return activated sludge ratio}$ )

$$V_1 + V_2 = V, V_1 = 0.75V, V_2 = 0.25V$$

(Solids in) = (Solids out)

$$RQ(X_2) + Q(0) = (RQ + Q)X_1$$

$$X_1 = \left( \frac{R}{R+1} \right) X_2 = \left( \frac{6}{6+1} \right) (12,000 \text{ mg/L})$$

$$X_1 = 10,286 \text{ mg/L}$$

2. Using the sludge production rate calculations for Problem 8-17 as a function of SRT, calculate the MBR compartment volumes and  $\tau$ . The following is shown for SRT = 10d.

- a. Use Eq. (7-57) to calculate the aeration mass required.

$$\text{Mass} = (P_{X,TSS})SRT$$

$$\text{At SRT} = 10\text{d}, P_{X,TSS} = 4369 \text{ kg/d}$$

$$\text{Mass} = V_1X_1 + V_2X_2 = (4369 \text{ kg/d})(10 \text{ d})$$

$$V_1X_1 + V_2X_2 = 43,690 \text{ kg}$$

- b. Solve for  $V_1$  and  $V_2$ .

$$0.75VX_1 + 0.25VX_2 = 43,690 \text{ kg}$$

$$V(0.75X_1 + 0.25X_2) = 43,690 \text{ kg}$$

$$V = \frac{43,690 \text{ kg}}{[0.75(10,286 \text{ g/m}^3) + 0.25(12,000 \text{ g/m}^3)](1\text{kg}/10^3\text{ g})}$$

$$V = 4077.7 \text{ m}^3$$

$$V_1 = 0.75(4077.7 \text{ m}^3) = 3058.3 \text{ m}^3$$

$$V_2 = (0.25/0.75)(3058.3 \text{ m}^3) = 1019.4 \text{ m}^3$$

- c. The hydraulic retention time,  $\tau$ , for the MBR aeration tank of SRT = 10d:

$$\tau = \frac{V}{Q} = \frac{(4077.7 \text{ m}^3)(24 \text{ h/d})}{(20,000 \text{ m}^3/\text{d})} = 4.89 \text{ h}$$

The MBR volume and  $\tau$  as a function of SRT alongside the volumes for the activated sludge clarifier system are summarized in the following tables for comparison.

MBR and conventional activated sludge (CAS) volumes as a function of SRT

SRT d	Mass kg	MBR Volume m <sup>3</sup>	CAS Volume m <sup>3</sup>	SRT d	Mass kg	MBR Volume m <sup>3</sup>	CAS Volume m <sup>3</sup>
3.00	16,345	1525	6175	12.00	53,486	4992	20,338
4.00	21,173	1976	7980	13.00	57,097	5329	21,734
5.00	25,720	2400	9702	14.00	60,676	5663	23,110
6.00	30,062	2806	11,354	15.00	64,186	5991	24,469
7.00	34,247	3196	12,949	16.00	67,653	6314	25,813
8.00	38,282	3573	14,497	17.00	71,106	6636	27,143
9.00	42,222	3941	16,004	18.00	74,526	6956	28,461
10.00	46,049	4298	17,477	19.00	77,892	7270	29,769
11.00	49,812	4649	18,920	20.00	81,232	7582	31,066

MBR and conventional activated sludge (CAS) hydraulic retention time as a function of SRT

SRT d	MBR HRT h	CAS HRT h	SRT d	MBR HRT h	CAS HRT h
3	1.83	7.85	12	5.99	25.67
4	2.37	10.16	13	6.39	27.41
5	2.88	12.35	14	6.80	29.12
6	3.37	14.43	15	7.19	30.81
7	3.84	16.44	16	7.58	32.47
8	4.29	18.38	17	7.96	34.13
9	4.73	20.27	18	8.35	35.77
10	5.16	22.10	19	8.72	37.39
11	5.58	23.91	20	9.10	38.99

The tables illustrate the space reduction with an MBR.

3. Determine the effluent NH<sub>4</sub>-N concentration in the first compartment of the MBR system.
  - a. Perform a mass balance for NH<sub>4</sub>-N in compartment 1 (refer to sketch).

$$V_1 \frac{dN_1}{dt} = QN_o + RQ(N_E) - (Q + RQ)N_1 = r_{NH4}(V_1)$$

Let N<sub>o</sub> be the NH<sub>4</sub>-N available after N is used for syntesis for biomass growth,

$$N_o = TKN - N_{syn}$$

$$N_o = TKN - \frac{(P_{X, bio})(0.12 \text{ g N/g VSS})}{Q} \quad (8-18a)$$

$P_{X, bio}$  was determined in Problem 8-17 as a function of SRT.

At steady state:

$$QN_o + RQ(N_E) = (Q + RQ)N_1 = r_{NH4}(V_1)$$

$r_{NH4}$  is determined with Eq. (7-101) in Table 8-10.

$$r_{NH4} = \left( \frac{\mu_{max, AOB}}{Y_{AOB}} \right) \left( \frac{N_1}{K_n + N_1} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,1}$$

where,  $N_1 = S_{NH4}$  in compartment 1.

Thus,

$$QN_o + RQ(N_E) = (Q + RQ)N_1$$

$$+ \left( \frac{\mu_{max, AOB}}{Y_{AOB}} \right) \left( \frac{N_1}{K_n + N_1} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,1}(V_1) \quad (8-18b)$$

- b. Provide equation for  $X_{AOB}$ .  $X_{AOB}$  is a function of SRT, amount of growth from  $NH_4$ -N oxidation, and compartment relative MLSS concentration. From Step 1a, the ratio of  $X_{1,AOB} + X_{2,AOB}$  can be determined as proportional to the MLSS ratio.

$$\frac{X_{AOB,1}}{X_{AOB,2}} = \frac{10,286 \text{ mg/L}}{12,000 \text{ mg/L}} = 0.857$$

The mass of  $X_{AOB}$  produced per day is determined from Part C in Eq. (8-20)

$$P_{AOB,VSS} = \frac{Q(Y_{AOB})(NO_x)}{1 + b_{AOB}(SRT)}$$

where,  $NO_x = N_o - N_E$

The mass of AOB in the system equals  $(P_{AOB,VSS})SRT$  as indicated by Eq. (7-56) in Table 8-10.

The AOB mass is divided between compartments 1 and 2, where:

$$X_{AOB,1}(V_1) + X_{AOB,2}(V_2) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,1}(0.75V) + X_{AOB,2}(0.25V) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,2} = \frac{X_{AOB,1}}{0.857}$$

$$X_{AOB,1}(0.75V) + \frac{X_{AOB,1}}{0.857}(0.25V) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,1}(1.042V) = P_{AOB,VSS}(SRT)$$

$$= \frac{Q(Y_{AOB})(N_o - N_E)SRT}{1 + b_{AOB}(SRT)}$$

$$X_{AOB,1} = \frac{Q(Y_{AOB})(N_o - N_E)SRT}{(1.042V)[1 + b_{AOB}(SRT)]} \quad (8-18c)$$

The equation coefficients at 15°C have been determined in Problem 8-17 and are summarized below.

$$\mu_{max,AOB,15^{\circ}C} = 0.90(1.072)^{15-20} = 0.636 \text{ g/g} \cdot \text{d}$$

$$K_{NH_4,15^{\circ}C} = 0.50(1.0)^{15-20} = 0.50 \text{ g NH}_4\text{-N/m}^3$$

$$b_{AOB,15^{\circ}C} = 0.17(1.029)^{15-20} = 0.147 \text{ g/g} \cdot \text{d}$$

$$Y_{AOB} = 0.15 \text{ g VSS/g NH}_4\text{-N oxidized (Table 8-14)}$$

$$K_o = 0.50 \text{ mg/L (Table 8-14)}$$

4. Determine the effluent NH<sub>4</sub>-N concentration for compartment 2 of the MBR system.

- a. Perform a mass balance for NH<sub>4</sub>-N in compartment 2 (refer to sketch).

Note that NH<sub>4</sub>-N concentration is the same as the effluent concentration, N<sub>E</sub>.

$$V_2 \frac{dN_E}{dt} = (Q + RQ)N_1 - (Q + RQ)N_E - r_{NH_4}(V_2)$$

$$r_{NH_4} = \left( \frac{\mu_{max,AOB}}{Y_{AOB}} \right) \left( \frac{N_E}{K_n + N_E} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,2}$$

- b. At steady state:

$$(Q + RQ)N_1 = (Q + RQ)N_E$$

$$+ \left( \frac{\mu_{max,AOB}}{Y_{AOB}} \right) \left( \frac{N_E}{K_n + N_E} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,2}(V_2) \quad (8-18d)$$

From Step 3b,

$$X_{AOB,1}(0.75V) + X_{AOB,2}(0.25V) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,1} = 0.857 X_{AOB,2}$$

$$0.857 X_{AOB,2}(0.75V) + X_{AOB,2}(0.25V) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,2}(0.893V) = P_{AOB,VSS}(SRT)$$

$$X_{AOB,2} = \frac{Q(Y_{AOB})(N_o - N_E)SRT}{0.893V[1 + b_{AOB}(SRT)]} \quad (8-18e)$$

5. Solution approach.

1. Select SRT
2. Determine  $P_{X1,bio}$  (obtain from Problem 8-17)
3. Determine  $N_o$  (Eq. 8-18a in this solution)
4. Assume  $N_E$
5. Determine  $X_{AOB,1}$  (Eq. 8-18c in this solution)
6. Solve for  $N_1$  in Eq. (8-18d) in this solution. Excel solver provides convenient solution
7. Determine  $X_{AOB,2}$  (Eq. 8-18e in this solution)
8. Solve for  $N_E$  in Eq. (8-18d) in this solution
9. Compare  $N_E$  from Step 8 to  $N_E$  in Step 4. Reiterate as necessary until they agree

Example for SRT = 10d

Step 2.  $P_{X1,bio}$  (from Problem 8-17) = 1874 kg VSS/d

Step 3. Determine  $N_o$

$$N_o = TKN - \frac{(P_{X,bio})(0.12 \text{ g N/g VSS})}{Q}$$

$$N_o = (40 \text{ g/m}^3) - \frac{(1874 \text{ kg VSS/d})(0.12 \text{ g N/g VSS})}{(20,000 \text{ m}^3/\text{d})}$$

$$= 28.8 \text{ g/m}^3$$

Step 4. Assume  $N_E = 0.20 \text{ g/m}^3$

Step 5. Determine  $X_{AOB,1}$

$$X_{AOB,1} = \frac{Q(Y_{AOB})(N_o - N_E)SRT}{(1.042V)[1 + b_{AOB}(SRT)]}$$

$$X_{AOB,1} = \frac{(20,000 \text{ m}^3 / \text{d})(0.15 \text{ g VSS / g N})[(28.8 - 0.20) \text{ g / m}^3](10 \text{ d})}{(1.042)(4298 \text{ m}^3)[1 + (0.147 \text{ g / g}\cdot\text{d})(10 \text{ d})]} \\ = 77.6 \text{ g / m}^3$$

Step 6. Solve for  $N_1$

$$V_1 = 0.75V = 0.75(4298 \text{ m}^3) = 3223.5 \text{ m}^3$$

$$QN_o + RQ(N_E) = (Q + RQ)N_1$$

$$+ \left( \frac{\mu_{max,AOB}}{Y_{AOB}} \right) \left( \frac{N_1}{K_n + N_1} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,1}(V_1)$$

$$(20,000 \text{ m}^3 / \text{d})(28.8 \text{ g / m}^3) + 6.0(20,000 \text{ m}^3 / \text{d})(0.20 \text{ g / m}^3)$$

$$= [(20,000 \text{ m}^3 / \text{d}) + 6.0(20,000 \text{ m}^3 / \text{d})]N_1$$

$$+ \left[ \frac{(0.636 \text{ g / g}\cdot\text{d})}{(0.15 \text{ g VSS / g N})} \right] \left[ \frac{N_1}{(0.50 \text{ g / m}^3) + N_1} \right] \left[ \frac{2.0}{0.50 + 2.0} \right] (77.6 \text{ g / m}^3)(3223.5 \text{ m}^3)$$

$$\text{From solver, } N_1 = 1.2 \text{ g/m}^3$$

Step 7. Determine  $X_{AOB,2}$

$$X_{AOB,2} = \frac{Q(Y_{AOB})(N_o - N_E)SRT}{0.893V[1 + b_{AOB}(SRT)]}$$

$$X_{AOB,2} = \frac{(20,000 \text{ m}^3 / \text{d})(0.15 \text{ g VSS / g N})[(28.8 - 0.20) \text{ g / m}^3](10 \text{ d})}{0.893(4298 \text{ m}^3)[1 + (0.147 \text{ g / g}\cdot\text{d})(10 \text{ d})]} \\ = 90.4 \text{ g / m}^3$$

Step 8. Solve for  $N_E$

$$(Q + RQ)N_1 = (Q + RQ)N_E$$

$$+ \left( \frac{\mu_{max,AOB}}{Y_{AOB}} \right) \left( \frac{N_E}{K_n + N_E} \right) \left( \frac{DO}{K_o + DO} \right) X_{AOB,2}(V_2)$$

$$V_2 = 0.25V = 0.25(4298 \text{ m}^3) = 1074.5 \text{ m}^3$$

$$\begin{aligned}
 & [(20,000 \text{ m}^3 / \text{d}) + 6.0(20,000 \text{ m}^3 / \text{d})](1.2 \text{ g/m}^3) \\
 & = [(20,000 \text{ m}^3 / \text{d}) + 6.0(20,000 \text{ m}^3 / \text{d})]N_E \\
 & + \left[ \frac{(0.636 \text{ g/g}\cdot\text{d})}{(0.15 \text{ g VSS/g N})} \right] \left[ \frac{N_E}{(0.50 \text{ g/m}^3) + N_E} \right] \left[ \frac{2.0}{0.50 + 2.0} \right] (90.5 \text{ g/m}^3)(1074.5 \text{ m}^3)
 \end{aligned}$$

From solver,  $N_E = 0.09 \text{ g/m}^3$

Reiteration results in  $N_1 = 0.68 \text{ mg/L}$  and  $N_E = 0.08 \text{ mg/L}$

A summary of the first compartment and effluent  $\text{NH}_4\text{-N}$  concentrations is provided as a function of SRT and compared to the effluent  $\text{NH}_4\text{-N}$  concentration for the single tank CAS system in Problem 8-17.

Effluent  $\text{NH}_4\text{-N}$  concentrations from conventional activated sludge (CAS) process and from first compartment and effluent of MBR process

SRT d	Px, bio kg VSS/d	No mg/L	$X_{AOB,1}$ mg/L	$X_{AOB,2}$ mg/L	MBR		CAS
					$N_1$ mg/L	$N_E$ mg/L	$N_E$ mg/L
3	2591	24.5	94.1	109.8	1.86	0.50	8.62
4	2459	25.2	91.5	106.8	1.43	0.30	1.79
6	2219	26.7	86.8	101.3	1.00	0.16	0.81
8	2027	27.8	82.1	95.8	0.80	0.11	0.58
10	1874	28.8	77.8	90.7	0.68	0.08	0.47
12	1749	29.5	73.7	86.0	0.61	0.07	0.42
14	1644	30.1	70.0	81.7	0.56	0.06	0.38
16	1554	30.7	66.7	77.8	0.52	0.05	0.35
18	1479	31.1	63.5	74.1	0.50	0.05	0.33
20	1412	31.5	60.7	70.8	0.47	0.04	0.32

The two stage reactor provides a much lower effluent  $\text{NH}_4\text{-N}$  concentration at the same SRT.

### PROBLEM 8-19

**Problem Statement** – see text, page 925

**Solution (Wastewater 1)**

**Solution**

1. Determine and summarize wastewater characteristics for **wastewater 1** after primary treatment and compute kinetic coefficients.
  - a. Determine wastewater characteristics; values are summarized below.

Parameter	Unit	Calculation	Value
Flowrate	m <sup>3</sup> /d		20,000
BOD	mg/L	(1 – 0.35) 220 mg/L	143
bCOD	mg/L	1.6 g/g (143 mg/L)	229
TSS	mg/L	(1 – 0.35) 220 mg/L	143
VSS	mg/L	(1 – 0.35) 200 mg/L	130
nbVSS	mg/L	(1 – 0.80) 100 mg/L	20
TKN	mg/L	(1 – 0.10) 40 mg/L	36
Temperature	°C		15

- b. Compute kinetic coefficients for T = 15°C with Eq. (1-44) in Table 8-10
 
$$\mu_{max,H,15^{\circ}C} = 6.0(1.07)^{15-20} = 4.3 \text{ g/g} \cdot \text{d}$$

$$K_s,15^{\circ}C = 8.0(1.0)^{15-20} = 8.0 \text{ g/m}^3$$

$$b_{H,15^{\circ}C} = 0.12(1.04)^{15-20} = 0.10 \text{ g/g} \cdot \text{d}$$

$$\mu_{max,AOB,15^{\circ}C} = 0.90(1.072)^{15-20} = 0.636 \text{ g/g} \cdot \text{d}$$

$$K_{NH,15^{\circ}C} = 0.50(1.0)^{15-20} = 0.50 \text{ g NH}_4\text{-N/m}^3$$

$$b_{AOB,15^{\circ}C} = 0.17(1.029)^{15-20} = 0.147 \text{ g/g} \cdot \text{d}$$

2. Determine the effluent sbCOD and ammonia-N concentration as a function of SRT.
  - a. Determine S as a function SRT using Eq. (7-46) where  $\mu_m = Yk$ , and kinetic coefficients computed in step 1b.

$$Y_H = 0.45 \text{ g VSS/g COD}, f_d = 0.15 \text{ g VSS/g VSS}$$

$$S = \frac{K_S[1 + (b_H)SRT]}{SRT(\mu_m - b_H) - 1}$$

$$S = \frac{(8.0 \text{ g/m}^3)[1 + (0.1 \text{ g/g} \cdot \text{d})SRT]}{SRT[(4.3 - 0.1) \text{ g/g} \cdot \text{d}] - 1}$$

$$S = \frac{8(1+0.1SRT)}{4.2SRT - 1} \text{ g/m}^3$$

At SRT = 3.0 d, S = 0.90 g/m<sup>3</sup>

S as a function of SRT is summarized in table below.

- b. Determine effluent NH<sub>4</sub>-N (N<sub>e</sub>) concentrations as a function of SRT by combining Eq. (7-94) and Eq. (7-98) in Table 10. Let S<sub>o</sub> = DO.

$$\frac{1}{SRT} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_o + DO} \right) - b_{AOB}$$

Solving for S<sub>NH4</sub> (let S<sub>NH4</sub> = N<sub>e</sub>):

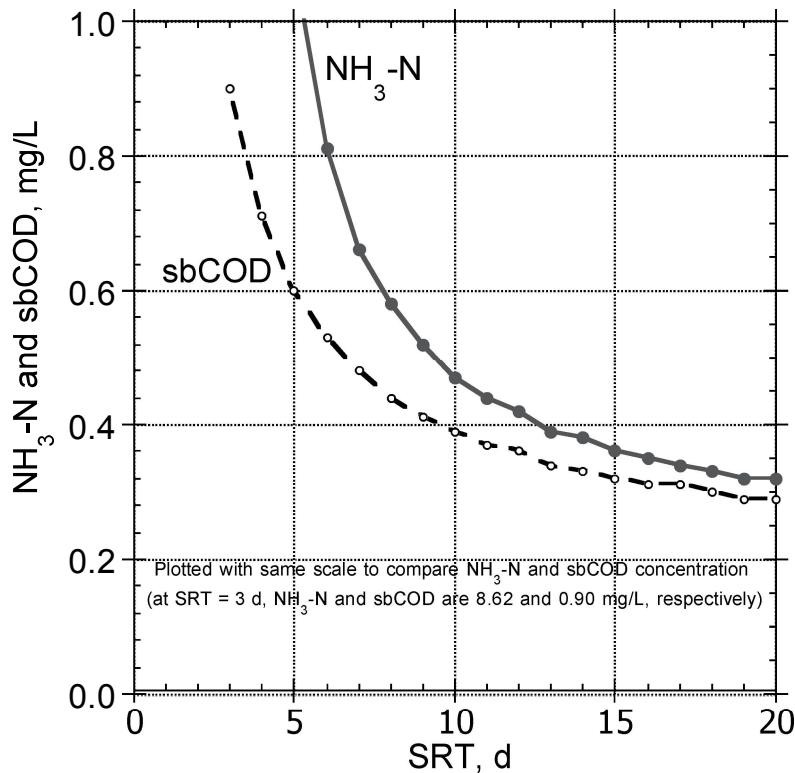
$$N_e = \frac{K_{NH4} (1 + b_{AOB} SRT)}{[\mu_{max,AOB} \left( \frac{DO}{K_o + DO} \right) - b_{AOB}] SRT - 1}$$

$$N_e = \frac{0.50 \text{ g/m}^3 [1 + (0.147 \text{ g/g-d}) SRT]}{SRT \left\{ 0.636 \text{ g/g-d} \left[ \frac{(2.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3 + 2.0 \text{ g/m}^3)} \right] - 0.147 \text{ g/g-d} \right\} - 1}$$

At SRT = 3.0 days, N<sub>e</sub> = 8.62 g/m<sup>3</sup>

Table showing Effluent NH<sub>4</sub>-N (N<sub>e</sub>) and effluent sbCOD (S) concentration as a function of SRT:

SRT d	Effl. sbCOD mg/L	Effl. NH <sub>4</sub> -N mg/L	SRT d	Effl. sbCOD mg/L	Effl. NH <sub>4</sub> -N mg/L
3	0.90	8.62	12	0.36	0.42
4	0.71	1.79	13	0.34	0.39
5	0.60	1.08	14	0.33	0.38
6	0.53	0.81	15	0.32	0.36
7	0.48	0.66	16	0.31	0.35
8	0.44	0.58	17	0.31	0.34
9	0.41	0.52	18	0.75	0.24
10	0.39	0.47	19	0.73	0.23
11	0.37	0.44	20	0.72	0.22

Figure 1. Effluent  $\text{NH}_3\text{-N}$  and sbCOD concentration vs SRT

3. Determine solids wasted as kg TSS/d as a function of SRT. At steady state solids wasted is equal to the solids production rate, which can be calculated using Eq. (8-20) and Eq. (8-21) in Table 8-10.

$$P_{X,TSS} = \frac{A}{0.85} + \frac{B}{0.85} + \frac{C}{0.85} + D + E$$

where  $E = Q(TSS_0 - VSS_0)$

- a. Calculate the terms in Eq. 8-21; For first calculation assume  $NO_X \approx 80\%$  of influent TKN

- i. Active biomass:

$$A = \frac{QY_H(S_0 - S)(1 \text{ kg} / 10^3 \text{ g})}{[1 + b_H(\text{SRT})]0.85}$$

$$= \frac{(20,000 \text{ m}^3/\text{d})(0.45 \text{ g VSS/g COD})(229 - S)(\text{g sbCOD/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.10 \text{ g/g} \cdot \text{d})\text{SRT}]0.85}$$

At SRT = 3.0 d, S = 0.90 mg/L, A = 1862 kg TSS/d

ii. Cell debris:

$$\begin{aligned} B &= \frac{(f_d)(b_H)(Q)(Y_H)(S - S_0)\text{SRT}(1 \text{ kg}/10^3 \text{ g})}{[1 + b_H(\text{SRT})]0.85} \\ &= \frac{(0.15 \text{ g/g})(0.10 \text{ g/g} \cdot \text{d})(20,000 \text{ m}^3/\text{d})(0.45 \text{ g VSS/g COD})(229 - S)(\text{g sbCOD/m}^3)\text{SRT}(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.10 \text{ g/g} \cdot \text{d})(\text{SRT})]0.85} \end{aligned}$$

At SRT = 3.0 d, S = 0.90 mg/L, B = 83 kg TSS/d

iii. Nitrifying bacteria:

$$C = \frac{QY_n(\text{NO}_x)(1 \text{ kg}/10^3 \text{ g})}{[1 + b_{AOB}(\text{SRT})]0.85}$$

Note  $Y_n = 0.20 \text{ g VSS/g NO}_x\text{-N}$  to account for growth of both AOB and NOB.

For first calculation assume  $\text{NO}_x\text{-N} = 0.80$  (Influent TKN)

$$= \frac{(20,000 \text{ m}^3/\text{d})(0.20 \text{ g VSS/g NO}_x\text{-N})(0.8)(36 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.147 \text{ g/g} \cdot \text{d})(\text{SRT})]0.85}$$

At SRT = 3.0 d, C = 94 kg TSS/d

iv. Nonbiodegradable VSS (VSS = TSS)

$$D = Q(nbVSS)(1 \text{ kg}/10^3 \text{ g})$$

$$D = (20,000 \text{ m}^3/\text{d})(20 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g}) = 400 \text{ kg VSS/d}$$

v. Inert inorganic TSS

$$E = (20,000 \text{ m}^3/\text{d})[(143 - 130) \text{ g/m}^3](1 \text{ kg}/10^3 \text{ d}) = 260 \text{ kg TSS/d}$$

- b. Iterate for  $\text{NO}_x\text{-N}$  value by calculating  $\text{NO}_x\text{-N}$  from  $P_{X,\text{bio}}$ , using Eq. (8-24), Table 8-10 and replacing the initial assume value.

$$\text{NO}_x\text{-N} = \text{TKN} - 0.12(P_{X,\text{bio}}) - N_e$$

where  $P_{X,\text{bio}} = \text{VSS}/d$  of active heterotrophs, debris, and nitrifiers

Solve for  $\text{NO}_x\text{-N}$  and change value inserted in Eq. C above to iterate

Insert A, B, C, D, and E into Eq. (8-21) to solve  $P_{X,\text{TSS}}$  as a function of SRT. Using a spreadsheet program, the values of  $P_{X,\text{TSS}}$  and  $P_{X,\text{bio},\text{VSS}}$  for SRTs ranging from 3 to 20 d are shown in the following table.

SRT, d	As kg TSS/d, except $P_{X,\text{bio}}$ which is kg VSS/d						$\text{NO}_x\text{-N}$ mg/L
	A	B	C	D	E	$P_{X,\text{TSS}}$	
3	1862	83	55	400	260	2660	1700
4	1732	102	71	400	260	2565	1620
5	1618	120	70	400	260	2468	1537
6	1518	135	65	400	260	2378	1460
7	1430	148	63	400	260	2301	1395
8	1352	160	58	400	260	2230	1334
9	1281	171	57	400	260	2168	1282
10	1218	180	53	400	260	2111	1233
11	1160	189	50	400	260	2059	1189
12	1108	197	49	400	260	2014	1151
13	1060	204	47	400	260	1971	1114
14	1016	210	45	400	260	1931	1080
15	976	217	43	400	260	1895	1050
16	938	222	42	400	260	1863	1022
17	904	227	40	400	260	1831	996
18	872	232	39	400	260	1803	971
19	842	237	36	400	260	1774	947
20	814	241	36	400	260	1751	927

- c. Determine tank volume  $V(\text{m}^3)$  and  $\tau$  (h) as a function of SRT using Eq. (7-57) in Table 8-10.

$$(X_{\text{TSS}})(V) = (P_{X,\text{TSS}})\text{SRT}$$

$$V = \frac{(P_{X,TSS})SRT}{X_{TSS}}$$

$$V = \frac{(P_{X,TSS}, \text{kg/d})(SRT, \text{d})}{(2500 \text{g/m}^3)(1 \text{kg}/10^3 \text{g})} = \frac{P_{X,TSS}(SRT)}{2.5} \text{m}^3$$

$$\tau = \frac{V}{Q}$$

$$\tau = \frac{[(P_{X,TSS})(SRT)](\text{m}^3)(24 \text{ h/d})}{2.5(20,000 \text{m}^3/\text{d})} = 4.8 \times 10^{-4} [(P_{X,TSS})(SRT)] \text{ h}$$

Using a spreadsheet program, compute the values of V and  $\tau$  for SRTs ranging from 3 to 20 d as shown in the following table and plot below:

SRT d	Volume $\text{m}^3$	HRT h	SRT d	Volume $\text{m}^3$	HRT h
3	3192	3.8	12	9666	11.6
4	4105	4.9	13	10,247	12.3
5	4937	5.9	14	10,814	13.0
6	5708	6.8	15	11,368	13.6
7	6442	7.7	16	11,920	14.3
8	7135	8.6	17	12,454	14.9
9	7806	9.4	18	12,978	15.6
10	8444	10.1	19	13,484	16.2
11	9060	10.9	20	14,004	16.8

Figure 2. Plot of Volume and hydraulic retention time (HRT) versus SRT.

- d. Determine observed yield as g TSS/g BOD and g TSS/g bCOD

$Y_{obs}$  based on g TSS/g BOD

Observed yield =  $P_{X,TSS}/\text{g BOD removed}$

$P_{X,TSS}$  was determined in Step 3a above.

BOD removed =  $Q(S_0 - S)$ , S is determined above as function of SRT

$$Y_{\text{obs, TSS/BOD}} = \frac{(P_{X,TSS} \cdot g \text{ TSS/d})}{(20,000 \text{ m}^3/\text{d})(143-S)g \text{ BOD / m}^3}$$

$$Y_{\text{obs, TSS/COD}} = (Y_{\text{obs, TSS/BOD}}) \left( \frac{\text{BOD}}{1.6\text{BOD}} \right)$$

$$Y_{\text{obs, TSS/COD}} = \frac{(Y_{\text{obs, TSS/BOD}})}{1.6}$$

Using a spreadsheet program, compute the values of  $Y_{\text{obs}}$  for SRTs ranging from 3 to 20 d as shown in the following table and plot.

SRT d	$Y_{\text{obs}}$ gTSS/gBOD	$Y_{\text{obs}}$ gTSS/gCOD	SRT d	$Y_{\text{obs}}$ gTSS/gBOD	$Y_{\text{obs}}$ gTSS/gCOD
3	0.93	0.58	12	0.70	0.44
4	0.90	0.56	13	0.69	0.43
5	0.86	0.54	14	0.68	0.42
6	0.83	0.52	15	0.66	0.41
7	0.80	0.50	16	0.65	0.41
8	0.78	0.49	17	0.64	0.40
9	0.76	0.47	18	0.63	0.39
10	0.74	0.46	19	0.62	0.39
11	0.72	0.45	20	0.61	0.38

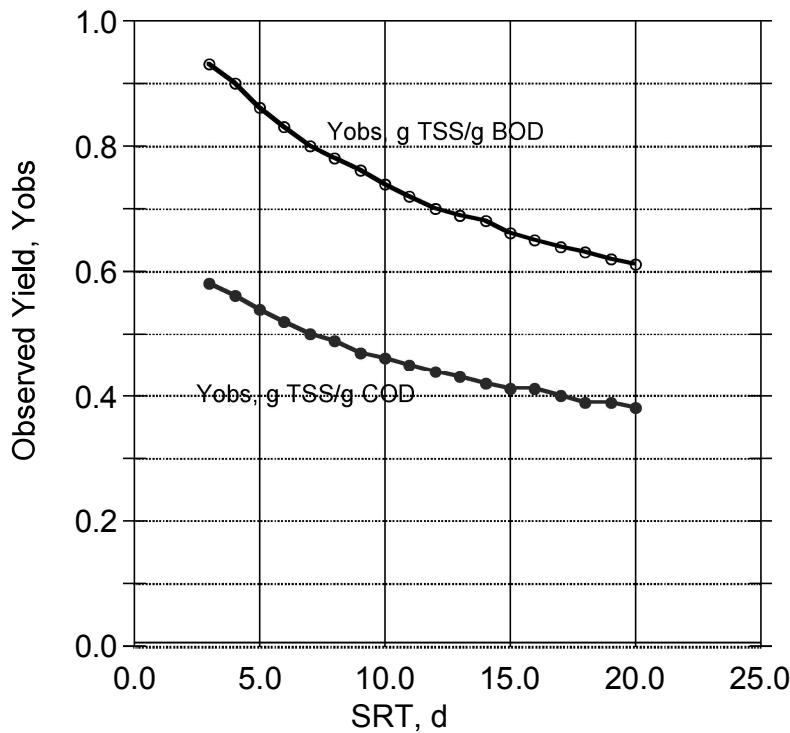


Figure 3. Observed yield vs SRT

- e. Determine oxygen requirement in kg/d as a function of SRT

- i. Calculate NO<sub>x</sub> using Eq. (8-24)

$$\text{NO}_x = \text{TKN} - N_e - 0.12 P_{X,\text{bio}}/Q$$

P<sub>X,bio</sub> is calculated as shown above from A, B, and C

Using a spreadsheet program, compute the values of NO<sub>x</sub> for SRTs ranging from 3 to 20 d as shown in the table following item ii. below.

- ii. Calculate O<sub>2</sub> demand rate using Eq. (8-23).

$$R_o = Q(S_o - S) - 1.42P_{X,\text{bio}} + 4.57Q(\text{NO}_x - N)$$

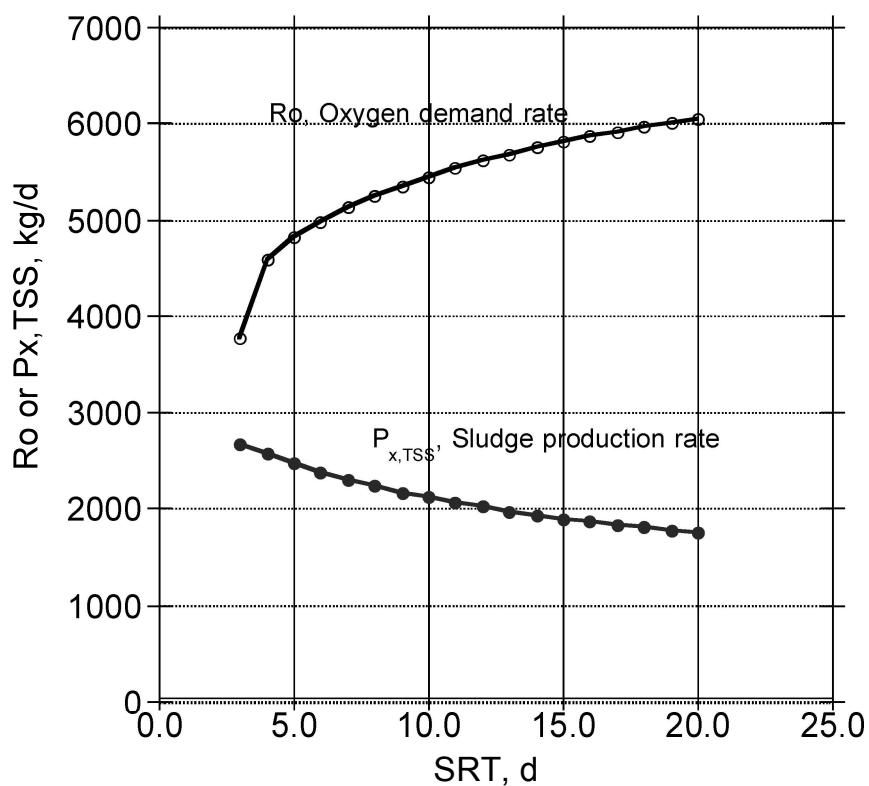
- f. Using a spreadsheet program, compute the values of R<sub>o</sub> for SRTs

ranging from 3 to 20 d as shown in the following table and plot.

The plot also includes the sludge production rate (kg TSS/d)

SRT	NO <sub>x</sub> -N	R <sub>o</sub>	SRT	NO <sub>x</sub> -N	R <sub>o</sub>
-----	--------------------	----------------	-----	--------------------	----------------

d	mg/L	kg/d	d	mg/L	kg/d
3	17	3781	12	29	5616
4	24	4587	13	29	5687
5	26	4815	14	29	5752
6	26	4986	15	29	5812
7	27	5126	16	30	5867
8	27	5249	17	30	5918
9	28	5356	18	30	5965
10	28	5452	19	30	6010
11	28	5538	20	30	6050



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**PROBLEM 8-20****Problem Statement** – see text, page 925**Solution (for effluent  $\text{NH}_4\text{-N} = 1.0 \text{ mg/L}$ )**

1. Summary of operating conditions given for nitrification.

DO = 2.0 mg/L

Temperature = 10°C

Design safety factor = Peak/average TKN = 1.8

2. Establish basis for selecting SRT.

- a. The ammonia-oxidizing bacteria (AOB) specific growth rate is related to the SRT in a complete-mix activated sludge process as shown by Eq. (7-98) in Table 8-10.

$$SRT = \frac{1}{\mu_{AOB}}$$

- b. The AOB specific growth rate is related to the ammonia-N and DO concentrations and kinetic coefficients as given by Eq. (7-94) in Table 8-10

$$\mu_{AOB} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

Thus, the required SRT is related to the above factors by substitution for  $\mu_{AOB}$

$$\frac{1}{SRT} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_o + DO} \right) - b_{AOB}$$

The design SRT is based on the selected safety factor (SF) value, and the SRT determined at the average design condition using Eq. (7-73) in Table 8-10.

Design SRT = SF (SRT)

3. Determine the kinetic coefficients. The coefficients for Eq. (7-94, 7-95) are obtained from Table 8-14. Use the temperature correction Eq. (1-44) shown in Table 8-10.

$$k_T = k_{20}(\theta)^{T-20}$$

Temperature = 10°C

$$\mu_{max,AOB} = 0.90 (1.072)^{10-20} = 0.449 \text{ g/g} \cdot \text{d}$$

$$K_{NH_4} = 0.50 (1.0)^{10-20} = 0.50 \text{ g/m}^3$$

$$Y_n = 0.15 \text{ g VSS/g N oxidized}$$

$$b_{AOB} = 0.17(1.029)^{10-20} = 0.128 \text{ g/g} \cdot \text{d}$$

$$K_o = 0.50 \text{ g/m}^3$$

4. Determine the design SRT.

- a. Calculate  $\mu_{AOB}$  for an effluent NH<sub>4</sub>-N concentration of 0.50 mg/L and a DO concentration = 2.0 mg/L.

$$\mu_{AOB} = \left\{ \frac{(0.449 \text{ g/g} \cdot \text{d})(1.0 \text{ g/m}^3)}{[(0.50 + 1.0) \text{ g/m}^3]} \right\} \left\{ \frac{(2.0 \text{ g/m}^3)}{[(0.50 + 2.0) \text{ g/m}^3]} \right\} - 0.128 \text{ g/g} \cdot \text{d}$$

$$\mu_{AOB} = 0.111 \text{ g/g} \cdot \text{d}$$

b. Calculate the SRT.

$$SRT = \frac{1}{(0.111 \text{ g/g} \cdot \text{d})} = 9.0 \text{ d}$$

c. Determine the design SRT.

$$\text{Design SRT} = 1.8 (9.0 \text{ d}) = 16.2 \text{ d}$$

## PROBLEM 8-21

**Problem Statement** – see text, page 926

**Solution**

1. Determine the SRT using Eqs. (8-20), (8-21), and (7-57) in Table 8-10.

a. Determine the total mass of solids for  $\tau = 8.3 \text{ h}$

$$P_{X,TSS} = \frac{QY_H(S_o - S)}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85} \\ + \frac{QY_n(NO_x)}{[1 + b_n(SRT)]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

Substituting  $P_{X,TSS}$  in Eq. (7-57).

$$(X_{TSS})(V) = \frac{QY_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)(SRT)^2}{[1 + b_H(SRT)]0.85} \\ + \frac{QY_n(NO_x)SRT}{[1 + b_n(SRT)]0.85} + Q(nbVSS)SRT + Q(TSS_o - VSS_o)SRT$$

- b. Obtain input values for equation and solve for SRT

$$\tau = \frac{V}{Q} = \frac{8.3 \text{ h}}{(24 \text{ h/d})} = 0.346 \text{ d}$$

$$V = 0.346 \text{ d} (15,000 \text{ m}^3/\text{d}) = 5187.5 \text{ m}^3$$

$S_o - S$  is given as 130 mg/L BOD removed

Convert to BOD to bCOD using Eq. (8-13)

$$S_o - S = 1.6 (130 \text{ mg/L}) = 208 \text{ mg/L}$$

$$\text{Assume } NO_x \sim 0.80 \text{ (TKN)} = 0.80 (40) = 32 \text{ mg/L}$$

(Note: Due to low yield of nitrifiers, the error with this assumption has only a small and insignificant effect on the SRT determination. An iterative process may also be used in which  $NO_x$  is calculated after the SRT is determined.)

- c. Determine coefficients from Table 8-14 and adjust for temperature using Eq. (1-44) and the table  $\mu$  values

$$k_T = k_{20}(\theta)^{T-20}$$

For heterotrophs:

$$Y = 0.45 \text{ gVSS/g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12(1.04)^{10-20} = 0.081 \text{ g/g}\cdot\text{d}$$

For nitrification:

$$\mu_{max,AOB} = (0.90 \text{ g/g}\cdot\text{d}) (1.072)^{10-20} = 0.449 \text{ g/g}\cdot\text{d}$$

$$k_{NH_4} = (0.50 \text{ mg/L}) (1.0)^{10-20} = 0.50 \text{ g/m}^3$$

$$b_{AOB} = (0.17 \text{ g/g}\cdot\text{d}) (1.029)^{10-20} = 0.128 \text{ g/g}\cdot\text{d}$$

$$Y_n = 0.15 \text{ g VSS / g NH}_4\text{-N}$$

$$K_o = 0.50 \text{ g/m}^3$$

- d. Summarize other design parameters to be used

$$X_{TSS} = 3000 \text{ g/m}^3$$

$$nbVSS = 30 \text{ g/m}^3$$

$$TSS_o - VSS_o = (70 - 60) \text{ g/m}^3 = 10 \text{ g/m}^3$$

$$Q = 15,000 \text{ m}^3/\text{d}$$

- e. Substitute the above values and other given information into the equation developed in 1a.

$$(3000 \text{ g/m}^3)(5187.5 \text{ m}^3) = \frac{(0.45 \text{ g/g})(15,000 \text{ m}^3/\text{d})(208 \text{ g/m}^3)(SRT)}{[1 + (0.081 \text{ g/g}\cdot\text{d})SRT]0.85}$$

$$+ \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(15,000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(208 \text{ g/m}^3)(SRT)^2}{[1 + (0.081 \text{ g/g}\cdot\text{d})SRT]0.85}$$

$$+ \frac{(0.15 \text{ g/g})(15,000 \text{ m}^3/\text{d})(32 \text{ g/m}^3)(SRT)}{[1 + (0.128 \text{ g/g}\cdot\text{d})SRT]0.85} + (15,000 \text{ m}^3/\text{d})(30 \text{ g/m}^3)(SRT)$$

$$+ (15,000 \text{ m}^3/\text{d})(30 \text{ g/m}^3)(SRT) + (15,000 \text{ m}^3/\text{d})(10 \text{ g/m}^3)(SRT)$$

$$15,562,500 =$$

$$\frac{1,651,765(SRT)}{1 + .081SRT} + \frac{20,069(SRT)^2}{1 + 0.081SRT} + \frac{84705(SRT)}{1 + 0.128SRT} + 450,000 SRT + 150,000 SRT$$

- f. Solve for SRT using spreadsheet – vary SRT until equation is solved or use Excel solver function:

$$SRT = 9.2 \text{ d}$$

The SRT for nitrification by ammonia-oxidizing bacteria (AOB) for a complete-mix process is related to the specific growth rate of the nitrifying bacteria by Eq. (7-98) in Table 8-10.

$$SRT = \frac{1}{\mu_{AOB}}$$

$$\mu_{AOB} = \frac{1}{SRT} = \frac{1}{9.2 \text{ d}} = 0.109 \text{ g/g} \cdot \text{d}$$

- g. Solve for effluent NH<sub>4</sub>-N concentration. The value for  $\mu_{AOB}$  is related to the kinetic coefficients, temperature, and DO and NH<sub>4</sub>-N concentration as shown by Eq. (7-94) in Table 8-10. The DO is given as 2.0 mg/L.

$$\mu_{AOB} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

and thus:

$$\frac{1}{SRT} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

This is rearranged to solve for effluent NH<sub>4</sub>-N concentration:

$$S_{NH4} = \frac{K_{NH4}(1+b_{AOB}SRT)}{[\mu_{max,AOB}\left(\frac{DO}{K_o+DO}\right)-b_{AOB}]SRT-1}$$

$$S_{NH4} = \frac{(0.50 \text{ g/m}^3)[1+(0.128 \text{ g/g} \cdot \text{d})(9.2 \text{ d})]}{\left\{ (0.449 \text{ g/g} \cdot \text{d}) \left[ \frac{2.0}{(0.5+2.0)} \right] - (0.128 \text{ g/g} \cdot \text{d}) \right\} (9.2) - 1}$$

$$S_{NH4} = 0.97 \text{ mg/L}$$

- h. Determine the SRT needed to obtain an effluent NH<sub>4</sub>-N concentration of 1.0 mg/L and safety factor.

$$\frac{1}{SRT} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

$$\frac{1}{SRT} = \left[ \frac{(0.449 \text{ g/g}\cdot\text{d})(1.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3) + (1.0 \text{ g/m}^3)} \right] \left[ \frac{(2.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3) + (2.0 \text{ g/m}^3)} \right] - 0.128 \text{ g/g}\cdot\text{d}$$

$$\frac{1}{SRT} = 0.1115$$

$$SRT = 9.0$$

Safety factor = 9.2/9.0 = 1.02, (not significant)

### PROBLEM 8-22

**Problem Statement** – see text, page 926

**Solution (wastewater 1)**

- Determine the volume using Eqs. (7-57), (8-20), and (8-21) in Table 8-10.

$$(X_{TSS})V = P_{X,TSS} (SRT)$$

$$P_{X,TSS} = \frac{QY(S_o - S)}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY(S_o - S)SRT}{[1 + b_H(SRT)]0.85}$$

$$+ \frac{QY_n(NO_x)}{[1 + b_n(SRT)]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

- Determine the value for S using Eq. (7-46) in Table 8-10 and **an SRT = 8 d**

$$S = \frac{K_s [1 + b_H(SRT)]}{SRT(Y_H k - b_H) - 1}$$

From Eq. (7-16), Table 8-10,  $\mu_{max} = Yk$

Substituting  $\mu_{max}$  and values from problem statement:

$$S = \frac{(60 \text{ g/m}^3)[1 + (0.08 \text{ g/g}\cdot\text{d})(8 \text{ d})]}{(8 \text{ d})[(3.0 \text{ g/g}\cdot\text{d}) - (0.08 \text{ g/g}\cdot\text{d})] - 1}$$

$$S = 4.4 \text{ g/m}^3 \text{ bCOD}$$

- Solve for V. (Note:  $NO_x$  is insignificant per problem statement,  $NO_x = 0$ )

The information given shows that it is a soluble wastewater, so nbVSS and  $(TSS_0 - VSS_0) = 0$ .

$$V = \frac{(3000\text{ m}^3 / \text{d})(0.40\text{ g/g})[(1800 - 4.4)\text{ g/m}^3](8.0\text{ d})}{[1 + (0.08\text{ g/g} \cdot \text{d})(8.0\text{ d})](0.85)(2500\text{ g/m}^3)}$$

$$+ \frac{(0.15\text{ g/g})(0.08\text{ g/g} \cdot \text{d})(0.40\text{ g/g})(3000\text{ m}^3 / \text{d})[(1800 - 4.4)\text{ g/m}^3](8.0\text{ d})^2}{[1 + (0.08\text{ g/g} \cdot \text{d})(8.0\text{ d})](0.85)(2500\text{ g/m}^3)}$$

$$V = 4,946.3\text{ m}^3 + 474.8\text{ m}^3 = 5421.1\text{ m}^3$$

$$\tau = \frac{V}{Q} = \frac{5421.1\text{ m}^3}{(3000\text{ m}^3 / \text{d})} = 1.81\text{ d} = 43.4\text{ h}$$

4. Calculate the oxygen required using Eq. (8-23) in Table 8-10.

$$R_o = Q(S_o - S) - 1.42 P_{X,\text{bio}}$$

Because nbVSS and  $(TSS_0 - VSS_0) = 0$ , the solids are produced from only the biomass [components A and B in Eq. (8-20)]. Thus, the biomass production rate is equal to

$$P_{X,\text{bio}} = P_{X,VSS} = 0.85 P_{X,TSS}$$

$$\text{From Eq. (7-57): } P_{X,TSS} = \frac{(X_{TSS})V}{SRT}$$

Thus:

$$P_{X,\text{bio}} = \frac{0.85(X_{TSS})V}{SRT} = \frac{0.85(2500\text{ g/m}^3)(5421.1\text{ m}^3)}{8.0\text{ d}}$$

$$P_{X,\text{bio}} = 1,439,980\text{ g/d}$$

$$R_o = (3000\text{ m}^3/\text{d})[(1800 - 4.4)\text{ g/m}^3] - [(1.42)(1,439,980\text{ g/d})](1\text{ kg}/10^3\text{ g})$$

$$R_o = 3,342\text{ kg/d}$$

5. Determine the sludge production using Eq. (7-57)

$$P_{X,TSS} = \frac{(2500\text{ g/m}^3)(5421.1\text{ m}^3)(1\text{ kg}/10^3\text{ g})}{8.0\text{ d}} = 1694\text{ kg/d}$$

6. Calculate the soluble BOD concentration in the effluent from the problem statement of bCOD/BOD = 1.6.

$$sBOD = \frac{(4.4\text{ mg/L})}{1.6} = 2.8\text{ mg/L}$$

7. Determine the secondary clarifier diameter.
- Select secondary clarifier overflow rate and solids loading from Table 8-34. Use the midpoint for the air-activated sludge process. (Note: no peak loadings are given)

$$\text{Overflow rate} = Q/A = 22 \text{ m}^3/\text{m}^2 \cdot \text{d}$$

$$\text{Solids loading} = \text{SLR} = 5.0 \text{ kg/m}^2 \cdot \text{h}$$

From Eq. (8-81), page 891

$$\text{SLR} = \frac{(Q + Q_R) \text{MLSS}}{A}$$

- Calculate area per clarifier based on overflow rate assuming 2 clarifiers are used.

$$A = \frac{(3000 \text{ m}^3 / \text{d})}{(22 \text{ m}^3 / \text{m}^2 \cdot \text{d})} = 136.4 \text{ m}^2$$

$$\text{Area/clarifier} = \frac{136.4 \text{ m}^2}{2} = 68.2 \text{ m}^2$$

- Calculate clarifier diameter

$$A = \frac{\pi D^2}{4} = 68.2 \text{ m}^2$$

$$D = 9.3, \text{ use } D = 9 \text{ m}$$

8. Check solids loading. (Assume recycle ratio =  $Q/Q_R = 0.50$ )

$$\text{SLR} = \frac{(Q + Q_R)X}{A} = \frac{(Q + 0.5Q)X}{A} = 1.5 \frac{Q}{A} X$$

$$\begin{aligned} \text{SLR} &= (1.5)(22 \text{ m}^3/\text{m}^2 \cdot \text{d})(2500 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})(1 \text{ d}/24 \text{ h}) \\ &= 3.4 \text{ kg/m}^2 \cdot \text{h} \end{aligned}$$

Solids loading rate is  $< 5.0 \text{ kg/m}^2 \cdot \text{h}$  and thus is acceptable.

9. Calculate the air flowrate

- The following information is provided to calculate the airflow rate for fine bubble aeration.

$$R_o = 3342 \text{ kg/d} = 139.3 \text{ kg/h} \text{ (step 4)}$$

$$\alpha = 0.45$$

$$F = 0.90$$

$$\beta = 1.0$$

Temperature = 15°C

Effective DO saturation depth = 2.5 m

Elevation = 300 m

Clean water O<sub>2</sub> transfer efficiency = 30%

Assume mixed liquor DO concentration = 2.0 mg/L

- b. Convert the oxygen transfer rate to that required at clean water standard conditions using Eq. (5-70) as shown in Example 8-3.

$$SOTR = \frac{(AOTR)C_{\infty,20}^*}{\left[ (\beta) \left( \frac{P_b}{P_s} \right) \left( \frac{C_{S,T}^*}{C_{\infty,20}^*} \right) C_{\infty,20}^* - C \right] \alpha F (1.024)^{(T-20)}}$$

- a. Determine effect of temperature and elevation on saturated DO concentration.
  - i. From Table E-1 (Appendix E),  $C_{\infty,20}^* = 9.09$  mg/L and  $C_{15} = 10.08$  mg/L.
  - ii. Determine the relative pressure at elevation 300 m to correct the DO concentration for altitude

$$\begin{aligned} \frac{P_b}{P_s} &= \exp \left[ -\frac{gM(z_b - z_a)}{RT} \right] \\ &= \exp \left\{ -\frac{(9.81 \text{ m/s}^2)(28.97 \text{ kg/kg-mole})[(300 - 0) \text{ m}]}{(8314 \text{ kg} \cdot \text{m}^2/\text{s}^2 \cdot \text{kg-mole} \cdot \text{K})[(273.15 + 15) \text{ K}]} \right\} \\ &= 0.965 \end{aligned}$$

$P_s$  = standard pressure at sea level, (760 mm)(10.33m)

- b. Determine the effective saturated DO concentration at 20°C. The problem provides an effective saturation depth of 2.5 m.

The effective DO saturation at 20°C is thus:

$$C_{\infty,20}^* = \frac{9.09(10.33 + 2.5)\text{m}}{10.33\text{m}} = 9.09(1.24)\text{m}$$

$$C_{\infty,20}^* = 11.27 \text{ mg/L}$$

- c. Determine the effect of temperature

$$\frac{C_{s,T}^*}{C_{\infty,20}^*} = \frac{10.08}{9.09} = 1.109$$

d. Determine the SOTR

$$SOTR = \frac{(AOTR)(11.27 \text{ mg/L})}{\{(1.0)(0.965)(1.109)(11.27) - 2.0\} \text{ mg/L} \cdot (0.45)(0.90)(1.024)^{(15-20)}}$$

$$SOTR = 3.11(AOTR)$$

$$SOTR = 3.11(139.3 \text{ kg/h}) = 433.2 \text{ kg/h}$$

e. Determine the air flow rate

$$\text{Air flowrate, m}^3/\text{min} = \frac{(SOTR \text{ kg/h})}{[(E)(60 \text{ min/h})(\text{kg O}_2/\text{m}^3 \text{ air})]}$$

From Appendix B, the density of air at 15°C and standard pressure is:

$$\rho_a = \frac{P_m}{RT} = \frac{(1.01325 \times 10^5 \text{ N/m}^2)(28.97 \text{ g/mole air})}{(8314 \text{ N}\cdot\text{m/mole air}\cdot\text{K})[(273.15 + 15)\text{K}]}$$

$$\rho_a = 1.225 \text{ kg/m}^3$$

At 300 m elevation,

$$\rho_a = 0.965(1.225 \text{ kg/m}^3) = 1.182 \text{ kg/m}^3$$

The corresponding amount of oxygen at 23.18 percent by weight

(Appendix B-2) is

$$(0.2318 \text{ kg/kg})(1.182 \text{ kg/m}^3) = 0.274 \text{ kg O}_2/\text{m}^3 \text{ air}$$

$$\text{Air flowrate} = \frac{(433.2 \text{ kg/h})}{(0.30)(60 \text{ min/h})(0.274 \text{ kg O}_2/\text{m}^3 \text{ air})}$$

$$\text{Air flowrate} = 87.8 \text{ m}^3/\text{min}$$

### PROBLEM 8-23

**Problem Statement** – see text, page 926

**Solution (Wastewater 1)**

- Determine the volume is using Eqs. (8-20), (8-21), and (7-57) in Table 8-10.

$$(X_{TSS})V = P_{X,TSS} (SRT)$$

$$P_{X,TSS} = \frac{QY_H(S_o - S)}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85}$$

$$+ \frac{QY_n(NO_x)}{[1 + b_n(SRT)]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

Combine equations

$$(X_{TSS})\left(\frac{V}{Q}\right) = \frac{Y_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)Y_H(S_o - S)SRT^2}{[1 + b_H(SRT)]0.85}$$

$$+ \frac{Y_n(NO_x)SRT}{[1 + b_n(SRT)]0.85} + (nbVSS)SRT + (TSS_o - VSS_o)SRT$$

2. Define input for above equation **for wastewater 1**

Influent bCOD = 1.6 (BOD) = 1.6 (270 mg/L) = 432 mg/L

Assume  $S_o - S \approx S_o = 432$  mg/L

Assume  $NO_x \sim 0.80$  (TKN) = 0.80(40 mg/L) = 32 mg/L

$V/Q = 1$  d

$X_{TSS} = 3500$  mg/L

3. Determine coefficients from Table 8-14 and adjust for temperature using Eq. (1-44) in Table 8-10.

$$k_T = k_{20}(\theta)^{T-20}$$

$$Y_H = 0.45 \text{ gVSS/g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12(1.04)^{10-20} = 0.081 \text{ g/g}\cdot\text{d}$$

$$b_n = (0.17 \text{ g/g}\cdot\text{d})(1.029)^{10-20} = 0.128 \text{ g/g}\cdot\text{d}$$

$Y_n = 0.20 \text{ g VSS/g NH}_4\text{-N}$  (includes growth from ammonia and nitrite oxidation).

4. Substitute values in the step 1 equation

$$(3500 \text{ g/m}^3)(1 \text{ d}) = \frac{0.45 \text{ g/g}(432 \text{ g/m}^3)(SRT)}{[1 + (0.081 \text{ g/g}\cdot\text{d})SRT]0.85} + \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(0.45 \text{ g/g})(432 \text{ g/m}^3)(SRT)^2}{[1 + (0.081 \text{ g/g}\cdot\text{d})SRT]0.85}$$

$$+ \frac{0.20 \text{ g/g}(32 \text{ g/m}^3)(\text{SRT})}{[1 + (0.128 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} + 130 \text{ g/m}^3(\text{SRT}) + (250 - 240)\text{g/m}^3(\text{SRT})$$

5. Solve equation with a spreadsheet by selecting SRT value where left and right sides of equation are equal.

$$3500 = \frac{260.47 (\text{SRT})}{1 + 0.081 \text{ SRT}} + \frac{3.16 (\text{SRT})^2}{1 + 0.081 \text{ SRT}} + \frac{7.53 (\text{SRT})}{1 + 0.128 \text{ SRT}} + 130 \text{ SRT} + 10 \text{ SRT}$$

$$\text{SRT} = 11.9 \text{ d}$$

6. Determine the sludge production rate using Eq. (7-57)

$$P_{X,\text{TSS}} = \frac{(X_{\text{TSS}})(V)}{\text{SRT}} = \frac{(3500 \text{ g/m}^3)(4000 \text{ m}^3)(1 \text{ kg}/10^3 \text{ g})}{11.9 \text{ d}}$$

$$P_{X,\text{TSS}} = 1176.5 \text{ kg/d}$$

7. Calculate MLVSS using Eq. (8-20) to determine  $P_{X,\text{VSS}}$  and  $P_{X,\text{VSS}} / P_{X,\text{TSS}}$  ratio.

$$\text{MLVSS} / \text{MLSS} = (P_{X,\text{VSS}}) / (P_{X,\text{TSS}})$$

$$P_{X,\text{VSS}} = \frac{Q(Y_H)(S_o - S)(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})} + \frac{f_d(b_H)QY_H(S_o - S)\text{SRT}(1 \text{ kg}/10^3 \text{ g})}{1 + b_H(\text{SRT})}$$

$$+ \frac{QY_n(\text{NO}_x)(1 \text{ kg}/10^3 \text{ g})}{1 + b_n(\text{SRT})} + Q(nbVSS)(1 \text{ kg}/10^3 \text{ g})$$

$$P_{X,\text{VSS}} = \frac{(4000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(432 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.081 \text{ g/g}\cdot\text{d})11.9 \text{ d}]}$$

$$+ \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(4000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(432 \text{ g/m}^3)(11.9 \text{ d})(1 \text{ kg}/10^3 \text{ g})}{[(1 + (0.081 \text{ g/g}\cdot\text{d})(11.9 \text{ d}))]$$

$$+ \frac{(4000 \text{ m}^3/\text{d})(0.20 \text{ g/g})(32 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{[1 + (0.128 \text{ g/g}\cdot\text{d})(11.9 \text{ d})]} + (4000 \text{ m}^3/\text{d})(130 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})$$

$$P_{X,\text{VSS}} = (395.9 + 57.2 + 10.2 + 520) \text{ kg/d} = 983.3 \text{ kg/d}$$

$$\text{MLVSS} = (3500 \text{ mg/L}) \left[ \frac{(983.3 \text{ kg/d})}{(1176.5 \text{ kg/d})} \right] = 2925.2 \text{ mg/L}$$

8. Determine the rate of oxygen required using Eq. (8-23) in Table 8-10.

$$R_o = Q(S_o - S) - 1.42 P_{X,\text{bio}} + 4.57 Q (\text{NO}_x)$$

- a. Calculate  $P_{X,\text{bio}}$  from components A and B in Eq. (8-20)

$$\begin{aligned} P_{X,\text{bio}} &= \frac{(4000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(432 \text{ g/m}^3)(1 \text{ kg}/10^3\text{g})}{[1 + (0.081 \text{ g/g}\cdot\text{d})(11.9 \text{ d})]} \\ &\quad + \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(4000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(432 \text{ g/m}^3)(1 \text{ kg}/10^3\text{g})}{[1 + (0.081 \text{ g/g}\cdot\text{d})(11.9 \text{ d})]} \\ &= 395.9 \text{ kg/d} + 57.2 \text{ kg/d} = 453.1 \text{ kg/d} \end{aligned}$$

- b. Calculate  $\text{NO}_x$  using Eq. (8-24) in Table 8-10.

$$\text{NO}_x = \text{TKN} - \text{N}_e - 0.12 P_{X,\text{bio}} / Q$$

$$\text{NO}_x = (40 - 1.0) \text{ g/m}^3 - \frac{0.12 (453.1 \text{ kg/d})(10^3 \text{ g/kg})}{(4000 \text{ m}^3/\text{d})}$$

$$\text{NO}_x = 25.4 \text{ g/m}^3$$

Note: This is lower than the assumed value of 32 g/m<sup>3</sup>. Recalculation using 25.4 g/m<sup>3</sup> results in the following values for the previously calculated parameters shown above.

Parameter	$\text{NO}_x$ 25.4 g/m <sup>3</sup>	$\text{NO}_x$ 32.0 g/m <sup>3</sup>
MLSS, mg/L	3500	3500
SRT, d	11.9	11.9
$P_{X,\text{TSS}}$ , kg/d	1176.5	1176.5
$P_{X,\text{VSS}}$ , kg/d	981.2	983.3
$\text{NO}_x\text{-N}$ , g/m <sup>3</sup>	25.4	25.4

- c. Calculate  $R_o$

$$\begin{aligned} R_o &= (4000 \text{ m}^3/\text{d}) (432 \text{ g/m}^3) (1 \text{ kg}/10^3 \text{ g}) - (1.42 \text{ g/g}) (453.1 \text{ kg/d}) \\ &\quad + 4.57 (4000 \text{ m}^3/\text{d}) (25.4 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g}) \end{aligned}$$

$$R_o = (1728.0 - 643.4 + 464.3) \text{ kg/d} = 1548.9 \text{ kg/d}$$

$$\text{AOTR} = \frac{(1548.9 \text{ kg/d})}{(24 \text{ h/d})} = 64.54 \text{ kg/h}$$

9. Determine the aeration horsepower at 10°C by first converting the oxygen transfer rate to that required at clean water standard conditions using Eq. (5-70) and the values given in the problem statement. The value for the

fouling factor ( $F$ ) is equal to 1.0 as fouling is not a factor for surface mechanical aerators.

$$\text{SOTR} = \frac{(\text{AOTR})C_{\infty,20}^*}{\left[ (\beta) \left( \frac{P_b}{P_s} \right) \left( \frac{C_{S,T}^*}{C_{\infty,20}^*} \right) C_{\infty,20}^* - C \right] \alpha F (1.024)^{(T-20)}}$$

From Appendix E, Table E-1,  $C_{S,20} = 9.09 \text{ mg/L}$

- From Appendix B-4, determine the barometric pressure at 500 in elevation to use for a pressure correction.

$$\begin{aligned} \frac{P_b}{P_s} &= \exp \left[ -\frac{gM(z_b - z_a)}{RT} \right] \\ &= \exp \left\{ \frac{9.81 \text{ m/s}^2 (28.97 \text{ kg/kg-mole})(500 - 0) \text{ m}}{(8314 \text{ kg}\cdot\text{m}^2/\text{s}^2\cdot\text{kg-mole}\cdot\text{K})[(273.15 + 10)\text{K}]} \right\} \end{aligned}$$

$$\frac{P_b}{P_s} = 0.941$$

- From Appendix E,  $C_{S,10^\circ\text{C}} = 11.29 \text{ mg/L}$

$$\frac{C_{S,T}^*}{C_{\infty,20}^*} = \frac{11.29}{9.09} = 1.242$$

- Calculate SOTR

$$\begin{aligned} \text{SOTR} &= \frac{(65.54 \text{ kg/h})(9.09 \text{ mg/L})}{[(0.98)(0.941)(1.242)9.09 - 2.0](0.90)(1.024)^{(10-20)}} \\ &= 103.3 \text{ kg/h} \end{aligned}$$

- Calculate the total aeration energy using clean water efficiency provided in problem statement.

$$\text{Installed energy} = \frac{(103.3 \text{ kg/h})}{(0.9 \text{ kg/kWh})} = 114.8 \text{ kW}$$

From Appendix A, Table A-1

$$\text{Horsepower} = \frac{114.8 \text{ kW}}{(0.746 \text{ kW/hp})} = 153.9$$

Note: For an actual aerator design application, these calculations should also be done at the high design temperature. At higher temperatures for the same SRT more oxygen will be consumed by the heterotrophic biomass and the aerator SOTR/AOTR calculation will be different.

10. Determine the SRT required for nitrification at the temperature given. Use Eq. (7-94) and Eq. (7-98) in Table 8-10 to calculate the specific growth rate of ammonia-oxidizing bacteria (AOB) in this complete-mix activated sludge system.

$$\mu_{AOB} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

and thus:

$$\frac{1}{SRT} = \left( \frac{\mu_{max,AOB} S_{NH4}}{K_{NH4} + S_{NH4}} \right) \left( \frac{DO}{K_{o,AOB} + DO} \right) - b_{AOB}$$

- a. Determine the design SRT using the safety factor (SF) based on Eq. (7-73) in Table 8-10:  
Design SRT = SF (required SRT)
- b. Determine nitrification kinetic coefficients at 10°C using values from Table 8-14. (based on ammonia oxidation)

$$\mu_{max,AOB} = (0.90 \text{ g/g-d}) (1.072)^{10-20} = 0.449 \text{ g/g-d}$$

$$k_{NH4} = (0.50 \text{ mg/L}) (1.0)^{10-20} = 0.50 \text{ g/m}^3$$

$$b_{AOB} = (0.17 \text{ g/g-d}) (1.029)^{10-20} = 0.128 \text{ g/g-d}$$

$$K_{o,AOB} = 0.50 \text{ g/m}^3$$

$$\frac{1}{SRT} = \left\{ \frac{(0.449 \text{ g/g-d})(1.0 \text{ mg/L})}{[(0.50+1.0)\text{mg/L}]} \right\} \left\{ \frac{(2.0 \text{ mg/L})}{[(0.50+2.0)\text{mg/L}]} \right\} - 0.128 \text{ g/g-d}$$

$$\frac{1}{SRT} = 0.111 \text{ d}^{-1}$$

$$SRT = \frac{1}{0.111 \text{ d}^{-1}} = 9.0 \text{ d}$$

Design SRT = 1.5(9.0 d) = 13.5 d

But the SRT is only 11.9 d, which gives a safety factor of 1.32.

For the 1.5 safety factor the SRT could be increased by increasing the MLSS concentration to approximately  $(1.5/1.32)(3500 \text{ mg/L}) = 3980 \text{ mg/L}$ , which may be possible if the secondary clarifiers have sufficient area. Otherwise the effluent NH<sub>4</sub>-N concentration may be higher during peak loading.

11. Determine ratio of total volume to required nitrification volume at average load:

$$\frac{\text{Total volume}}{\text{Nitrification volume}} = \frac{11.9 \text{ d}}{9.0 \text{ d}} = 1.32$$

Note: By controlling DO concentration, a portion of the oxidation ditch channel volume can be at low to zero DO concentration to accomplish denitrification.

### **PROBLEM 8-24**

**Problem Statement** – see text page 927

**Solution**

1. Determine fill time ( $t_F$ ) by applying uniform flow assumption for 2 tanks and assuming idle time  $t_I = 0$

$$T_C = t_F + t_A + t_S + t_D$$

for 2 Tanks

$$t_F = t_A + t_S + t_D = (2.0 + 1.0 + 0.5) \text{ h} = 3.5 \text{ h}$$

$$\text{Total cycle time, } T_c = (3.5 + 2.0 + 1.0 + 0.5) \text{ h} = 7.0 \text{ h}$$

2. Determine the total volume. The full volume is related to the feed volume per cycle and fraction of the tank volume removed (and filled) each cycle.  
Feed volume/cycle = flow rate (fill time)

$$= (4000 \text{ m}^3/\text{d})(1 \text{ d}/24 \text{ h})(3.5 \text{ h/fill}) = 583.3 \text{ m}^3$$

As given:  $\frac{V_F}{V_T} = 0.20$

where  $V_F$  = fill volume and  $V_T$  = total volume

$$V_T = \frac{V_F}{0.20} = \frac{583.3 \text{ m}^3}{0.20} = 2916.7 \text{ m}^3$$

3. Determine the SRT using Eqs. (8-20), (8-21), and (7-57) in Table 8-10 and total volume of 2916.7 m<sup>3</sup> and flow of 2000 m<sup>3</sup>/d per tank (4000 m<sup>3</sup>/d for 2 tanks)

$$(X_{TSS})V = P_{X,TSS} (\text{SRT})$$

$$\begin{aligned} P_{X,TSS} &= \frac{QY_H(S_o - S)}{[1 + b_H(\text{SRT})]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})]0.85} \\ &\quad + \frac{QY_n(\text{NO}_X)}{[1 + b_n(\text{SRT})]0.85} + Q(nb\text{VSS}) + Q(TSS_o - VSS_o) \end{aligned}$$

Combine equations

$$\begin{aligned} (X_{TSS})\left(\frac{V}{Q}\right) &= \frac{Y_H(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})](0.85)X} + \frac{(f_d)(b_H)Y_H(S_o - S)(\text{SRT})^2}{[1 + b_H(\text{SRT})](0.85)X} \\ &\quad + \frac{Y_n(\text{NO}_X)\text{SRT}}{[1 + b_n(\text{SRT})](0.85)X} + (nb\text{VSS})\text{SRT} + (TSS_o - VSS_o)\text{SRT} \end{aligned}$$

4. Define input for above equation **for wastewater A**

Influent bCOD = 1.6 (BOD) = 1.6 (270 mg/L) = 432 mg/L

Assume  $S_o - S \approx S_o = 432 \text{ mg/L}$

Assume  $\text{NO}_X \sim 0.80 \text{ (TKN)} = 0.80 (40) = 32 \text{ mg/L}$

(Note: Nitrifier growth has very small effect on MLSS concentration compared to other factors)

5. Determine coefficients from Table 8-14 and adjust for temperature using Eq. (1-44) in Table 8-10.

$$k_T = k_{20}(0)^{T-20}$$

$$Y_H = 0.45 \text{ gVSS/g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12(1.04)^{10-20} = 0.081 \text{ g/g} \cdot d$$

$$Y_n = 0.20 \text{ g VSS/g NH}_4\text{-N} \text{ (includes ammonia and nitrite oxidizers)}$$

$$b_n = 0.17(1.029)^{10-20} = 0.128 \text{ g/g} \cdot d$$

6. Substitute values in the step 3 equation

$$(3500 \text{ g/m}^3) \left[ \frac{2916.7 \text{ m}^3}{(2000 \text{ m}^3/d)} \right] = \frac{0.45 \text{ g/g}(432 \text{ g/m}^3)(SRT)}{[1 + (0.081 \text{ g/g} \cdot d)SRT]0.85}$$

$$+ \frac{(0.15 \text{ g/g})(0.081 \text{ g/g} \cdot d)(0.45 \text{ g/g})(432 \text{ g/m}^3)(SRT)^2}{[1 + (0.081 \text{ g/g} \cdot d)SRT]0.85}$$

$$+ \frac{0.20 \text{ g/g}(32 \text{ g/m}^3)(SRT)}{[1 + (0.128 \text{ g/g} \cdot d)SRT]0.85} + 130 \text{ g/m}^3(SRT) + (250 - 240) \text{ g/m}^3(SRT)$$

7. Solve equation on spreadsheet by selecting SRT value where left and right sides of equation are equal, or use Excel solver function.

$$5104.2 = \frac{228.7(SRT)}{1 + 0.081SRT} + \frac{2.78(SRT)^2}{1 + 0.081SRT} + \frac{7.53(SRT)}{1 + 0.128SRT} + 130SRT + 10SRT$$

$$SRT = 20.5 \text{ d}$$

8. Determine the decant pumping rate

$$Q_{decant} = \frac{\text{volume/fill}}{t_D} = \frac{583.3 \text{ m}^3}{0.5 \text{ h} (60 \text{ m/h})} = 19.44 \text{ m}^3/\text{min}$$

### PROBLEM 8-25

**Problem Statement – see text, page 927**

**Instructors Note:** The approach used in example problem 8-3 can be followed to solve this problem. First, the biomass production rate ( $P_{X,\text{bio}}$ ) is calculated and used to determine the nitrogen used for cell synthesis, so that the oxidizable nitrogen ( $\text{NO}_x$ ) can be determined. Then the oxidizable N concentration at the beginning of the aeration period is calculated and the time necessary to reduce it

to 0.5 mg/L NH<sub>4</sub>-N is determined using the batch reaction Eq. (8-49). The time can be then compared to the actual aeration time.

### Solution (Wastewater #1)

- Determine P<sub>X, bio</sub> from the A, B, and C terms in Eq. (8-20)

$$P_{X,\text{bio}} = \frac{Q(Y_H)(S_0 - S)}{1 + b_H(\text{SRT})} + \frac{f_d(b_H)Q(Y_H)(S_0 - S)\text{SRT}}{1 + b_H(\text{SRT})} + \frac{QY_n(\text{NO}_x)}{1 + b_n(\text{SRT})}$$

- Define inputs for above equation **for wastewater #1**

Flowrate = 4800 m<sup>3</sup>/d

Influent bCOD = 1.6BOD = 1.6(250 mg/L) = 400 mg/L

Assume S<sub>0</sub> - S ≈ S<sub>0</sub>

Assume NO<sub>x</sub>-N ~ 0.80(TKN) = 0.80(45 mg/L) = 36 mg/L

# of SBR tanks = 2

Volume per SBR Tank = 3000 m<sup>3</sup>

$$\text{Flow/tank} = \frac{(4800 \text{ m}^3/\text{d})}{2 \text{ tanks}} = 2400 \text{ m}^3/\text{d} \cdot \text{tank}$$

SRT = 20 d

Aeration DO concentration = 2.0 mg/L

Fill volume fraction (V<sub>F</sub>/V<sub>T</sub>) per cycle = 0.20

Aeration Time per cycle = 2.0 h

Temperature = 15°C

- Determine non-aerated time and fraction of aerobic time during cycle

Non-aerated time = fill + settle + decant times

Fill volume per cycle = (V<sub>F</sub>/V<sub>T</sub>)(V<sub>T</sub>) = 0.20(3000 m<sup>3</sup>) = 600 m<sup>3</sup>/cycle

$$\text{Number of cycles per day per tank} = \frac{(2400 \text{ m}^3/\text{d-tank})}{(600 \text{ m}^3/\text{cycle})} = 4 \text{ cycles/d}$$

$$\text{Cycle time} = \frac{(24 \text{ h/d})}{(4 \text{ cycles/d})} = 6 \text{ h/cycle}$$

From Example 8-5:  $T_C = t_F + t_A + t_S + t_D$

$$6.0 \text{ h} = t_F + 2.0 \text{ h} + t_S + t_D$$

$$t_F + t_S + t_D = 6.0 - 2.0 = 4.0 \text{ h}$$

$$\text{Fraction aerobic time} = \frac{t_A}{T_C} = \frac{2 \text{ h}}{6 \text{ h}} = 0.33$$

4. Determine coefficients from Table 8-14 and adjust for temperature using Eq. (1-44) in Table 8-10, where  $T = 15^\circ\text{C}$

$$k_T = k_{20}(\theta)^{T-20}$$

$$Y_H = 0.45 \text{ g VSS/g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12(1.04)^{(15-20)} = 0.0986 \text{ g/g} \cdot \text{d}$$

$$\mu_{max,AOB,15} = \mu_{max,AOB,20}(1.072)^{(15-20)} = 0.90(0.706) = 0.636 \text{ g/g} \cdot \text{d}$$

$$K_n = 0.50 \text{ mg/L}$$

$$Y_n = 0.20 \text{ g VSS/g NH}_3\text{-N} \text{ (assumes minimal NO}_2\text{ at end of aeration)}$$

Per Example 8-5 for weighted average  $b_n$  for nitrifiers

$$\text{Aerobic } b_n = 0.17(1.029)^{(15-20)} = 0.147 \text{ g/g} \cdot \text{d}$$

$$\text{Anoxic } b_n = 0.07(1.029)^{(15-20)} = 0.061 \text{ g/g} \cdot \text{d}$$

$$\text{Weighted average } b_n = 0.147 \text{ g/g} \cdot \text{d} \left( \frac{t_A}{T_C} \right) + 0.061 \text{ g/g} \cdot \text{d} \left( 1 - \frac{t_A}{T_C} \right)$$

$$\text{Weighted average } b_n = 0.147 \text{ g/g} \cdot \text{d} (0.33) + 0.061 \text{ g/g} \cdot \text{d} (0.67) = 0.089 \text{ g/g} \cdot \text{d}$$

4. Determine  $P_{X,\text{bio}}$

$$P_{X,\text{bio}} = \frac{(2400 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)}{[1 + (0.0986 \text{ g/g} \cdot \text{d})(20 \text{ d})]}$$

$$+ \frac{(0.15 \text{ g/g})(0.0986 \text{ g/g}\cdot\text{d})(2400 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)(20 \text{ d})}{[1 + (0.0986 \text{ g/g}\cdot\text{d})(20 \text{ d})]}$$

$$+ \frac{(0.20 \text{ g/g})(2400 \text{ m}^3/\text{d})(0.80)(45 \text{ g/m}^3)}{[1 + (0.089 \text{ g/g}\cdot\text{d})(20 \text{ d})]}$$

$$P_{X,\text{bio}} = (145,357 + 42,997 + 6216) \text{ g/d} = 194,570 \text{ g/d}$$

5. Determine NO<sub>x</sub>-N from Eq. (8-24), Table 8-10.

$$\text{NO}_x\text{-N} = \text{TKN} - N_e - 0.12 P_{X,\text{bio}}/Q$$

$$\text{Assume } N_e = 0.50 \text{ g/m}^3$$

$$\text{NO}_x\text{-N} = 45.0 \text{ g/m}^3 - 0.50 \text{ g/m}^3 - \frac{0.12(194,570 \text{ g/d})}{(2400 \text{ m}^3/\text{d})}$$

$$\text{NO}_x\text{-N} = (45.0 - 0.50 - 9.73) \text{ g/m}^3 = 34.8 \text{ g/m}^3$$

Note: replace NO<sub>x</sub>-N of [(0.8)(45) = 36] with 34.8 part C of P<sub>X,bio</sub>. The iteration results in NO<sub>x</sub>-N = 34.8.

6. Determine amount of oxidizable N available at start of aeration

$$\text{NO}_x\text{-N available in feed} = 34.8 \text{ g/m}^3$$

$$\text{NO}_x \text{ added/cycle} = V_F (\text{NO}_x)$$

$$\text{NO}_x \text{ added/cycle} = (600 \text{ m}^3/\text{cycle})(34.8 \text{ g/m}^3) = 20,880 \text{ g}$$

$$\text{NH}_4\text{-N remaining before fill} = (V_T - V_F)(N_e)$$

$$\text{Assumed } N_e = 0.50 \text{ g/m}^3$$

$$(V_T - V_F)(N_e) = (0.50 \text{ g/m}^3)(3000 - 600) \text{ m}^3 = 1200 \text{ g}$$

$$\text{Total oxidizable N} = (20,880 + 1200) \text{ g} = 22,080 \text{ g}$$

$$\text{Initial concentration} = N_o = \frac{22,080 \text{ g}}{3000 \text{ m}^3} = 7.36 \text{ g/m}^3$$

7. Solve for final NH<sub>4</sub>-N concentration (N<sub>t</sub>) at aeration time = 2.0 h

- a. Define equations needed

$$K_n \ln \frac{N_o}{N_t} + (N_o - N_t) = X_n \left( \frac{\mu_{nm}}{Y_n} \right) \left( \frac{DO}{K_o + DO} \right) t$$

where t = aeration time = 2.0 h

$$X_n = \frac{Q(Y_n)(NO_x - N)SRT}{[1 + b_n(SRT)]V}$$

- b. Apply coefficients from step 4 to determine AOB concentration.

$$X_n = \frac{(2400 \text{ m}^3/\text{d})(0.15 \text{ g/g})(34.8 \text{ g/m}^3)(20 \text{ d})}{[1 + (0.089 \text{ g/g}\cdot\text{d})(20 \text{ d})](3000 \text{ m}^3)} = 30.0 \text{ g/m}^3$$

- c. Solve for  $N_t$  for aeration time = 2.0 h (use solver on Excel)

$$K_n \ln \frac{N_o}{N_t} + (N_o - N_t) = X_n \left( \frac{\mu_{nm}}{Y_n} \right) \left( \frac{DO}{K_o + DO} \right) t$$

$$t = 2 \text{ h}/(24 \text{ h/d}) = 0.0833 \text{ d}$$

$$(0.50 \text{ g/m}^3) \ln \left[ \frac{(7.36 \text{ g/m}^3)}{N_t} \right] + (7.36 \text{ g/m}^3 - N_t) = \\ 29.6 \text{ g/m}^3 \left[ \frac{(0.636 \text{ g/g}\cdot\text{d})}{(0.15 \text{ g/g})} \right] \left[ \frac{(2.0 \text{ g/m}^3)}{(0.5 \text{ g/m}^3 + 2.0 \text{ g/m}^3)} \right] 0.0833 \text{ d}$$

$$N_t = 0.37 \text{ g/m}^3$$

This value must be used in place of the assumed value of 0.50 g/m<sup>3</sup> and thus the previous calculations must be iterated on spreadsheet. At each iteration the NO<sub>x</sub>-N will change and thus must be adjusted before solving for N<sub>t</sub>. By the 4<sup>th</sup> iteration the following was determined with an exact solution;

$$N_t = 0.30 \text{ mg/L}$$

$$NO_x - N = 35.0 \text{ mg/L}$$

$$X_n = 30.2 \text{ mg/L}$$

## PROBLEM 8-26

**Problem Statement** – see text, page 928

### Solution

- Determine the settled volume mixed liquor concentration with **SVI = 150** mL/g using Eq. (8-43).

$$X_R = \frac{1}{SVI} \frac{(10^3 \text{ mg}/1 \text{ g})}{(1 \text{ L}/10^3 \text{ mL})} = \frac{10^6}{150 \text{ mL/g}} = 6666 \text{ mg/L}$$

2. Determine the fraction of the depth occupied by the settled mixed liquor.

The depth fraction is equal to the settled volume divided by the total volume.

$$\frac{V_S}{V_T} = \frac{X}{X_S} = \frac{(3500 \text{ mg/L})}{(6666 \text{ mg/L})} = 0.525 = 0.525$$

3. Determine the settled, decant, and fill depths.

Settled mixed liquor depth = 0.525 (total depth) = 0.525 (5.5 m) = 2.9 m

The allowable settled depth including the 0.6 m clear liquid = 0.6 m + 2.9 m  
= 3.5 m

The decant depth = total depth – settled depth

$$= (5.5 - 3.5) \text{ m} = 2.0 \text{ m}$$

The fill depth = decant depth = 2.0 m

4. Determine the fill volume/total volume ratio

The fill volume ( $V_F$ ) to total volume ( $V_T$ ) ratio is proportional to fill depth/total depth

$$\frac{V_F}{V_T} = \frac{2.0 \text{ m}}{5.5 \text{ m}} = 0.36$$

## PROBLEM 8-27

**Problem Statement** – see text, page 928

### Solution

Design conditions and assumptions given in Example 8-6.

### Solution

- Determine the SRT value and the concentration of the nitrifying bacteria for a single-stage system,  $\tau = 8 \text{ h} = 0.33 \text{ d}$ ,  $N = 1.0 \text{ g/m}^3$ .
  - Solve for the specific growth rate using Eq. (7-94) in Table 8-10.

$$\mu_{AOB} = \mu_{max,AOB,16} \left[ \frac{S_{NH}}{S_{NH} + K_{NH}} \right] \left[ \frac{S_o}{S_o + K_{o,AOB}} \right] - b_{AOB}$$

$$\mu_{AOB} = \left\{ \frac{(0.681 \text{ g/g} \cdot \text{d})(1.0 \text{ g/m}^3)}{[(0.50 + 1.0) \text{ g/m}^3]} \right\} \left\{ \frac{(2.0 \text{ g/m}^3)}{[(0.50 + 2.0) \text{ g/m}^3]} \right\} - 0.151 = 0.212 \text{ g/g} \cdot \text{d}$$

- b. Solve for SRT using Eq. (7-98) in Table 8-10.

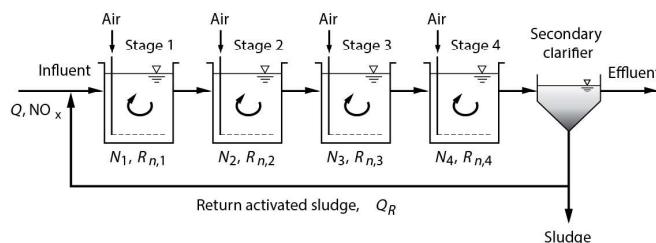
$$SRT = \frac{1}{\mu_{AOB}} = \frac{1}{(0.212 \text{ g/g} \cdot \text{d})} = 4.72 \text{ d}$$

- c. Solve for the concentration of nitrifying bacteria using a modified form of Eq. (7-42).

$$X_n = \frac{(SRT)Y_n(NO_x)}{\tau[1+b_n(SRT)]}$$

$$= \frac{(4.72 \text{ d})(0.15 \text{ g/g})(30 \text{ g/m}^3)}{(0.33 \text{ d})[1+(0.151 \text{ g/g} \cdot \text{d})(4.72 \text{ d})]} = 37.5 \text{ g/m}^3$$

2. Perform nitrogen mass balances for a four-stage system shown on the following figure using equal volumes per stage. The total volume of the four-stage system is equal to the volume of the CMAS system,  $\tau/\text{stage} = 0.333 \text{ d}/4 = 0.0833 \text{ d/stage}$ .



- a. For Stage 1

Accumulation = in – out + generation

$$\frac{dN_1}{dt} V = Q(NO_x) + Q_R N_4 - (Q + Q_R)N_1 - R_{n,1}V$$

The rate expression for nitrification, derived from Eq. (7-101) in Table 8-10 includes a correction for the DO concentration, and is given by

$$r_{NH4} = \left[ \frac{\mu_{max,AOB}}{Y_{AOB}} \right] \left[ \frac{S_{NH4}}{S_{NH4} + K_{NH4}} \right] \left[ \frac{S_o}{S_o + K_{o,AOB}} \right] X_{AOB}$$

where  $Q$  = wastewater flowrate,  $\text{m}^3/\text{d}$

$\text{NO}_x$  = amount of available influent  $\text{NH}_4\text{-N}$  oxidized,  $30 \text{ g/m}^3$

$Q_R$  = recycle flowrate from stage 4,  $\text{m}^3/\text{d}$

$Q/Q_R = 0.50$

$N_4$  =  $\text{NH}_4\text{-N}$  concentration for stage 4,  $\text{g/m}^3$

$N_1$  =  $\text{NH}_4\text{-N}$  concentration for stage 1,  $\text{g/m}^3$

$R_{n,1}$  = nitrification rate for stage 1,  $\text{g/m}^3 \cdot \text{d}$

$X_n$  = nitrifying bacteria concentration,  $\text{g/m}^3$

The nitrifying bacteria concentration is the same as that calculated for the CMAS system assuming that the same amount of  $\text{NH}_4\text{-N}$  is removed and the systems are at the same SRT.

At steady state  $dN_1/dt = 0$ , and

$$\text{NO}_x + Q_R / Q N_4 - (1 + Q_R / Q) / N_1 - R_{n,1} V / Q = 0$$

$$\text{NO}_x + 0.5N_4 = 1.5N_1 + R_{n,1}(\tau)$$

where  $\tau = 0.0833 \text{ d}$ , detention time of stage 1

$$\text{NO}_x = 30 \text{ g/m}^3$$

- b. For Stage 2, use the same procedure as Stage 1.

$$V \frac{dN_2}{dt} = (Q + Q_R) N_1 - (Q + Q_R) N_2 - R_{n,2} V$$

$$1.5N_1 = 1.5N_2 + R_{n,2}(\tau)$$

- c. For Stage 3

$$1.5N_2 = 1.5N_3 + R_{n,3}(\tau)$$

- d. For Stage 4

$$1.5N_3 = 1.5N_4 + R_{n,4}(\tau)$$

- 3.  $R_{n,i(i=1-4)}$  is a function of the  $\text{NH}_4\text{-N}$  concentration ( $N$ ) in each stage:

For stage 1,

$$R_{n,i} = \left[ \frac{(0.681 \text{ g/g} \cdot \text{d})}{(0.15 \text{ g VSS/g NH}_4\text{-N})} \right] \left\{ \frac{N_i}{[(0.50+N_i) \text{ g/m}^3]} \right\} \left\{ \frac{(2.0 \text{ g/m}^3)}{[(0.5+2.0) \text{ g/m}^3]} \right\} (37.5 \text{ g/m}^3)$$

$$R_{n,i} = 136.2 \left[ \frac{N_i}{[(0.50+N_i) \text{ g/m}^3]} \right], \text{ where } i = 1, 2, 3, \text{ or } 4 \text{ for stages 1-4}$$

4. The above equations for the four stages are solved with a spreadsheet program starting with Stage 1 either by using Solver in the Excel software or by an iterative technique. In the iterative technique the value for  $N_4$  is assumed and  $N_1$  is calculated. Subsequently  $N_2$ ,  $N_3$  and  $N_4$  are calculated. Using Solver, the following effluent  $\text{NH}_4\text{-N}$  concentrations are computed for each stage for a return sludge recycle ratio of 1.0. In addition a solutions is also shown for a return sludge recycle ratio of 6.0 as would be typical for an MBR system:

Stage	$\text{NH}_4\text{-N concentration, g/m}^3$	
	Recycle Ratio = 0.50	Recycle Ratio = 6.0
1	13.11	3.73
2	6.17	2.40
3	1.07	1.25
4	0.08	0.47

### Comment

Based on the above results, the same effluent  $\text{NH}_4\text{-N}$  concentration of 1.0 mg/L can be achieved with a little over 3 of the 4 stages for the aerobic staged nitrification system showing that staging reduces the aeration tank volume needed by about 25% compared to that required for a CMAS design at a recycle ratio of 0.50. At the higher recycle ratio the amount of volume reduction is not as much due to the greater dilution of the influent  $\text{NH}_4\text{-N}$  concentration with lower  $\text{NH}_4\text{-N}$  concentrations driving the nitrification reaction rates in the first two stages. Thus, a staged nitrification reactor is more efficient than a CMAS reactor design and compared to the CMAS the staged system can have a lower SRT and thus

lower total volume. Or for the same SRT and volume, the staged system would produce a lower average effluent NH<sub>4</sub>-N concentration. The above solution is also illustrative of the importance of the return activated sludge recycle ratio. The effluent NH<sub>4</sub>-N concentration is higher for the MBR system, which has a higher recycle ratio. The effect of the higher recycle ratio is to dilute the influent NH<sub>4</sub>-N concentration more so that the NH<sub>4</sub>-N concentration is lower in the first stage. Because the nitrification rate is related to the NH<sub>4</sub>-N concentration, the nitrification rate is lower and thus the effluent concentration is higher.

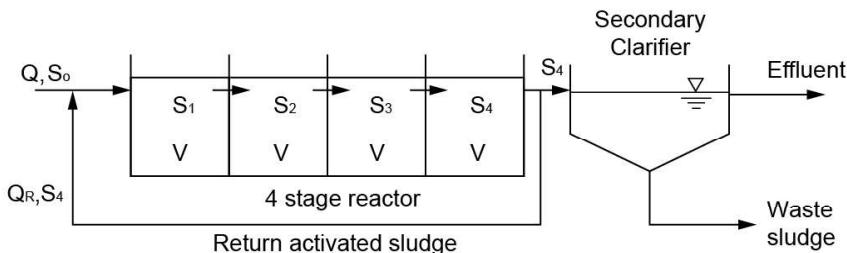
### PROBLEM 8-28

**Problem Statement** – see text, page 928

**Instructors Note:** This problem is solved in a manner similar to that used for nitrification for the staged system in Example 8-6. A mass balance is performed at each stage using Eq. (7-12) in Table 8-10 for the substrate utilization rate, and the biomass concentration X is given. Changes in X in each stage is small relative to the stage concentration and can be ignored.

### Solution

1. Develop a flow diagram



2. Prepare a mass balance; use Eq. (7-12)  $r_{su} = \frac{kXS}{K_s + S}$

Stage 1 mass balance:

$$V \frac{dS_1}{dt} = QS_0 + Q_R S_4 - (Q + Q_R) S_1 - V r_{su,1}$$

at steady state,  $\frac{dS_1}{dt} = 0$ , divide by Q,  $Q_R/Q = R$

$$S_o + RS_4 - (1+R) S_1 - \frac{V}{Q} r_{su} = 0$$

Substitute  $r_{su}$ :

$$S_o + RS_4 - (1 + R) S_1 - \frac{V}{Q} \left( \frac{kXS_1}{K_s + S_1} \right) = 0$$

By assuming  $S_4$ , a value for  $S_1$  can be calculated.  $S_4$  is selected and an iterative spreadsheet solution is done until the  $S_4$  calculated for Stage 4 equals the assumed  $S_4$ .

Stage 2:

$$V \frac{dS_2}{dt} = (Q + Q_R)S_1 - (Q + Q_R) S_2 - Vr_{su,2}$$

$$(1 + R) S_1 - (1 + R) S_2 - \frac{V}{Q} \left( \frac{kXS_2}{K_s + S_2} \right) = 0$$

Similarly:

$$\text{Stage 3: } (1 + R) S_2 - (1 + R) S_3 - \frac{V}{Q} \left( \frac{kXS_3}{K_s + S_3} \right) = 0$$

$$\text{Stage 4: } (1 + R) S_3 - (1 + R) S_4 - \frac{V}{Q} \left( \frac{kXS_4}{K_s + S_4} \right) = 0$$

3. Summarize the parameters to be used in the above equations.

a. From table in Problem Statement for **wastewater 1**:

$$k = 1.2 \text{ g COD/g VSS} \cdot d$$

$$K_s = 50 \text{ g/m}^3$$

b. Given values:

$$X = 1600 \text{ g/m}^3$$

$$S_o = 300 \text{ g/m}^3 \text{ BOD}$$

$$= 1.6 (300 \text{ g/m}^3) = 480 \text{ g/m}^3 \text{ COD}$$

$$\frac{V}{Q} = \frac{240 \text{ m}^3}{(4000 \text{ m}^3/d)} = 0.06 \text{ d}$$

$$R = 0.5$$

4. Use a spreadsheet program to solve the equations.

The spreadsheet solution is given in the following table

Stage	S, bCOD, mg/L
1	293.4
2	230.3
3	170.9
4	117.0

5. Determine the oxygen consumption rate. The oxygen consumption rate in each stage is related to oxygen consumed for substrate utilization, nitrification, and for endogenous decay as shown in Eq. (8-25). For this problem there is no nitrification. Thus, the oxygen demand is calculated as follows:

Stage 1

$$R_{o,1} = [(QS_0 + Q_RS_4) - (Q + Q_R)S_1](1 - Y_H) + 1.42b_HX(V_1)$$

$$Y_H = (0.35 \text{ g VSS/g COD})(1.42 \text{ g COD/g VSS}) = 0.50 \text{ g COD/g COD}$$

$$Q_R = RQ = 0.5(4000 \text{ m}^3/\text{d}) = 2000 \text{ m}^3/\text{d}$$

$$\begin{aligned} R_{o,1} = & [(4000 \text{ m}^3/\text{d})(480 \text{ g/m}^3) + (2000 \text{ m}^3/\text{d})(117 \text{ g/m}^3) \\ & -(6000 \text{ m}^3/\text{d})(293.4 \text{ g/m}^3)][1 - (0.5 \text{ g/g})] \\ & + 1.42(0.10 \text{ g/g}\cdot\text{d})(1600 \text{ g/m}^3)(240 \text{ m}^3) \end{aligned}$$

Two oxygen demand terms are shown; for substrate utilization rate ( $R_{os}$ ) and for endogenous decay rate ( $R_{oe}$ )

$$R_{o,1} = R_{os} + R_{oe}$$

$$R_{o,1} = 198,129 \text{ g O}_2/\text{d} + 54,528 \text{ g O}_2/\text{d}$$

Stage 2

$$R_{o,2} = [(Q + Q_R)(S_1 - S_2)](1 - Y_H) + 1.42b_HX(V_2)$$

$$\begin{aligned} R_{o,2} = & [(6000 \text{ m}^3/\text{d})[(293.4 - 230.3) \text{ g/m}^3][(1 - 0.5) \text{ g/g}] \\ & + 1.42(0.10 \text{ g/g}\cdot\text{d})(1600 \text{ g/m}^3)(240 \text{ m}^3)] \end{aligned}$$

$$R_{o,2} = 190,432 \text{ g O}_2/\text{d} + 54,528 \text{ g O}_2/\text{d}$$

Similar calculations follow for Stages 3 and 4.

The oxygen demand for substrate utilization and endogenous decay is summarized for each stage.

Stage	S, bCOD, g/m <sup>3</sup>	R <sub>os</sub> , kg/d	R <sub>oe</sub> , kg/d	O <sub>2</sub> Total, kg/d	Fraction of total
1	293.4	198.1	54.5	252.6	0.27
2	230.3	190.4	54.5	244.9	0.26
3	170.9	179.3	54.5	233.8	0.25
4	117.0	162.4	54.5	216.9	0.22
				948.2	1.00

Note: The oxygen demand per stage is similar as the substrate concentration is high relative to the half-velocity coefficient value, K<sub>s</sub>, so that the reaction rate approaches zero order in each stage.

The solution for a higher value for k of 10.0 g COD/g VSS • d is shown in the following table.

Stage	S, bCOD, g/m <sup>3</sup>	R <sub>os</sub> , kg/d	R <sub>oe</sub> , kg/d	O <sub>2</sub> Total, kg/d	Fraction of total
1	39.1	847.7	54.5	902.2	0.76
2	3.0	109.0	54.5	163.5	0.14
3	0.22	8.4	54.5	62.9	0.05
4	0.02	0.6	54.5	55.1	0.05
				1183.7	1.00

76% of oxygen required is in the first stage for this case with a higher specific substrate utilization rate coefficient value.

### PROBLEM 8-29

**Problem Statement – see text, page 928**

**Solution**

The comparison is given in the following table.

Parameter	Processes			
	Complete-mix	Pure oxygen	Contact stabilization	Oxidation ditch
Effluent quality Good nitrification	Low BOD/TSS	Low BOD/TSS Nitrification not common due to low SRT and low pH	Higher BOD/TSS but less than 30 mg/L possible Little or no nitrification	Low BOD/TSS Good nitrification Some denitrification possible
Space requirements	Moderate	Low	Low but more than pure oxygen system	High
Complexity	Low	Most complex with covered system and O <sub>2</sub> supply	Low	Low
Energy requirements	Moderate	Higher than complete-mix system	Moderate to low	Highest
Operational requirements	Moderate	High	Moderate	Lowest
Ability to handle variable loads	Moderate	Low	Moderate	High

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### PROBLEM 8-30

**Problem Statement** – see text, page 928

**Solution (wastewater #1)**

1. Prepare a solids balance for each tank to determine the MLVSS concentration (ignore biomass or solids production – low relative to solids flow in/out). **Use parameters for wastewater #1.**

Assume steady state: in = out.

Pass 1:

$$Q_R X_R + Q_1(O) = (Q_1 + Q_R) X_1$$

$$X_1 = \frac{Q_R X_R}{Q_1 + Q_R} = \frac{(2000 \text{ m}^3/\text{d})(10,000 \text{ g/m}^3)}{[(800 + 2000) \text{ m}^3/\text{d}]} = 7142.9 \text{ g/m}^3$$

Pass 2

$$(Q_1 + Q_R) X_1 + Q_2(0) = (Q_1 + Q_2 + Q_R) X_2$$

$$X_2 = \frac{(Q_1 + Q_R)X_1}{Q_1 + Q_2 + Q_R} = \frac{[(800 + 2,000)m^3/d](7142.9\text{ g/m}^3)}{[(800 + 1200 + 2000)m^3/d]} = 5000 \text{ g/m}^3$$

Pass 3

$$(Q_1 + Q_2 + Q_R) X_2 + Q_3(0) = (Q_1 + Q_2 + Q_3 + Q_R) X_3$$

$$X_3 = \frac{(Q_1 + Q_2 + Q_R)X_2}{Q_1 + Q_2 + Q_3 + Q_R} = \frac{[(800 + 1200 + 2,000)m^3/d](5000\text{ g/m}^3)}{[(800 + 1200 + 1000 + 2000)m^3/d]}$$

$$X_3 = 4000 \text{ mg/L}$$

Pass 4

Similarly,

$$X_4 = \frac{(Q_1 + Q_2 + Q_3 + Q_R)X_3}{Q_1 + Q_2 + Q_3 + Q_4 + Q_R} = \frac{[(800 + 1200 + 1000 + 2,000)m^3/d](4000\text{ mg/L})}{[(800 + 1,200 + 1000 + 1000 + 2000)m^3/d]}$$

$$X_4 = 3333 \text{ mg/L}$$

Summary:

Tank #	MLVSS, mg/L
1	7143
2	5000
3	4000
4	3333

### PROBLEM 8-31

**Problem Statement** – see text, page 929

#### Solution

1. Use Eq. (8-62) to determine the internal recycle ratio and recycle flow rate.

$$IR = \frac{NO_x}{N_e} - 1.0 - R$$

2. Determine the effluent  $NO_3$ -N concentration ( $N_e$ ) based on requirement of 85 percent N removal and given effluent  $NH_4$ -N = 1.0 mg/L. Assume effluent  $NO_2$ -N concentration ≈ 0.0 and ignore soluble organic nitrogen concentration (conservative design).

$$N_e = (1 - 0.85) TKN - NH_4\text{-N}$$

$$N_e = 0.15 (35 \text{ mg/L}) - (1.0 \text{ mg/L}) = 4.25 \text{ mg/L } NO_3\text{-N}$$

3. Estimate sludge recycle ratio by simple mass balance around secondary clarifier (ignore sludge wasting) per Step 21 in Example 8-3.

$$R = \frac{X}{X_R - X} = \frac{(3500 \text{ mg/L})}{[(10,000 - 3,500) \text{ mg/L}]} = 0.54$$

4. Determine  $\text{NO}_x$  using Eq. (8-24) in Table 8-10.

$$\text{NO}_x = \text{TKN} - N_e - 0.12 P_{X,\text{bio}}/Q$$

$P_{X,\text{bio}}$  can be determined using Eq. (7-56), Table 8-10, and the information provided by using  $X_b$  in place of  $X_{\text{vss}}$ .

$$X_b V = P_{X,\text{bio}} (\text{SRT})$$

$$P_{X,\text{bio}} = \frac{X_b V}{\text{SRT}} = \frac{(1620 \text{ g/m}^3)460 \text{ m}^3}{10 \text{ d}} = 74,520 \text{ g/d}$$

$$\text{NO}_x = 35.0 \text{ g/m}^3 - 1.0 \text{ g/m}^3 - \frac{(0.12 \text{ g/g})(74,520 \text{ g/d})}{(1000 \text{ m}^3/\text{d})} = 25.1 \text{ g/m}^3$$

5. Determine internal recycle rate (IR) using Eq. (8-62)

$$\text{IR} = \frac{25.1}{4.25} - 1.0 - 0.54 = 4.4$$

$$\text{Internal recycle rate} = \text{IR} (Q) = 4.4 (1000 \text{ m}^3/\text{d}) = 4400 \text{ m}^3/\text{d}$$

6. Determine the anoxic tank volume and  $\tau$  for a single stage anoxic tank by the following steps:

- Determine the  $\text{NO}_3\text{-N}$  feed rate to the anoxic zone.
- Select an anoxic volume and use Eq. (8-52) to determine if the nitrate that can be removed is nearly equal to that determined above.
- Use the coefficients in Table 8-22 with Eq. (8-57) or Eq. (8-58) to obtain  $\text{SDNR}_b$ . Use E. (8-56) to obtain  $F/M_b$ .
- Use Eq. (8-60) to correct for  $\text{SDNR}_b$  for recycle and  $\theta$  value of 1.026 (page 808) to correct for temperature using Eq. (1-44). Use the final  $\text{SDNR}$  in Eq. (8-52) to determine if the nitrate removal is sufficient.

- a.  $\text{NO}_3\text{-N}$  feed to anoxic zone:

$$[(\text{IR}) Q + RQ] N_e = [4.4 + 0.54](1000 \text{ m}^3/\text{d})(4.25 \text{ g/m}^3) = 20,995 \text{ g/d}$$

- b. Determine anoxic volume. Use Eq. (8-52) (based on biomass)

$$NO_r = V_{nox} (\text{SDNR}) (\text{MLVSS}_{\text{biomass}})$$

Select anoxic volume,  $\tau_{\text{anoxic}} = 2 \text{ h}$

$$V_{nox} = Q\tau_{\text{anoxic}} = (1000 \text{ m}^3/\text{d})(2.0 \text{ h})/(24\text{h}/\text{d}) = 83.3 \text{ m}^3$$

c. Determine SDNR for wastewater 1

Use Eq. (8-56) to compute  $F/M_b$

$$F / M_b = \frac{QS_o}{X_b V_{nox}} = \frac{(1000 \text{ m}^3/\text{d})(200 \text{ g/m}^3 \text{ BOD})}{(1620 \text{ g/m}^3)(83.3 \text{ m}^3)} = 1.48 \text{ g/g}\cdot\text{d}$$

Compute rbCOD fraction and determine SDNR based on rbCOD fraction:

$$\text{rbCOD fraction} = \frac{(60 \text{ g/m}^3)}{(1.6 \text{ g COD/g BOD})(200 \text{ g/m}^3 \text{ BOD})} = 0.19$$

From Eq. (8-57) and Table 8-22,

$$\begin{aligned} \text{SDNR}_b &= 0.213 + 0.118[\ln(F/M_b)] \\ &= 0.213 + 0.118[\ln(1.49)] \end{aligned}$$

$$\text{SDNR}_b = 0.26$$

Correct SDNR for internal recycle (Eq. 8-60) and temperature (Eq. 1-44)

$$\begin{aligned} \text{SDNR}_{\text{adj}} &= \text{SDNR}_{IR1} - 0.029 \ln(F/M_b) - 0.012 \\ &= 0.26 - 0.029(\ln 1.48) - 0.012 = 0.236 \text{ g/g}\cdot\text{d} \end{aligned}$$

$$\text{SDNR}_{15} = \text{SDNR}_{20} (1.026)^{15-20} = 0.236 (1.026)^{-5} = 0.21 \text{ g/g}\cdot\text{d}$$

$$NO_r = (83.3 \text{ m}^3)(0.21 \text{ g/g}\cdot\text{d})(1620 \text{ g/m}^3) = 28,339 \text{ g/d}$$

$NO_x$  required = 20,995 g/d, so select lower  $\tau_{\text{anoxic}}$

Use a spreadsheet solution to recomputed values, as follows.

$\tau, \text{ h}$	$V_{NO_x}, \text{ m}^3$	$F/M_b, \text{ g/g}\cdot\text{d}$	$\text{SDNR}, \text{ g/g}\cdot\text{d}$	$\text{SDNR}_{\text{adj}}, \text{ g/g}\cdot\text{d}$	$\text{SDNR}_T, \text{ g/g}\cdot\text{d}$	$NO_r, \text{ g/d}$	Required $NO_r, \text{ g/d}$
1.4	58.3	2.1	0.301	0.268	0.235	22,250	20,995

Thus,  $\tau_{\text{anoxic}} = 1.4 \text{ h}$  is reasonable solution

7. Determine  $V_{NO_x}$  and  $\tau$  for each stage of a 3 stage anoxic tank with equal volumes per stage.

The same procedure is used and  $NO_r$  is calculated for each stage.

Calculate the  $F/M_b$  for each stage as follows:

Stage	$F/M_b$
1	$\frac{QS_o}{X_b V_1}$
2	$\frac{QS_o}{X_b(V_1 + V_2)}$
3	$\frac{QS_o}{X_b(V_1 + V_2 + V_3)}$

The spreadsheet solution summary for three iterations is shown on the following table:

Parameter	Iteration		
	1	2	3
Flow, m <sup>3</sup> /d	1000	1000	1000
BOD, mg/L	200	200	200
$X_b$ , mg/L	1620	1620	1620
Temp, °C	15	15	15
rbCOD, mg/L	60	60	60
bCOD, mg/L	320	320	320
Fraction rbCOD	0.19	0.19	0.19
Required removal, g/d	20,995	20,995	20,995

#### Stage 1:

Volume, m <sup>3</sup>	19.4	13.9	16.7
HRT, min	28.0	20.0	24.0
$F/M_b$	6.3	8.9	7.4
$SDNR_b$ (graph)	0.43	0.47	0.45
$SDNR_{corr}$	0.37	0.40	0.38
$SDNR_T$	0.32	0.35	0.33

$\text{NO}_3\text{-N}_r$ , g/d	10126	7826	9005
<b>Stage 2</b>			
Volume, m <sup>3</sup>	19.4	13.9	16.7
HRT, min	28.0	20.0	24.0
F/M <sub>b</sub>	3.2	4.4	3.7
SDNR <sub>b</sub> (graph)	0.35	0.39	0.37
SDNR <sub>corr</sub>	0.30	0.33	0.32
SDNR <sub>T</sub>	0.27	0.29	0.28
$\text{NO}_3\text{-N}_r$ , g/d	8417	6605	7540
<b>Stage 3</b>			
Volume, m <sup>3</sup>	19.4	13.9	16.7
HRT, min	28.0	20.0	24.0
F/M <sub>b</sub>	2.1	4.4	3.7
SDNR <sub>b</sub> (graph)	0.30	0.39	0.37
SDNR <sub>corr</sub>	0.27	0.33	0.32
SDNR <sub>T</sub>	0.24	0.29	0.28
$\text{NO}_3\text{-N}_r$ , g/d	7417	6605	7540
Total removal, g/d	25,962	21,036	24,087
Required removal	20,995	20,995	20,995

The first column solution is based on the same HRT of 1.4 h as used above for the single-stage anoxic zone. With 3 stages the removal capacity is about 24 percent higher. The total HRT used for 3 stages in the solution shown in the second column is 1.0 h. This lower HRT results in a  $\text{NO}_3\text{-N}$  removal rate that is similar to the single stage anoxic zone with an HRT of 1.4 h.

8. Determine the final alkalinity.

The final alkalinity (as  $\text{CaCO}_3$ ) is determined based on 7.14 g alkalinity used/g  $\text{NH}_4\text{-N}$  oxidized and 3.57 g alkalinity produced/g  $\text{NO}_3\text{-N}$  reduced.

$$\text{NO}_x = 25.1 \text{ mg/L, final } \text{NO}_3\text{-N} = 4.25 \text{ mg/L}$$

$$\begin{aligned} \text{Final alkalinity} &= (200 \text{ g/m}^3) - (7.14 \text{ g/g})(25.1 \text{ g/m}^3) + (3.57 \text{ g/g})(25.1 - 4.25) \text{ g/m}^3 \\ &= 95.9 \text{ mg/L as CaCO}_3 \end{aligned}$$

9. Determine the oxygen required. The oxygen demand is calculated first for BOD removal and nitrification and then a credit is applied for the oxygen demand satisfied by BOD removal using nitrate in the anoxic zone before the aeration tank.

Using Eq. (8-24), Table 8-10,

$$R_o = Q (S_0 - S) - 1.42 P_{X,\text{bio}} + 4.57 Q (NO_x)$$

$$S_0 - S \approx S_0 = 320 \text{ g/m}^3$$

$$R_o = [1000 \text{ m}^3/\text{d} (320 \text{ g/m}^3) - 1.42 (74,520 \text{ g/d})]$$

$$+ 4.57 (25.1 \text{ g/m}^3) (1000 \text{ m}^3/\text{d}) (1 \text{ kg}/10^3 \text{ g})$$

$$= (320 - 105.8 + 114.7) \text{ kg/d} = 328.9 \text{ kg/d}$$

Oxygen equivalent from denitrification

$$O_2 = 2.86 \frac{\text{g O}_2}{\text{g NO}_x} [(25.1 - 4.25) \text{ g/m}^3] (1000 \text{ m}^3/\text{d}) (1 \text{ kg}/10^3 \text{ g}) = 59.6 \text{ kg/d}$$

$$\text{Net Oxygen required} = (328.9 - 59.6) \text{ kg/d} = 269.3 \text{ kg/d}$$

$$\text{Required oxygen for BOD removal/nitrification} = 328.9 \text{ kg/d}$$

$$\text{Required oxygen with anoxic/aerobic process} = 269.3 \text{ kg/d}$$

$$\text{Energy savings} = \frac{[(328.9 - 269.3)\text{kg/d}]}{(328.9 \text{ kg/d})} (100\%) = 18.1\%$$

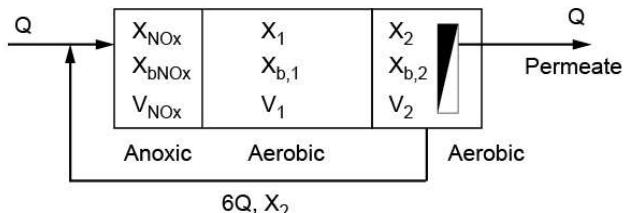
### PROBLEM 8-32

**Problem Statement** – see text, page 929

**Solution**

The effect of using an anoxic/aerobic MBR compared to the activated sludge system in Problem 8-31 is that a higher MLSS concentration is used and thus a smaller volume is used for the same SRT of 10 days. In addition the recycle ratio is given for the MBR system, which results in a different effluent  $NO_3^-$ -N concentration. The MBR system anoxic tank volume is then a function of the  $NO_3^-$ -N removed and the higher biomass concentration.

1. Sketch of MBR system



Given:

$$X_2 = 10,000 \text{ mg/L}$$

$$\text{Membrane flux} = 20 \text{ L/m}^2 \cdot \text{h}$$

$$\text{Membrane reactor volume} = 0.025 \text{ m}^3/\text{m}^2 \text{ (membrane area, m}^2\text{)}$$

2. Determine MBR aerobic volumes.

- a. Membrane area

$$\text{Area} = \frac{Q}{\text{Flux}} = \frac{(1000 \text{ m}^3 / \text{d})(10^3 \text{ L} / \text{m}^3)}{(20 \text{ L} / \text{m}^2 \cdot \text{h})(24 \text{ h} / \text{d})} = 2083 \text{ m}^3$$

- b. Membrane compartment volume,  $V_2$

$$V_2 = (0.025 \text{ m}^3/\text{m}^2)(2083 \text{ m}^3) = 52 \text{ m}^3$$

- c. Determine total volume and  $V_1$

At same SRT, the mass of solids for  $V_1 + V_2$  = mass of solids for aerobic system in Problem 8-31.

$$V_1 X_1 + V_2 X_2 = (460 \text{ m}^3)(3500 \text{ g TSS/m}^3)$$

$$6Q(X_2) + Q(0) = 7QX_1$$

$$X_1 = \frac{6}{7}(X_2) = \left(\frac{6}{7}\right)(10,000 \text{ g/m}^3) = 8571 \text{ g/m}^3$$

$$V_1(8571) + V_2(10,000) = (460)(3500)$$

$$V_2 = 52 \text{ m}^3$$

$$V_1 = 127.2 \text{ m}^3$$

The two stage nitrification system for the MBR will produce a lower effluent  $\text{NH}_4\text{-N}$  concentration than that for the single-stage aeration tank in Problem 8-31. However, because the volume for  $V_2$  is small relative to  $V_1$ , the effluent  $\text{NH}_4\text{-N}$  will be only slightly lower. To simplify the problem, the same effluent  $\text{NH}_4\text{-N}$  concentration for Problem 8-31 will be

used.

3. Determine  $X_{b,\text{NOX}}$ ,  $X_{b,1}$ , and  $X_{\text{bio}}$  for MBR system.

At same SRT of 10 d, the same ratio for  $X_b/X$  in Problem 8-31 can be used.

$$\frac{X_{b1,\text{NOX}}}{X_{\text{NOX}}} = \frac{X_{b,1}}{X_1} = \frac{X_{b,2}}{X_2} = \frac{(1620 \text{ g/m}^3)}{(3500 \text{ g/m}^3)} = 0.463$$

Note  $X_{\text{NOX}} = X_1$

$$X_{b,\text{NOX}} = X_{b,1} = 0.463(8571 \text{ g/m}^3) = 3968.4 \text{ g/m}^3$$

$$X_{b,2} = 0.463(10,000 \text{ g/m}^3) = 4630 \text{ g/m}^3$$

4. Determine the  $\text{NO}_3\text{-N}$  removed in the anoxic zone.

- a. Determine  $\text{NO}_x$ , using Eq. (8-24) in Table 8-10. This calculation will be the same as for Problem 8-31, but it is repeated here.

$$P_{X,\text{bio}} = \frac{V_1(X_{b,1}) + V_2(X_{b,2})}{\text{SRT}}$$

$$P_{X,\text{bio}} = \frac{(127.2 \text{ m}^3)(3968.4 \text{ g/m}^3) + (52 \text{ m}^3)(4630 \text{ g/m}^3)}{10 \text{ d}}$$

$$P_{X,\text{bio}} = 74,550 \text{ g/d}$$

$$\text{NO}_x = \text{TKN} - \text{N}_e - 0.12P_{X,\text{bio}}/Q$$

$$= 35 \text{ g/m}^3 - 1.0 \text{ g/m}^3 - \frac{0.12(74,550 \text{ g/d})}{(1000 \text{ m}^3/\text{d})}$$

$$\text{NO}_x = 25.1 \text{ g/m}^3$$

Assume all the  $\text{NO}_3\text{-N}$  in the recycle to the anoxic zone is removed.

Mass balance on  $\text{NO}_x$  produced to obtain effluent  $\text{NO}_3\text{-N}$  concentration,

$\text{NO}_E$ .

$$\text{NO}_x(Q) = 6Q(\text{NO}_E) + Q(\text{NO}_E)$$

$$25.1 = 6(\text{NO}_E) + 1(\text{NO}_E)$$

$$\text{NO}_E = 3.6 \text{ g/m}^3$$

$$\text{NO}_3\text{-N removed in anoxic zone} = 6(1000 \text{ m}^3/\text{d})(3.6 \text{ g/m}^3) = 21,600 \text{ g/d}$$

5. Determine the anoxic tank volume and  $\tau$  for a single stage anoxic tank by the following steps:

- Determine the  $\text{NO}_3\text{-N}$  feed rate to the anoxic zone.
- Select an anoxic volume and use Eq. (8-52) to determine if the nitrate that can be removed is nearly equal to that determined above.
- Use the coefficients in Table 8-22 with Eq. (8-57) or Eq. (8-58) to obtain  $\text{SDNR}_b$ . Use Eq. (8-56) to obtain  $F/M_b$ .
- Use Eq. (8-60) to correct for  $\text{SDNR}_b$  for recycle and  $\theta$  value of 1.026 (page 808) to correct for temperature using Eq. (1-44). Use the final  $\text{SDNR}$  in Eq. (8-52) to determine if the nitrate removal is sufficient.
  - a.  $\text{NO}_3\text{-N}$  feed to anoxic zone = 21,600 g/d
  - b. Determine anoxic volume. Use Eq. (8-52) (based on biomass)

$$\text{NO}_r = V_{\text{nox}} (\text{SDNR}) (\text{MLVSS}_{\text{biomass}})$$

The following has been determined by initial guess and then iteration.

Select anoxic volume,  $\tau_{\text{anoxic}} = 0.55 \text{ h} = 33 \text{ min}$

$$V_{\text{nox}} = Q\tau_{\text{anoxic}} = (1000 \text{ m}^3/\text{d})(0.55 \text{ h})/(24\text{h}/\text{d}) = 22.9 \text{ m}^3$$

- c. Determine SDNR for wastewater 1

Use Eq. (8-56) to compute  $F/M_b$

$$F/M_b = \frac{QS_o}{X_b V_{\text{nox}}} = \frac{(1000 \text{ m}^3/\text{d})(200 \text{ g/m}^3 \text{ BOD})}{(3968 \text{ g/m}^3)(22.9 \text{ m}^3)} = 2.20 \text{ g/g}\cdot\text{d}$$

Compute rbCOD fraction and determine SDNR based on rbCOD fraction:

$$\text{rbCOD fraction} = \frac{(60 \text{ g/m}^3)}{(1.6 \text{ g COD/g BOD})(200 \text{ g/m}^3 \text{ BOD})} = 0.19$$

From Eq. (8-57) and Table 8-22,

$$\text{SDNR}_b = 0.213 + 0.118[\ln(F/M_b)]$$

$$= 0.213 + 0.118[\ln(2.2)]$$

$$\text{SDNR}_b = 0.306$$

Correct SDNR for internal recycle (Eq. 8-60) and temperature (Eq. 1-44)

$$\text{SDNR}_{\text{adj}} = \text{SDNR}_{IR1} - 0.029 \ln(F/M_b) - 0.012$$

$$= 0.306 - 0.029(\ln 2.2) - 0.012 = 0.271 \text{ g/g} \cdot \text{d}$$

$$SDNR_{15} = SDNR_{20} (1.026)^{15-20} = 0.271 (1.026)^{-5} = 0.238 \text{ g/g} \cdot \text{d}$$

$$NO_r = (22.9 \text{ m}^3) (0.238 \text{ g/g} \cdot \text{d}) (3968 \text{ g/m}^3) = 21,626 \text{ g/d}$$

10. Determine the final alkalinity.

The final alkalinity (as  $\text{CaCO}_3$ ) is determined based on 7.14 g alkalinity used/g  $\text{NH}_4\text{-N}$  oxidized and 3.57 g alkalinity produced/g  $\text{NO}_3\text{-N}$  reduced.

$$NO_x = 25.1 \text{ mg/L}, \text{ final } NO_3\text{-N} = 3.6 \text{ mg/L}$$

$$\begin{aligned} \text{Final alkalinity} &= (200 \text{ g/m}^3) - (7.14 \text{ g/g})(25.1 \text{ g/m}^3) + (3.57 \text{ g/g})(25.1 - 3.6) \text{ g/m}^3 \\ &= 91.0 \text{ mg/L as } \text{CaCO}_3 \end{aligned}$$

11. Determine the oxygen required. The oxygen demand is calculated first for BOD removal and nitrification and then a credit is applied for the oxygen demand satisfied by BOD removal using nitrate in the anoxic zone before the aeration tank.

Using Eq. (8-24), Table 8-10,

$$R_o = Q (S_o - S) - 1.42 P_{X:\text{bio}} + 4.57 Q (NO_x)$$

$$S_o - S \approx S_o = 320 \text{ g/m}^3$$

$$\begin{aligned} R_o &= [(1000 \text{ m}^3/\text{d})(320 \text{ g/m}^3) - 1.42 (74,520 \text{ g/d}) \\ &\quad + 4.57(25.1 \text{ g/m}^3) (1000 \text{ m}^3/\text{d})] (1 \text{ kg}/10^3 \text{ g}) \\ &= (320 - 105.8 + 114.7) \text{ kg/d} = 328.9 \text{ kg/d} \end{aligned}$$

Oxygen equivalent from denitrification

$$O_2 = 2.86 \frac{\text{g O}_2}{\text{g } NO_x} [(25.1 - 3.6) \text{ g/m}^3](1000 \text{ m}^3/\text{d})(1 \text{ kg}/10^3 \text{ g}) = 61.5 \text{ kg/d}$$

$$\text{Net Oxygen required} = (328.9 - 61.5) \text{ kg/d} = 267.4 \text{ kg/d}$$

$$\text{Required oxygen for BOD removal/nitrification} = 328.9 \text{ kg/d}$$

$$\text{Required oxygen with anoxic/aerobic process} = 267.4 \text{ kg/d}$$

$$\text{Energy savings} = \frac{[(328.9 - 267.4)\text{kg/d}]}{(328.9 \text{ kg/d})} (100\%) = 18.7\%$$

### PROBLEM 8-33

**Problem Statement** – see text, page 929

**Solution**

- Determine the anoxic and aerobic volumes. Based on the problem statement the anoxic volume is 10 percent of the total volume:

$$V_{NO_x} = 0.10 (3600 \text{ m}^3) = 360 \text{ m}^3$$

$$\text{Aerobic volume} = (3600 - 360) \text{ m}^3 = 3240 \text{ m}^3$$

- Determine the effluent NH<sub>4</sub>-N concentration. To determine the effluent NH<sub>4</sub>-N concentration, the aerobic SRT must be first calculated, using Eqs. (7-57), (8-20) and (8-21) in Table 8-10.

$$(X_{TSS})V = P_{X,TSS} (\text{SRT})$$

$$P_{X,TSS} = \frac{QY_H(S_o - S)}{[1 + b_H(\text{SRT})]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})]0.85}$$

$$+ \frac{QY_n(NO_x)}{[1 + b_n(\text{SRT})]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

Combine equations

$$(X_{TSS})\left(\frac{V}{Q}\right) = \frac{Y(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})](0.85)X} + \frac{(f_d)(b_H)Y_H(S_o - S)(\text{SRT})^2}{[1 + b_H(\text{SRT})](0.85)X}$$

$$+ \frac{Y_n(NO_x)\text{SRT}}{[1 + b_n(\text{SRT})](0.85)} + (nbVSS)\text{SRT} + (TSS_o - VSS_o)\text{SRT}$$

- Define input for above equation

$$\text{Assume } S_o - S \approx S_o = 240 \text{ mg/L}$$

$$\text{Assume } NO_x \sim 0.80 \text{ (TKN)} = 0.80 (40) = 32 \text{ mg/L}$$

(Note: Nitrifier growth has very small effect on MLSS concentration compared to other factors)

- Define coefficients from Table 8-14 at 10°C:

$$Y = 0.45 \text{ gVSS / g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12 (1.04)^{10-20} = 0.081 \text{ g/g} \cdot \text{d}$$

$$Y_n = 0.20 \text{ g VSS / g NH}_4\text{-N} \text{ (Includes NH}_4\text{-N and NO}_2\text{-N oxidizers)}$$

$$b_n = 0.17 (1.029)^{10-20} = 0.128 \text{ g/g} \cdot \text{d}$$

- Insert data and coefficients into equation

$$\begin{aligned}
 (3500 \text{ g/m}^3) (3240 \text{ m}^3) &= \frac{(0.45 \text{ g/g})(8000 \text{ m}^3/\text{d})(240 \text{ g/m}^3)(\text{SRT})}{[1 + (0.081 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} \\
 &+ \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(8000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(240 \text{ g/m}^3)(\text{SRT})^2}{[1 + (0.081 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} \\
 &+ \frac{(0.20 \text{ g/g})(8000 \text{ m}^3/\text{d})(32 \text{ g/m}^3)(\text{SRT})}{[1 + (0.128 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} + (8000 \text{ m}^3/\text{d})(60 \text{ g/m}^3)(\text{SRT}) \\
 &+ (8000 \text{ m}^3/\text{d})[(80 - 70)\text{g/m}^3](\text{SRT})
 \end{aligned}$$

6. Solve equation on spreadsheet by selecting SRT value where left and right side of equation are equal.

$$\begin{aligned}
 11,340,000 \text{ g} &= \frac{1,106,470(\text{SRT})}{1 + 0.081\text{SRT}} + \frac{12,350(\text{SRT})^2}{1 + 0.081\text{SRT}} + \frac{60,235(\text{SRT})}{1 + 0.128\text{SRT}} \\
 &+ 480,000 \text{ SRT} + 80,000 \text{ SRT}
 \end{aligned}$$

$$\text{SRT} = 9.2 \text{ d}$$

7. Calculate effluent NH<sub>4</sub>-N concentration.

Determine effluent NH<sub>4</sub>-N (N<sub>e</sub>) concentrations as a function of SRT by combining Eq. (7-94) and Eq. (7-98) in Table 10. Let S<sub>o</sub> = DO.

$$\frac{1}{\text{SRT}} = \left( \frac{\mu_{\max, \text{AOB}} S_{\text{NH}_4}}{K_{\text{NH}_4} + S_{\text{NH}_4}} \right) \left( \frac{\text{DO}}{K_o + \text{DO}} \right) - b_{\text{AOB}}$$

The nitrification coefficients are obtained from Table 8-14. Use the temperature correction Eq. (1-44) shown in Table 8-10.

$$k_T = k_{20}(\theta)^{T-20}$$

$$\text{Temperature} = 10^\circ\text{C}$$

$$\mu_{\max, \text{AOB}} = 0.90 (1.072)^{10-20} = 0.449 \text{ g/g} \cdot \text{d}$$

$$K_{\text{NH}_4} = 0.50 (1.0)^{10-20} = 0.50 \text{ g/m}^3$$

$$b_{\text{AOB}} = 0.17(1.029)^{10-20} = 0.128 \text{ g/g} \cdot \text{d}$$

$$K_o = 0.50 \text{ g/m}^3$$

$$Y_n = 0.15 \text{ g VSS/g NH}_4\text{-N oxidized}$$

Solving for S<sub>NH<sub>4</sub></sub> (let S<sub>NH<sub>4</sub></sub> = N<sub>e</sub>):

$$N_e = \frac{K_{NH_4}[1 + b_{AOB}(SRT)]}{\left[ \mu_{max,AOB} \left( \frac{DO}{K_o + DO} \right) - b_{AOB} \right] SRT - 1}$$

$$N_e = \frac{(0.50 \text{ g/m}^3)[1 + (0.128 \text{ g/g}\cdot\text{d})(9.2 \text{ d})]}{(9.2 \text{ d}) \left\{ (0.449 \text{ g/g}\cdot\text{d}) \left[ \frac{(2.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3) + (2.0 \text{ g/m}^3)} \right] - (0.128 \text{ g/g}\cdot\text{d}) \right\} - 1}$$

At SRT = 9.2 d,  $N_e = 0.97 \text{ g/m}^3$

8. Calculate effluent  $NO_3\text{-N}$  concentration. To determine the effluent  $NO_3\text{-N}$  concentration, the amount of  $NO_3\text{-N}$  produced ( $NO_x$ ) in the aerobic zone and the amount of  $NO_3\text{-N}$  that can be removed in the anoxic zone must be determined. The difference is the  $NO_3\text{-N}$  in the effluent.
- a. To determine  $NO_x$ , use equation (8-24) in Table 8-10:

$$NO_x = TKN - N_e - 0.12 P_{X,\text{bio}}/Q$$

$P_{X,\text{bio}}$  is determined from appropriate components of Eq. (8-15)

$$P_{X,\text{bio}} = \frac{Q(Y_H)(S_o - S)}{1 + b_H(SRT)} + \frac{f_d(b_H)Q(Y_H)(S_o - S)SRT}{1 + b_H(SRT)} + \frac{QY_n(NO_x)}{1 + b_n(SRT)}$$

$$P_{X,\text{bio}} = \frac{(8000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(240 \text{ g/m}^3)}{[1 + 0.081 \text{ g/g}\cdot\text{d}(9.2 \text{ d})]} + \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(8000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(240 \text{ g/m}^3)(9.2 \text{ d})}{[1 + (0.081 \text{ g/g}\cdot\text{d})(9.2 \text{ d})]}$$

$$+ \frac{(8000 \text{ m}^3/\text{d})(0.15 \text{ g/g})(32 \text{ g/m}^3)}{[1 + 0.128 \text{ g/g}\cdot\text{d}(9.2 \text{ d})]}$$

$$P_{X,\text{bio}} = (495,072 + 55,339 + 17,634) \text{ g/d} = 568,045 \text{ g/d}$$

$$NO_x = 40 \text{ g/m}^3 - 0.97 \text{ g/m}^3 - \frac{0.12(568,045 \text{ g/d})}{(8000 \text{ m}^3/\text{d})} = 30.5 \text{ g/m}^3$$

- b. To determine the nitrate removed in the anoxic zone use Eq. (8-52) (based on biomass)

$$NO_r = V_{nox} (\text{SDNR})(\text{MLVSS}_{\text{biomass}})$$

The SDNR is a function of the anoxic zone  $F/M_b$  ratio.

Use Eq. (8-56) to compute F/M<sub>b</sub>

$$F / M_b = \frac{QS_o}{X_b V_{nox}} \text{ Where } S_o = \text{BOD}$$

$$\text{BOD} = 240/1.6 = 150 \text{ g/m}^3$$

- c. Determine X<sub>b</sub> using Eq. (8-20) in Table 8-10.

Assume S<sub>o</sub> – S ≈ S<sub>o</sub>

$$X_b = \frac{QY_H(S_o - S)SRT}{[1 + (b_H)SRT]V} = \frac{(8000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(240 \text{ g/m}^3)(9.2 \text{ d})}{[(1 + 0.081 \text{ g/g}\cdot\text{d})(9.2 \text{ d})](3240 \text{ m}^3)}$$

$$X_b = 1406 \text{ g/m}^3$$

- d. From Step 1 V<sub>nox</sub> = 360 m<sup>3</sup>

$$F / M_b = \frac{QS_o}{X_b V_{nox}} = \frac{(8000 \text{ m}^3/\text{d})(150 \text{ g/m}^3 \text{ BOD})}{(1406 \text{ g/m}^3)(360 \text{ m}^3)} = 2.37 \text{ g/g}\cdot\text{d}$$

#### 9. Determine SDNR for wastewater 1

- a. Compute rbCOD fraction and determine SDNR based on rbCOD fraction:

$$\text{rbCOD fraction} = \frac{(25 \text{ g/m}^3)}{(240 \text{ g/m}^3 \text{ bCOD})} = 0.10$$

From Eq. (8-57) and coefficients in Table 8-22,

$$SDNR_b = 0.186 + 0.078[\ln(F/M_b)]$$

$$= 0.186 + 0.078[\ln(2.37)]$$

$$SDNR_b = 0.253$$

- b. Correct SDNR for internal recycle (Eq. 8-60) (assume ratio = 3-4) and for temperature (Eq. 1-44)

$$SDNR_{adj} = SDNR_{IR1} - 0.029 \ln(F/M_b) - 0.012$$

$$= 0.253 - 0.029(\ln 2.37) - 0.012 = 0.216 \text{ g/g}\cdot\text{d}$$

$$SDNR_{10} = SDNR_{20} (1.026)^{10-20} = 0.216 (1.026)^{-10} = 0.167 \text{ g/g}\cdot\text{d}$$

$$NO_r = (360 \text{ m}^3)(0.167 \text{ g/g}\cdot\text{d})(1406 \text{ g/m}^3) = 84,528 \text{ g/d}$$

$$\text{Based on flow; NO}_3\text{-N removal} = \frac{(84,528 \text{ g/d})}{(8000 \text{ m}^3/\text{d})} = 10.6 \text{ g/m}^3$$

$$\text{Effluent } \text{NO}_3\text{-N} = \text{NO}_x - \text{NO}_3\text{-N removal}$$

$$= (30.5 - 10.6) \text{ g/m}^3 = 19.9 \text{ g/m}^3$$

9. Determine the internal recycle ratio using Eq. (8-62)

$$\text{IR} = \frac{\text{NO}_x}{\text{N}_e} - 1.0 - R$$

$$\text{IR} = \frac{(30.5 \text{ g/m}^3)}{(19.9 \text{ g/m}^3)} - 1.0 - 0.5 = 0.03$$

An iteration is required as the nitrate that can be removed in the anoxic zone can be supplied by the recycle. Thus, there is no correction to the SDNR based on recycle.

10. Recalculate effluent  $\text{NO}_x\text{-N}$  concentration.

$$\text{SDNR}_b = 0.253$$

Correct SDNR for temperature only.

$$\text{SDNR}_{10} = \text{SDNR}_{20} (1.026)^{10-20} = 0.253 (1.026)^{-10} = 0.196 \text{ g/g} \cdot \text{d}$$

$$\text{NO}_r = (360 \text{ m}^3) (0.196 \text{ g/g} \cdot \text{d}) (1406 \text{ g/m}^3) = 99,207 \text{ g/d}$$

$$\text{Based on flow; } \text{NO}_3\text{-N removal} = \frac{(99,207 \text{ g/d})}{(8000 \text{ m}^3/\text{d})} = 12.4 \text{ g/m}^3$$

$$\text{Effluent } \text{NO}_3\text{-N} = \text{NO}_x - \text{NO}_3\text{-N removal}$$

$$= (30.5 - 12.4) \text{ g/m}^3 = 18.1 \text{ g/m}^3$$

$$\text{IR} = \frac{(30.5 \text{ g/m}^3)}{(18.1 \text{ g/m}^3)} - 1.0 - 0.5 = 0.18$$

So again no significant internal recycle is needed. In lieu of recycle, the RAS recycle rate can be increased slightly.

### PROBLEM 8-34

**Problem Statement** – see text, page 930

**Solution**

Provide solution assuming steady state operating conditions with no safety factor for nitrification.

- Determine the design effluent NH<sub>4</sub>-N concentration. To determine the design effluent NH<sub>4</sub>-N concentration, calculate the aerobic SRT using Eqs. (8-20), (8-21), and (7-57) in Table 8-10.

Eq. 7-57.  $(X_{TSS})V = P_{X,TSS} \text{ (SRT)}$

$$P_{X,TSS} = \frac{QY_H(S_o - S)}{[1 + b_H(\text{SRT})]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})]0.85}$$

$$+ \frac{QY_n(NO_X)}{[1 + b_n(\text{SRT})]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

Substituting  $P_{X,TSS}$  in Eq. (7-57).

$$(X_{TSS})(V) = \frac{QY_H(S_o - S)\text{SRT}}{[1 + b_H(\text{SRT})]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)(\text{SRT})^2}{[1 + b_H(\text{SRT})]0.85}$$

$$+ \frac{QY_n(NO_X)\text{SRT}}{[1 + b_n(\text{SRT})]0.85} + Q(nbVSS)\text{SRT} + Q(TSS_o - VSS_o)\text{SRT}$$

- Define input for above equation for **wastewater 1**

Influent bCOD = 1.6 (BOD) = 1.6 (250) = 400 mg/L

Assume  $S_o - S \approx S_o = 400$  mg/L

Assume  $NO_X \sim 0.80$  (TKN) = 0.80 (40) = 32 mg/L

(Note: Nitrifier growth has very small effect on MLSS concentration compared to other factors)

- Determine coefficients from Table 8-14 and adjust for temperature using Eq. (1-44) and the table  $\theta$  values

$$k_T = k_{20}(\theta)^{T-20}$$

For heterotrophs:

$$Y = 0.45 \text{ gVSS/g bCOD}$$

$$f_d = 0.15 \text{ g/g}$$

$$b_H = 0.12(1.04)^{10-20} = 0.081 \text{ g/g}\cdot\text{d}$$

For nitrification:

$$\mu_{max,AOB} = (0.90 \text{ g/g}\cdot\text{d}) (1.072)^{10-20} = 0.449 \text{ g/g}\cdot\text{d}$$

$$k_{NH_4} = (0.50 \text{ mg/L}) (1.0)^{10-20} = 0.50 \text{ g/m}^3$$

$$b_{AOB} = (0.17 \text{ g/g}\cdot\text{d}) (1.029)^{10-20} = 0.128 \text{ g/g}\cdot\text{d}$$

$Y_n = 0.20 \text{ g VSS / g NH}_4\text{-N}$  (including both ammonia- and nitrite-oxidizers)

$Y_n = 0.15 \text{ g VSS / g NH}_4\text{-N}$  for ammonia-oxidizers

$$K_o = 0.50 \text{ g/m}^3$$

4. Determine the aerobic volume

$$\text{Aerobic volume} = 0.50 (4600 \text{ m}^3) = 2300 \text{ m}^3$$

5. Insert data and coefficients into above equation. Assume a typical ditch detention time of 24 hours, so flow = 4600 m<sup>3</sup>/d. Thus:

$$(3500 \text{ g/m}^3) (2300 \text{ m}^3) = \frac{(0.45 \text{ g/g})(4600 \text{ m}^3/\text{d})(400 \text{ g/m}^3)(\text{SRT})}{[1 + (0.081 \text{ g/g}\cdot\text{d})\text{SRT}]0.85}$$

$$+ \frac{(0.15 \text{ g/g})(0.081 \text{ g/g}\cdot\text{d})(4600 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)(\text{SRT})^2}{[1 + (0.081 \text{ g/g}\cdot\text{d})\text{SRT}]0.85}$$

$$+ \frac{(0.20 \text{ g/g})(4600 \text{ m}^3/\text{d})(32 \text{ g/m}^3)(\text{SRT})}{[1 + (0.128 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} + (4600 \text{ m}^3/\text{d})(80 \text{ g/m}^3)(\text{SRT})$$

$$+ (4600 \text{ m}^3/\text{d})[(220 - 210) \text{ g/m}^3](\text{SRT})$$

6. Solve equation on spreadsheet by selecting SRT value where left and right side of equation are equal.

$$8,050,000 \text{ g} =$$

$$\frac{974,117(\text{SRT})}{1 + .081\text{SRT}} + \frac{11,836(\text{SRT})^2}{1 + 0.081\text{SRT}} + \frac{34,635(\text{SRT})}{1 + 0.128\text{SRT}} + 368,000\text{SRT} + 46,000\text{SRT}$$

$$\text{SRT} = 8.0 \text{ d}$$

7. Determine effluent NH<sub>4</sub>-N ( $N_e$ ) concentrations as a function of SRT by combining Eq. (7-94) and Eq. (7-98) in Table 10. Let  $S_o$  = DO. Assume average DO concentration = 1.0 mg/L as it varies in the ditch from 0 to 2.0 mg/L.

$$\frac{1}{\text{SRT}} = \left( \frac{\mu_{max,AOB} S_{NH_4}}{K_{NH_4} + S_{NH_4}} \right) \left( \frac{DO}{K_o + DO} \right) - b_{AOB}$$

Solving for  $S_{NH_4}$  (let  $S_{NH_4} = N_e$ ):

$$N_e = \frac{K_{NH_4}(1 + b_{AOB}SRT)}{\left[ \mu_{max,AOB} \left( \frac{DO}{K_0 + DO} \right) - b_{AOB} \right] SRT - 1}$$

$$N_e = \frac{(0.50 \text{ g/m}^3)[1 + (0.128 \text{ g/g}\cdot\text{d})(8.0 \text{ d})]}{\left\{ (0.449 \text{ g/g}\cdot\text{d}) \left[ \frac{(1.0 \text{ g/m}^3)}{(0.50 \text{ g/m}^3) + (1.0 \text{ g/m}^3)} \right] - (0.128 \text{ g/g}\cdot\text{d}) \right\} (8.0 \text{ d}) - 1}$$

$$N_e = 2.7 \text{ g/m}^3$$

8. Calculate nitrate removal. The amount of nitrate removed in the half of the ditch that is anoxic is calculated from Eq. (8-52) and Eqs. (8-66), (8-67), and (8-68).

$$\text{Eq. (8-52): } NO_r = V_{nox}(SDNR_b)(MLVSS \text{ biomass})$$

$$\text{Eq. (8-66): } SDNR_b = \frac{0.175 A_n}{(Y_{net})SRT}$$

The total system SRT is used in Eq. (8-66) to reflect the endogenous decay activity of the mixed liquor for nitrate reduction. The same equation used above for the nitrification aerobic SRT calculation is used with the exception that the volume is 4600 m<sup>3</sup> instead of 2300 m<sup>3</sup>:

$$8,050,000 \left( \frac{4600 \text{ m}^3}{2300 \text{ m}^3} \right) =$$

$$\frac{974,117(SRT)}{1+0.081SRT} + \frac{11,836(SRT)^2}{1+0.081SRT} + \frac{34,635(SRT)}{1+0.128SRT} + 368,000SRT + 46,000SRT$$

$$SRT = 17.7 \text{ d}$$

To obtain the SDNR<sub>b</sub> value  $A_n$  and  $Y_{net}$  values must be calculated for use in Eq. (8-66).  $A_n$  is calculated using Eq. (8-67).

$$A_n = 1.0 - 1.42Y_H + \frac{1.42(b_H)(Y_H)SRT}{1+(b_H)SRT}$$

$$A_n = 1.0 - 1.42 (0.45 \text{ g/g}) + \frac{1.42(0.081\text{g/g}\cdot\text{d})(0.45\text{g/g})17.7\text{d}}{[1+(0.081\text{g/g}\cdot\text{d})(17.7\text{d})]}$$

$$A_n = 0.737 \text{ g O}_2 / \text{g bCOD}$$

$Y_{net}$  is calculated using Eq. (8-68).

$$Y_{net} = \frac{Y}{1+(b_H)SRT} = \frac{(0.45\text{g/g})}{[1+(0.081\text{g/g}\cdot\text{d})(17.7\text{d})]} = 0.185 \text{ g VSS / g bCOD}$$

$$\text{Then SDNR}_b = \frac{0.175 A_N}{(Y_{net})SRT} = \frac{0.175(0.737\text{g/g})}{(0.185\text{g/g})(17.7\text{d})} = 0.039 \text{ g/g} \cdot \text{d}$$

$V_{nox} = 2300 \text{ m}^3$  and

$$NO_r = (2300 \text{ m}^3) (0.039 \text{ g/g} \cdot \text{d}) (X_b)$$

$X_b$  is calculated using Eq. (8-20) in Table 8-10:

$$X_b = \frac{Q(Y_H)(S_o - S)SRT}{[1+(b_H)SRT]V} = \frac{(4600\text{m}^3/\text{d})(0.45\text{g/g})(400\text{g/m}^3)(17.7\text{d})}{[1+(0.081\text{g/g}\cdot\text{d})(17.7\text{d})](4600\text{m}^3)} = 1309$$

g/m<sup>3</sup>

$$NO_r = (2300 \text{ m}^3)(0.039 \text{ g/g} \cdot \text{d})(1309 \text{ g/m}^3) = 117,417 \text{ g/d}$$

$$NO_3\text{-N removed, normalized to flow} = \frac{(117,417 \text{ g/d})}{(4600\text{m}^3/\text{d})} = 25.5 \text{ g/m}^3$$

The effluent  $NO_3\text{-N}$  equals the  $NO_3\text{-N}$  produced minus the  $NO_3\text{-N}$  reduced in the ditch anoxic volume. The  $NO_3\text{-N}$  produced ( $NO_x$ ) is determined using Eq. (8-24) in Table 8-10:

$$NO_x = TKN - N_e - 0.12 P_{X,bio}/Q$$

$P_{X,bio}$  is determined from the appropriate components of Eqs. (8-20) and (8-21):

$$P_{X,bio} = \frac{QY_H(S_o - S)}{[1+b_H(SRT)]} + \frac{(f_d)(b_H)QY_H(S_o - S)SRT}{[1+b_H(SRT)]} + \frac{QY_n(NO_X)}{[1+b_n(SRT)]}$$

$$P_{X,bio} = \frac{(4600\text{m}^3/\text{d})(0.45\text{g/g})(400\text{g/m}^3)}{[1+(0.081\text{g/g}\cdot\text{d})(17.7\text{d})]}$$

$$+ \frac{(0.15\text{g/g})(0.081\text{g/g}\cdot\text{d})(4600\text{m}^3/\text{d})(0.45\text{g/g})(400\text{g/m}^3)(17.7\text{d})}{[1+(0.081\text{g/g}\cdot\text{d})(17.7\text{d})]}$$

$$+ \frac{(4600 \text{ m}^3/\text{d})(0.15 \text{ g/g})(32 \text{ g/m}^3)}{[1 + (0.128 \text{ g/g}\cdot\text{d})(17.7 \text{ d})]}$$

$$P_{X,\text{bio}} = (340,222 + 73,166 + 6,761) \text{ g/d} = 420,149 \text{ g/d}$$

$$\text{NO}_x = 40 \text{ g/m}^3 - 2.7 \text{ g/m}^3 - \frac{(0.12 \text{ g/g})(420,149 \text{ g/d})}{(4600 \text{ m}^3/\text{d})} = 26.3 \text{ g/m}^3$$

$$\text{Effluent NO}_3\text{-N} = \text{NO}_x - \text{NO}_3\text{-N removed} = (26.3 - 25.5) \text{ g/m}^3 = 0.80 \text{ g/m}^3$$

### PROBLEM 8-35

**Problem Statement** – see text, page 930

**Solution**

**Instructors Note:** For the SBR design, there is no mixing during the fill so that nitrate remaining after aeration, settling, and decanting will likely be consumed by the influent BOD during the non-aerated, anoxic fill period. The effluent NO<sub>3</sub>-N concentration is then a function of how much nitrate is produced during each cycle and its dilution by the SBR tank volume.

1. Determine the nitrate produced in each cycle for **wastewater 1**. The NO<sub>3</sub>-N produced each cycle is:

$$V_F (\text{NO}_x), \text{ g/d}$$

where V<sub>F</sub> is the fill volume (and effluent volume) per cycle. The NO<sub>3</sub>-N produced is equal to the mass in the total volume, assuming that all the NO<sub>3</sub>-N is reduced in the mixed un-aerated fill step.

$$V_F (\text{NO}_x) = V_T (\text{NO}_e)$$

where, NO<sub>e</sub> = reactor NO<sub>3</sub>-N concentration before settling

$$\frac{V_F}{V_T} (\text{NO}_x) = 6 \text{ mg/L NO}_3\text{-N}$$

Thus, the fill volume fraction,  $\frac{V_F}{V_T}$ , determines the effluent NO<sub>3</sub>-N concentration.

An iterative solution is necessary and the procedure is as follows:

- Assume  $\text{NO}_x = 0.80$  (TKN)
  - Determine  $\frac{V_F}{V_T}$
  - Solve for  $V_F$  based on flow and cycle times and then calculate  $V_T$
  - From  $V_T$  and the assumed MLSS concentration, determine the SRT
  - From the SRT, determine  $P_{X,\text{bio}}$  and  $\text{NO}_x$
  - If  $\text{NO}_x$  is not equal or close to assumed  $\text{NO}_x$ , perform the calculation with another  $\text{NO}_x$  value
  - With final solution SRT, determine the nitrifying bacteria concentration ( $X_N$ ) and calculate the  $\text{NH}_4\text{-N}$  concentration at the end of the aeration period.
1. Compute  $\text{NO}_x$ ;  $\text{NO}_x = 0.80$  (45 mg/L) = 36 mg/L
  2. Determine  $\frac{V_F}{V_T}$ ;  $\frac{V_F}{V_T}$  (36 mg/L) = 6.0 mg/L  

$$\frac{V_F}{V_T} = \frac{(6.0 \text{ mg/L})}{(36.0 \text{ mg/L})} = \frac{1}{6} = 0.167$$
  3. Determine the number of cycles/day and  $V_F$  by assuming uniform flow and the fill time ( $t_F$ ) for one tank equals the sum of the aeration time ( $t_A$ ), settle time ( $t_S$ ), and decant time ( $t_D$ ) for the second SBR tank.  
 $t_F = t_A + t_S + t_D$   
 $T_C = \text{cycle time} = t_F + t_A + t_S + t_D$   
From information provided,  $t_F = (2.0 + 1.0 + 0.5) \text{ h} = 3.5 \text{ h}$   
 $T_C = 3.5 \text{ h} + 3.5 \text{ h} = 7.0 \text{ h/cycle}$   
Average number of cycle/d =  $\frac{(24 \text{ h/d})}{(7.0 \text{ h/cycle})} = 3.43 \text{ cycle/d}$   
For 2 tanks, total number of cycle/d = 2 (3.43) = 6.86  
 $V_F = \frac{(\text{flow/d})}{(\text{cycles/d})} = \frac{(5000 \text{ m}^3/\text{d})}{(6.86 \text{ cycles/d})} = 792.2 \text{ m}^3/\text{cycle}$

$$\frac{V_F}{V_T} = \frac{792.2 \text{ m}^3}{V_T} = 0.167$$

$$V_T = \frac{792.2 \text{ m}^3}{0.167} = 4374 \text{ m}^3$$

4. Determine the SRT using Eqs. (8-20), (8-21), and (7-57).

a. From Eqs. (8-20) and (8-21)

$$P_{X,TSS} = \frac{QY_H(S_o - S)}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85}$$

$$+ \frac{QY_n(NO_x)}{[1 + b_n(SRT)]0.85} + Q(nbVSS) + Q(TSS_o - VSS_o)$$

Substituting  $P_{X,TSS}$  in Eq. (7-57).

$$(X_{TSS})(V) = \frac{QY_H(S_o - S)SRT}{[1 + b_H(SRT)]0.85} + \frac{(f_d)(b_H)QY_H(S_o - S)(SRT)^2}{[1 + b_H(SRT)]0.85}$$

$$+ \frac{QY_n(NO_x)SRT}{[1 + (b_n)SRT]0.85} + Q(nbVSS)SRT + Q(TSS_o - VSS_o)SRT$$

b. Define values for solution to above equation:

$$\text{Influent bCOD} = 1.6 \text{ (BOD)} = 1.6(250) = 400 \text{ mg/L}$$

$$\text{Assume } S_o - S \approx \text{influent bCOD} = 1.6(\text{BOD}) = 1.6(250 \text{ g/m}^3)$$

$$= 400 \text{ g/m}^3$$

$$\text{Volume/tank} = 4374 \text{ m}^3$$

$$\text{Flow/tank} = \frac{(5000 \text{ m}^3/\text{d})}{2} = 2500 \text{ m}^3/\text{d}$$

c. Develop coefficients from Tables 8-14 at 12°C:

$$Y = 0.45 \text{ g/g}$$

$$K_n = 0.50(1.0)^{12-20} = 0.50 \text{ g/m}^3$$

$$b_H = 0.12(1.04)^{12-20} = 0.088 \text{ g/g} \cdot \text{d}$$

$$Y_n = 0.20 \text{ g/g (including ammonia- and nitrite- oxidizers)}$$

$$b_n = 0.17(1.029)^{12-20} = 0.135 \text{ g/g} \cdot \text{d}$$

$$\mu_{max,AOB} = 0.90(1.072)^{12-20} = 0.516 \text{ g/g} \cdot \text{d}$$

$$K_o = 0.50 \text{ g/m}^3$$

- d. Insert values and coefficients in equation developed in 4a and compute SRT.

$$(4000 \text{ g/m}^3) (4374 \text{ m}^3) = \frac{(0.45 \text{ g/g})(2500 \text{ m}^3/\text{d})(400 \text{ g/m}^3)(\text{SRT})}{[1 + (0.088 \text{ g/g}\cdot\text{d})\text{SRT}]0.85}$$

$$+ \frac{(0.15 \text{ g/g})(0.088 \text{ g/g}\cdot\text{d})(2500 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)(\text{SRT})^2}{[1 + (0.088 \text{ g/g}\cdot\text{d})\text{SRT}]0.85}$$

$$+ \frac{(0.20 \text{ g/g})(2500 \text{ m}^3/\text{d})(36 \text{ g/m}^3)(\text{SRT})}{[1 + (0.135 \text{ g/g}\cdot\text{d})\text{SRT}]0.85} + (2500 \text{ m}^3/\text{d})(120 \text{ g/m}^3)(\text{SRT})$$

$$+ (2500 \text{ m}^3/\text{d})[(220 - 210)\text{g/m}^3](\text{SRT})$$

$$17,496,000 \text{ g} =$$

$$\frac{529,411(\text{SRT})}{1 + .088(\text{SRT})} + \frac{6988(\text{SRT})^2}{1 + 0.088(\text{SRT})} + \frac{21,176(\text{SRT})}{1 + 0.135(\text{SRT})} + 300,000(\text{SRT}) + 25,000(\text{SRT})$$

$$\text{SRT} = 33.5 \text{ d}$$

5. Determine  $P_{X,\text{bio}}$  using appropriate components of Eq. (8-15)

$$P_{X,\text{bio}} = \frac{Q(Y_H)(S_o - S)}{1 + b_H(\text{SRT})} + \frac{f_d(b_H)Q(Y_H)(S_o - S)\text{SRT}}{1 + b_H(\text{SRT})} + \frac{QY_n(\text{NO}_x)}{1 + b_n(\text{SRT})}$$

$$P_{X,\text{bio}} = \frac{(2500 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)}{[1 + (0.088 \text{ g/g}\cdot\text{d})(33.5 \text{ d})]}$$

$$+ \frac{(0.15 \text{ g/g})(0.088 \text{ g/g}\cdot\text{d})(2500 \text{ m}^3/\text{d})(0.45 \text{ g/g})(400 \text{ g/m}^3)(33.5 \text{ d})}{[1 + 0.088 \text{ g/g}\cdot\text{d}(33.5 \text{ d})]}$$

$$+ \frac{(2500 \text{ m}^3/\text{d})(0.20 \text{ g/g})(36 \text{ g/m}^3)}{[1 + 0.135 \text{ g/g}\cdot\text{d}(33.5 \text{ d})]}$$

$$P_{X,\text{bio}} = (113,981 + 50,402 + 3259) \text{ g/d} = 167,642 \text{ g/d}$$

6. Determine  $\text{NO}_x$  using Eq. (8-24):

$$\text{NO}_x = \text{TKN} - N_e - 0.12 P_{X,\text{bio}}/Q$$

Considering a long SRT, assume  $N_e = 0.5 \text{ mg/L NH}_4\text{-N}$

$$\text{NO}_x = 45.0 \text{ g/m}^3 - 0.5 \text{ g/m}^3 - \frac{0.12(167,642 \text{ g/d})}{(2500 \text{ m}^3/\text{d})}$$

$\text{NO}_x = 36.5 \text{ g/m}^3$  (close to assumption of 36.0 mg/L; an additional iteration is not necessary)

7. Volume of each SBR tank =  $4374 \text{ m}^3$
8. Compute the decant pumping rate. The decant pumping rate equals the fill volume divided by decant time:

$$Q_D = \frac{V_F}{t_D} = \frac{729.2 \text{ m}^3}{30 \text{ min}} = 24.3 \text{ m}^3/\text{min}$$

9. Compute the nitrification safety factor
  - a. Compute the ammonia oxidizing bacteria concentration by using Eq. (7-42) in Table 8-10:

$$X_n = \frac{Q(Y_n)(\text{NO}_x)\text{SRT}}{[1 + (b_n)\text{SRT}](V)}$$

Per Example 8-5, calculate weighted average nitrifier endogenous decay rate:

$$\text{Aerobic } b_n = 0.135 \text{ g/g}\cdot\text{d}$$

$$\text{Anoxic } b_n = (0.07 \text{ g/g}\cdot\text{d})(1.029)^{12-20} = 0.056 \text{ g/g}\cdot\text{d}$$

$$\text{Fraction of cycle aerobic} = \frac{t_A}{t_C} = \frac{2 \text{ h}}{7 \text{ h}} = 0.285$$

$$\text{Fraction of cycle anoxic} = (1 - \frac{2 \text{ h}}{7 \text{ h}}) = 0.715$$

$$\text{Average } b_{n,12^\circ\text{C}} = 0.285(0.135) + 0.715(0.056)$$

$$= 0.078 \text{ g/g}\cdot\text{d}$$

$$X_n = \frac{(2500 \text{ m}^3/\text{d})(0.15 \text{ g/g})(36.5 \text{ g/m}^3)(33.5 \text{ d})}{[1 + (0.078 \text{ g/g}\cdot\text{d})(33.5 \text{ d})](4374 \text{ m}^3)}$$

$$X_n = 29.0 \text{ g/m}^3$$

- b. Solve for  $\text{NH}_4\text{-N}$  as a function of aeration time in the batch reaction using Eq. (8-53)

$$K_n \ln \left( \frac{N_o}{N_t} \right) + (N_o - N_t) = X_n \left( \frac{\mu_{max}}{Y_n} \right) \left( \frac{DO}{K_o + DO} \right) t$$

Assuming effluent  $\text{NH}_4\text{-N} = 0.50 \text{ mg/L}$ , a mass balance on available  $\text{NH}_4\text{-N}$  after the fill is done to obtain  $N_o$ , the initial available  $\text{NH}_4\text{-N}$  concentration.

$$(V_T - V_F) N_e + V_F (NO_x) = V_T (N_o)$$

$$\left(1 - \frac{V_F}{V_T}\right) N_e + \frac{V_F}{V_T} (NO_x) = N_o$$

$$(1 - 0.167) (0.5 \text{ g/m}^3) + 0.167 (36.5 \text{ g/m}^3) = N_o$$

$$N_o = 6.5 \text{ g/m}^3$$

$$0.50 \ln\left(\frac{6.5}{N_t}\right) + (6.5 - N_t) = (29.0 \text{ g/m}^3) \left[ \frac{(0.516 \text{ g/g}\cdot\text{d})}{(0.15 \text{ g/g})} \right] + \left[ \frac{(2.0 \text{ g/m}^3)}{(0.5 + 2.0) \text{ g/m}^3} \right] t$$

$$0.50 \ln\left(\frac{6.5}{N_t}\right) + (6.5 - N_t) = 79.8 t$$

$$\text{at } N_t = 1.0 \text{ g/m}^3,$$

$$0.94 + 5.5 = 79.8 t$$

$$t = 0.08 \text{ d} = 1.92 \text{ h}$$

$$\text{Aeration time} = 2.0 \text{ h}$$

Thus, safety factor  $\approx 1.0$

### PROBLEM 8-36

**Problem Statement** – see text, page 931

**Solution**

- Using synthesis yield values given, determine exogenous carbon dose in mg COD/L to remove 5 mg/L  $\text{NO}_3\text{-N}$  for methanol, acetate, and ethanol.

Use Eq. (8-69) to determine the carbon consumptive ratio  $C_R$ , g COD/g  $\text{NO}_3\text{-N}$ .

$$C_{R,\text{NH}_3} = \frac{2.86}{1 - 1.42 Y_H}$$

a. For methanol,

$$C_{R,\text{NO}_3} = \frac{2.86}{1 - 1.42(0.25 \text{ gVSS/gCOD})}$$

$$C_R = 4.43 \text{ g COD/g NO}_3\text{-N}$$

$$\text{Dose} = (4.43 \text{ g/g})(5.0 \text{ mg/L})$$

$$\text{Dose} = 22.2 \text{ mg/L methanol COD}$$

b. For acetate,

$$C_{R,\text{NO}_3} = \frac{2.86}{1 - 1.42(0.40 \text{ gVSS/gCOD})}$$

$$C_R = 6.62 \text{ g COD/g NO}_3\text{-N}$$

$$\text{Dose} = (6.62 \text{ g/g})(5.0 \text{ mg/L})$$

$$\text{Dose} = 33.1 \text{ mg/L acetate COD}$$

c. For ethanol,

$$C_{R,\text{NO}_3} = \frac{2.86}{1 - 1.42(0.36 \text{ gVSS/gCOD})}$$

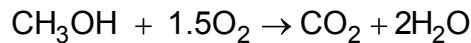
$$C_R = 5.85 \text{ g COD/g NO}_3\text{-N}$$

$$\text{Dose} = (5.85 \text{ g/g})(5.0 \text{ mg/L})$$

$$\text{Dose} = 29.3 \text{ mg/L ethanol COD}$$

2. Describe dose needed in terms of the substrate concentration, in g COD/g substrate.

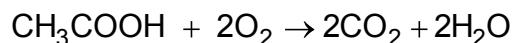
a. Methanol



$$\frac{\text{g O}_2}{\text{g methanol}} = \frac{1.5(32 \text{ g/mole})}{1.0(32 \text{ g/mole})} = 1.5 \text{ gCOD/g methanol}$$

$$\begin{aligned} \text{Dose as methanol} &= (22.2 \text{ mg COD/L}) \left[ \frac{1}{(1.5 \text{ gCOD/g methanol})} \right] \\ &= 14.8 \text{ mg/L methanol} \end{aligned}$$

b. Acetate

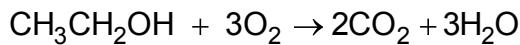


$$\frac{\text{g O}_2}{\text{g acetate}} = \frac{2.0(32 \text{ g/mole})}{1.0(60 \text{ g/mole})} = 1.067 \text{ gCOD/g acetate}$$

$$\text{Dose as acetate} = (33.1 \text{ mg COD/L}) \left[ \frac{1}{(1.067 \text{ g COD/g acetate})} \right]$$

$$= 31.0 \text{ mg/L acetate}$$

## c. Ethanol



$$\frac{\text{g O}_2}{\text{g ethanol}} = \frac{3.0(32 \text{ g/mole})}{1.0(46 \text{ g/mole})} = 2.09 \text{ g COD/g ethanol}$$

$$\text{Dose as ethanol} = (29.3 \text{ mg COD/L}) \left[ \frac{1}{(2.09 \text{ g COD/g ethanol})} \right]$$

$$= 14.0 \text{ mg/L ethanol}$$

## 3. Summary

Substrate dose to remove 5.0 mg/L NO<sub>3</sub>-N

Substrate	mg COD/L	mg substrate/L
Methanol	22.2	14.8
Acetate	33.1	31.0
Ethanol	29.3	14.0

**PROBLEM 8-37****Problem Statement** – see text, page 931**Solution (Wastewater 1)**

1. Determine the acetate consumptive ratio using Eq. (8-69).

$$C_{R,\text{NO}_3} = \frac{2.86}{1 - 1.42(0.4 \text{ g VSS/g COD})} = 6.62 \text{ g COD/g NO}_3\text{-N}$$

2. Determine the amount of NO<sub>3</sub>-N reduced due to endogenous decay using Eq. (8-63).

$$R_{\text{NO}_3} = \frac{1.42}{2.86} (b_{H,\text{anox}})(X_H)(V_{\text{anox}})$$

From Table 8-14, the endogenous decay rate at 15°C is

$$b_{H,15} = b_{H,20}(\theta)^{T-20} = 0.12(1.04)^{15-20} = 0.098 \text{ g/g·d}$$

$$R_{NO_3} = \frac{1.42}{2.86} (0.098 \text{ g/g·d}) (1200 \text{ g/m}^3) (250 \text{ m}^3)$$

$$R_{NO_3} = 14,597.2 \text{ g/d}$$

$$\text{Normalized to flow, } R_{NO_3} = \frac{(14,597.2 \text{ g/d})}{(5000 \text{ m}^3/\text{d})} = 2.9 \text{ g/m}^3$$

3. Determine the post anoxic tank acetate concentration using Eq. (8-70).

$$SDNR = \left( \frac{1 - 1.42Y_H}{2.86} \right) \left[ \frac{\mu_{max} S_s}{Y_H(K_s + S_s)} \right] \left( \frac{S_{NO_3}}{K_{NO_3} + S_{NO_3}} \right) \left( \frac{\eta X_H}{X_{VSS}} \right)$$

Determine the SDNR needed to remove the remaining  $NO_3$ -N after accounting for endogenous decay.

$$NO_3\text{-N removal by acetate} = (6.0 - 2.9 - 0.3) \text{ g/m}^3$$

$$= 2.8 \text{ g/m}^3$$

$$R_{NO_3} = (2.8 \text{ g/m}^3)(5000 \text{ m}^3/\text{d}) = 14,000 \text{ g/d}$$

From Eq. (8-52),

$$R_{NO_3} = SDNR(MLVSS)V$$

$$14,000 \text{ g/d} = SDNR(3000 \text{ g/m}^3)(250 \text{ m}^3)$$

$$SDNR = 0.0187 \text{ g/g·d}$$

Apply Eq. (8-70) and solve for the anoxic tank acetate concentration.

Determine  $\mu_{max,15}$  with Eq. (1-44) in Table 8-10.

$$\mu_{max,15} = \mu_{max,20} e^{T-20} = (4.46 \text{ g/g·d})(1.21)^{15-20}$$

$$\mu_{max,15} = 1.71 \text{ g/g·d}$$

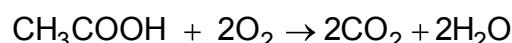
$$0.0187 = \left[ \frac{1 - 1.42(0.40 \text{ gVSS/gCOD})}{2.86} \right] \left[ \frac{(1.71 \text{ g/g·d})S_s}{(0.40 \text{ gVSS/gCOD})(5.0 + S_s)} \right]$$

$$\left\{ \frac{(0.30 \text{ g/m}^3)}{[(0.10 + 0.30) \text{ g/m}^3]} \right\} \left[ \frac{0.80(1200 \text{ g/m}^3)}{(3000 \text{ g/m}^3)} \right]$$

Solve for  $S_s$ :

$$S_s = 0.69 \text{ g/m}^3 \text{ acetate}$$

As acetate COD,



$$\frac{\text{g O}_2}{\text{g acetate}} = \frac{2.0(32 \text{ g / mole})}{1.0(60 \text{ g / mole})} = 1.067 \text{ g COD / g acetate}$$

$$S_s = (0.69 \text{ g/m}^3)(1.067 \text{ g COD/g acetate}) = 0.74 \text{ g COD/m}^3$$

4. Determine the carbon dose using Eq. (8-76).

$$C_D = SDNR(X_{VSS})(V)C_{R,NO_3} + Q(1+R)(S_s)$$

$$C_D = (14,000 \text{ g/d})(6.62 \text{ g COD/g NO}_3\text{-N})$$

$$+ (5000 \text{ m}^3/\text{d})(1+0.5)(0.74 \text{ g COD/m}^3)$$

$$C_D = 98,230 \text{ g COD/d} = 98.23 \text{ kg COD/d}$$

$$C_{D,acetate} = \frac{(98.23 \text{ kg COD / d})}{(1.067 \text{ g COD / g acetate})} = 92.1 \text{ kg acetate/d}$$

Dose in mg/L

$$\text{Dose} = \frac{(98,230 \text{ g COD / d})}{(5000 \text{ m}^3 / \text{d})} = 19.6 \text{ g COD / m}^3$$

$$\text{Dose} = \frac{(19.60 \text{ g COD / m}^3)}{(1.067 \text{ g COD / g acetate})} = 18.4 \text{ g acetate / m}^3$$

5. Determine the amount of NH<sub>4</sub>-N released.

From Example 8-10, 0.06 g NH<sub>4</sub>-N released/g VSS in endogenous decay.

$$\begin{aligned} \text{Increase in NH}_4\text{-N concentration} &= \frac{(0.06 \text{ g N / g VSS})(b_H)(X_H)V}{Q(1+R)} \\ &= \frac{(0.06 \text{ g N / g VSS})(0.098 \text{ g / g}\cdot\text{d})(1200 \text{ g VSS / m}^3)(250 \text{ m}^3)}{(5000 \text{ m}^3 / \text{d})(1+0.50)} \\ &= 0.20 \text{ g/m}^3 \end{aligned}$$

### PROBLEM 8-38

**Problem Statement** – see text, page 932

**Solution (Wastewater 1)**

- Determine the Prevalence by PAOs consuming rbCOD from the influent wastewater.
  - rbCOD is first consumed for NO<sub>3</sub>-N reduction. Assume return sludge recycle ratio = 0.50 mg/L.

$\text{NO}_3\text{-N}$  available based on influent flow

$$Q(\text{NO}_3\text{-N})_{\text{available}} = (\text{NO}_3\text{-N}_R)RQ$$

$$(\text{NO}_3\text{-N})_{\text{available}} = 5.0(0.5) = 2.5 \text{ mg/L}$$

From page 879 rbCOD consumption for  $\text{NO}_3\text{-N}$  reduction

$$= \frac{5.0 \text{ g rbCOD}}{\text{g NO}_3\text{-N}} (2.5 \text{ mg/L})$$

$$\text{rbCOD consumption} = 13.0 \text{ mg/L}$$

$$\text{rbCOD available for PAOs} = 70 - 13 = 57 \text{ mg/L}$$

- b. Determine rbCOD/P ratio from Figure 8-38.

$$\text{At VFA/rbCOD} = 0.50, \text{rbCOD/P} = 10.0$$

$$\begin{aligned} \text{P removal by PAOs} &= \frac{(57 \text{ mg rbCOD/L})}{(10.0 \text{ g rbCOD/g P})} \\ &= 5.7 \text{ mg/L} \end{aligned}$$

- 2. Determine P removal by biomass production. Assume 0.015 g P/g VSS from Example 8-13.

$$\text{Biomass growth} = (0.30 \text{ g VSS/g BOD})(160 \text{ mg/L}) = 48.0 \text{ mg/L VSS}$$

$$\text{P removal by synthesis} = (0.015 \text{ g P/g VSS})(48.0 \text{ mg/L}) = 0.7 \text{ mg P/L}$$

$$\text{Effluent soluble P} = 7.0 - 0.7 - 5.7 = 0.6 \text{ mg/L}$$

- 3. Determine the phosphorus content of the waste sludge

$$\begin{aligned} \text{Sludge production} &= (0.60 \text{ g TSS/g BOD})(160 \text{ g BOD/m}^3) \\ &= 96.0 \text{ g/m}^3 \end{aligned}$$

$$\text{P removed} = 7.0 - 0.60 = 6.4 \text{ g/m}^3$$

$$\text{g P/g sludge} = \frac{(6.4 \text{ g/m}^3)}{(96 \text{ g/m}^3)} = 0.067 \text{ g/g, P content of dry solids} = 6.7\%$$

- 4. Eliminate or reduce the amount of  $\text{NO}_3\text{-N}$  in the return sludge flow to the EBPR anaerobic contact zone. This could be done by incorporating the JHB or UCT process in the treatment process. The feasibility and preferred method would depend on the actual plant layout.

### PROBLEM 8-39

**Problem Statement** – see text, page 932**Solution**

- Determine the change in effluent phosphorus content. The amount of nitrate fed to the anaerobic zone affects enhanced biological phosphorus removal efficiency due to rbCOD consumption by nitrate. Per page 879, 1.0 mg NO<sub>3</sub>-N consumes 5.2 mg rbCOD.

In the A<sup>2</sup>O process, NO<sub>3</sub>-N is fed to the anaerobic zone in the return activated sludge (RAS). Assuming no NO<sub>3</sub>-N removal in the secondary clarifier, the NO<sub>3</sub>-N concentration in RAS is equal to the effluent concentration. In this problem, the internal recycle for the A<sup>2</sup>O process is to be decreased, which will increase the effluent and RAS NO<sub>3</sub>-N concentration. Eq. (8-62) is used to determine changes in the effluent NO<sub>3</sub>-N concentration as a function of the internal recycle ratio (IR).

$$IR = \frac{NO_x}{N_e} - 1.0 - R$$

Solve for NO<sub>x</sub> for the present condition as this will not change with changes in recycle rates. Rearranging the equation:

$$NO_x = N_e (1 + R + IR)$$

$$NO_x = 5.0 \text{ mg/L} (1 + 0.50 + 3.0) = 22.5 \text{ mg/L}$$

Determine N<sub>e</sub> for IR = 2.0 and R = 1.0

$$N_e = \frac{NO_x}{(1+R+IR)} = \frac{(22.5 \text{ mg/L})}{(1+1.0+2.0)} = 5.63 \text{ mg/L}$$

The amount of nitrate fed to the anaerobic zone is equal to the RAS flow rate and NO<sub>3</sub>-N concentration and is shown as follows:

$$g \text{ NO}_3\text{-N fed/d} = R Q N_e$$

The rbCOD required in the influent flow for NO<sub>3</sub>-N consumption is shown as follows:

$$Q (\text{rbCOD}_{NO_3}) = \left( \frac{5.2 \text{ g rbCOD}}{\text{g NO}_3\text{-N}} \right) R Q N_e$$

Thus, the rbCOD used in the influent flow for  $\text{NO}_3\text{-N}$  removal is:

$$\text{rbCOD}_{\text{NO}_3}, \text{ mg/L} = 5.2 R N_e$$

For the initial case,  $R = 0.5$ ,  $N_e = 5.0 \text{ mg/L}$

$$\text{rbCOD}_{\text{NO}_3} = 5.2 (0.5) (5.0 \text{ mg/L}) = 13.0 \text{ mg/L}$$

For the new recycle condition,  $R = 1.0$ ,  $N_e = 5.63 \text{ mg/L}$

$$\text{rbCOD}_{\text{NO}_3} = 5.2 (1.0) (5.63 \text{ mg/L}) = 29.3 \text{ mg/L}$$

Thus, the additional rbCOD consumed in the anaerobic zone =  $(29.3 - 13.0)$   
 $\text{mg/L} = 16.3 \text{ mg/L}$

Assuming 10 g rbCOD / g P removal,

$$\text{the loss of P removal} = \frac{(16.3 \text{ mg/L})}{(10 \text{ g/g})} = 1.6 \text{ mg/L}$$

### PROBLEM 8-40

**Problem Statement** – see text, page 932

**Solution (Solids loading rate = 4.0 kg/m<sup>2</sup>•h)**

1. Determine the influent flow rate given the return activated sludge recycle ratio, MLSS concentration, and clarifier number and diameter.
  - a. Determine the clarifier average surface overflow rate (SOR) using Eq. (8-82).

$$\text{MLSS} = 3000 \text{ g/m}^3 = 3.0 \text{ kg/m}^3$$

$$\text{SLR} = \frac{(Q + RQ)\text{MLSS}}{A} = (1+R)(\text{SOR})\text{MLSS}$$

$$\text{SOR} = \frac{\text{SLR}}{(1+R)\text{MLSS}} = \frac{(4.0 \text{ kg / m}^2 \cdot \text{h})}{(1+0.5)(3.0 \text{ kg / m}^3)}$$

$$\text{SOR} = 0.88 \text{ m/h}$$

$$\text{SOR} = Q/A$$

- b. Determine the influent flowrate

$$Q = A(\text{SOR})$$

$$\text{Clarifier area} = (2)(\pi D^2/4)$$

$$= (2)(3.14/4)(20 \text{ m})^2$$

$$= 628 \text{ m}^2$$

$$Q = (628 \text{ m}^2)(0.88 \text{ m/h})(24 \text{ h/d})$$

$$Q = 13,263 \text{ m}^3/\text{d}$$

2. Determine the return sludge MLSS concentration.

Ideal mass balance on the clarifier:

Solids in = Solids out

Ignore effluent TSS and solids wasting

$$Q(1+R) X = RQ(X_R)$$

$$X_R = \frac{(1+R)X}{R} = \frac{1.5(3000 \text{ mg/L})}{0.5}$$

$$X_R = 9000 \text{ mg/L}$$

### PROBLEM 8-41

**Problem Statement** – see text, page 933

#### Solution

1. The effects are summarized in the following table.

Change in process or wastewater characteristics	Effect on effluent process concentration
SRT is increased	Effluent P decreases. Less phosphorus accumulating organism (PAO) bacteria biomass is produced due to lower yield at higher SRT
Influent rbCOD concentration increases	Effluent P decreases. Higher rbCOD provides more food for PAOs and thus more growth and P removal
Clarifier effluent suspended solids concentration increases	Effluent P increases. Effluent suspended solids contain P
Higher NO <sub>3</sub> -N concentration in RAS	Effluent P increases. More NO <sub>3</sub> -N is fed to the anaerobic zone, which means that rbCOD is consumed by NO <sub>3</sub> -N with less available for PAOs.
Influent particulate BOD concentration increases	No change. Because the PAOs rely mainly on the availability of rbCOD fed to the anaerobic zone, changes in influent particulate BOD concentration have little or no effect on biological

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P removed.

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**PROBLEM 8-42****Problem Statement** – see text, page 933**Solution**

Using the column test data a gravity flux curve is first developed by determining the initial interfacial settling from the data provided. Then the limiting solids flux can be determined graphically for each underflow MLSS concentration given.

The underflow velocity ( $Q_R/A$ ) is obtained as the negative slope of the underflow operating rate curve. The Q/A value is given for the problem, so the percent RAS recycle rate is:

$$\frac{(Q_R / A)100}{(Q / A)} = \text{percent RAS recycle rate}$$

## 1. Gravity flux curve from data

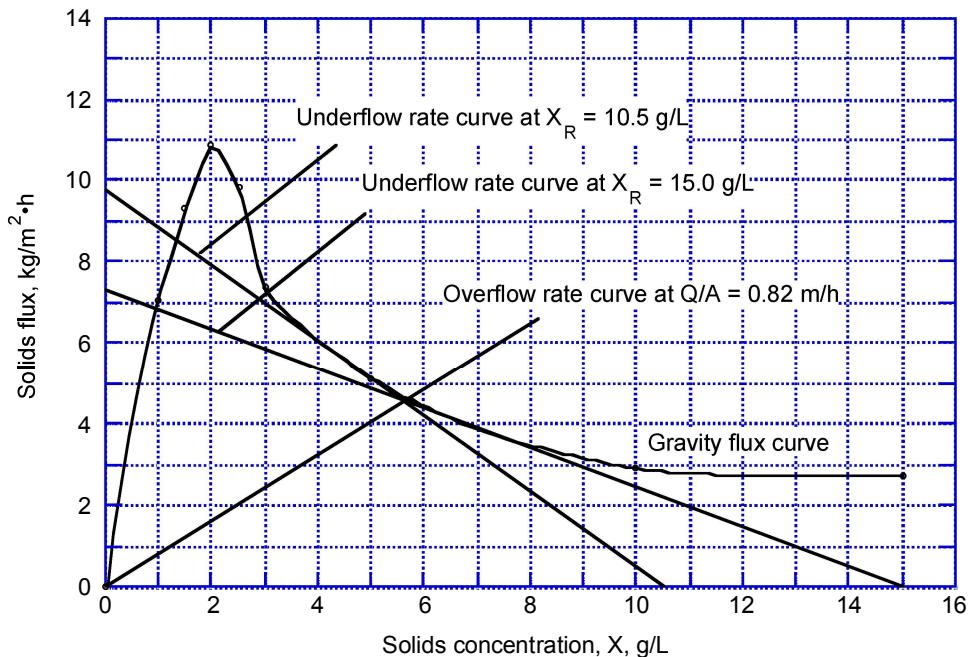
$C_i, \text{ g/L}$	$V_i, \text{ m/h}$	$SF_g, \text{ kg/m}^2 \cdot \text{h}$
1.0	7.03	7.03
1.5	6.21	9.32
2.0	5.43	10.86
2.5	3.95	9.87
3.0	2.47	7.41
5.0	1.03	5.15
10.0	0.29	2.90
15.0	0.18	2.70

For  $C_i = 1 \text{ g/L}$ ,

$$V_i = \frac{117.1 \text{ cm}}{10 \text{ min}} \left( \frac{\text{m}}{100 \text{ cm}} \right) \frac{60 \text{ m}}{\text{h}} = 7.03 \text{ m/h}$$

$$SF_g = C_i V_i = \left( \frac{1 \text{ g}}{\text{L}} \right) (7.03 \text{ m/h}) \left( \frac{10^3 \text{ L}}{\text{m}^3} \right) \left( \frac{1.0 \text{ kg}}{10^3 \text{ g}} \right) = 7.03 \text{ kg/m}^2 \cdot \text{h}$$

2. Plot solids flux graph with  $X_R = 10,500 \text{ mg/L}$  and  $15,000 \text{ mg/L}$ . Compute percent recycle for a clarifier overflow rate of  $0.82 \text{ m/h}$ .



a. At  $X_R = 10,500 \text{ mg/L}$

$$SF_L = 9.8 \text{ kg/m}^2 \cdot \text{h}$$

$$\frac{Q_R}{A} = \frac{(9.8 \text{ kg/m}^2 \cdot \text{h})}{(10.5 \text{ g/L})} = 0.93 \text{ m/h}$$

$$\text{Percent recycle} = \frac{[0.93 \text{ m/h}(100)]}{(0.82 \text{ m/h})} = 114$$

b. At  $X_R = 15,000 \text{ mg/L}$

$$SF_L = 7.0 \text{ kg/m}^2 \cdot \text{h}$$

$$\frac{Q_R}{A} = \frac{(7.0 \text{ kg/m}^2 \cdot \text{h})}{(15.0 \text{ g/L})} = 0.47 \text{ m/h}$$

$$\text{Percent recycle} = \frac{(0.47 \text{ m/h})(100)}{(0.82 \text{ m/h})} = 57$$

### PROBLEM 8-43

**Problem Statement** – see text, page 933

**Solution**

- First calculate the solids flux due to gravity thickening using equation given for  $V_i$

$$SF_g = V_i C_i = \left[ X_i V_o (e^{-kX_i}) \right] \left( \frac{1.0 d}{24 h} \right)$$

$$k = 0.4004 \text{ L/g}$$

$$V_o = 172 \text{ m/d}$$

$$X_i = \text{MLSS, g/L}$$

$$SF_g = \text{kg/m}^2 \cdot \text{h}$$

- The solids flux is summarized as follows and graphed as shown:

$X_i$ , g/L	$SF_g$ , $\text{kg/m}^2 \cdot \text{h}$	$X_i$ , g/L	$SF_g$ , $\text{kg/m}^2 \cdot \text{h}$
1.0	4.80	8.0	2.34
2.0	6.44	9.0	1.76
3.0	6.48	10.0	1.31
4.0	5.79	12.0	0.71
5.0	4.85	14.0	0.37
6.0	3.90	16.0	0.19
7.0	3.05	18.0	0.10

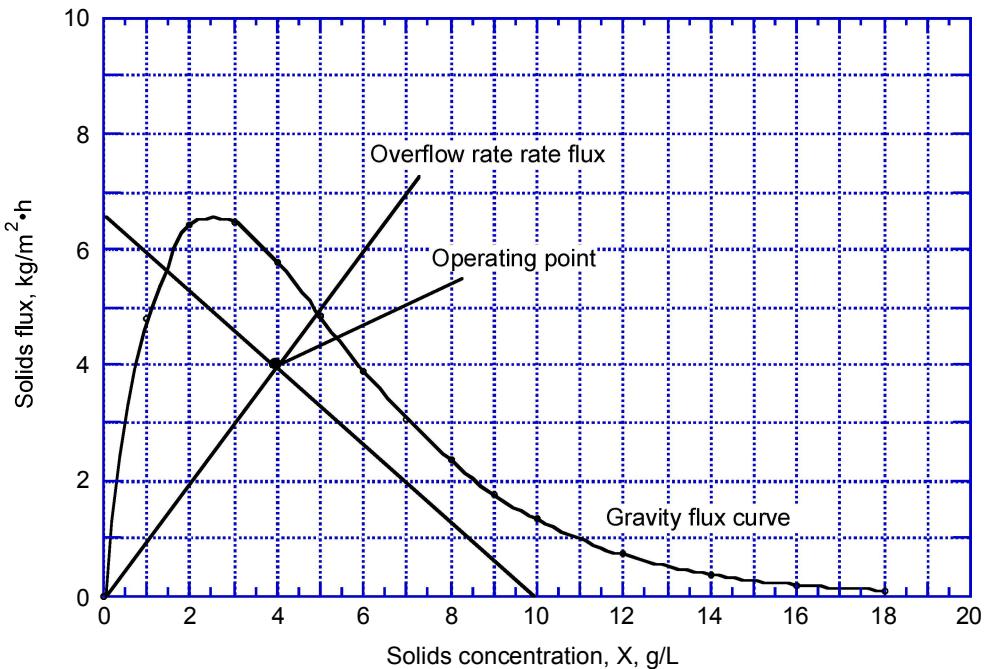
- The overflow rate operating flux line =  $\frac{Q}{A}(X_i)$

$$Q/A = 1 \text{ m/h}$$

Shown on graph, at  $X_i = 5 \text{ g/L}$ , the overflow rate operating flux

$$= 5 \text{ kg/m}^2 \cdot \text{h}$$

- Underflow concentration,  $X_R = 10 \text{ g/L}$



The underflow line is drawn by starting at 10 g/L on the X-axis and intersecting the operating state point.

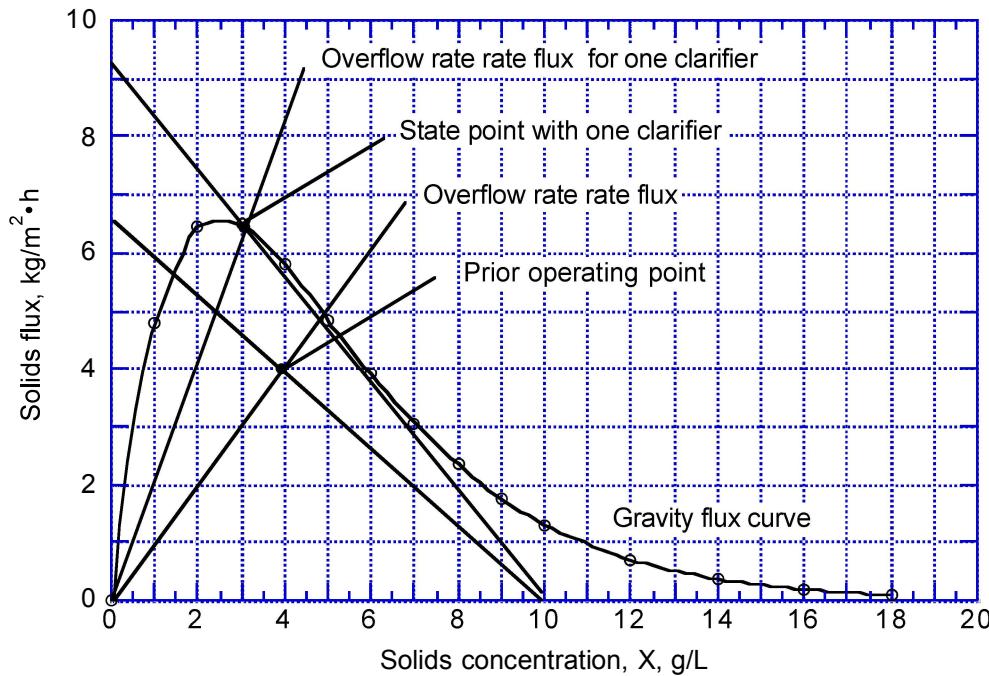
The solids flux rate is determined from the y-axis intercept and is 6.5  $\text{kg}/\text{m}^2 \cdot \text{h}$ .

The value for  $Q_R/A$  is the negative slope:

$$Q_R/A = \frac{(6.5 \text{ kg} / \text{m}^2 \cdot \text{h})}{(10 \text{ g} / \text{L})} = 0.65 \text{ m} / \text{h}$$

$$\text{Recycle ratio} = \frac{Q_R}{Q} = \frac{(Q_R / A)}{(Q / A)} = \frac{(0.65 \text{ m} / \text{h})}{(1.0 \text{ m} / \text{h})} = 0.65$$

- d. With only one clarifier in operation the overflow rate is doubled and  $Q/A = 2 \text{ m/h}$ . The new overflow rate operating flux line is shown on the graph. The recycle flux line is drawn so that it is just below the gravity flux curve and thus does not exceed the solids flux limitation. A new graph is shown below.



The maximum MLSS concentration is 3000 mg/L and the solids flux is 9.3 kg/m<sup>2</sup>·h. The recycle overflow rate is:

$$\frac{Q_R}{A} = \frac{(9.3 \text{ kg} / \text{m}^2 \cdot \text{h})}{(10 \text{ g} / \text{L})} = 0.93 \text{ m} / \text{h}$$

$$\text{The recycle ratio} = \frac{(0.93 \text{ m} / \text{h})}{(2.0 \text{ m} / \text{h})} = 0.47$$

#### PROBLEM 8-44

**Problem Statement** – see text, page 934

**Solution (MBR MLSS = 10,000 mg/L)**

1. The SRTs and MLSS concentrations are given for the two cases. The flow that can be treated is related to sludge production,  $P_{X,TSS}$ .  $P_{X,TSS}$  is related to the SRT and MLSS by Eq. (7-57) in Table 8-10.

$$\frac{(X_{TSS})(V)}{SRT} = P_{X,TSS}$$

The solids production  $P_{X,TSS}$  is obtained using Eq. (8-20) and (8-21) in Table 8-10.

$$P_{X,TSS} = \frac{Q Y_H (S_o - S)}{[1 + (b_H) SRT] 0.85} + \frac{(f_d)(b_H) Q Y_H (S_o - S) SRT}{[1 + (b_H) SRT] 0.85} \\ + \frac{Q Y_n (NO_X)}{[1 + (b_n) SRT] 0.85} + Q(n b VSS) + Q(TSS_o - VSS_o)$$

For the 6 d SRT operation,

$$P_{X,TSS} = \frac{(2500 \text{ g/m}^3)(4600 \text{ m}^3)}{6 \text{ d}} = 1,916,667 \text{ g/d}$$

As the temperature is not given the above equation, the relationship for  $P_{X,TSS}$  must be used with the flow rate at the 6-d SRT condition to determine  $b_H$ , which will be the same value for the 12-d SRT membrane reactor application. The following coefficients are used in the equation.

$$Y_H = 0.45 \text{ gVSS / g bCOD}$$

$$f_d = 0.15 \text{ g VSS/g VSS}$$

$$Y_n = 0.20 \text{ g VSS / g NH}_4\text{-N}$$

Use  $b_n$  at 20°C as error in this case for low solids production nitrification has small effect:

$$b_n = 0.17 \text{ g VSS/g VSS}\cdot\text{d}$$

Thus:

$$1,916,667 \text{ g/d} = \frac{0.45 \text{ g/g}(15,000 \text{ m}^3/\text{d})(240 \text{ g/m}^3)}{[1 + (b_H \text{ g/g}\cdot\text{d})(6 \text{ d})] 0.85} \\ + \frac{(0.15 \text{ g/g})(b_H)(15,000 \text{ m}^3/\text{d})(0.45 \text{ g/g})(240 \text{ g/m}^3)(6 \text{ d})}{[1 + (b_H \text{ g/g}\cdot\text{d})(6 \text{ d})] 0.85} \\ + \frac{0.20 \text{ g/g}(15,000 \text{ m}^3/\text{d})(28 \text{ g/m}^3)}{[1 + (0.17 \text{ g/g}\cdot\text{d})(6 \text{ d})] 0.85} + (15,000 \text{ m}^3/\text{d})(35 \text{ g/m}^3) \\ + (15,000 \text{ m}^3/\text{d})(80 - 68) \text{ g/m}^3$$

$$1,916,667 = \frac{1,905,882}{[1+b_H(6d)]} + \frac{1,715,292(b_H)}{[1+b_H(6d)]} + 753,922$$

Use a spreadsheet to solve for  $b_H$ .

$$b_H = 0.14 \text{ g/g}\cdot\text{d}$$

2. For the membrane reactor, SRT = 12 d

**MLSS = 10,000 mg/L**, and V also = 4600 m<sup>3</sup>

$$P_{X,TSS} = \frac{XV}{SRT} = \frac{(10,000 \text{ g/m}^3)(4600 \text{ m}^3)}{12 \text{ d}} = 3,833,333 \text{ g/d}$$

Use equation for  $P_{X,TSS}$  and solve for Q with same input values as for the 6 d SRT application.

$$\begin{aligned} 3,833,333 \text{ g/d} &= \frac{Q(0.45 \text{ g/g})(240 \text{ g/m}^3)}{[1+(0.14 \text{ g/g}\cdot\text{d})(12 \text{ d})]0.85} \\ &+ \frac{(0.15 \text{ g/g})(0.14 \text{ g/g}\cdot\text{d})(Q)(0.45 \text{ g/g})(240 \text{ g/m}^3)12 \text{ d}}{[1+(0.14 \text{ g/g}\cdot\text{d})(12 \text{ d})]0.85} \\ &+ \frac{(Q)(0.20 \text{ g/g})(28 \text{ g/m}^3)}{[1+(0.17 \text{ g/g}\cdot\text{d})(12 \text{ d})]0.85} + (Q)(35 \text{ g/m}^3) + Q(80 - 68) \text{ g/m}^3 \end{aligned}$$

$$Q = 35,320 \text{ m}^3/\text{d}$$

Thus, the MLSS concentration was increased by a factor of 4 and the SRT and flowrate were increased by factors of 2 and 2.3, respectively.

3. The volumetric BOD loading ( $L_{org}$ ) and F/M ratio are calculated using Eq. (7-69) and (7-62), respectively in Table 8-10.

$$L_{org} = \frac{(Q)(S_o)}{V}$$

$$F/M = \frac{QS_o}{VX}$$

$$SRT = 6 \text{ d}$$

$$L_{org} = \frac{(15000 \text{ m}^3/\text{d})(150 \text{ g/m}^3)(1 \text{ kg}/10^3 \text{ g})}{4600 \text{ m}^3} = 0.49 \text{ kg BOD/m}^3 \cdot \text{d}$$

$$F/M = \frac{(15,000 \text{ m}^3 / \text{d})(150 \text{ g/m}^3)}{(4600 \text{ m}^3)(2500 \text{ g/m}^3)} = 0.20 \text{ gBOD/gMLSS} \cdot \text{d}$$

SRT = 12 d with membrane

$$L_{org} = \frac{(35,320 \text{ m}^3 / \text{d})(150 \text{ g/m}^3)(1 \text{ kg/10}^3 \text{ g})}{4600 \text{ m}^3} = 1.15 \text{ kgBOD/m}^3 \cdot \text{d}$$

$$F/M = \frac{(35,320 \text{ m}^3 / \text{d})(150 \text{ g/m}^3)}{(4600 \text{ m}^3)(10,000 \text{ g/m}^3)} = 0.11 \text{ gBOD/gMLSS} \cdot \text{d}$$

4. The flowrate divided by the allowable membrane flux of 900 L/m<sup>2</sup>·d determines the membrane surface area:

$$\text{Area} = \frac{(35,320 \text{ m}^3 / \text{d})}{(20.0 \text{ L/m}^2 \cdot \text{h})(1.0 \text{ m}^3 / 10^3 \text{ L})(24 \text{ h/d})} = 73,583 \text{ m}^2$$