SOLUTIONS MANUAL

Wastewater Engineering:

Treatment and Resource Recovery
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CONTENTS

1
INTRODUCTION TO WASTEWATER TREATMENT

PROBLEM 1-1

Instructors Note: The first six problems are designed to illustrate the application of the mass balance principle using examples from hydraulics with which the students should be familiar.

Problem Statement - See text, page 53

Solution

1. Write a materials balance on the water in the tank

   Accumulation = inflow – outflow + generation

   $$\frac{dV}{dt} = \frac{dh}{dt}A = Q_{in} - Q_{out} + 0$$

2. Substitute given values for variable items and solve for h

   $$\frac{dh}{dt}A = 0.2\ m^3/s - 0.2\left(1 - \cos\frac{\pi t}{43{,}200}\right)\ m^3/s$$

   A = 1000 m^2

3. $$dh = 2x10^{-4}\left(\cos\frac{\pi t}{43{,}200}\right)dt$$

   Integrating the above expression yields:

   $$h - h_o = \left[\frac{(43{,}200)\ (2x10^{-4})}{\pi}\right]\left(\sin\frac{\pi t}{43{,}200}\right)$$

4. Determine h as a function of time for a 24 hour cycle

Mass loading to plant, kg/h = $[(V_T)(X_{ic}) + (V_{sp})(X_{sp})]/10^3$ g/kg)

For example, for the time period M-1, the mass loading rate is

= $[(990\ m^3)(150\ g/m^3) + (116\ m^3)(214\ g/m^3)]/10^3$ g/kg)

= 174 kg/h (rounded)

e. Set up a spreadsheet and computation table similar to that below.

1. Using the data given above, determine the tank dimensions.

   V/Q = 3 min at peak flowrate (20,000 m^3/d per channel)

$$V = \frac{(3\,\text{min})(20{,}000\,\text{m}^3/\text{d})}{(60\,\text{min/h})(24\,\text{h/d})} = 41.7\,\text{m}^3$$

$$A_s = \frac{41.7\,\text{m}^3}{4\,\text{m}} = 10.4\,\text{m}^2$$

   Length x width = 4w x w = $4w^2$ = 10.4 m^2

   Width = 1.6 m

   Length = 6.4 m

2. Determine the maximum air requirement.

$$Q_{air} = \left(\frac{0.3\,\text{m}^3}{\text{m}\bullet\text{min}}\right)(6.4\,\text{m})(2\text{ channels}) = 3.84\ \text{m}^3/\text{min}$$

3. Determine the horsepower requirements. Assume the blower efficiency is 70%. The specific weight of water is 9.81 kN/m^3 (9,810 N/m^3) (Appendix C). 1 W = 1 J/s or 1 N•m/s (Table 2 in Front section) Thus, 1 kW = 1000 N•m/s.

   h = 0.250 m (diffusers) + 3 m (submergence) + 0.40 m = 3.65 m

   h = (3.65 m)(9810 N/m^3) = 35,806 N/m^2

$$\text{Power} = \left(\frac{Q_{air}h}{\text{efficiency}}\right)$$

$$\text{Power} = \left[\frac{(3.84\ \text{m}^3/\text{min})(35{,}806\ \text{N/m}^2)}{(0.70)(60\ \text{s/min})}\right]\left(\frac{1\,\text{kW}}{1000\ \text{Ngm/s}}\right) = 3.274\ \text{kW}$$

4. Determine the power cost. Assume the electric motor efficiency is 92%.

$$\text{Power cost} = \left[\frac{(3.724\ \text{kW})(24\,\text{h/d})}{(0.9)}\right](\$0.12/\text{kWh}) = \$10.48/\text{d}$$

   Note: In the above computation, it was assumed that the blower operates at maximum capacity regardless of average flow or peak flow conditions. In small plants, this situation is often the case. Under actual operating

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PROBLEM 7-3

Problem Statement – see text, page 675

Instructors Note: The purpose of this problem is to have the students familiarize themselves with appropriate literature for developing responses to the problem statement.

PROBLEM 7-4

Problem Statement – see text, page 675

Instructors Note: The purpose of this problem is to have the students familiarize themselves with appropriate literature for developing responses to the problem statement.

PROBLEM 7-5

Problem Statement – see text, page 675

Solution

1. Prepare a COD balance to determine the amount of casein COD oxidized (O_2 consumed)

   g COD cells + g COD oxidized = g COD removed

2. **Determine COD of 22 g casein removed**

   a. Basic equation for casein oxidation:

      $C_8H_{12}O_3N_2 + O_2 \rightarrow CO_2 + H_2O + NH_3$

   b. Balance equation

      $C_8H_{12}O_3N_2 + 8.0\ O_2 \rightarrow 8\ CO_2 + 3\ H_2O + 2\ NH_3$

      8.0 moles O_2 / mole casein

   c. Compute g COD removed

      MW casein: 8(12) + 12(1) + 3(16) + 2(14) = 184

      $$\text{g COD/g casein} = \frac{8.0(32)}{184} = 1.39$$

      g COD removed = (1.39 g COD/g casein)(22g) = 30.6 g

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

At SRT = 3.0 d, S = 0.90 g/m^3

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

b. Determine effluent NH_4-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.

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

Solving for S_{NH4} (let $S_{NH4} = N_e$):

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

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

At SRT = 3.0 days, N_e = 8.62g/m^3

Table showing Effluent NH_4-N (N_e) and effluent sbCOD (S) concentration as a function of SRT:

SRT d	Effl. sbCOD mg/L	Effl. NH_4-N mg/L	SRT d	Effl. sbCOD mg/L	Effl. NH_4-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

3. The trickling filter clarifier area is the same as in the BOD removal only application as shown in Step A3 above.

   Area = 860 m^2

   BOD removal only and BOD and nitrification design information is found in Example 8-3. These results are included in the summary comparison tables below.

Summary Table (BOD removal only)

Parameter	Unit	Trickling filter	Activated sludge
Aeration volume	m^3		4446
Aeration depth	m		5.0
Media volume	m^3	4672	
Media deph	m	6.1	
Aerobic tank area	m^2		889
Trickling filter area	m^2	766	
Clarifier area	m^2	860	946
Total area	m^2	1626	1835
Pumping rate	m^3/d	34,050	
Pumping energy	$kW/10^3\ m^3/d$	1.5	
Air supply rate	m^3/min		60.5
Aeration energy	$kW/m^3{\bullet}min$		1.8
Monthly energy	kWh/mo	38,736	78,408

Note: Activated sludge monthly energy = (60.5)(1.8)(24)(30) = 78,408 kWh.

Summary Table (combined BOD and nitrification)

Parameter	Unit	Trickling filter	Activated sludge
Aeration volume	m^3		13,418
Aeration depth	m		5.0
Media volume	m^3	25,608	
Media deph	m	6.1	
Aerobic tank area	m^2		2684
Trickling filter area	m^2	4198	
Clarifier area	m^2	860	946
Total area	m^2	5058	3630
Pumping rate	m^3/d	179,330	
Pumping energy	$kW/10^3\ m^3/d$	1.5	
Air supply rate	m^3/min		115.5

2. The recovery rate is found with Eq. (11-40).

$$r,\ \% \ = \ \frac{Q_p}{Q_f} \cdot 100 = \frac{(3650\ m^3/d)}{(4000\ m^3/d)}\ x\ 100 = 91\%$$

3. Estimate the rejection rate using Eq. (11-41).

$$R,\% = \frac{C_f - C_p}{C_f} \cdot 100$$

$$R = \frac{[(191\ \text{-}\ 65)\ g/m^3]}{(191\,kg/m^3)}\ x\ 100 = 66\%$$

4. Summary of results for Problem 11-17

		Reverse osmosis unit			
Item	Unit	1	2	3	4
C_f	g/m^3	191	329	1742	2583
Q_p	m^3/d	3650	5400	500	1000
r	%	91	90	6	10
R	%	66	73	93	93

PROBLEM 11-18

Problem Statement - See text, page 1283

Solution

1. Determine the permeate flowrate for **water 1** using Eq. (11-40).

$$Q_p = \frac{r \cdot Q_f}{100} = \frac{(88\%)(4000\ m^3/d)}{100} = 3520\ m^3/d$$

2. Rearrange Eq. (11-38) to compute the water mass transfer coefficient, k_W.

$$k_w = \frac{(Q_p)}{(A)(\Delta P_a - \Delta\Pi)} = \frac{(3520\ m^3/d)(10^3\,kg/m^3)}{(1600\ m^2)(2.7\,x\,10^6\ kg/m \bullet s^2)(86{,}400\ s/1d)}$$

$$= 9.09\ x\ 10^{-9}\ s/m$$

3. Estimate the concentrate stream TDS using Eq. (11-44).

$$C_c \ = \ \frac{Q_f\ C_f\ \text{-}\ Q_p\ C_p}{Q_c}$$

i. Determine the BOD influent concentration (BOD_C) to the aeration tank. (Note: the flowrate of the primary clarifier underflow is neglected).

$$BOD_C = \frac{(12{,}301\ kg/d)(10^3\ g/kg)}{(54{,}000\ m^3/d)} = 228\ mg/L$$

ii. Determine the mass of VSS produced that must be wasted using Eq. (8-19).

$$P_{x,VSS} = \frac{Y_{obs}\,Q(S_o - S)}{(10^3\ g/kg)}$$

$$P_{x,VSS} = \frac{(0.3125^*)(54{,}000\ m^3/d)[(228 - 6.2^*)\ g/m^3]}{(10^3\ g/1\ kg)} = 3743\ kg/d$$

iii. Determine the TSS_M that must be wasted.

TSS_M = (3743 kg/d)/0.80* = 4679 kg/d

iv. Determine the effluent mass quantities.

BOD_M = (54,000 m^3/d)(20 g/m^3*)/(10^3 g/kg) = 1080 kg/d

TSS_M = (54,000 m^3/d)(22 g/m^3*)/(10^3 g/kg) = 1188 kg/d

v. Determine the waste quantities discharged to the thickener (assume wasting from the aeration tank).

TSS_M = (4679 – 1188) kg/d = 3491 kg/d

$$Flowrate = \frac{(3491 kg/d)(10^3\ g/kg)}{(4375\,g/m^3)^*} = 798\,m^3/d$$

d. Flotation thickener.

i. Determine the flowrate of the thickened sludge.

$$Flowrate = \frac{(3491\ kg/d)(0.9^*)}{(10^3\ kg/m^3)(0.04)^*} = 78.5\ m^3/d$$

ii. Determine the flowrate recycled to the plant influent.