CHAPTER 6
SOLUTIONS

6-1 Highway rest area septic tank and tile field

Given: traffic data; soil percolation rate = 5 min/cm; and GWT at 4.2 m below grade

Solution:

a. Compute volume of wastewater at 10% turn in

Avg. day = (6,000 v/d)(0.10)(20.0 L/turn in) = 12,000 L/d

Max. day = 2.5(12,000) = 30,000 L/d

b. Septic tank design

Assume volume = 24 h detention of max day flow.
V = (30,000 L/d)(1 d)(10^{-3} m^3/L) = 30.0 m^3

c. Tile field design

Area of trench
Application rate is found from Table 6-7 at 5 min/cm
(= 0.5 min/mm) to be 0.03 m^3/m^2

$$A = \frac{30.0\,m^3}{0.03\,m^3/m^2} = 1000\,m^2$$

With a 1 m wide trench, need 1,000 m length. Use 10 trenches of 100 m length.

NOTE: it is obvious from the tank and tile field size why septic tanks and tile fields are limited to flows of 40 m^3/d.

6-2 Ginger Snap's septic tank and tile field

Given: 4.0 m^3 septic tank; 4000 L/d flow; 100 m^2 tile field and sandy loam soil

Solution:

a. Check septic tank volume

For 24 h detention time 4000 L/d = 4.0 m^3 so septic tank volume is okay.

b. Check area of tile field

From Table 6-7 with a sandy loam, the application rate is 0.02 m^3/m^2

$$A = \frac{4.0 m^3}{0.02 \, m^3/m^2} = 200 m^2$$

Therefore, the tile field is too small.

6-3 Terminal settling velocity

Given: particle radius = 0.0170 cm; density = 1.95 g/cm^3; water temperature = 4 ^oC

Solution:

a. Convert to SI units

diameter = 2r = 2(0.017 cm)(10^{-2} m/cm) = 3.40 x 10^{-4} m

density = (1.95 g/cm^3)(10^{-3} kg/g)(10^6 cm^3/m^3) = 1950 kg/m^3

b. From Appendix A, Table A-1 at 4 ^0C find

μ = 1.567 x 10^{-3} Pa-s

(NOTE: factor of 10^{-3} to convert from mPa-s to Pa-s)

c. Solve Eqn. 4-98

$$v_s = \frac{9.80}{18}\left(\frac{1950 - 1000}{1.567 \times 10^{-3}}\right)\left(3.40 \times 10^{-4}\right)^2 = (0.5444)\left(6.063 \times 10^5\right)\left(1.156 \times 10^{-7}\right)$$

v_s = 3.816 x 10^{-2} or 3.82 x 10^{-2} m/s

6-4 Diameter of settling particle

Given: terminal settling velocity = 0.0950 cm/s; particle density = 2.05 g/cm^3; water temperature = 15 ^0C

Solution:

a. Convert to SI units

velocity = (0.0950 cm/s)(10^{-2} m/cm) = 9.50 x 10^{-4} m/s

density = (2.05 g/cm^3)(10^{-3} kg/g)(10^6 cm^3/m^3) = 2050 kg/m^3

b. From Appendix A, Table A-1 at 15 ^{0}C find

μ = 1.139 x 10^{-3} Pa-s

(NOTE: factor of 10^{-3} to convert from mPa-s to Pa-s)

c. Solve Eqn. 4-98 for d

$$d = \left[(v_s)\left(\frac{18}{9.80}\right)\left(\frac{\mu}{\rho_s - \rho}\right)\right]^{1/2}$$

$$d = \left[(9.50 \times 10^{-4})\left(\frac{18}{9.80}\right)\left(\frac{1.139 \times 10^{-3}}{2050 - 1000}\right)\right]^{1/2} = 4.35 \times 10^{-5}\,\text{m}$$

6-5 Horizontal flow, gravity grit chamber in winter and summer

Given: diameter = 0.020 cm; particle density = 1.83 g/cm^3; water temperature = 12 ^{o}C; grit chamber depth = 1.0 m; detention time in grit chamber = 60 s; assume density of water = 1000 kg/m^3

Solution:

For winter conditions

a. Convert diameter to m

$$\frac{0.020\text{cm}}{100\,\text{cm/m}} = 0.00020\text{m}$$

b. Convert density to kg/m^3

$$(1.83\,\text{g/cm}^3)(10^{-3}\,\text{kg/g})(10^6\,\text{cm}^3/\text{m}^3) = 1830\,\text{kg/m}^3$$

c. From Appendix A, Table A-1 at 12 ^{o}C

$$\mu = 1.235 \times 10^{-3}\,\text{Pa} \cdot \text{s}$$

d. Solve for velocity

$$v_s = \frac{g(\rho_s - \rho)d^2}{18\mu}$$

$$v_s = \frac{9.80(1830 - 1000)(0.00020)^2}{18(1.1235 \times 10^{-3})} = 0.01464\,\text{m/s}$$

e. In 60 s (the detention time) the particle will fall:

h = (0.01464m/s)(60s) = 0.88 m

This is less than 1.0 m depth of the grit chamber. The particle will not be captured in winter.

For summer conditions

a. Data for (a) and (b) in winter still apply

b. From Appendix A at 25 ^{o}C

$$\mu = 0.890 \times 10^{-3}\,\text{Pa} \cdot \text{s}$$

c. Solving

$$v_s = \frac{9.80(1830 - 1000)(0.00020)^2}{18(0.890 \times 10^{-3})} = 0.02031\,\text{m/s}$$

d. In 60 s

h = (0.02031m/s)(60s) = 1.2 m

This is greater than 1.0 m depth. The particle will be captured.

6-6 Size of equalization basin for Cynusoidal City

Given: hourly flows; average daily flow of 0.400 m^3/s

Solution:

a. The solution was computed using a spreadsheet.

b. The spreadsheet is set up with the first flow after the basin has emptied as the first entry. This occurs just before the "volume-in" begins to exceed the "volume-out". This is the beginning of the cycle.

The "volume-out" = (0.400 m^3/s)(3,600 s/h)(1 h) = 1440 m^3. Because of space limitations the volume out is not shown in the table below.

Time	Flow (m^3/s)	Volume-in (m^3)	dS/dt (m^3)	Accumulated dS/dt (m^3)
0900	0.446	1605.6	165.6	165.6
1000	0.474	1706.4	266.4	432.0
1100	0.482	1735.2	295.2	727.2
1200	0.508	1828.8	388.8	1116.0
1300	0.526	1893.6	453.6	1569.6
1400	0.530	1908.0	468.0	2037.6
1500	0.552	1987.2	547.2	2584.8
1600	0.570	2052.0	612.0	3196.8
1700	0.596	2145.6	705.6	3902.4
1800	0.604	2174.4	734.4	4636.8
1900	0.570	2052.0	612.0	5248.8
2000	0.552	1987.2	547.2	5796.0
2100	0.474	1706.4	266.4	6062.4
2200	0.412	1483.2	43.2	6105.6
2300	0.372	1339.2	-100.8	6004.8
0000	0.340	1224.0	-216.0	5788.8
0100	0.254	914.4	-525.6	5263.2
0200	0.160	576.0	-864.0	4399.2
0300	0.132	475.2	-964.8	3434.4
0400	0.132	475.2	-964.8	2469.6
0500	0.140	504.0	-936.0	1533.6
0600	0.160	576.0	-864.0	669.6
0700	0.254	914.0	-525.0	144.0
0800	0.360	1296.0	-144.0	0.0

c. The maximum volume and the volume of the equalization basin is 6105.6 plus 25% excess = 7630 m^3

6-7 Equalization basin volume

Given: hourly flows

Solution:

a. The solution was computed using a spreadsheet.

b. The spreadsheet is set up with the first flow after the basin has emptied as the first entry. This occurs just before the "volume-in" begins to exceed the "volume-out". This is the beginning of the cycle. The "volume-out" is equal to the average volume-in = 352.215 m^3. Because of space limitations the volume out is not shown in the table below.

Time	Flow (m^3/s)	Volume-in (m^3)	dS/dt (m^3)	Accumulated dS/dt (m^3)
0800	0.1130	406.80	54.585	54.585
0900	0.1310	471.60	119.385	173.970
1000	0.1350	486.00	133.785	307.755
1100	0.1370	493.20	140.985	448.740
1200	0.1350	486.00	133.785	582.525
1300	0.1290	464.40	112.185	694.710
1400	0.1230	442.80	90.585	785.295
1500	0.1110	399.60	47.385	832.680
1600	0.1030	370.80	18.585	851.265
1700	0.1040	374.40	22.185	873.450
1800	0.1050	378.00	25.785	899.235
1900	0.1160	417.60	65.385	964.620
2000	0.1270	457.20	104.985	1069.605
2100	0.1280	460.80	108.585	1178.190
2200	0.1210	435.60	83.385	1261.575
2300	0.1100	396.00	43.785	1305.360
0000	0.0875	315.00	-37.215	1268.145
0100	0.0700	252.00	-100.215	1167.930
0200	0.0525	189.00	-163.215	1004.715
0300	0.0414	149.04	-203.175	801.540
0400	0.0334	120.24	-231.975	596.565
0500	0.0318	114.48	-237.735	331.830
0600	0.0382	137.52	-214.695	117.135
0700	0.0653	235.08	-117.135	0.000

c. The maximum volume and the volume of the equalization basin is 1305.36 plus 25% excess = 1632 m^3

6-8 Equalization basin volume for Excel

Given: Hourly flows

Solution:

See previous problem for sample calculations.

See following spreadsheet.

Time	Flow (m^3/s)	Volume-in (m^3)	Volume-out (m^3)	dS/dt (m^3)	Accumulated dS/dt (m^3)
0800	0.0033	11.88	10.875	1.005	1.005
0900	0.0039	14.04	10.875	3.165	4.17
1000	0.0047	16.92	10.875	6.045	10.215
1100	0.0044	15.84	10.875	4.965	15.18
1200	0.0041	14.76	10.875	3.885	19.065
1300	0.0041	14.76	10.875	3.885	22.95
1400	0.0042	15.12	10.875	4.245	27.195
1500	0.0038	13.68	10.875	2.805	30
1600	0.0033	11.88	10.875	1.005	31.005
1700	0.0039	14.04	10.875	3.165	34.17
1800	0.0046	16.56	10.875	5.685	39.855
1900	0.0046	16.56	10.875	5.685	45.54
2000	0.0044	15.84	10.875	4.965	50.505
2100	0.0034	12.24	10.875	1.365	51.87
2200	0.0031	11.16	10.875	0.285	52.155
2300	0.002	7.2	10.875	-3.675	48.48
0000	0.0012	4.32	10.875	-6.555	41.925
0100	0.0011	3.96	10.875	-6.915	35.01
0200	0.0009	3.24	10.875	-7.635	27.375
0300	0.0009	3.24	10.875	-7.635	19.74
0400	0.0009	3.24	10.875	-7.635	12.105
0500	0.0013	4.68	10.875	-6.195	5.91
0600	0.0018	6.48	10.875	-4.395	1.515
0700	0.0026	9.36	10.875	-1.515	7.99361E-15

Average =	10.875	m^3
Maximum volume =	52.155	m^3
Design volume =	65.19375	m^3

6-9 Compare equalized and unequalized BOD loadings

Given: Cynusoidal City data from Problem 6-6

Solution:

a. The solution was computed using a spreadsheet program.

b. The following example calculations are given for 0900 h. Note that mg/L = g/m^3

$M_{BOD\text{-}in} = (Q)(S_o)(t)$

$= (0.446\ m^3/s)(170\ g/m^3)(1\ h)(3{,}600\ s/h)(10^{-3}\ kg/g)$

$= 272.952\ kg$

$$S = \frac{V_i S_o + V_S S}{V_i + V_S}$$

$$S = \frac{(1605.6)(170) + (0)}{1605.6 + 0} = 170\ g/m^3$$

$M_{BOD\text{-}out} = (Q)(S)(t)$

$= (0.400\ m^3/s)(170\ g/m^3)(1\ h)(3{,}600\ s/h)(10^{-3}\ kg/g)$

$= 244.80\ kg$

At 1000

$$S = \frac{(1706.4)(220) + (165.6)(170)}{1706.4 + 165.6} = 215.577\ g/m^3$$

c. Tabulation of BOD mass flow

Time	M_{BOD} in (kg)	S	M_{BOD} out (kg)
0900	272.95	170.00	244.80
1000	375.41	215.58	310.43
1100	433.80	243.14	350.12
1200	490.12	260.93	375.73
1300	534.00	274.19	394.83
1400	534.24	277.38	399.42
1500	532.57	272.75	392.76
1600	513.00	262.68	378.26
1700	439.85	239.51	344.90
1800	365.30	213.93	308.05
1900	287.28	191.25	275.39
2000	258.34	174.43	251.17
2100	249.13	167.96	241.86
2200	234.35	166.00	239.04
2300	206.24	163.84	235.94
0000	150.55	156.92	225.98
0100	107.90	151.62	218.33
0200	54.72	146.03	210.29
0300	38.02	39.59	201.02
0400	40.39	132.96	191.46
0500	47.88	126.53	182.20
0600	57.60	119.28	171.77
0700	107.90	118.54	170.70
0800	176.26	34.25	193.33
Average	271.16		271.16

d. Average BOD concentration flowing out of equalization basin

$$BOD_{AVG} = \frac{(271.16\,kg)(1000\,g/kg)}{(0.400\,m^3/s)(1h)(3600\,s/h)} = 188.303\,mg/L$$

	Unequalized	**Equalized**
P/A	534.24/271.16 = 1.97	399.42/271.16 = 1.47
M/A	38.02/271.16 = 0.14	170.70/127.16 = 0.63
P/M	534.24/38.02 = 14.05	399.42/170.70 = 2.34

6-10 Compare equalized and unequalized BOD loadings

Given: Data from Problem 6-7

Solution:

a. The solution was computed using a spreadsheet program.

	Time	M_{BOD} in (kg)	S	M_{BOD} out (kg)
	0800	50.85	125.00	44.03
	0900	66.02	138.44	48.76
	1000	72.90	146.95	51.76
	1100	76.45	151.91	53.50
	1200	77.76	156.12	54.99
	1300	69.66	153.40	54.03
	1400	61.99	148.19	52.19
	1500	53.95	143.74	50.63
	1600	48.20	139.51	49.14
	1700	44.93	133.55	47.04
	1800	47.25	130.97	46.13
	1900	62.64	137.00	48.25
	2000	91.44	157.26	55.39
	2100	99.07	174.64	61.51
	2200	74.05	173.39	61.07
	2300	51.48	163.02	57.42
	0000	34.65	152.72	53.79
	0100	20.41	140.83	49.60
	0200	10.02	128.59	45.29
	0300	5.22	116.50	41.03
	0400	3.85	105.48	37.15
	0500	4.81	94.86	33.41
	0600	9.08	86.40	30.43
	0700	21.63	90.14	31.75
Average		48.26		48.26

d. Average BOD concentration flowing out of equalization basin

$$BOD_{AVG} = \frac{(48.26\,kg)(1000\,g/kg)}{(0.0978\,m^3/s)(1\,h)(3600\,s/h)} = 137.07\,mg/L$$

	Unequalized	Equalized
P/A	99.07/48.26 = 2.05	61.51/48.26 = 1.27
M/A	3.85/48.26 = 0.08	30.43/48.26 = 0.63
P/M	99.07/3.85 = 25.73	61.51/30.43 = 2.02

6-11 Compare equalized and unequalized BOD loading

Given: Excel data from Problem 6-8

Solution: See following spreadsheet

Time	Flow (m^3/s)	Volume-In (m^3)	BOD In (mg/L)	M_{BOD} (kg)	Volume-Out (m^3)	dS/dt (m^3)	Accumulated dS/dt (m^3)	S (g/m^3)	M_{BOD} out (kg)
0800	0.0033	11.88	150	1.78	10.875	1.005	1.01	150.00	1.63
0900	0.0039	14.04	195	2.74	10.875	3.165	4.17	191.99	2.09
1000	0.0047	16.92	235	3.98	10.875	6.045	10.22	226.50	2.46
1100	0.0044	15.84	265	4.20	10.875	4.965	15.18	249.90	2.72
1200	0.0041	14.76	290	4.28	10.875	3.885	19.07	269.67	2.93
1300	0.0041	14.76	290	4.28	10.875	3.885	22.95	278.54	3.03
1400	0.0042	15.12	275	4.16	10.875	4.245	27.20	277.14	3.01
1500	0.0038	13.68	225	3.08	10.875	2.805	30.00	259.69	2.82
1600	0.0033	11.88	170	2.02	10.875	1.005	31.01	234.25	2.55
1700	0.0039	14.04	180	2.53	10.875	3.165	34.17	217.34	2.36
1800	0.0046	16.56	190	3.15	10.875	5.685	39.86	208.41	2.27
1900	0.0046	16.56	190	3.15	10.875	5.685	45.54	203.01	2.21
2000	0.0044	15.84	190	3.01	10.875	4.965	50.51	199.65	2.17
2100	0.0034	12.24	160	1.96	10.875	1.365	51.87	191.92	2.09
2200	0.0031	11.16	125	1.40	10.875	0.285	52.16	180.07	1.96
2300	0.002	7.2	80	0.58	10.875	-3.675	48.48	167.93	1.83
0000	0.0012	4.32	50	0.22	10.875	-6.555	41.93	158.28	1.72
0100	0.0011	3.96	34	0.13	10.875	-6.915	35.01	147.56	1.60
0200	0.0009	3.24	30	0.10	10.875	-7.635	27.38	137.60	1.50
0300	0.0009	3.24	30	0.10	10.875	-7.635	19.74	126.21	1.37
0400	0.0009	3.24	33	0.11	10.875	-7.635	12.11	113.07	1.23
0500	0.0013	4.68	55	0.26	10.875	-6.195	5.91	96.88	1.05
0600	0.0018	6.48	73	0.47	10.875	-4.395	1.52	84.39	0.92
0700	0.0026	9.36	110	1.03	10.875	-1.515	0.00	106.43	1.16
	Average	10.875	151	2.03				187	2.03

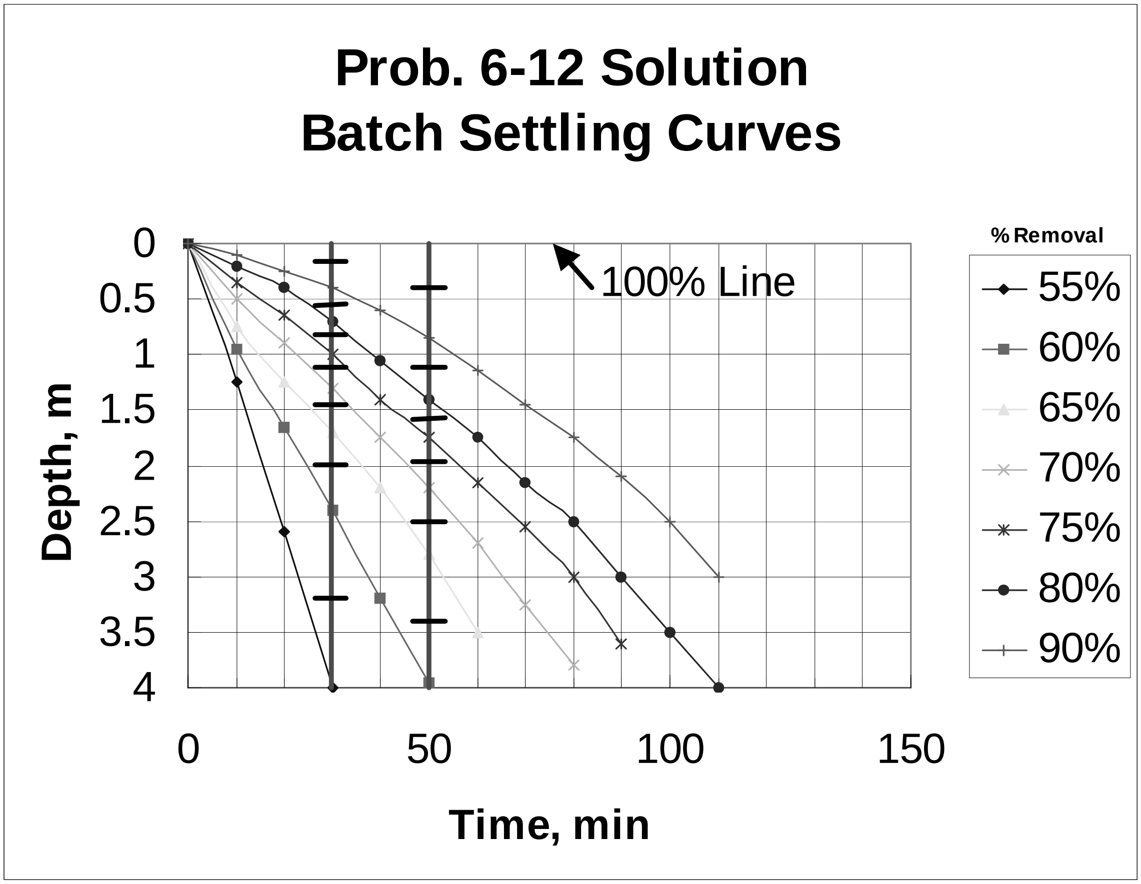
Maximum volume	52.155	m^3
Design volume	65.19375	m^3

	Unequalized	Equalized
P/A	2.11	1.44
M/A	0.05	0.45
P/M	31.50	3.18

6-12 Primary settling tank design

Given: Graph of batch settling data

Solution: Note: This solution follows example 4-23



Figures S-6-12a: Batch settling curves

a. Required removal is

$$\%\,\text{Removal} = \frac{286\,\text{mg/L} - 85\,\text{mg/L}}{286\,\text{mg/L}} \times 100\% = 70.3\%$$

b. Calculate overflow rate, % removal, and detention time for 65% removal

1. Overflow rate (note this is when the 60% line intersects the bottom of the settling column, i.e. 4.0 m)

$$v_0 = \frac{4.0\,\text{m}}{50\,\text{min}}(1440\,\text{min/d}) = 87.3\,\text{m/d}$$

2. Detention time at 60% removal

t_0 = 50 min

3. % removal (from vertical line at 50 min)

$$R_{T50} = 60 + \frac{3.4}{4.0}(65-60) + \frac{2.5}{4.0}(70-65) + \frac{1.95}{4.0}(75-70) + \frac{1.6}{4.0}(80-75) + \frac{1.1}{4.0}(90-80) + \frac{0.4}{4.0}(100-90)$$
= 75.55%

This is too high. Plot another vertical at 55%. The overflow rate and detention time are:

$$v_0 = \frac{4.0\,\text{m}}{40\,\text{min}}(1440\,\text{min/d}) = 144.0\,\text{m/d}$$

t_0 = 40 min

The % removal (from vertical line at 40 min)

$$R_{T50} = 55 + \frac{3.2}{4.0}(60-55) + \frac{2.0}{4.0}(65-60) + \frac{1.5}{4.0}(70-65) + \frac{1.15}{4.0}(75-70) + \frac{0.85}{4.0}(80-75) + \frac{0.55}{4.0}(90-80) + \frac{0.2}{4.0}(100-90)$$
= 67.74%

c. Plot % removal vs v_o and % removal vs t_0

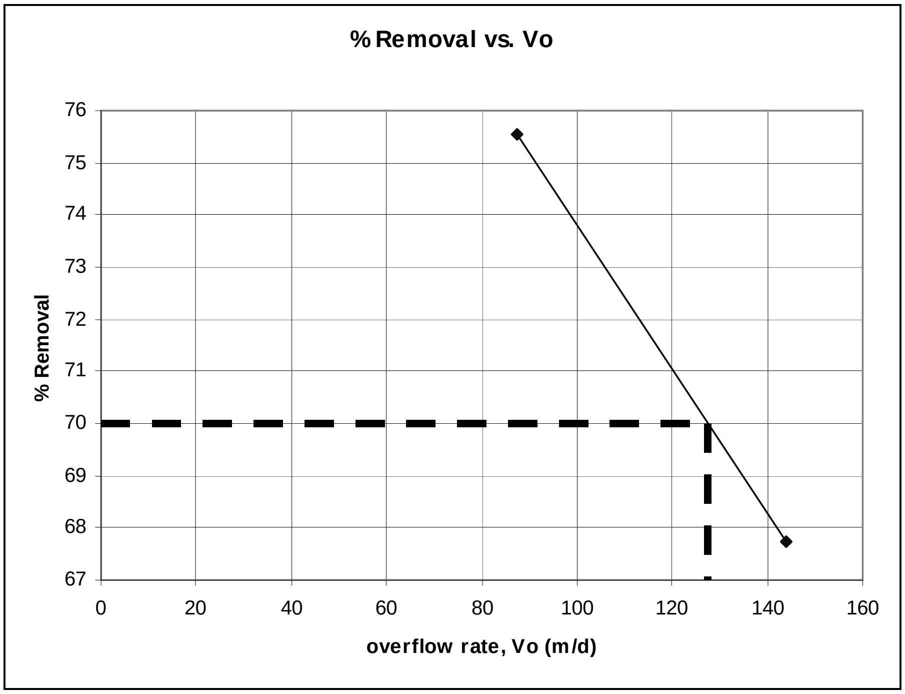


Figure S-6-12b: % Removal vs. v_o

Read v_o = 125 m/d

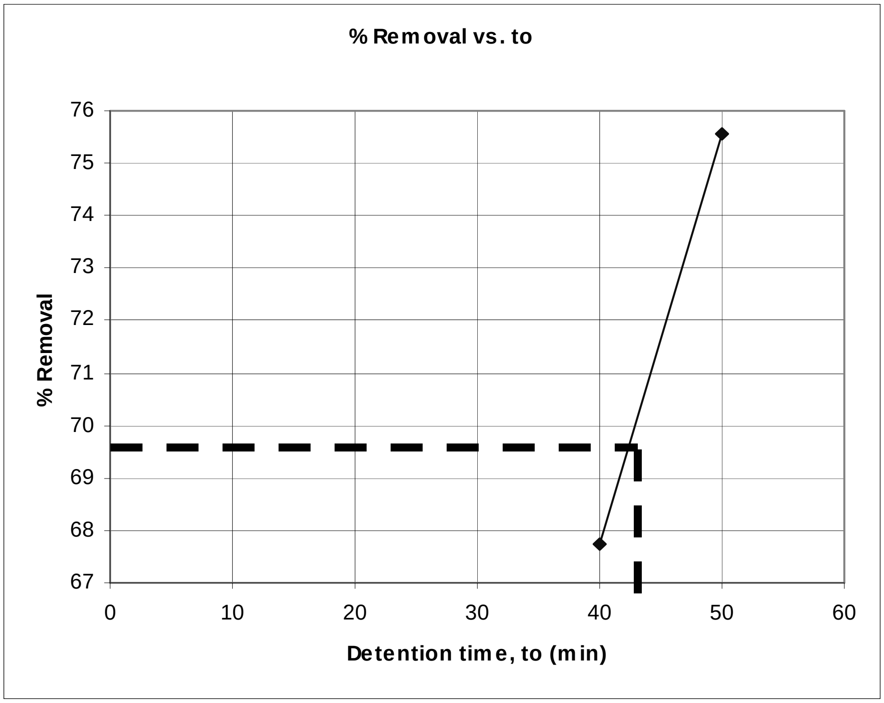


Figure S-6-12c: % Removal vs. t_o

Read t_o = 43 min

d. Apply scale up factors (See example 4-23)

v_o = (125 m/d)(0.65) = 81.25 or 80 m/d

t_o = (43 min)(1.75) = 75.25 or 75 min

6-13 Primary settling tank design

Given: Settling column data

Solution:

This problem is virtually the same as Problem 4-98. The only difference is that the influent suspended solids concentration is a factor of ten higher. The solution is the same as that for Problem 4-98.

6-14 Primary settling tank design

Given: Settling column data

Solution:

This problem is virtually the same as Problem 4-99. The only difference is that the influent suspended solids concentration is a factor of ten higher. The solution is the same as that for Problem 4-99.

6-15 Size primary tanks for Cynusoidal City

Given: Average flow in Problem 6-9 (which is average flow in Problem 6-6 = 0.400 m^3/s) is design flow, overflow rate is 26.0 m/d, detention time is 2.0 h. Assume 15 sedimentation tanks with length to width ratio of 4.7.

Solution:

a. Convert flow rate to m^3/d

Q = (0.400 m^3/s)(86400 s/d) = 34560 m^3/d

b. Compute surface area of one tank

$$A_s = \frac{Q}{v_0} = \frac{34560\,m^3/d}{(15\tan ks)(26\,m/d)} = 88.62\,m^2$$

c. Compute volume of one tank

$$\forall\!\!\!\!V = (Q)(t_0) = (34560\,m^3/d)(2h)\left(\frac{1}{24\,h/d}\right)\left(\frac{1}{15\tan ks}\right) = 192.0m^3$$

d. Compute depth of tank

$$h = \frac{\forall\!\!\!\!V}{A_s} = \frac{192.0m^3}{88.62m^2} = 2.17m$$

e. Compute width of tank using assumption that length to width ratio is 4.7

$(w)(4.7\ w) = A_s = 88.62\ m^2$

$$w^2 = \frac{88.62}{4.7} = 18.8553$$

$w = (18.8553)^{1/2} = 4.34$ m

f. Compute length of tank

l = (4.7)(4.34 m) = 20.398 or 20.4 m

g. Tank dimensions = 2.17 m x 4.34 m x 20.4 m

h. Maximum overflow rate

$$v_0 = \frac{Q_{max}}{A_s} = \frac{(0.604\,m^3/s)(86400\,s/d)}{(15\tan ks)(88.62m^2)} = 39.3\,m/d$$

6-16 Surface area of tank and detention time

Given: Flow rate = 0.570 m^3/s; overflow rate = 60.0 m/d; depth = 3.0 m

Solution:

a. Convert flow rate to m^3/d

Q = (0.570 m^3/s)(86,400 s/d) = 49,248 m^3/d

b. Compute surface area of tank

$$A_s = \frac{Q}{v_0} = \frac{49248\,m^3/d}{60\,m/d} = 821m^2$$

c. Detention time

$$t_0 = \frac{V}{A_s} = \frac{(821m^2)(3m)}{49248\,m^3/d}(24\,h/d) = 1.20h$$

6-17 New overflow rate and detention time for Problem 6-16

Given: Flow rate = 0.400 m^3/s, surface area = 821 m^2, depth = 3.0 m

Solution:

a. Convert flow rate to m^3/d

Q = (0.400 m^3/s)(86,400 s/d) = 34,560 m^3/d

b. Compute overflow rate

$$v_0 = \frac{Q}{A_s} = \frac{34560\,m^3/d}{821m^2} = 42.1\,m/d$$

c. Detention time

$$t_0 = \frac{V}{A_s} = \frac{(821m^2)(3m)}{34560\,m^3/d}(24\,h/d) = 1.71h$$

6-18 BOD_5 removal in primary tank

Given: Influent BOD_5 = 345 mg/L; average flow rate = 0.050 m^3/s; removal efficiency = 30%

Solution:

a. Mass of BOD_5 entering primary tank
(NOTE: 1.0 mg/L = 1.0 g/m^3)

$$M_{BOD_5} = (345\,g/m^3)(0.050\,m^3/s)(86400\,s/d)(10^{-3}\,kg/g) = 1490.4\,kg/d$$

b. Mass of BOD_5 removed

$$M_{removed} = (0.30)(1490.4\,kg/d) = 447.12\,kg/d$$

6-19 Suspended solids removal in primary tank

Given: Influent suspended solids = 435 mg/L; average flow rate = 0.050 m^3/s; removal efficiency = 60%

Solution:

a. Mass of suspended solids entering primary tank
(NOTE: 1.0 mg/L = 1.0 g/m^3)

$$M_{ss} = (435\,g/m^3)(0.050\,m^3/s)(86400\,s/d)(10^{-3}\,kg/g) = 1879.2\,kg/d$$

b. Mass of suspended solids removed

$$M_{removed} = (0.60)(1879.2\,kg/d) = 1127.5\,kg/d$$

6-20 Number of generations

Given: P_0 = 3.0 x 10^5; P at 36 hours = 9.0 x 10^8

Solution:

a. Solve Eqn. 6-2 for n

$$n = 3.3\log\frac{P}{P_0}$$

b. Substitute values

$$n = 3.3\log\frac{9.0\times10^8}{3.0\times10^5} = 11.47 \text{ or 11 generations}$$

6-21 Time of log growth and number of generations

Given: Time and count data

Solution:

a. Plot time and count data and find that:

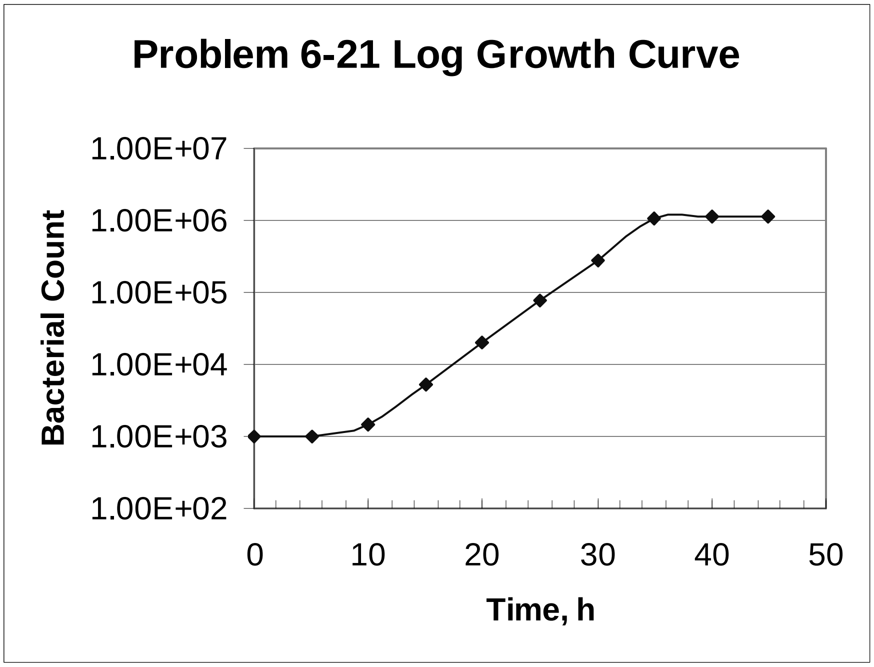


Figure S-6-21: Log growth curve

log growth starts at 10 h
log growth stops at 35 h

b. Number of generations by solving Eqn. 6-2 as in Prob. 6-20

$$n = 3.3\log\frac{1.05\times10^6}{1.5\times10^3} = 9.39 \text{ or 9 generations}$$

6-22 *E. Coli* growth curve

Given: Time, bacterial count, pH data

Solution:

a. Plot semi-logarithmic graph of the data and label the phases of log growth, stationary, and death.

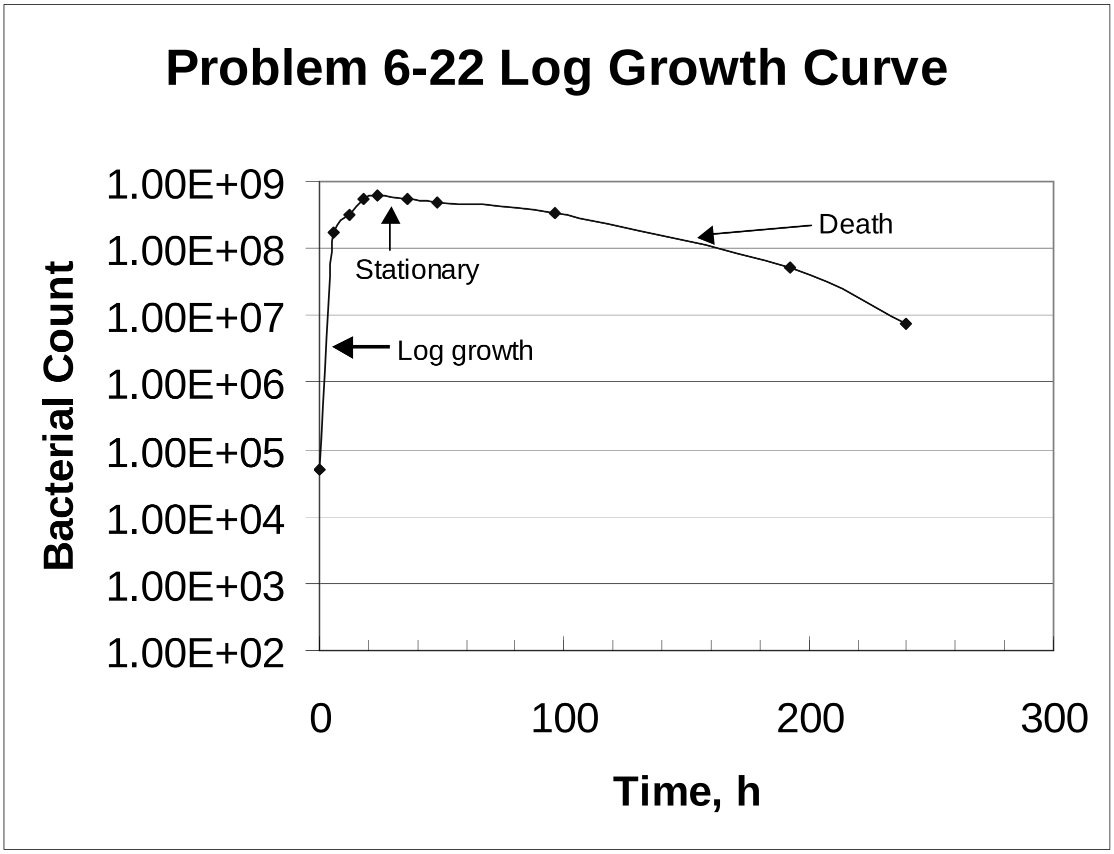


Figure S-6-22: *E. Coli* log growth curve

6-23 Volume of aeration tank

Given: Example 6-5 assumptions, BOD from Problem 6-6, Q from Problem 6-6, 32% removal of BOD in primary tank

Solution:

a. From Problem 6-6

$Q_{avg} = 0.400 \text{ m}^3/\text{s}$

BOD_{avg} after equalization = 188 mg/L

b. BOD from primary tank

$S_o = (1 - 0.32)(188) = 127.8 \text{ mg/L}$

c. From Example 6-5

$S = 30.0 - (0.63)(30.0) = 11.1$ mg/L

d. Calculate mean cell residence time from Eqn 6-21 and assumptions for growth constants from Example 6-5

$$11.1 = \frac{100(1 + 0.05\theta_C)}{\theta_C(2.5 - 0.05) - 1}$$

$$11.1[\theta_c (2.45) - 1] = 100 + 5.0 (\theta_c)$$

$$21.195\ \theta_c - 11.1 = 100 + 5.0 (\theta_c)$$

$$22.195\ \theta_c = 111.1$$

$$\theta_c = 5.0 \text{ d}$$

e. Calculate hydraulic residence time using Eqn. 6-23 and assumptions for growth constants from Example 6-5

$$2000 = \frac{(5.0)(0.5)(127.8 - 11.1)}{\theta(1 + (0.05)(5.0))}$$

$$\theta = \frac{291.75}{(2000)(1.25)} = 0.1167\text{d} \text{ or } 2.80 \text{ h}$$

f. Calculate volume using Eqn 6-18

$$V = \theta Q = (2.80 \text{ h})(0.400 \text{ m}^3/\text{s})(3,600 \text{ s/h}) = 4,032 \text{ or } 4,000 \text{ m}^3$$

6-24 Volume of aeration tank

Given: Example 6-5 assumptions, BOD from Problem 6-7, Q from Problem 6-7, 32% removal of BOD in primary tank

Solution:

a. From Problem 5-8

$Q_{avg} = 0.0978$ m^3/s

BOD_{avg} after equalization = 137 mg/L

b. BOD from primary tank

$S_o = (1 - 0.32)(137) = 93.16$ mg/L

c. From Example 6-5

$S = 30.0 - (0.63)(30.0) = 11.1$ mg/L

d. Calculate mean cell residence time from Eqn 6-21 and assumptions from Example 6-5

$$11.1 = \frac{100(1 + 0.05\theta_C)}{\theta_C(2.5 - 0.05) - 1}$$

$11.1[\theta_c (2.45) - 1] = 100 + 5.0 (\theta_c)$

$21.195\ \theta_c - 11.1 = 100 + 5.0 (\theta_c)$

$22.195\ \theta_c = 111.1$

$\theta_c = 5.0$ d

e. Calculate hydraulic residence time using Eqn. 6-23 and assumptions in Table 6-11

$$2000 = \frac{(5.0)(0.5)(93.16 - 11.1)}{\theta(1 + (0.05)(5.0))}$$

$$\theta = \frac{205.15}{(2000)(1.25)} = 0.0821\text{d} \ \text{ or } 1.97 \text{ h}$$

f. Calculate volume using Eqn 6-18

$V = \theta Q = (1.97 \text{ h})(0.0978 \text{ m}^3/\text{s})(3{,}600 \text{ s/h}) = 693.6 \text{ or } 700 \text{ m}^3$

6-25 Volume of aeration tank

Given: Example 6-5 assumptions; BOD_{avg} and Q_{avg} from Problem 6-8; 32% removal of BOD in primary tank

Solution:

a. From Problem 6-8/6-11

Q_{avg} = 0.0030 m^3/s
BOD_{avg} after equalization = 187 mg/L

b. BOD from primary tank

So = (1 – 0.32)(187) = 127.16

c. From Example 6-5

S = 30.0 – (0.63)(30.0) = 11.1 mg/L

d. Calculate mean cell residence time from Equation 6-21

$$11.1 = \frac{100(1+0.05\theta_C)}{\theta_C(2.5-0.05)-1}$$

11.1[θ_c (2.45) - 1] = 100 + 5.0 (θ_c)

21.195 θ_c - 11.1 = 100 + 5.0 (θ_c)

22.195 θ_c = 111.1

θ_c = 5.0 d

e. Calculate hydraulic residence time using Equation 6-23 and assumptions in Table 6-11

$$2000 = \frac{(5.0)(0.5)(127.16-11.1)}{\theta(1+(0.05)(5.0))}$$

$$\theta = \frac{290.15}{(2000)(1.25)} = 0.116\text{d} \text{ or } 2.785 \text{ h}$$

f. Calculate volume using Equation 6-18

V = θQ = (2.785 h)(0.0030 m^3/s)(3,600 s/h) = 30.08 or 30 m^3

6-26 Volume of aeration tank for Camp Verde

Given: Effluent standards 25.0 mg/L BOD_5 and 30 mg/L suspended solids; flow rate = 0.029 m^3/s; primary effluent BOD_5 = 240 mg/L; BOD5 of effluent suspended solids = 70% of allowable; assume K_s = 100 mg/L BOD_5; k_d = 0.025 d^{-1}; μ_m = 10 d^{-1}; Y = 0.8 mg VSS/mg BOD_5; MLVSS = 3000 mg/L

Solution:

a. Calculate allowable S

$$S = (25.0 \text{ mg/L BOD}_5) - (0.70)(30 \text{ mg/L suspended solids}) = 4 \text{ mg/L}$$

b. Calculate S_o

$$S_o = (240 \text{ mg/L}) - (240 \text{ mg/L})(0\% \text{ removed}) = 240 \text{ mg/L}$$

c. Calculate θ_c

$$\theta_c = \frac{K_s + S}{(\mu_m)(S) - (S)(k_d) - (K_s)(k_d)}$$

$$\theta_c = \frac{100 \text{ mg/L} + 4 \text{ mg/L}}{(10\text{d}^{-1})(4 \text{ mg/L}) - (4 \text{ mg/L})(0.025\text{d}^{-1}) - (100 \text{ mg/L})(0.025\text{d}^{-1})} = 2.78\text{d}$$

d. Calculate θ

$$\theta = \frac{\theta_c Y(S_o - S)}{\text{MLVSS}(1 + (k_d)(\theta_c))}$$

$$\theta = \frac{(2.78\text{d})(0.8)(240 - 4)}{3000(1 + (0.025)(2.78))} = 0.164\text{d}$$

e. Calculate the volume

$$V = (0.029 \text{ m}^3/\text{s})(0.164 \text{ d})(86400 \text{ s/d}) = 410 \text{ m}^3$$

6-27 Rework Example 6-5 using spreadsheet

Given: Example 6-5 and MLVSS concentrations of 1000; 1500; 2500; and 3000 mg/L

Solution:

a. The solution was computed using a spreadsheet program

b. Results from runs of spreadsheet

	MLVSS concentration							
	1000		**1500**		**2500**		**3000**	
Total BOD allowed	30	mg/L	30	mg/L	30	mg/L	30	mg/L
Sus. Solids allowed	30	mg/L	30	mg/L	30	mg/L	30	mg/L
% of SS = BOD	63	%	63	%	63	%	63	%
Flow rate	0.15	m^3/s	0.15	m^3/s	0.15	m^3/s	0.15	m^3/s
Soluble BOD raw	84	mg/L	84	mg/L	84	mg/L	84	mg/L
% Removed in P.S.	0		0		0		0	
Growth constants								
K_s	100	mg/L BOD	100	mg/L BOD	100	mg/L BOD	100	mg/L BOD
k_d	0.05	d^{-1}	0.05	d^{-1}	0.05	d^{-1}	0.05	d^{-1}
μ_m	2.5	d^{-1}	2.5	d^{-1}	2.5	d^{-1}	2.5	d^{-1}
Y	0.5	mg VSS/mg BOD	0.5	mg VSS/mg BOD	0.5	mg VSS/mg BOD	0.5	mg VSS/mg BOD
Design MLVSS	1000	mg/L	1500	mg/L	2500	mg/L	3000	mg/L
Allowable S	11.1	mg/L	11.1	mg/L	11.1	mg/L	11.1	mg/L
S_o	84	mg/L	84	mg/L	84	mg/L	84	mg/L
θ_c	5.0056	d	5.006	d	5.0056	d	5.0056	d
θ	0.1459	d	0.097	d	0.0584	d	0.0486	d
Volume of A.T.	1891.3	m^3	1261	m^3	756.51	m^3	630.42	m^3

6-28 Effect of MLVSS on effluent soluble BOD

Given: Example 6-5 and MLVSS values from 6-27

Solution:

a. The solution was computed using a spreadsheet program

b. Results from spreadsheet

Volume of A.T.	970 m3	970 m3	970 m3	970 m3
Flow rate	0.15 m3/s	0.15 m3/s	0.15 m3/s	0.15 m3/s
S_o	84 mg/L	84 mg/L	84 mg/L	84 mg/L
Growth constants				
K_s	100 mg/L BOD	100 mg/L BOD	100 mg/L BOD	100 mg/L BOD
k_d	0.05 d(-1)	0.05 d(-1)	0.05 d(-1)	0.05 d(-1)
μ_m	2.5 d(-1)	2.5 d(-1)	2.5 d(-1)	2.5 d(-1)
Y	0.5 mg VSS/mg BOD	0.5 mg VSS/mg BOD	0.5 mg VSS/mg BOD	0.5 mg VSS/mg BOD
Design MLVSS	1000 mg/L	1500 mg/L	2500 mg/L	3000 mg/L
θ_c	5 d	5 d	5 d	5 d
θ	0.074846 d	0.074846 d	0.074846 d	0.074846 d
S	46.57716	27.86574	-9.557099	-28.26852

6-29 Volume of aeration tank using F/M

Given: Q = 0.4380 m^3/s, F/M = 0.200 d^{-1}, BOD = 150 mg/L, MLVSS = 2200 mg/L

Solution:

a. Using Eqn. 6-26 (Note: mg/L = g/m^3)

$$0.200\text{d}^{-1} = \frac{(0.4380\,\text{m}^3/\text{s})(86400\,\text{s/d})(150\,\text{g/m}^3)}{(2200\,\text{g/m}^3)(\text{V})}$$

$$\text{V} = \frac{5676480}{(0.200)(2200)} = 1.29\times10^4\,\text{m}^3$$

6-30 Settled volume

Given: Sludge in Example 6-8; X_r = 5700 mg/L
Solution:

a. From Eqn. 6-33

$$\text{SVI} = \frac{10^6}{X_r} = \frac{10^6}{5700} = 175.439$$

b. From Eqn. 6-27

$$\text{SV} = \frac{(\text{MLSS})(\text{SVI})}{1000} = \frac{(2860)(175.439)}{1000} = 501.75\text{mL or 500 mL}$$

6-31 Reduce return sludge flow

Given: Example 6-8; $Q_r = 0.150\ m^3/s$,Q_r desired = $0.0375\ m^3/s$

Solution:

a. Derive an expression for Q_w in terms of SVI using Eqn 6-19 and the ratio of MLSS to MLVSS from Example 6-8 and a conversion factor to make units consistent

$$Q_W = \frac{VX}{\theta_c X_r} = \frac{(970)(2000)}{5\left(\frac{X_r'}{1.43}\right)}\left(\frac{1}{86400\, s/d}\right)$$

$$Q_W = \frac{6.4213}{X_r'} = \frac{6.4213(SVI)}{10^6}$$

b. Using Eqn 6-33 in Eqn 6-29 with the derived expression above

$$(Q + Q_r)(X') = Q_r\left(\frac{10^6}{SVI}\right) + Q_W\left(\frac{10^6}{SVI}\right)$$

$$(0.150 + 0.0375)(2860) = \frac{(0.0375)(10^6)}{SVI} + \frac{(6.4213)(SVI)(10^6)}{(10^6)(SVI)}$$

$$536.25 = \frac{(0.0375)(10^6)}{SVI} + 6.4213$$

$$SVI = \frac{(0.0375)(10^6)}{529.827} = 70.78 \text{ or } 70\ mL/g$$

6-32 Activated sludge tanks at Turkey Run

Given: size and operating characteristics

Solution:

a. Aeration period (Eqn. 6-18)

$$\theta = \frac{(7.0\,\text{m})(30.0\,\text{m})(4.3\,\text{m})(2\tan\text{ks})}{0.0796\,\text{m}^3/\text{s}} = 22688\text{s} \text{ or } 6.3 \text{ h}$$

b. F/M ratio (Eqn. 6-26 and note that mg/L = g/m^3)

$$\frac{F}{M} = \frac{(0.0796\,\text{m}^3/\text{s})(86400\,\text{s/d})(130\,\text{g/m}^3)}{(1806\,\text{m}^3)(1500\,\text{g/m}^3)} = 0.33\,\text{mg/mg}\cdot\text{d}$$

c. SVI (Eqn. 6-27)

$$\text{SVI} = \frac{230.0\,\text{mL/L}}{(1.40)(1500\,\text{mg/L})}(1000\,\text{mg/g}) = 109.52 \text{ or } 110 \text{ mL/g}$$

d. Solids concentration in return sludge (Eqn. 6-20)

$$X_r = \frac{10^6}{109.5} = 9132.4 \text{ or } 9130 \text{ mg/L}$$

6-33 Evaluation of Lotta Hart hospital activated sludge plant

Given: size and operating characteristics

Solution:

a. Aeration period (Eqn. 6-18)

$$\theta = \frac{(10.0\,\text{m})(10.0\,\text{m})(4.5\,\text{m})}{(500\,\text{beds})(1.200\,\text{m}^3/\text{bed}\cdot\text{d})} = 0.750\text{d} \text{ or } 18 \text{ h}$$

b. F/M ratio (Eqn. 6-26 and note that mg/L = g/m^3)

$$\frac{F}{M} = \frac{(750\,\text{m}^3/\text{d})(500\,\text{g/m}^3)}{(450\,\text{m}^3)(2500\,\text{g/m}^3)} = 0.33\,\text{mg/mg}\cdot\text{d}$$

c. SVI (Eqn. 6-18)

$$\text{SVI} = \frac{200.0\,\text{mL/L}}{(1.20)(2500\,\text{mg/L})}(1000\,\text{mg/g}) = 66.67\,\text{mL/g}$$

d. Solids concentration in return sludge (Eqn. 6-33)

$$X_r = \frac{10^6}{66.67} = 14999.25 \text{ or } 15000 \text{ mg/L}$$

6-34 Evaluation of Jambalaya activated sludge plant

Given: size and operating characteristics

Solution:

a. Aeration period (Eqn. 6-18)

$$\theta = \frac{(8.0\text{m})(8.0\text{m})(5.0\text{m})}{0.012\,\text{m}^3/\text{s}} = 26666.67\text{s} \text{ or } 7.4 \text{ h or } 0.31 \text{ d}$$

b. F/M ration (Eqn. 6-26) Note: mg/L = g/m^3

$$\frac{F}{M} = \frac{(0.012\,\text{m}^3/\text{s})(86400\,\text{s/d})(966\,\text{g/m}^3)}{(320\text{m}^3)(2000\,\text{g/m}^3)} = 1.565 \text{ or } 1.6 \text{ mg/mg-d}$$

c. SVI (Eqn. 6-27)

$$\text{SVI} = \frac{225.0\text{mL}}{(1.25)(2000\,\text{mg/L})(1.0\text{L})}(1000\,\text{mg/g}) = 90.0\,\text{mL/g}$$

d. Solids concentration in return sludge (X_r) (Eqn. 6-33)

$$X_r = \frac{10^6}{90} = 11111 \text{ or } 11000 \text{ mg/L}$$

6-35 Sludge age and wastage at Turkey Run

Given: Data from Problem 6-32 and operating assumptions

Solution:

a. Sludge age (Eqn. 6-23; θ = 6.3 h or 0.2625 d from Prob. 6-32

$$1500 = \frac{\theta_c(0.40)(130-5.0)}{(0.2625)(1+0.040\cdot\theta_c)}$$

θ_c = 11.5 d

b. Sludge wasting (Eqn. 6-19)

Recognize that wasting from aeration tank means that $X_r = X$ so Eqn 6-19 reduces to

$$\theta_c = \frac{V}{Q_W}$$

and

$$Q_W = \frac{V}{\theta_c} = \frac{(7.0\text{m})(30.0\text{m})(4.3\text{m})(2\tan\text{ks})}{11.5\text{d}}$$

Q_w = 157.04 m^3/d or 0.00182 m^3/s

c. Return sludge flow rate (Eqn. 6-30)

From Problem 6-32

X' = MLSS = (1.40)(1,500) = 2100 mg/L
X_r' = 9132.4 mg/L
Q = 0.0796 m^3/s

Then

$$Q_r = \frac{(0.0796)(2100) - (0.00182)(9132.4)}{9132.4 - 2100}$$

Q_r = 0.02141 or 0.0214 m^3/s

6-36 Solids retention and wastage at Lotta Hart

Given: Data from Problem 6-33 and operating assumptions

Solution:

a. Find S from effluent suspended solids and inert fraction assuming the allowable effluent BOD is 25.00 mg/L. The BOD fraction is = (1.0 - inert fraction)

S = 25.0 -[(1.000 - 0.6667)(25.0)] = 16.675 mg/L

b. Sludge age (Eqn. 6-23; θ = 0.75 d from Prob. 6-33

$$2500 = \frac{\theta_c (0.60)(500 - 16.675)}{(0.75)(1 + (0.06)\theta_c)}$$

$$1875 = \frac{289.995\theta_c}{1 + 0.06\theta_c}$$

$$177.495\theta_c = 1875$$

$$\theta_c = 10.56\text{d}$$

c. Sludge wasting (Eqn. 6-20)

Note that the assumption in deriving Eqn. 6-11 , namely that $X_e = 0$ is not true because the effluent suspended solids are 30.0 mg/L. Thus, Eqn. 6-11 must include this loss.

$$\theta_c = \frac{VX}{Q_w X_r + (Q - Q_w) X_e}$$

The effluent suspended solids is

X_e = (1.000 - 0.6667)(25.0 mg/L) = 8.3325 mg/L

The return sludge MLVSS is computed using the ratio of MLVSS to MLSS from Prob. 6-33

X_r = 15000/1.2 = 12500 mg/L

$$10.56 = \frac{(450\text{m}^3)(2500\,\text{g/m}^3)}{Q_w(12500\,\text{g/m}^3) + (750 - Q_w)(8.3325\,\text{g/m}^3)}$$

Q_w = 8.03 m^3/d or 0.000093 m^3/s

d. Return sludge flow rate (Eqn. 6-30)

From Problem 6-33

X' = MLSS = (1.20)(2500) = 3000 mg/L, X_r' = 15000 mg/L, and Q = 0.00868 m^3/s

Then

$$Q_r = \frac{(0.00868)(3000)-(0.000093)(15000)}{15000-3000} = 0.0023\,m^3/s$$

6-37 Solids retention and wastage at Jambalaya

Given: Data from 6-34 and operating assumptions

Solution:

a. Find S from effluent suspended solids and inert fraction s in Example 6-5

$$S = 25.0 - [(1.0-0.30)(30.0)] = 4.0$$

b. Sludge age

$$2000 = \frac{\theta_c(0.50)(966-4.0)}{(0.31)(1+0.075\cdot\theta_c)}$$

$$620 = \frac{(481.0)\theta_c}{1+0.075\cdot\theta_c}$$

$\theta_c = 1.427$ or 1.43 d

c. Sludge wasting (Eqn. 6-20)

The effluent suspended solids is

$$X_e = (1.00-0.30)(30.0\,mg/L) = 21.0\,mg/L$$

The return sludge flow is computed using the ratio of MLVSS to MLSS from Problem 6-34

$$X_r = \frac{11000}{1.25} = 8800\,mg/L$$

Using Eqn. 6-20 with (0.012 m^3/s)(86400 s/d) = 1036.8 m^3/d

$$1.427d = \frac{(320m^3)(2000\,g/m^3)}{Q_W(8800\,g/m^3)+(1036.8-Q_W)(21.0\,g/m^3)}$$

$$12528Q_W + 31070 = 640000$$

$Q_W = 48.6\ m^3/d$

d. Return sludge flow rate

X' = MLSS = (1.25)(2000) = 2500 mg/L

X_r' = 11000 mg/L

$Q = 0.012\ m^3/s$

$$Q_W = \frac{48.61\,m^3/d}{86400\,s/d} = 0.0056\,m^3/s$$

$$Q_r = \frac{(0.012)(2500)-(0.0056)(11000)}{11000-2500} = 0.0028\,m^3/s$$

6-38 Evaluation of secondary settling tanks at Turkey Run

Given: Problem 6-32; tanks are 16.0 m diameter and 4.0 m deep at side wall.

Solution:

a. Overflow rate

The design standard is 33 m/d. The overflow Q = Q of wastewater into the plant = $0.0796\ m^3/s$ from Prob. 6-32. The radius of the tank is 16.0/2 = 8.0 m.

$$v_o = \frac{(0.0796\,m^3/s)(86400\,s/d)}{\pi(8.0m)^2\,(2\tan ks)} = 17.1\,m/d$$

This is less than 33 m/d, therefore okay.

b. Side water depth

Check Table 6-12: Recommended depth for 16.0 m diameter is 3.7 m. Therefore, side water depth of 4.0 m is okay.

c. Solids loading

$$SL = \frac{(1+r)(Q)(X)(86400\,s/d)}{(A_s)(1000\,g/kg)}$$

where r = recycle ratio; X = MLSS = (1.40)(MLVSS)

From Prob. 6-35, Q_r = 0.0214 m^3/s and then

$$r = \frac{Q_r}{Q} = \frac{0.0214}{0.0796} = 0.2688$$

So

$$SL = \frac{(1 + 0.2668)(0.0796)(1.40)(1500)(86400)}{(402.12)(1000)} = \frac{1.833 \times 10^7}{4.021 \times 10^5} = 45.57\ \mathrm{kg/m^2 \cdot d}$$

Checking with Figure 6-28, we find this is much less than the 253 kg/m^2-d allowed.

d. Weir loading

$$WL = \frac{(0.0796\ \mathrm{m^3/s})(86400\ \mathrm{s/d})}{\pi(16.0\mathrm{m})(2\ \tan \mathrm{ks})} = 68.4\ \mathrm{m^3/d \cdot m}$$

This is less than the design standard of 125 m^3/d-m to 250 m^3/d-m.

6-39 Evaluation of secondary settling tank at Lotta Hart

Given: Problem 6-33, 10.0 m diameter, 3.4 m deep tank

Solution:

a. Overflow rate

The design standard is 33 m/d. The overflow Q = Q of wastewater into the plant from Prob. 6-33. The radius of the tank is 10.0/2 = 5.0 m.

$$v_o = \frac{(500\mathrm{beds})(1.2\ \mathrm{m^3/d \cdot bed})}{\pi(5.0\mathrm{m})^2(2\ \tan \mathrm{ks})} = 7.64\ \mathrm{m/d}$$

This is less than 33 m/d , therefore okay.

b. Side water depth

Check Table 6-12: Recommended depth for 10.0 m diameter is 3.4 m. Therefore, side water depth of 3.4 m is okay.

c. Solids loading

$$SL = \frac{(1+r)(Q)(X)(86400\,s/d)}{(A_s)(1000\,g/kg)}$$

where r = recycle ratio; X = MLSS = (1.20)(MLVSS)

From Prob. 6-36, Q_r = 0.0023 m^3/s and then

$$r = \frac{Q_r}{Q} = \frac{0.00157}{0.00694} = 0.3314$$

So

$$SL = \frac{(1+0.3314)(0.00694)(1.20)(2000)(86400)}{(78.54)(1000)} = \frac{1.916\times10^6}{7.854\times10^4} = 24.395\,kg/m^2\cdot d$$

Checking with Figure 6-28, we find this is much less than the 300 kg/m^2-d allowed.

d. Weir loading

$$WL = \frac{(0.00694\,m^3/s)(86400\,s/d)}{\pi(10.0m)} = \frac{599.62}{31.42} = 19.1\,m^3/d\cdot m$$

This is less than the design standard of 125 m^3/d-m to 250 m^3/d-m.

6-40 Evaluation of secondary settling time at Jambalaya

Given: Problem 6-34; tank diameter = 5.0 m; 2.5 m depth at side wall

Solution:

a. Overflow rate

The design standard is 33 m/d. Overflow Q = Q of wastewater into the plant. Q = 0.012 m^3/s

$$v_o = \frac{Q}{A_s} = \frac{(0.012\,m^3/s)(86400\,s/d)}{\pi\frac{(5.0m)^2}{4}} = \frac{1036.8\,m^3/d}{19.63m^2} = 52.80\,m/d$$

This exceeds the design standard. The diameter is too small.

b. Sidewater depth

Recommended depth = 3.4 m from Table 6-12
The actual depth (2.5 m) is too small.

c. Solids loading

$$SL = \frac{(1+r)(Q)(X)(86400\ s/d)}{(A_s)(1000\ g/kg)}$$

From Problem 6-37

$$r = \frac{Q_r}{Q} = \frac{0.0028\ m^3/s}{0.012\ m^3/s} = 0.2333$$

So

$$SL = \frac{(1+0.2333)(0.012)(1.25)(2000)(86400)}{(19.63)(1000)} = 162.81\ kg/m^2 \cdot d$$

Check with Figure 6-28 with SVI = 90 mL/g from Problem 6-34. The loading of 162.81 is much less than 300 kg/m^2-d allowed.

d. Weir Loading

$$WL = \frac{(0.012\ m^3/s)(86400\ s/d)}{\pi(5.0)} = 66.0\ m^3/d \cdot m$$

This is less than the design standard of 125 to 250 m^3/d-m.

6-41 Determine treatability factor

Given: Envirosystems equation and treatment test data

Solution:

a. Compute temperature correction factor

$$\theta = \left(1.035^{13-20}\right) = 0.78599 = 0.786$$

b. Solve for k using a depth of 2.00 m

$$\frac{L_e}{L_i} = 0.645 = \exp\left[\frac{-k(0.786)(2.00)}{(41.1)^{0.5}}\right]$$

0.645 = exp[-k(0.245)]

ln(0.645) = ln(exp[-k(0.245)])

-0.4385 = -k(0.245)

k = 1.7898 or 1.79 d^{-1}

6-42 Depth of Envirotech filter to achieve 82.7% removal

Given: k for Problem 6-41 = 1.79 d^{-1} at 20 ^oC; wastewater temperature is 20 ^oC

Solution:

a. Note that for 82.7% removal the amount remaining is

1 – 0.827 = 0.173

which is equal to L_e/L_o

b. Solve Envirotech equation for D

$$0.173 = \exp\left[\frac{(-1.79)(1)D}{(4.1)^{0.5}}\right]$$

$$0.173 = \exp\left[\frac{-1.79D}{6.41}\right] = \exp[-0.279D]$$

$$\ln 0.173 = \ln(\exp[-0.279D])$$

$$-1.754 = -0.279D$$

D = 6.28 or 6.3 m

6-43 Efficiency of filter

Given: Koon's equation and data

Solution:

a. Compute temperature correction factor

$$\theta = (1.035)^{16-20} = 0.871$$

b. Compute efficiency

$$\frac{L_e}{L_i} = \frac{\exp\left[\frac{(-1.79)(0.871)(1.8)}{(5)^{0.5}}\right]}{(1+2.00) - 2.00\left\{\exp\left[\frac{(-1.79)(0.871)(1.8)}{(5)^{0.5}}\right]\right\}}$$

$$\frac{L_e}{L_i} = \frac{0.285}{3.0 - 2(0.285)} = 0.117$$

$$\text{Efficiency} = \left(1 - \frac{L_e}{L_i}\right)(100\%) = (1 - 0.117)(100) = 88.3\%$$

6-44 Trickling filter effluent BOD_5

Given: NRC equations apply, two stage trickling filter, wastewater temperature = 17 °C, Q = 0.0509 m^3/s, C_{in} = 260 mg/L, diameter of each filter = 24.0 m, depth of each filter = 1.83 m, Q_r = 0.0594 m^3/s

Solution:

a. Computer the volume of each filter

$$V = \left(\frac{\pi(24.0\text{m})^2}{4}\right)(1.83\text{m}) = 827.87\text{m}^3$$

b. Compute recirculation ratio

$$\frac{Q_r}{Q} = \frac{0.0594\,\text{m}^3/\text{s}}{0.0509\,\text{m}^3/\text{s}} = 1.167$$

c. Calculate recirculation factor using Eqn 6-40

$$F = \frac{1 + 1.167}{[1 + 0.1(1.167)]^2} = 1.7377$$

d. The efficiency of the first filter is

$$E_1 = \frac{1}{1 + 4.12\left(\frac{(0.0509)(260)}{(827.87)(1.7377)}\right)^{0.5}}$$

$$E_1 = \frac{1}{1 + 4.12(0.0092)^{0.5}} = \frac{1}{1 + 0.3952} = 0.7168$$

e. Correct the efficiency for temperature using Eqn 6-42

$E_{17} = (0.7168)(1.035)^{17 - 20} = (0.7168)(0.9019) = 0.6465$

f. The effluent concentration from the first stage is

$C_e = (1 - 0.6465)(260) = 91.91$ mg/L

g. The efficiency of the second stage is

$$E_2 = \frac{1}{1 + \frac{4.12}{1 - 0.6465}\left(\frac{(0.0509)(91.91)}{(827.87)(1.7377)}\right)^{0.5}}$$

$$E_2 = \frac{1}{1 + 11.6549(0.0033)^{0.5}} = \frac{1}{1 + 11.6549(0.0570)} = 0.6007$$

h. Correct the efficiency for temperature using Eqn 6-42

$E_{17} = (0.6007)(1.035)^{17 - 20} = (0.6007)(0.9019) = 0.5418$

i. The final effluent BOD_5

effluent $BOD_5 = (1 - 0.5418)(91.91) = 42.11$ or 42 mg/L

6-45 Effluent of flow rate on trickling filter performance

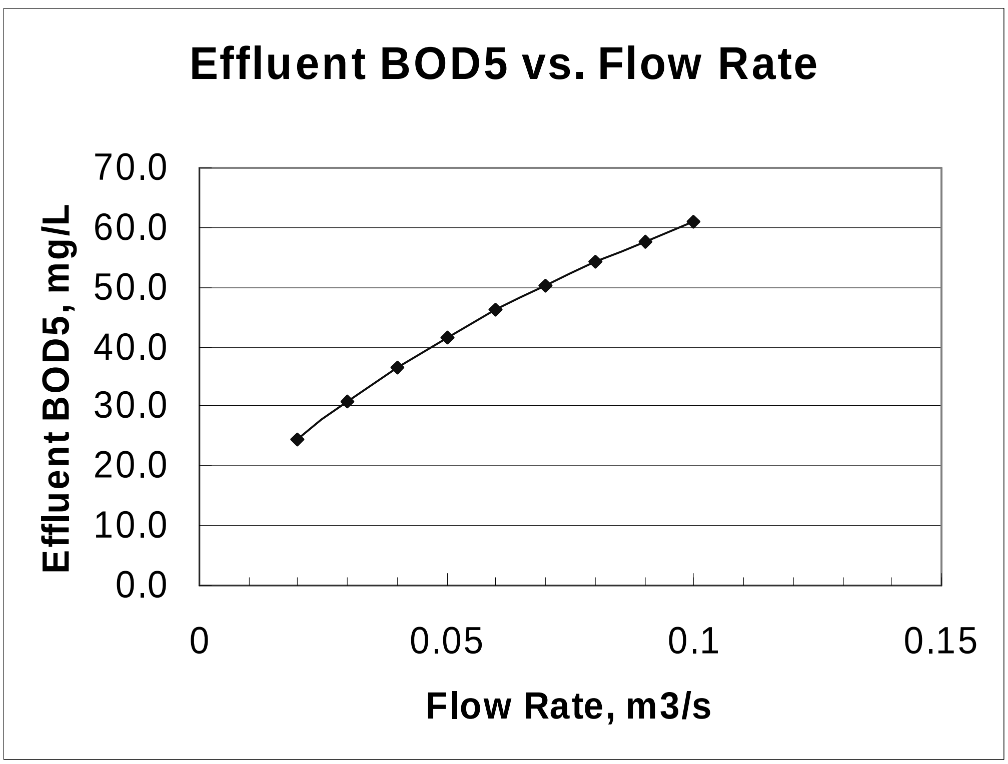
Given: Data from Problem 6-44 and flow rates

Solution:

Notes: NRC eqns., 2 stage filter, constant recirculation flow rate at 0.0594 m^3/s

Influent BOD_5 =	260 mg/L
Filter diameter =	24 m
Filter depth =	1.83 m
WW Temp.	17 ^oC

Volume of ea. Fltr (m^3)	827.8744								
Recirc. Flow rate (m^3/s)	0.0594								
Flow rates (m^3/s)	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Recirc. ratio	2.97	1.98	1.49	1.19	0.99	0.85	0.74	0.66	0.59
Recirc. Factor (F)	2.36	2.08	1.88	1.75	1.65	1.57	1.51	1.46	1.42
1st Filter Efficiency	0.82	0.78	0.75	0.72	0.69	0.67	0.65	0.64	0.62
Corr. For Temp.	0.74	0.71	0.67	0.65	0.63	0.61	0.59	0.57	0.56
Eff. From 1st filter (mg.L)	66.60	76.44	84.53	91.35	97.22	102.34	106.87	110.93	114.58
2nd Filter Efficiency	0.70	0.66	0.63	0.60	0.58	0.56	0.55	0.53	0.52
Corr. For Temp.	0.64	0.60	0.57	0.54	0.52	0.51	0.49	0.48	0.47
Final effluent BOD_5 (mg/L)	24.3	30.8	36.6	41.7	46.3	50.4	54.2	57.6	60.8
Flow rates	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1



Figures S-6-45: Effluent BOD_5 vs. flow rate

6-46 Diameter of single stage rock filter

Given: Applied BOD_5 = 125 mg/L, effluent BOD_5 = 25 mg/L, Q = 0.14 m^3/s, R = 12.0 and depth = 1.83 m. Assume NRC equations apply and the wastewater temperature is 20 °C. NOTE: In the first printing of the 3rd edition, a hydraulic loading rate rather than the flow rate was given and no temperature was given.

Solution:

a. Calculate E_1

$$E_1 = \frac{125-25}{125} = 0.80$$

b. Calculate recirculation factor

$$F = \frac{1+12.0}{[1+0.1(12.0)]^2} = 2.686$$

c. Solve Eqn 6-39 for volume

$$0.80 = \frac{1}{1+4.12\left(\frac{(0.14)(125)}{V(2.686)}\right)^{0.5}}$$

$$0.80 = \frac{1}{1+4.12(2.5525)\left(\frac{1}{V}\right)^{0.5}} = \frac{1}{1+10.5163\left(\frac{1}{V}\right)^{0.5}}$$

$$0.80\left[1+10.5163\left(\frac{1}{V}\right)^{0.5}\right] = 1$$

$$10.5613\left(\frac{1}{V}\right)^{0.5} = \frac{1}{0.80} - 1 = 0.25$$

$$\left(\frac{1}{V}\right)^{0.5} = \frac{0.25}{10.5163} = 0.0238$$

$$\frac{1}{V} = (0.0238)^2 = 5.65\times10^{-4}$$

$$V = 1769.48 \text{ m}^3$$

d. The area of the filter is then

$$A = \frac{1769.48\text{m}^3}{1.83\text{m}} = 966.93\text{m}^2$$

e. The diameter of the filter is

$$\frac{\pi D^2}{4} = 966.93\text{m}^2$$

$$D = \left[\frac{(966.93\text{m}^2)(4)}{\pi}\right]^{0.5} = 35\text{m}$$

6-47 Effect of loading rate on trickling filter performance

Given: Data from Problem 6-4, filter diameter of 35.0 m, loading rates

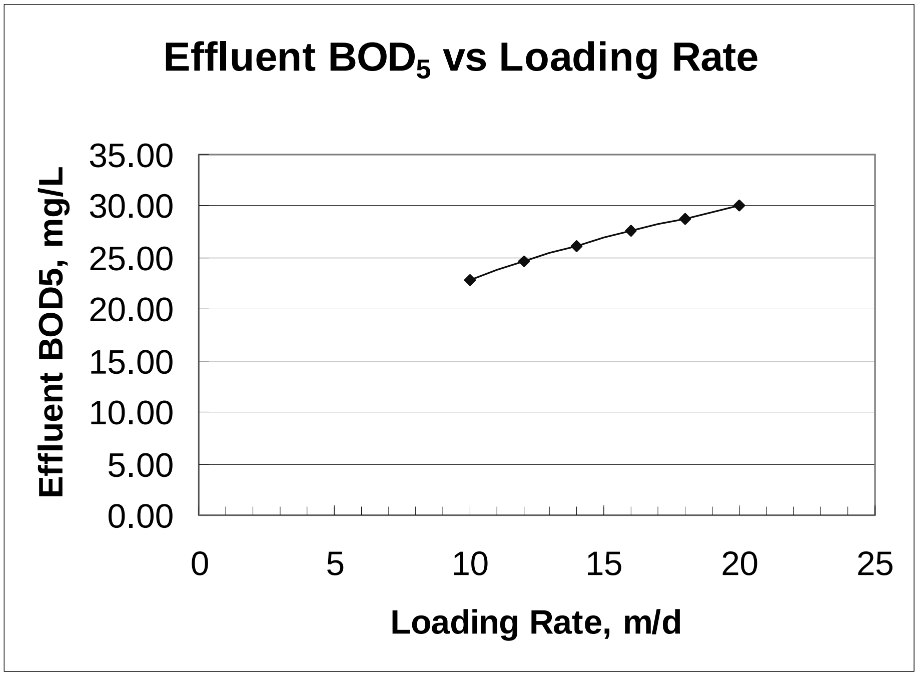
Solution:

Notes: NRC eqns., single stage filter, constant recirculation ratio = 12

Influent BOD_5	125	mg/L
Filter diameter	35	m
Filter depth	1.83	m
Recirculation ratio	12	
WW Temp.	20	^oC

Filter area	962.0844	m^2
Filter volume	1760.614	m^3

Loading rates (m/d)	10	12	14	16	18	20
Flow rates (m^3/s)	0.111352	0.133623	0.155893	0.178164	0.200434	0.222705
Recirc. Factor (F)	2.69	2.69	2.69	2.69	2.69	2.69
1st Filter Efficiency	0.82	0.80	0.79	0.78	0.77	0.76
Corr. For Temp.	0.82	0.80	0.79	0.78	0.77	0.76
Eff. From 1st filter (mg/L)	22.84	24.59	26.14	27.55	28.84	30.02
Loading rates (m/d)	10	12	14	16	18	20



Figures S-6-47: Effluent BOD_5 vs. loading rate

6-48 Evaluation of oxidation pond

Given: A_s = 90,000 m^2, Q = 500 m^3/d, 180 kg/d of BOD, operating depth ranges from 0.6 m to 1.6 m

Solution:

a. Loading rate

$$LR = \frac{180\,\text{kg/d}}{(90000\text{m}^2)(1\times10^{-4}\ \text{ha/m}^2)} = 20.0\,\text{kg/ha}\cdot\text{d}$$

This is less than the allowable of 22 kg/ha-d, so okay.

b. Detention time

$$t_o = \frac{(90000\text{m}^2)(1.6\text{m} - 0.6\text{m})}{500\,\text{m}^3/\text{d}} = 180\text{d}$$

This is equal to the 6 month minimum desired, so okay.

6-49 Surface area and loading rate

Given: Q = 3,800 m^3/d, BOD_5 = 100 mg/L

Solution:

a. Loading rate (Note: 1.0 mg/L = 1.0 g/m^3)

L = (3,800 m^3/d)(100 g/m^3)(1 x 10^{-3} kg/g) = 380.0 kg/d

b. Surface area (at 22.0 kg/ha -d)

$$SA = \frac{380.0\,\text{kg/d}}{22.0\,\text{kg/ha}\cdot\text{d}} = 17.2727\text{ha}$$

SA = (17.2727 ha)(1 x 10^4 m^2/ha) = 172,727 or 1.73 x 10^5 m^2

6-50 Alum required to remove P

Given: Example 6-15, alum as $Al_2(SO_4)_3$-18 H_2O

Solution:

a. The gram molecular weights are

Alum = 666.4094 or 666.41
P = 30.97376 or 30.97

b. Compute theoretical amount of alum

From Eqn. 6-47 each mole of alum removes one mole of P, thus, the theoretical amount of alum is

$$(4.00\,\text{mg/L}\cdot\text{of}\cdot\text{P})\left(\frac{666.41}{30.97}\right) = 86.07 \text{ or } 86.1 \text{ mg/L}$$

6-51 Lime required to remove P

Given: Example 6-15, lime as CaO

Solution:

a. The gram molecular weights are

CaO = 56.0794 or 56.08

$Ca(OH)_2$ = 74.0946 or 74.09
P = 30.97376 or 30.97

b. Compute theoretical amount of alum

From Eqn. 6-48 the ratio is 5 moles of $Ca(OH)_2$ to remove three moles of P, and one mole of CaO yields one mole of $Ca(OH)_2$ from Chapter 3. Thus, the theoretical amount of lime is

$$(4.00\,\text{mg/L}\cdot\text{of}\cdot\text{P})\left(\frac{(5)(56.08)}{30.97}\right) = 3.02\,\text{mg/L}$$

6-52 Spray irrigation storage (Wheatville, Iowa)

Given: Pop. = 1000, 280.0 Lpcd, maximum application rate is 27.74 mm/mo, percolation rate = 150 mm/mo

Solution:

a. Assume "spray season" is when temperature is above 0 °C. In fact spraying can continue to about - 4 °C but once spraying has stopped it may not recommence until temperatures exceed + 4 °C. With this assumption, the "season" excludes JAN. Since runoff is contained and reapplied, R = 0 in Eqn. 3-3. The wastewater available for application (in mm) in any month (WW_m) is computed from the following based on the available area of 40 ha:

$$WW_m = \frac{(\text{population})(\text{Lpcd})(\text{days}\cdot\text{in}\cdot\text{mo})(1\times10^6\ \text{mm}^3/\text{L})}{(40\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})}$$

For example for JAN

$$WW_m = \frac{(1000)(280)(31)(1\times10^6\ \text{mm}^3/\text{L})}{(40\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})} = 21.70\,\text{mm}^3/\text{mm}^2\cdot\text{mo}$$

The maximum WW application rate is that limited by nitrogen balance, i.e. 27.74 mm/mo. The difference between the maximum allowed and the wastewater available for application allows for application of the WW stored during the non-spray season.

b. To determine the storage required a water balance table is constructed as follows. Note that the table begins in MAR with an accumulated storage of 41.3 mm from JAN & FEB because no spraying can occur when the temperature is below 0°C and cannot begin until the temperature is over + 4 °C. Explanation of table and continuation of problem follows table.

Population	1000	
WW	280	Lpcd
Area	40	ha
No. of mo. can spray	10	
Max. Appl. Rate	25.55	mm^3/mm^2 - mo

Month	Evapotranspiration (mm)	Water losses (mm)	Precip. (mm)	WW Available (mm)	WW Applied (mm)	Total Water Avail. (mm)	Monthly Water Balance (mm)	ds/dt	Σds/dt
JAN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21.7	21.7
FEB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	19.6	41.3
MAR	43	193	63	63	25.55	88.55	-104.45	-3.85	37.45
APR	79	229	90	58.45	25.55	115.55	-113.45	-4.55	32.9
MAY	112	262	112	54.6	25.55	88.55	-173.45	-3.85	29.05
JUN	155	305	116	50.05	25.55	115.55	-189.45	-4.55	24.5
JUL	203	353	81	46.2	25.55	137.55	-215.45	-3.85	20.65
AUG	198	348	96	42.35	25.55	141.55	-206.45	-3.85	16.8
SEP	152	302	83	38.5	25.55	106.55	-195.45	-4.55	12.95
OCT	114	264	73	34.65	25.55	121.55	-142.45	-3.85	9.1
NOV	64	214	46	30.8	25.55	108.55	-105.45	-4.55	5.25
DEC	25	175	39	26.95	25.55	98.55	-76.45	-3.85	1.4

Note: The last value in the Σds/dt column is a positive value of 1.4 mm, therefore an additionally 1.4 mm must be sprayed sometime during the spray season. This additionally amount will not result in exceeding the nitrogen limit of 27.74 mm.

Max.sum from table	41.3	Look up in Σds/dt column. Not calculated
Storage volume	16,520	m^3

c. Explanation of columns

(2) Evapotranspiration = from data in table
(3) Water losses = sum of (1) and 150 mm/mo percolation
(4) Precip. = from data in table
(5) WW available = (Σds/dt) + WW avail for month (WW_m)
(6) WW Appl. = wastewater applied (up to max. of 27.74 mm/mo)
(7) Total Water Avail. = (4) + (6)
(8) Balance = (7) - (3)
(If balance is + then must reduce WW applied until balance is 0.0)
(9) dS/dt = (WW_m) - (6)
(10) Σds/dt = ((10) from previous month) - dS/dt

d. Storage is required for 41.3 mm on 40.0 ha

$$V = \frac{(41.3\text{mm})(40.0\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})}{(1\times10^{6}\ \text{mm}^3/\text{L})(1000\,\text{L}/\text{m}^3)} = 16520 \text{ or } 16500\ \text{m}^3$$

6-53 Spray irrigation storage

Given: Pop. = 8800, 485.0 Lpcd, percolation rate = 150 mm/mo, available area = 150.0 ha, no nitrogen limit

Solution:

a. Assume "spray season" is when temperature is above 0 °C. In fact spraying can continue to about - 4 °Cbut once spraying has stopped it may not recommence until temperatures exceed + 4 °C. With this assumption, the "season" excludes DEC through MAR. Since runoff is contained and reapplied, R = 0 in Eqn. 2-2. The average monthly wastewater application rate (in mm) to dispose of the annual generation in 8 months (WW_m) is computed from the following based on the available area of 125 ha:

$$WW_m = \frac{(\text{population})(\text{Lpcd})(\text{days}\cdot\text{in}\cdot\text{y})(1\times10^{6}\ \text{mm}^3/\text{L})}{(125.0\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})(8\text{months})}$$

$$WW_m = \frac{(8800)(485)(365)(1\times10^{6}\ \text{mm}^3/\text{L})}{(125.0\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})(8\text{mo})} = 155.8\,\text{mm}^3/\text{mm}^2\cdot\text{mo}$$

The maximum WW application rate is not limited by nitrogen balance. The difference between the maximum allowed and the wastewater available for application allows for application of the WW stored during the non-spray season.

b. To determine the storage required a water balance table is constructed as follows. Note that the table begins in APR with an accumulated storage of 413.15 mm from DEC through MAR because no spraying can occur when the temperature is below 0 °C and cannot begin until the temperature is over + 4 °C. Explanation of table is in following paragraph.

Population	8,800	
WW	485	Lpcd
Area	125	ha
No. of mo. can spray	8	
Max. Appl. Rate	155.8	mm^3/mm^2 - mo

Month	Evapotranspiration (mm)	Water losses (mm)	Precip. (mm)	WW Available (mm)	WW Applied (mm)	Total Water Avail. (mm)	Monthly Water Balance (mm)	ds/dt	Σds/dt
DEC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.85	105.85
JAN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.85	211.69
FEB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	95.60	307.30
MAR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.85	413.14
APR	58	258	59	515.57	155.8	214.8	-43.2	-53.35	359.79
MAY	89	289	102	465.64	155.8	257.8	-31.2	-49.94	309.86
JUN	117	317	106	412.29	155.8	261.8	-55.2	-53.35	256.51
JUL	142	342	100	362.35	155.8	255.8	-86.2	-49.94	206.57
AUG	130	330	73	312.42	155.8	228.8	-101.2	-49.94	156.64
SEP	104	304	67	262.48	155.8	222.8	-81.2	-53.35	106.70
OCT	76	276	54	212.55	155.8	209.8	-66.2	-49.94	56.76
NOV	41	241	63	162.61	155.8	218.8	-22.2	-53.35	6.83

Note: The last value in the Σds/dt column is a positive value of 6.8 mm, therefore an additionally 6.8 mm must be sprayed sometime during the spray season. There is no nitrogen limit for this problem.

Max.sum frm table	413.1	Look up in Σds/dt column. Not calculated
Storage volume	516,375	m^3

c. Explanation of columns

(2) Evapotranspiration = from data in table
(3) Water losses = sum of (1) and 150 mm/mo percolation
(4) Precip. = from data in table
(5) WW available = (Σds/dt) + WW avail for month (WW_m)
(6) WW Appl. = wastewater applied (up to max. of 27.74 mm/mo)
(7) Total Water Avail. = (4) + (6)
(8) Balance = (7) - (3)
(If balance is + then must reduce WW applied until balance is 0.0)
(9) dS/dt = (WW_m) - (6)
(10) Σds/dt = ((10) from previous month) - dS/dt

d. Storage is required for 413.15 mm on 125.0 ha

$$V = \frac{(413.15\text{mm})(125.0.0\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})}{(1\times10^{6}\ \text{mm}^3/\text{L})(1000\,\text{L}/\text{m}^3)} = 516375 \ \text{ or } 516000\ \text{m}^3$$

6-54 Spray irrigation storage (Weeping Water)

Given: population = 10080; 385 Lpcd; area = 200.0 ha, percolation rate = 150 mm/mo

Solution:

a. Assume "spray season" is when temperature is above 0^{o}C and once spraying is stopped it may not recommence until the temperature exceeds 4^{o}C. With this assumption, the "season" excludes JAN, FEB, and MAR. The wastewater available for application (in mm) in any month (WW_m) is computed from the following based on the available area of 200.0 ha.

$$WW_m = \frac{(\text{population})(\text{Lpcd})(\text{days}\cdot\text{in}\cdot\text{mo})(1\times10^6\ \text{mm}^3/\text{L})}{(200\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})}$$

Note: The 200.0 ha is the land available

For example in JAN

$$WW_m = \frac{(10080)(385.0)(31)(1\times10^6\ \text{mm}^3/\text{L})}{(200.0\text{ha})(1\times10^{10}\ \text{mm}^2/\text{ha})} = 64.45\,\text{mm}^3/\text{mm}^2\cdot\text{mo}$$

b. To determine the storage required a water balance table is constructed as follows. Note that the table begins in APR with an accumulated storage of 165.17 mm from JAN through MAR because no spraying can occur when the temperature is below 0 °C and cannot begin until the temperature is over + 4 °C. Explanation of table is in following paragraph.

Population	10,800	
WW	385	Lpcd
Area	200	ha
No. of mo. can spray	9	
Max. Appl. Rate	84.315	mm^3/mm^2 - mo

Month	Evapotranspiration (mm)	Water losses (mm)	Precip. (mm)	WW Available (mm)	WW Applied (mm)	Total Water Avail. (mm)	Monthly Water Balance (mm)	ds/dt	Σds/dt
JAN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	64.45	64.45
FEB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	58.21	122.66
MAR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	64.45	187.11
APR	6.7	156.7	23	249.48	84.3	107.3	-49.4	-21.95	165.17
MAY	11.6	161.6	45	229.61	84.3	129.3	-32.3	-19.87	145.30
JUN	16.2	166.2	46	209.75	84.3	130.3	-35.9	-21.95	125.43
JUL	19.9	169.9	34	189.88	84.3	118.3	-51.6	-19.87	105.57
AUG	19.3	169.3	32	170.02	84.3	116.3	-53.0	-19.87	85.70
SEP	13.4	163.4	27	150.15	84.3	111.3	-52.1	-21.95	65.84

OCT	8.4	158.4	16	130.28	84.3	100.3	-58.1	-19.87	45.97
NOV	4.3	154.3	12	110.42	84.3	96.3	-58.0	-21.95	26.10
DEC	3.1	153.1	12	90.55	84.3	96.3	-56.8	-19.87	6.24

Note: The last value in the Σds/dt column is a positive value of 6.2 mm, therefore an additional 6.2 mm must be sprayed sometime during the spray season. There is no nitrogen limit for this problem.

Max.sum frm table	187.11	Look up in Σds/dt column. Not calculate
Storage volume	374,220	m^3

6-55 Daily and annual sludge production

Given: Operating data from WWTP

Solution:

a. Specific gravity of solids (Eqn. 6-54)

As in example problem, recognize that mass fraction may be used instead of actual mass of volatile and fixed solids.

$$S_s = \frac{1}{1000}\left[\frac{(2.50)(1000)(0.970)(1000)}{(0.970)(0.3)(1000)+(2.50)(0.7)(1000)}\right]$$

All the 1000's cancel out and then

$$S_s = \frac{2.425}{0.291+1.75} = 1.188$$

b. Specific gravity of sludge (Eqn. 6-59)

$$S_{sl} = \frac{1.188}{0.0450+(1.188)(0.955)} = 1.007$$

c. Mass of sludge per day at 53% removal efficiency

M_s = (0.530)(155.0 g/m^3)(0.0500 m^3/s)(86,400 s/d)(10^{-3} kg/g)

M_s = 354.89 or 355 kg/d

c. Volume of sludge per day (Eqn. 6-60)

$$V_{sl} = \frac{354.89\,kg/d}{(1000\,kg/m^3)(1.007)(0.0450)} = 7.83\,m^3/d$$

d. Annual sludge production

V_{sl} = (7.83 m^3/d)(365 d/y) = 2,857.95 or 2,860 m^3/y

6-56 Daily and annual sludge production

Given: Operating data from WWTP

Solution:

a. Specific gravity of solids (Eqn. 6-54)

As in example problem, recognize that mass fraction may be used instead of actual mass of volatile and fixed solids.

$$S_s = \frac{1}{1000}\left[\frac{(2.50)(1000)(0.999)(1000)}{(0.999)(0.32)(1000)+(2.50)(0.68)(1000)}\right]$$

All the 1000's cancel out and then

$$S_s = \frac{2.4975}{0.3197+1.70} = 1.237$$

b. Specific gravity of sludge (Eqn. 6-59)

$$S_{sl} = \frac{1.237}{0.0520+(1.237)(0.948)} = 1.0098$$

c. Mass of sludge per day at 47% removal efficiency

M_s = (0.470)(179.0 g/m^3)(2.00 m^3/s)(86,400 s/d)(10^{-3} kg/g)

M_s = 14,537.66 or 1.45 x 10^4 kg/d

c. Volume of sludge per day (Eqn. 6-60)

$$V_{sl} = \frac{14537.66\,kg/d}{(1000\,kg/m^3)(1.0098)(0.0520)} = 277\,m^3/d$$

d. Annual sludge production

$$V_{sl} = (277\ m^3/d)(365\ d/y) = 101{,}105 \text{ or } 1.01 \times 10^5\ m^3/y$$

6-57 Sludge production as a function of efficiency

Given: Data for Problem 6-56 and removal efficiency of 40, 45, 50, 55, 60, and 65%

Solution:

Flow	2	m^3/s
Influent suspended solids	179	mg/L
Sp. grav. of fixed solids	2.5	
Sp. grav. of volatile solids	0.999	
Fixed solids fraction	0.32	
Volatile solids fraction	0.68	
Sludge concentration	5.2	%

Sp. grav. of solids	1.236582
Sp. grav. of sludge	1.010049

Removal efficiency	0.4	0.45	0.5	0.55	0.6	0.65
Mass of sludge (kg/d)	12,372	13,919	15,466	17,012	18,559	20,105
Daily sludge volume (m^3/d)	236	265	294	324	353	383
Annual sludge volume (m^3/y)	85,981	96,729	107,477	118,224	128,972	139,720
Removal efficiency	40	45	50	55	60	65

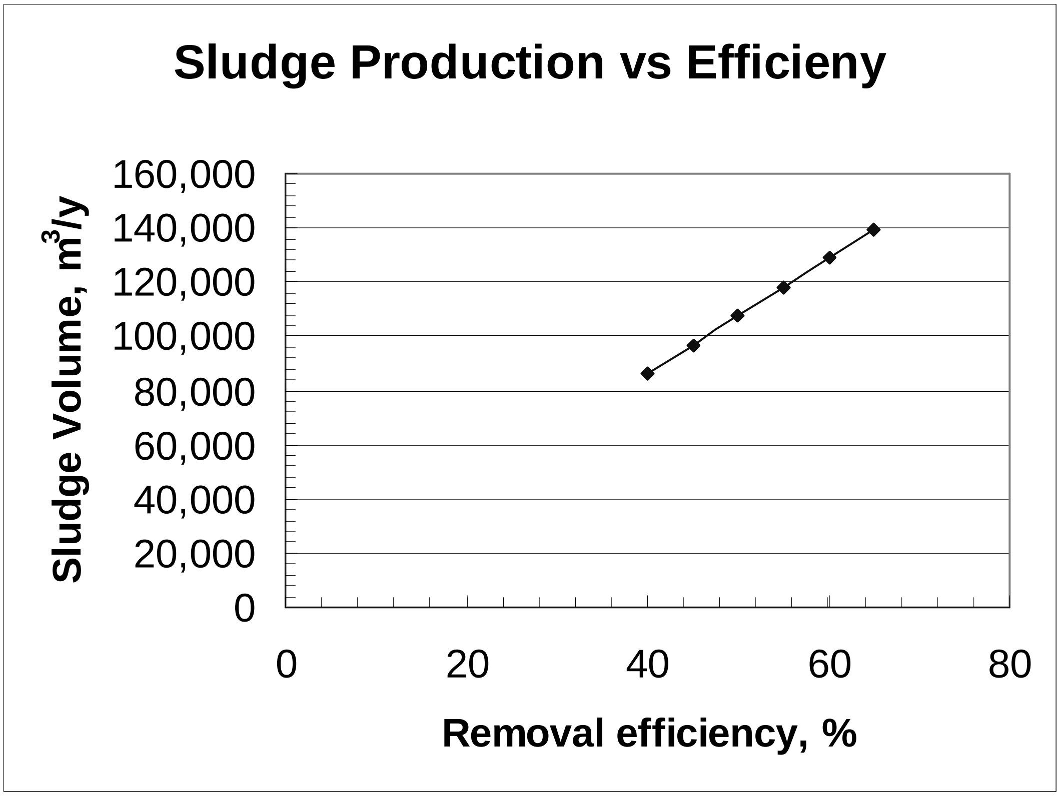


Figure S-6-57: Sludge production vs. Efficiency

6-58 Sludge mass balance

Given: Figure 6-36, Table 6-14 and efficiencies

Solution:

a. Effluent from primary sedimentation tank

$$E = \frac{185.686}{\left(\frac{1}{0.900}\right) - 0.0 - 0.150[(1 - 0.250 - 0.0)(1 + 0.190)]} = 190\,\text{Mg/d}$$

b. Return filtrate

$$M = \frac{190.011}{0.9} - 185.686 = 25.44$$

c. Effluent from primary sedimentation

B = (1 - 0.900)(185.686 + 25.44) = 21.112 or 21.1 Mg/d

d. Solids destroyed

J = (0.250)(190.011) = 47.503 or 47.5 Mg/d

e. Solids to dewatering

K = (190.011)(1 - 0.250 - 0.0) = 142.508 or 143 Mg/d

f. Solids to ultimate disposal

L = 142.508(1 + 0.190)(1 - 0.150) = 144.147 or 144 Mg/d

6-59 Rework 6-58 with dewatering removed

Given: Prob. 6-58, K = L

Solution:

a. With no dewatering n_P = 0, so

$$E = \frac{A}{1/n_E} = \frac{185.686}{1/0.900} = 167.117$$

b. Solids from digestion

$$K = E(1 - n_J - 0.0)$$

K = 167.117(1 - 0.250 -0.0) = 125.34 or 125 Mg/d

6-60 Sludge mass balance

Given: Problem 6-58, n_E = 0.5

Solution:

a. Effluent from primary sedimentation

$$E = \frac{185.686}{\left(\frac{1}{0.50}\right) - 0.0 - 0.150[(1 - 0.250 - 0.0)(1 + 0.190)]} = 99.5\,\text{Mg/d}$$

b. Return filtrate

$$M = \frac{99.5}{0.9} = 110.56$$

c. Effluent from primary sedimentation

B = (1 - 0.50)(185.686 + 110.56) = 148.122 Mg/d

d. Solids destroyed

J = (0.250)(99.5) = 24.9 Mg/d

e. Solids dewatering

K = (99.5)(1 – 0.250 – 0.0) = 74.6 Mg/d

f. Solids to ultimate disposal

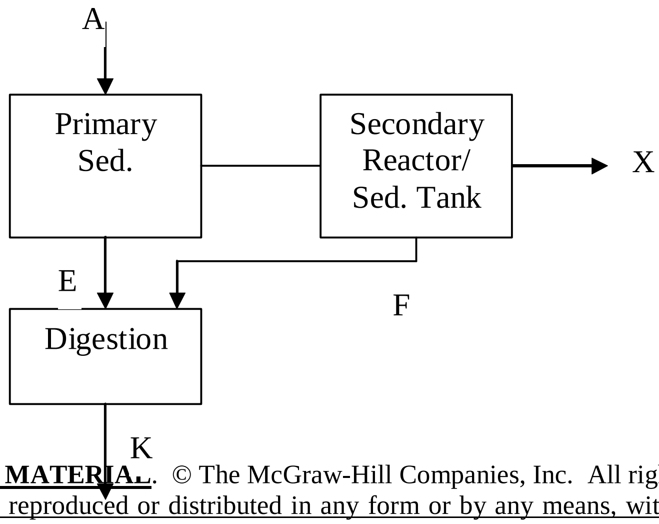
L = 74.625(1 + 0.190)(1-0.150) = 75.5 Mg/d

6-61 Doubtful WWTP mass flow to ultimate disposal

Given: Flow chart in Figure P-6-61, efficiencies from Figure 6-37, A = 7.250, X = 1.288, N = 0.0

Solution:

a. Revised flow chart



b. Table 6-15 with appropriate assumptions may be used to solve mass balances. Since we need K, note that the following functional dependencies exist: K = f(E,H), E = f(A,X), H = f(F), F = f(E,X). Since A and X are given the solution sequence is: E, F, H and then K. Note that since N = 0.0 then n_N = 0.0 and that no filtration and no dewatering means that n_R = 0.0 and n_P = 0.0.

c. Primary sludge

$$\alpha = 0.0 + 0.0 = 0.0$$

$$\beta = \frac{(1-0.650)(1-0.08)}{0.650} = 0.4954$$

$$\gamma = 0.0 + 0.0(1-0.0) = 0.0$$

$$E = \frac{7.250 - \left(\frac{1.288}{1-0.0}\right)(0.0-0.0)}{\left(\frac{1}{0.650}\right) - 0.0 - (0.4954)(0.0)} = 4.7125$$

d. Secondary sludge

Since there is no thickening H = F.

$$H = F = (0.4954)(4.7125) - \frac{1.288}{1-0.0} = 1.0465$$

e. Sludge to ultimate disposal

K = (1 - 0.350 - 0.0)(4.7125 + 1.0466) = 3.743 Mg/d

In kg/d K = (3.743 Mg/d)(1,000 kg/Mg) = 3,743 kg/d

6-62 Efficiencies for Doubtful WWTP

Given: Mass flows and Figure P-6-61

Solution:

a. Primary clarifier

$$n_E = \frac{E}{A+N} = \frac{8.910}{7.280+9.428} = 0.533$$

b. Aeration tank solids destruction

$$n_D = \frac{D}{B} = \frac{0.390}{7.798} = 0.050$$

c. Anaerobic digester supernatant

$$n_N = \frac{N}{E+F} = \frac{9.428}{8.910+6.940} = 0.595$$

d. Anaerobic digester solids destruction

$$n_J = \frac{J}{E+F} = \frac{4.755}{8.190+6.940} = 0.595$$

e. Secondary clarifier

$$n_X = \frac{X}{B-D} = \frac{0.468}{7.798+0.390} = 0.063$$

6-63 Doubtful thickening and dewatering

Given: Figure 6-37, values for n and A = 7.250 Mg/d, X = 1.288 Mg/d

Solution:

a. Table 6-15 with appropriate assumptions may be used to solve the mass balances. Note that the following functionally dependencies exist: L = f(K), K = f(E,H), H = f(F), F = f(E,X), E = f(A,X). A and X are given. The solution sequence is then E, F, H, K, L.

b. Underflow from primary sedimentation

Begin by calculating α, β, and γ. Note that η_R = 0.0 because there is no filtration

$$\alpha = 0.100(1-0.350-0.05)(1+0.190)+0.05 = 0.1214$$

$$\beta = \frac{(1-0.650)(1-0.0800)}{0.650} = 0.4954$$

$$\gamma = 0.150 + 0.1214(1 - 0.150) = 0.2532$$

$$E = \frac{7.250 - \left(\frac{1.288}{1 - 0.0}\right)(0.2532 - 0.0)}{\left(\frac{1}{0.650}\right) - 0.1214 - (0.4954)(0.2532)} = 5.3605$$

c. Underflow from secondary settling

$$F = (0.4954)(5.3605) - \frac{1.288}{1 - 0.0} = 1.3675$$

d. Thickened sludge to digester

$$H = (1 - 0.150)(1.3675) = 1.1624$$

e. Digester effluent to dewatering

$$K = (1 - 0.350 - 0.05)(5.3605 + 1.1624) = 3.9138$$

f. To ultimate disposal

$$L = 3.9138(1 + 0.190)(1 - 0.100) = 4.19\ \mathrm{Mg/d}$$

6-64 Gravity thickening for WAS

Given: WAS flow = 3255 m^3/d, thicken from 10600 mg/L to 2.50%,

Solution:

a. Compute points for batch flux curve

SS (kg/m^3)	v (m/d)	F_s ($kg/d\text{-}m^2$)
30	0.1	3
25	0.15	3.75
20	0.2	4
14	0.4	5.6
10	0.95	9.5
7	2.2	15.4
5	4.8	24

b. Plot as shown on next page

c. Note that sludge is to be thickened from 10600 mg/L to 2.50%. Plot tangent from 2.5% to find:

F_s = 14.5 kg/d-m^2

d. Solids to thickener (Note: mg/L = g/m^3)

M_s = (10600 g/m^3)(3255 m^3/d)(10^{-3} kg/g) = 34,503 kg/d

e. Surface area required

$$A_s = \frac{34503\,\text{kg/d}}{14.5\,\text{kg/d} \cdot \text{m}^2} = 2379.5\text{m}^2$$

f. Diameter of tank

$$D = \left[\frac{(2379.5)(4)}{\pi}\right]^{1/2} = 55.04$$

This exceeds the 30 m maximum.

g. Try 4 tanks

$$\frac{2379.5}{4} = 594.87\text{m}^2$$

$$D = \left[\frac{(594.87)(4)}{\pi}\right]^{1/2} = 27.5\text{m}$$

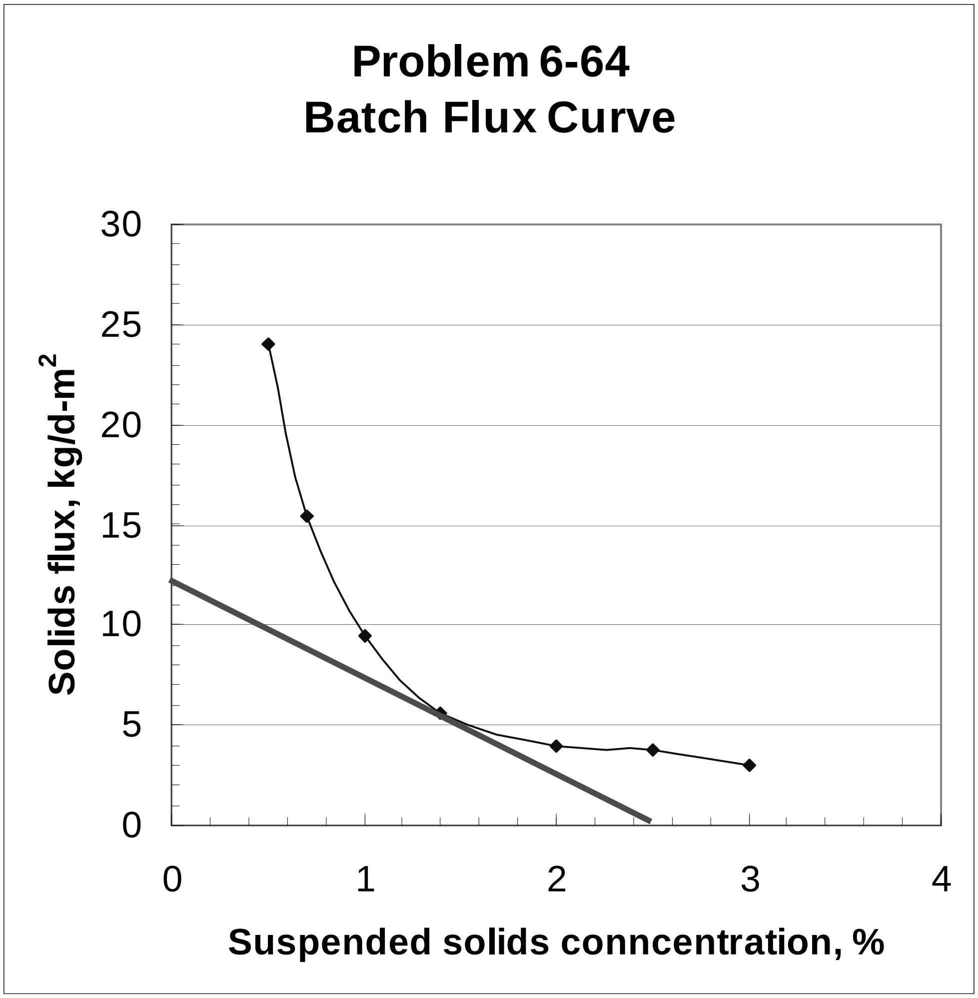


Figure S-6-64: Batch flux curve

6-65 Gravity thickening for mixed WAS and primary sludge

Given: WAS flow = 3255 m^3/d, primary flow = 710 m^3/d, thicken from 2.00% to 5.00%,

Solution:

a. Compute points for batch flux curve

SS (kg/m^3)	v (m/d)	F_s ($kg/d\text{-}m^2$)
50	0.175	8.75
40	0.22	8.8
30	0.33	9.9
25	0.5	12.5
15	3	45

b. Plot as shown below

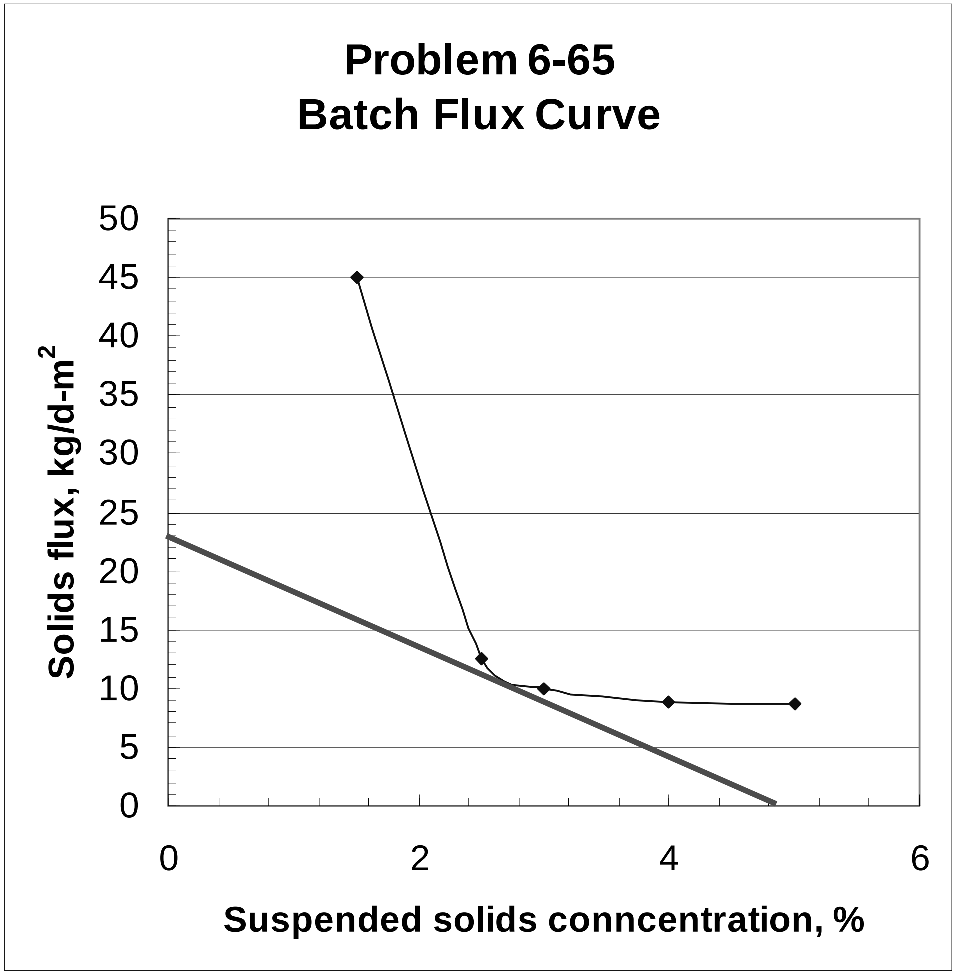


Figure S-6-65: Batch flux curve

c. Note that sludge is to be thickened from 2.00% to 5.00%. Plot tangent from 5.00% to find:

F_s = 24 kg/d-m^2

d. Solids to thickener (Note: mg/L = g/m^3)

M_s = (20,000 g/m^3)(3,255 + 710 m^3/d)(10^{-3} kg/g) = 79,300 kg/d

e. Surface area required (assuming 5 tanks)

$$A_s = \frac{79300\,\text{kg/d}}{(5\,\tan\text{ks})(14.5\,\text{kg/d}\cdot\text{m}^2)} = 635.8\text{m}^2$$

f. Diameter of tank

$$D = \left[\frac{(635.8)(4)}{\pi}\right]^{1/2} = 28.5\text{m}$$

6-66 Surface area for gravity thickener for Little Falls

Given: Q = 7.33 m^3/d, final sludge concentration of 3.6%, settling test data

Solution:

a. Compute the flux (spreadsheet)

SS Conc. (kg/m^3)	Init. Sett. Vel. (m/d)	SS conc. (%)	F(s) ($kg/d\text{-}m^2$)
4	58.5	0.4	234
6	36.6	0.6	219.6
8	24.1	0.8	192.8
14	8.1	1.4	113.4
29	2.2	2.9	63.8
41	0.73	4.1	29.93

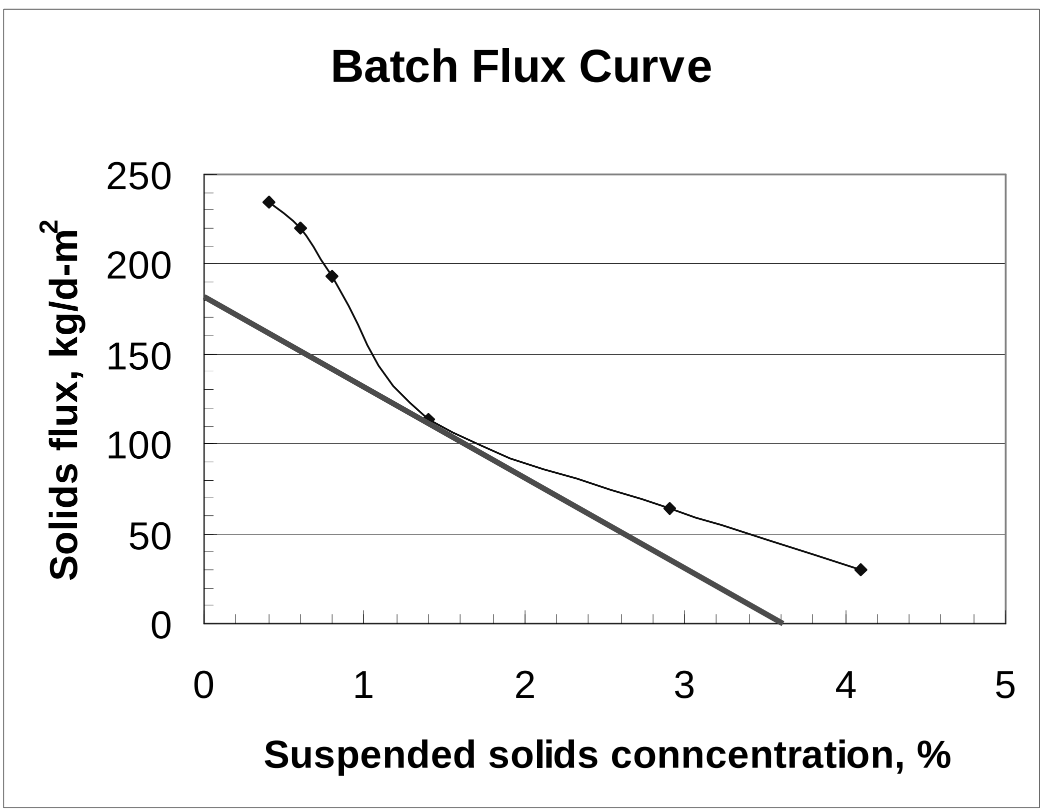


Figure S-6-66: Batch flux curve

b. From the tangent line read a solids flux of 180 kg/d-m^2

c. Compute the mass loading

M_{se} = (36000 g/m^3)(733 m^3/d)(10^{-3} kg/g) = 26388 kg/d

d. Surface area of gravity thickener

$$A_s = \frac{26388\,\mathrm{kg/d}}{180\,\mathrm{kg/d\cdot m^2}} = 146.6\mathrm{m}^2$$

6-67 Pomdeterra sludge dewatering volume savings

Given: Suspended solids = 3.8%, filter press yields 24% solids, current sludge volume = 33 m^3/d

Solution:

a. Sludge volume after filter press

$$\frac{33\,\mathrm{m^3/d}}{V_2} = \frac{0.24}{0.038}$$

Solve for V_2

$$V_2 = \frac{(33)(0.038)}{0.24} = 5.225\,\mathrm{m^3/d}$$

b. Annual volume savings

V = (33 m^3/d - 5.225 m^3/d)(365 d/y) = 10,137.8 or 10,000 m^3

6-68 Sludge volume for disposal a Ottawa

Given: Digester produces 13 m^3/d of sludge at 7.8% solids, sand drying yields 35% solids

Solution:

a. Sludge volume after sand bed

$$\frac{13\,\mathrm{m^3/d}}{V_2} = \frac{0.35}{0.078}$$

Solve for V_2

$$V_2 = \frac{(13)(0.078)}{0.35} = 2.897\,m^3/d$$

b. Annual volume

$$V = (2.897\ m^3/d)(365\ d/y) = 1{,}057 \text{ or } 1{,}000\ m^3/y$$

6-69 Concentration to reduce sludge volume

Given: 30 m^3/mo of sludge, suspended solids concentration of 2.5%

Solution:

a. Solids concentration

$$\frac{30\,m^3/mo}{3.0\,m^3/mo} = \frac{X}{0.025}$$

$$X = 10(0.025) = 0.25$$

In percent X = (0.25)(100%) = 25% solids

DISCUSSION QUESTIONS

6-1 Electron acceptor

Given: Biological reactors with and without odor

Solution:

Reactor A operating at 35 °C, with a strong odor is probably anaerobic. The potential electron acceptors are sulfate, carbon dioxide, and organic compounds that can be reduced.

Reactor B, also operating at 35 °C, is either aerobic or anoxic. There are not enough data given to differentiate between the two reactor types. If the reactor is aerobic, the electron acceptor is oxygen. If it is anoxic a potential electron acceptor is nitrate.

6-2 Processes preceding tertiary

Given: Regulatory agency requires tertiary treatment

Solution:

Probable treatment processes: bar rack, grit chamber, activated sludge including secondary settling tank or trickling filter with secondary settling tank.

6-3 Recirculation versus return sludge

Given: Differentiate between two processes

Solution:

The purpose of recirculation is to reduce the organic loading on the trickling filter. Return sludge is to return biomass to the activated sludge process. They differ in that recirculation is pumped from the supernatant of the secondary clarifier while return sludge is pumped from the bottom of the secondary clarifier.

6-4 Cost of sludge disposal

Given: SRT = 3 d and SRT = 10 d

Solution:

The shorter sludge retention time will produce more sludge and, therefore, have higher sludge disposal cost.

6-5 Removal of NH_4

Given: Industrial wastewater containing only NH_4 at pH = 7.00, being stripped with oxygen

Solution:

It cannot be denitrified. The NH_4 cannot be stripped without raising the pH.