CHAPTER 1
SOLUTIONS

1-1 Total daily withdrawal

Given: Population in 2000 = 281,421,906

Solution:

a. Using the total daily withdrawal of 5,400 Lpcd:

(281,421,906 people)(5,400 Lpcd) = 1.52 x 10^{12} L/d

b. Converting to m^3

$$\frac{1.52\times10^{12}\ \text{L/d}}{1000\ \text{L/m}^3} = 1.52\times10^{9}\ \text{m}^3\text{/d}$$

1-2 Estimate per capita withdrawal for public supply

Given: Population data from 1950 to 2000 and corresponding public supply withdrawal

Solution:

a. Use a spreadsheet to estimate the withdrawal

Problem 1-2
Intro. To ENE 5th Edition

Population	Withdrawal, m^3/d	Year	Withdrawal, Lpcd
151325798	5.30E+07	1950	350.24
179323175	7.95E+07	1960	443.33
203302031	1.02E+08	1970	501.72
226542203	1.29E+08	1980	569.43
248709873	1.46E+08	1990	587.03
281421906	1.64E+08	2000	582.75

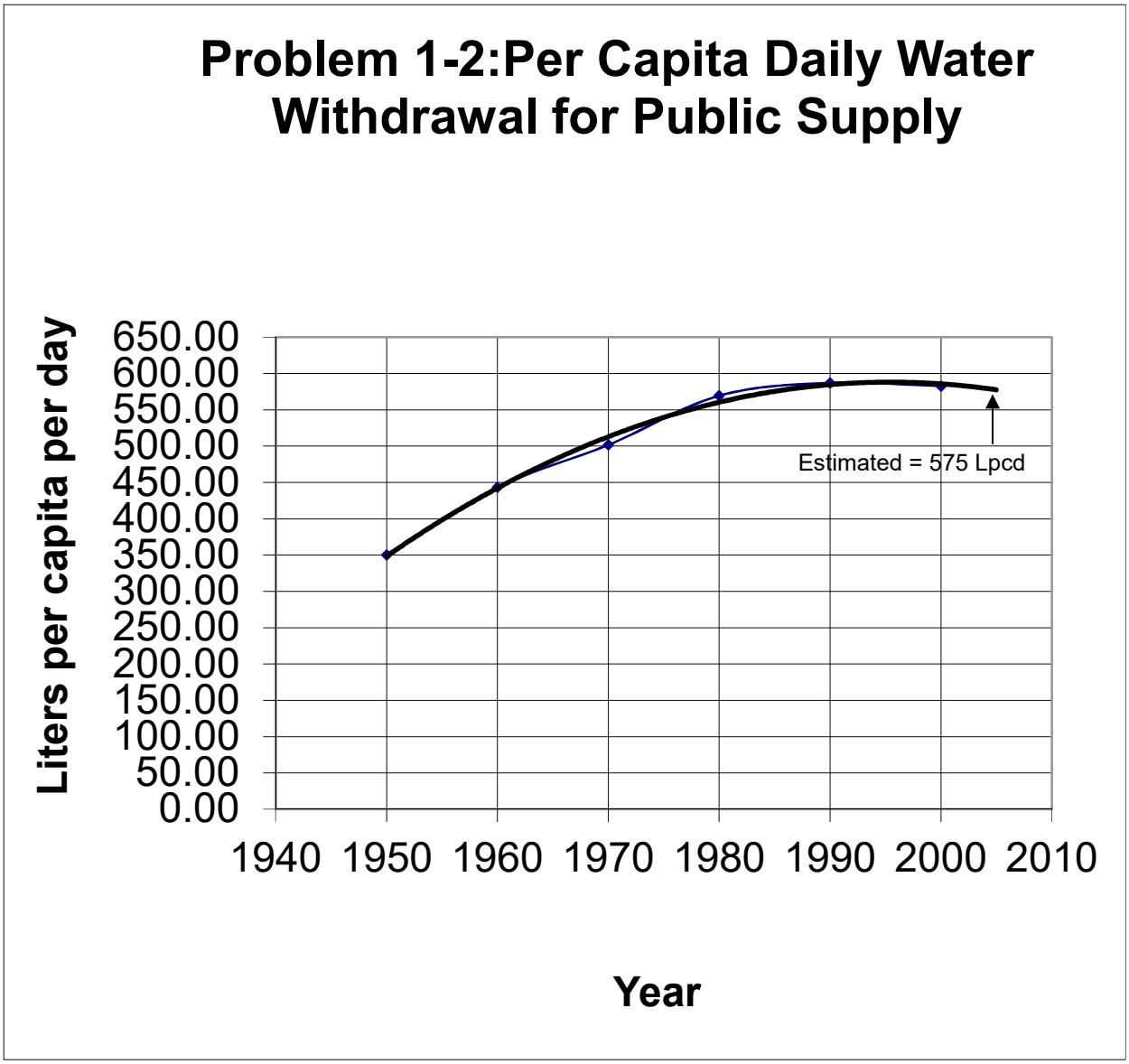


Figure S-1-2: Per capita daily water withdrawal

1-3 Additional average daily water production required

Given: 280 houses and, from text: 1,320 L/d - house

Solution:

(280 houses)(1,320 L/d - house) = 3.7×10^5 L/d

1-4 Additional average water production required with low-flush toilets

Given: 320 houses that have low flush valves that reduce water consumption by 14% and, from text, 1,320 L/d - house

Solution:

Additional demand = (320 houses)(1,320 L/d - house)(1 – 0.14) = 3.18×10^5 L/d

1-5 Repeat Prob. 1-3 for peak demand

Given: 280 metered houses, AWWA average

Solution:

a. From text: peak hour = 5.3(avg. day)

(5.3)(280 houses)(1,320 L/d - house) = 1.96×10^6 or 2×10^6 L/d at the peak hour

1-6 Water lost (in liters) in one year

Given: One drop per second, 0.150 mL per drop

Solution:

(0.150 mL/s)(86,400 s/d)(365 d/y)(1×10^{-3} L/mL) = 4,730 L/y

1-7 Monthly cost of not repairing valve

Given: Valves deliver 130.0 L/min, Water cost = $0.45 per cubic meter

Solution:

a. Assuming 30 d/mo

(130.0 L/min)(1440 min/d)(30 d/mo)(1×10^{-3} m^3/L) = 5,616 m^3/mo

(5,616 m^3/mo)($0.45/$m^3$) = $2,527.20 or $2,530/mo

1-8 Value of water lost

Given: Year 2000 data from Prob. 1-2, 15% water loss, cost of water = $0.45/$m^3$

Solution:

a. Amount of water lost

(1.6×10^8 m^3/d)(0.15) = 2.4×10^7 m^3/d

b. Value

$(2.4 \times 10^7\ m^3/d)(\$0.45/m^3) = \$1.08 \times 10^7$ or $\$1.1 \times 10^7/d$

1-9 Cost of bottled water

Given: 0.5 L bottle of water costs $1.00

Solution:

a. Convert L to m^3

$$\frac{0.5L}{1000L/m^3} = 0.0005 \text{ or } 5.0 \times 10^{-4}\ m^3$$

b. Cost

$$\frac{\$1.00}{5.0\times10^{-4}\,m^3} = \$2\times10^3 \text{ or } \$2000/m^3$$

1-10 Daily per capita withdrawal for South Carolina

Given: USGS circular 1268 at /usgs.gov

Solution:

a. From the web site

Domestic withdrawal for SC = 63.5×10^6 gal/d

Population = $4{,}010 \times 10^3$

b. Per capita

$$\frac{63.5\times10^6\ gal/d}{(4010\times10^3\ people)(0.2642\,gal/L)} = 59.94 \text{ or Lpcd}$$

1-11 Lowest domestic withdrawal in the world

Given: Pacific Institute web site (www.worldwater.org/table2.html)

Solution:

a. From the web site column labeled “Domestic Use” in $m^3/p/y$

Gambia and Haiti tied at 1 m^3/person – y

b. Convert to Lpcd

$$\frac{\left(1\,\mathrm{m}^3/\mathrm{person}\cdot\mathrm{y}\right)\left(1000\,\mathrm{L}/\mathrm{m}^3\right)}{365\,\mathrm{d}/\mathrm{y}} = 2.74 \text{ or } 3 \text{ Lpcd}$$

DISCUSSION QUESTIONS

1-1 Effect of price on demand

Given: Doubling of price of water

Solution:

In the U.S. the price of water does not severely affect the demand because water is so cheap. Doubling of the price would reduce the demand but it would not drop in half.

1-2 Type of water treatment

Given: water is from wells and proposed treatment is filtration. NOTE: it is assumed that the well water is either hard or has a high iron content.

Solution:

The answer is False.

The revised statement is: A softening plant or iron removal plant would be appropriate to improve the quality of the water.

1-3 Water pressure problems

Given: Gettysburg, PA has difficulty in supplying water over 4th of July weekend but not other times of year.

Solution:

Because of its historical significance, thousands of tourists descend on Gettysburg on the 4th of July weekend. The visitors use a large quantity of water before and after their sightseeing tours. The large demand exceeds the systems capacity to maintain the pressure in the system. This may be because of the lack of adequate storage, the small capacity of the water treatment plant, or the large pressure drops due to friction in the distribution system, or some combination of the three.

1-4 Recommended plan for a new water treatment plant

Given: Average daily demand = 11,400 m^3/d. Proposal A is for 475 m^3/h and 2,500 m^3 of storage. Proposal B is for 1,080 m^3/h and no storage.

Solution:

Proposal A is preferred for several reasons. First, the 475 m^3/h will meet the average daily demand of 11,400 m^3/d (475 m^3/h x 24 h/d = 11,400 m^3/d). Second, the 2,500 m^3

of storage will provide a reserve capacity equal to the maximum hour (5.3 times the average day). Third, the smaller plant will be more economical to build.
Proposal B will not be able to meet the maximum hour demand (5.3 x 475 m^3/h = 2,520 m^3/h) and will, on the average, be over designed for capacity and, thus, not be economical to build.

1-5 Infiltration & Inflow

Given: Homeowners have connected downspouts and sump pumps to sanitary sewer.
Solution:

The water entering the sewer is called inflow. (Choice = (b).)

These connections, in effect, make the sanitary sewer a combined sewer. (Choice = (d).)

1-6 Shiny Plating Co. ethics problem

Given: Long ethics problem dealing with the Shiny Plating Co.
Solution:

In the interest of waste minimization, the company should install the pollution control equipment. The two year payback is reasonable. "Lack of capital and high interest rates," are common excuses for not installing control equipment. The short payback time is indicative of long term profitability of the control device.

1-7 Leather tannery ethics problem

Given: Long ethics problem dealing with leather tannery.
Solution:

Select answer A. The discharge was illegal and not reporting is likewise illegal. Both professional ethics and environmental ethics

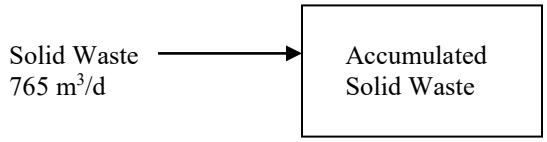
CHAPTER 2
SOLUTIONS

2-1 Expected life of landfill

Given: 16.2 ha at depth of 10 m, 765 m^3 dumped 5 days per week, compacted to twice delivered density

Solution:

a. Mass balance diagram



b. Total volume of landfill

$$(16.2 \text{ ha})(10^4 \text{ m}^2/\text{ha})(10 \text{ m}) = 1.620 \times 10^6 \text{ m}^3$$

c. Volume of solid waste is ½ delivered volume after it is compacted to 2 times its delivered density

$$(765 \text{ m}^3)(0.5) = 382.5 \text{ m}^3$$

d. Annual volume of solid waste placed in landfill

$$(382.5 \text{ m}^3)(5 \text{ d/wk})(52 \text{ wk/y}) = 9.945 \times 10^4 \text{ m}^3/\text{y}$$

e. Estimated expected life

$$\frac{1.620 \times 10^6 \text{ m}^3}{9.945 \times 10^4 \text{ m}^3/\text{y}} = 16.29 \text{ or } 16 \text{ years}$$

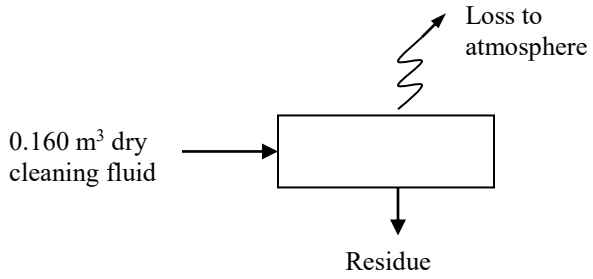
NOTE: the actual life will be somewhat less due to the need to cover the waste with soil each day.

2-2 Estimated emission of dry cleaning fluid

Given: 1 barrel (0.160 m^3) of dry cleaning fluid per month, density = 1.5940 g/mL, 90% lost to atmosphere.

Solution:

a. Mass balance diagram



b. Mass of dry cleaning fluid into tank

$$\frac{(0.160\,m^3/mo)(1.5940\,g/mL)(1000\,mL/L)(1000\,L/m^3)}{1000\,g/kg} = 255.04\,kg/mo$$

c. Mass emission rate at 90% loss

(0.90)(255.04 kg/month) = 229.54 kg/month

2-3 Estimated emission of a new dry cleaning fluid

Given: Problem 2-2, Volatility = 1/6 of former fluid, Density = 1.622 g/mL

Solution:

a. Mass balance diagram same as problem 2-2

b. Mass of dry cleaning fluid into tank

$$\frac{(0.160\,m^3/mo)(1.6620\,g/mL)(1000\,mL/L)(1000\,L/m^3)}{1000\,g/kg} = 265.92\,kg/mo$$

c. Mass emission rate at 1/6 volatility

(1/6)(0.90)(265.92 kg/mo) = 39.89 kg/mo

d. Savings in volume (note: 1.0 g/mL = 1000 kg/m^3)

Old dry cleaning fluid (from problem 2-2)

$$\text{Mass}_{out} = (0.90)(255.04\ \text{kg/mo}) = 229.54\ \text{kg/mo}$$

$$\forall_{out} = \frac{229.54\,\text{kg/mo}}{1594\,\text{kg/m}^3} = 0.1440\,\text{m}^3/\text{mo}$$

New dry cleaning volume

$$\forall_{out} = \frac{39.89\,\text{kg/mo}}{1622\,\text{kg/m}^3} = 0.0240\,\text{m}^3/\text{mo}$$

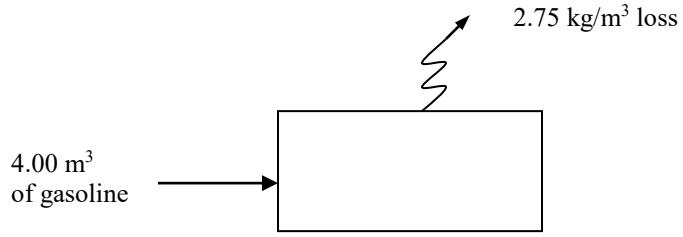
Savings = (0.1440 m^3/mo – 0.0240 m^3/mo)(12 mo/y) = 1.44 m^3/y

2-4 Annual loss of gasoline

Given: Uncontrolled loss = 2.75 kg/m^3 of gasoline
Controlled loss = 0.095 kg/m^3 of gasoline
Refill tank once a week
Tank volume = 4.00 m^3
Specific gravity of gasoline is 0.80
Condensed vapor density = 0.80 g/mL
Cost of gasoline = \$0.80/L

Solution:

a. Mass balance diagram



b. Annual loss with splash fill method

Loss = (4.00 m^3/wk)(2.75 kg/m^3)(52 wk/y) = 572 kg/y

c. Value of fuel captured with vapor control

Mass captured = (4.00 m^3/wk)(2.75 kg/m^3 – 0.095 kg/m^3)(52 wk/y) = 552.24 kg/y

Value (note: 1.0 g/mL = 1000 kg/m^3)

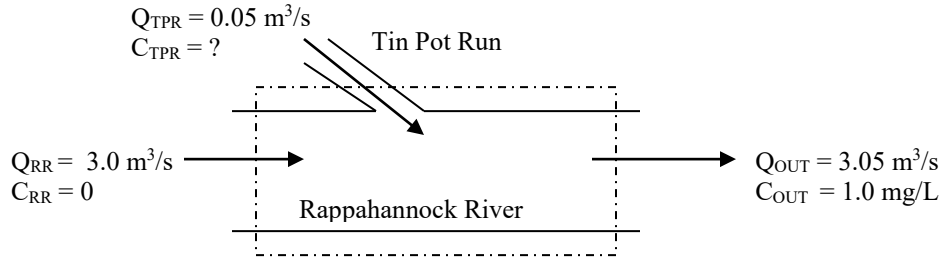
$$\frac{(552.24\,\text{kg/y})(1000\,\text{L/m}^3)}{800\,\text{kg/m}^3}(\$1.06/\text{L}) = \$731.72 \text{ or } \$732/\text{y}$$

2-5 Mass rate of tracer addition

Given: $Q_{RR} = 3.00\ m^3/s$, $Q_{TPR} = 0.05\ m^3/s$, detection limit = 1.0 mg/L

Solution:

a. Mass balance diagram (NOTE: $Q_{out} = Q_{RR} + Q_{TPR} = 3.05\ m^3/s$)



b. Mass balance equation

$$C_{RR}Q_{RR} + C_{TRP}Q_{TPR} = C_{out}Q_{out}$$

Because C_{RR} in = 0 this equation reduces to:

$$C_{TPR}Q_{TPR} = C_{out}Q_{out}$$

c. Note that the quantity $C_{TPR}Q_{TPR}$ is the mass flow rate of the tracer into TPR and substitute values

$$C_{TPR}Q_{TPR} = \frac{1.0\text{mg}}{\text{L}} \times \frac{3.05\text{m}^3}{\text{s}} \times \frac{1000\text{L}}{\text{m}^3} \times \frac{1\text{kg}}{10^6\,\text{mg}} \times \frac{86400\text{s}}{\text{d}} = 264\,\text{kg/d}$$

d. Concentration in Tin Pot Run

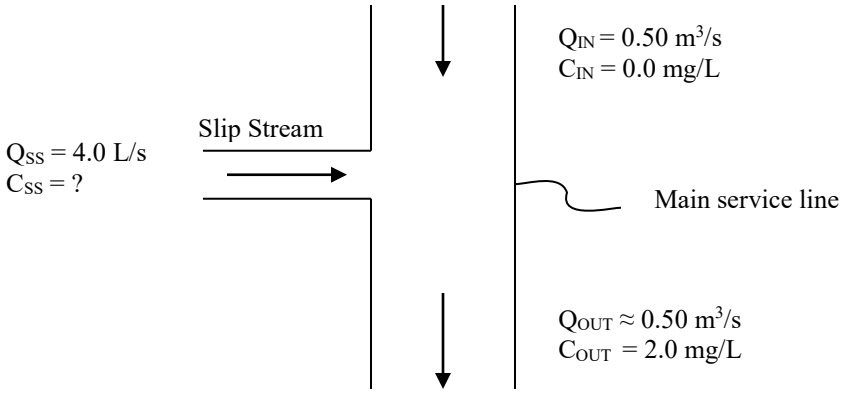
$$C_{TPR} = \frac{C_{TPR}Q_{TPR}}{Q_{TPR}} = \frac{(264\,\text{kg/d})(10^6\,\text{mg/kg})}{(0.05\,\text{m}^3/\text{s})(86400\,\text{s/d})(1000\,\text{L/m}^3)} = 61 \text{ or } 60\ \text{mg/L}$$

2-6 NaOCl pumping rate

Given: NaOCl at 52,000 mg/L
Piping scheme in figure P-2-6
Main service line flow rate = 0.50 m^3/s
Slip stream flow rate 4.0 L/s

Solution:

a. Mass balance at return of slip stream to main service line



b. Calculate C_{SS}

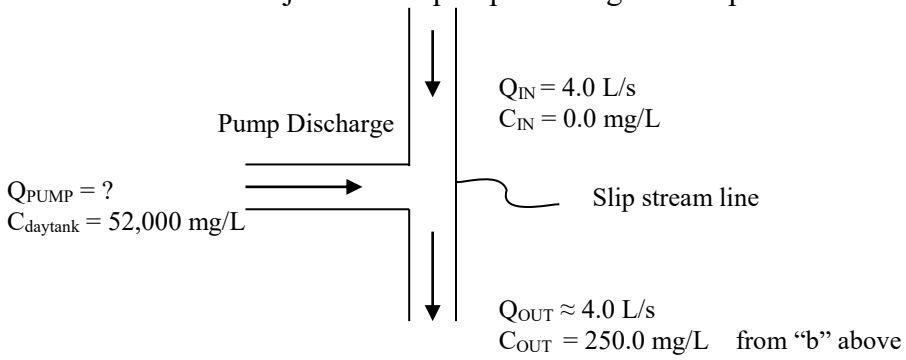
Mass out = Mass in

$(0.50\ m^3/s)(2.0\ mg/L)(1000\ L/m^3) = (4.0\ L/s)(C_{SS})$

$1000\ mg/s = (4.0\ L/s)(C_{SS})$

$$C_{SS} = \frac{1000 mg/s}{4.0 L/s} = 250 mg/L$$

c. Mass balance at the junction of pump discharge and slip stream line



d. Calculate Q_{PUMP}

Mass in = Mass out

$(Q_{PUMP})(52{,}000\ mg/L) = (4.0\ L/s)(250\ mg/L)$

$$Q_{PUMP} = \frac{(4.0\,L/s)(250\,mg/L)}{52{,}000\,mg/L} = 0.0192\,L/s$$

2-7 Dilution of NaOCl in day tank

Given: Pump rated at 1.0 L/s
8 hour shift
NaOCl feed rate 1000 mg/s
Stock solution from Prob 2-6 = 52,000 mg/L

Solution:

a. Mass of NaOCl to be fed in 8 h

$(8\ h)(3600\ s/h)(1000\ mg/s) = 2.88 \times 10^7\ mg$

b. Volume of stock solution

$$\frac{2.88\times10^7\,mg}{52{,}000\,mg/L} = 5.54\times10^2\,L \text{ or } 0.554\ m^3$$

c. Volume of dilution water

$(8\ h)(3600\ s/h)(1.0\ L/s) = 2.88 \times 10^4\ L$ or $28.8\ m^3$

d. Check

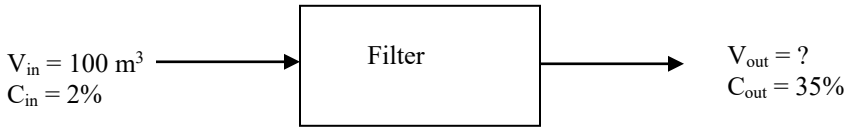
$28.8\ m^3 + 0.554\ m^3 = 29.4\ m^3 < 30\ m^3$

2-8 Volume of sludge after filtration

Given: Sludge concentration of 2%, sludge volume = 100 m^3, sludge concentration after filtration = 35%

Solution:

a. Mass balance diagram



b. Mass balance equation

$$C_{in}\forall_{in} = C_{out}\forall_{out}$$

c. Solve for $\forall_{out}$

$$V_{out} = \frac{C_{in}\forall_{in}}{C_{out}}$$

d. Substituting values

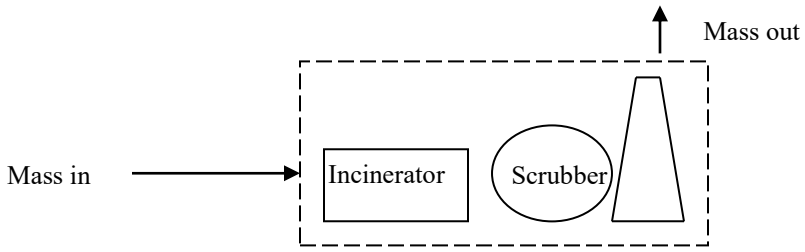
$$V_{out} = \frac{(0.02)(100\text{m}^3)}{0.35} = 5.71\text{m}^3$$

2-9 Hazardous waste incinerator emission

Given: Four nines DRE
Mass flow rate in = 1.0000 g/s
Incinerator is 90% efficient

Solution:

a. Mass balance diagram



b. Allowable quantity in exit stream

Mass out = (1 - DRE)(Mass in)

= (1 – 0.9999)(1.0000 g/s) = 0.00010 g/s

c. Scrubber efficiency

Mass out of incinerator = (1 – 0.90)(1.000 g/s) = 0.10000 g/s

Mass out of scrubber must be 0.00010 g/s from "b", therefore

$$\eta = \frac{0.1000 g/s - 0.00010 g/s}{0.1000 g/s} = 0.999 \text{ or } 99.9\%$$

2-10 Sampling filter efficiency

Given: First filter captures 1941 particles
Second filter captures 63 particles
Figure P-2-10
Each filter has same efficiency

Solution:

a. Note that

$$\eta = \frac{C_2}{C_1} \text{ and } \eta = \frac{C_3}{C_2}$$

b. The concentration C_2 is

$$C_2 = C_1 - 1{,}941$$

c. Substitute efficiency for C_1 and C_2

$$\frac{63}{\eta} = \frac{1941}{\eta} - 1941$$

d. Solve for η

$$63 = 1{,}941 - 1941\eta$$

$$-1{,}941\eta = 63 - 1941 = -1{,}878$$

$$\eta = \frac{1878}{1941} = 0.9675$$

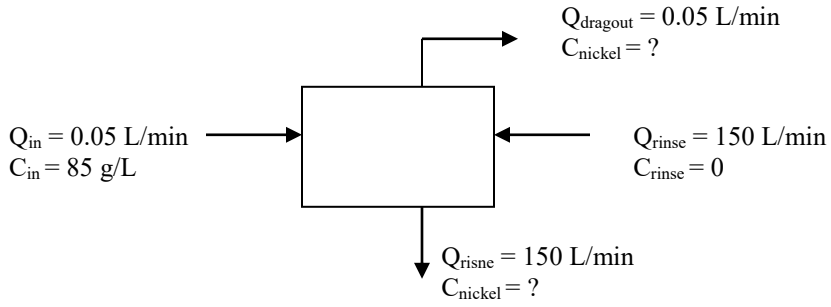
e. The efficiency of the sampling filters is 96.75%

2-11 Concentration of nickel in wastewater stream

Given: Figure P – 2-11, concentration of plating solution = 85 g/L, drag-out rate = 0.05 L/min, flow into rinse tank = 150 L/min, assume no accumulation in tank.

Solution:

a. Mass balance diagram



b. Mass balance equation

$$Q_{in}C_{in} + Q_{rinse}C_{rinse} - Q_{dragout}C_{nickel} - Q_{rinse}C_{nickel} = 0$$

c. Because $C_{rinse} = 0$ this reduces to

$$Q_{in}C_{in} = Q_{dragout}C_{nickel} + Q_{rinse}C_{nickel}$$

d. Solving for C_{nickel}

$$C_{nickel} = \frac{Q_{in}C_{in}}{Q_{dragout} + Q_{rinse}}$$

e. Substituting values

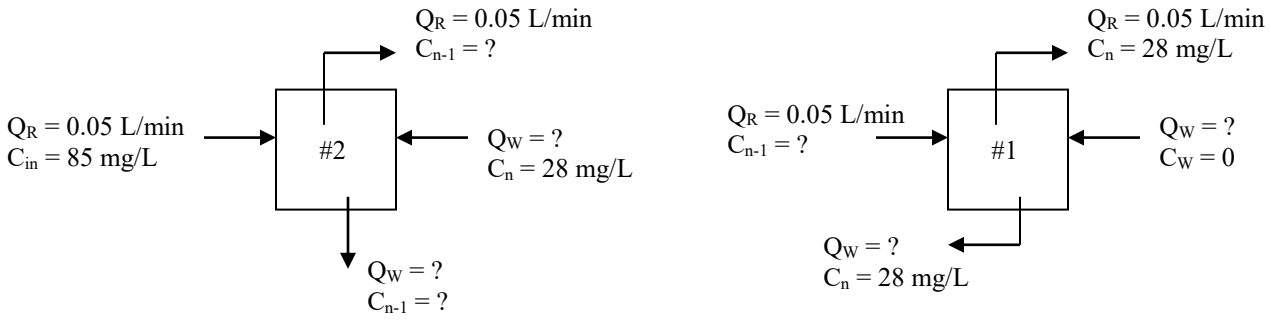
$$C_{nickel} = \frac{(0.05\,\mathrm{L/min})(85\,\mathrm{g/L})}{0.05\,\mathrm{L/min} + 150\,\mathrm{L/min}} = 28\,\mathrm{mg/L}$$

2-12 Counter-current rinse tanks

Given: Figure P-2-12, C_n = 28 mg/L, assume no accumulation in tanks

Solution:

a. Because there are two unknowns we must set up two mass balance equations and solve them simultaneously. The mass balance diagrams are:



b. Mass balance equation, starting with the right-hand rinse tank (#1)

$$(C_{n-1})(Q_R) + (C_W)(Q_W) = (C_n)(Q_R) + (C_n)(Q_W)$$

c. Note that $(C_w)(Q_R) = 0$ because $C_W = 0$, then solve for Q_W

$$Q_W = \frac{(C_{n-1})(Q_R) - (C_n)(Q_R)}{C_n}$$

$$Q_W = \frac{Q_R[(C_{n-1}) - C_n]}{C_n}$$

d. Mass balance equation for tank at the left hand side (#2)

$$(C_{in})(Q_R) + (C_n)(Q_W) = (C_{n-1})(Q_R) + (C_{n-1})(Q_W)$$

e. Solving for C_{n-1}

$$C_{n-1} = \frac{(C_{in})(Q_R) + (C_n)(Q_W)}{Q_R + Q_W}$$

f. Substitute solution for tank #2 into solution for tank #1 and simplify

$$Q_W = \frac{Q_R\left[\frac{C_{in}Q_R + C_nQ_W}{Q_R + Q_W} - C_n\right]}{C_n}$$

$$Q_W{}^2 + Q_RQ_W + Q_R{}^2\left(\frac{C_n - C_{in}}{C_n}\right) = 0$$

This equation is a quadratic equation with a = 1, b = Q_R and $c = Q_R{}^2\left(\frac{C_n - C_{in}}{C_n}\right)$

g. The solution to the quadratic equation is

$$Q_W = \frac{-Q_R + \left[Q_R{}^2 - 4Q_R{}^2 \left(\frac{C_n - C_{in}}{C_n} \right) \right]^{1/2}}{2}$$

h. Substituting the values for the variables, note C_n is in mg/L and C_{in} is in g/L

$$Q_W = \frac{-0.05 + \left[0.05^2 - 4(0.05)^2 \left(\frac{0.028 - 85}{0.028} \right) \right]^{1/2}}{2}$$

$$Q_W = \frac{-0.05 + 5.51}{2} = 2.73 \text{ or } 3 \text{ L/min}$$

2-13 Multiple countercurrent rinse tanks

Given: EPA equation for multiple tanks; Figure P-2-13

Solution:

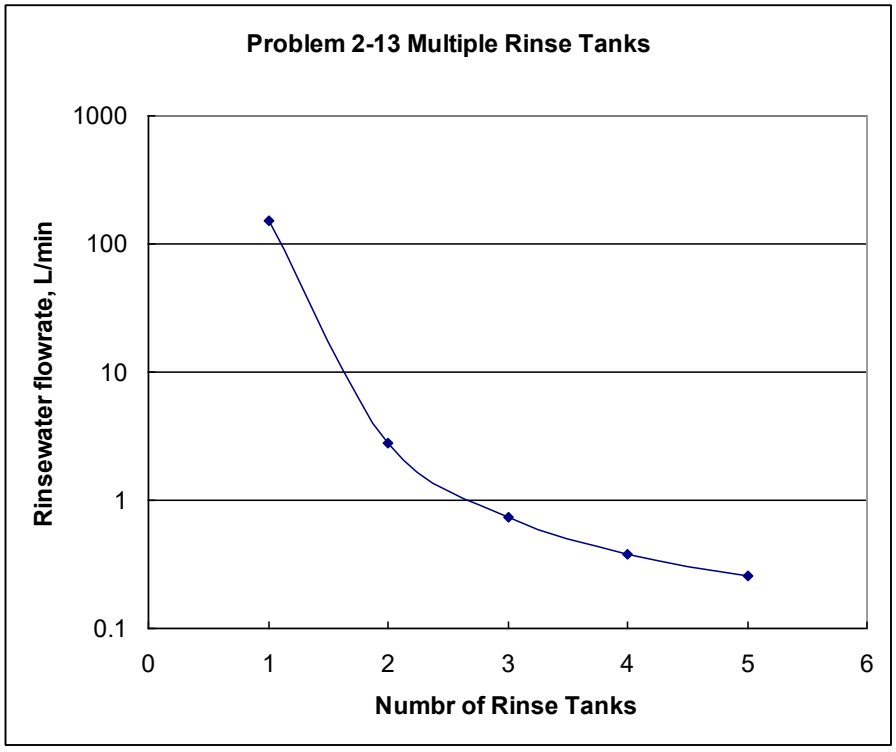


Figure S-2-13: Multiple rinse tanks

2-14 Oxygen concentration in bottle

Given: Starting O_2 concentration = 8 mg/L, rate constant of 0.35 d^{-1}

Solution:

a. General mass balance equation for the bottle is Eqn 2-28

$$C_t = C_o e^{-kt}$$

b. With C_o = 8.0 mg/L and k = 0.35, the plotting points for oxygen remaining are:

Day	Oxygen Remaining, mg/L
1	5.64
2	3.97
3	2.79
4	1.97
5	1.39

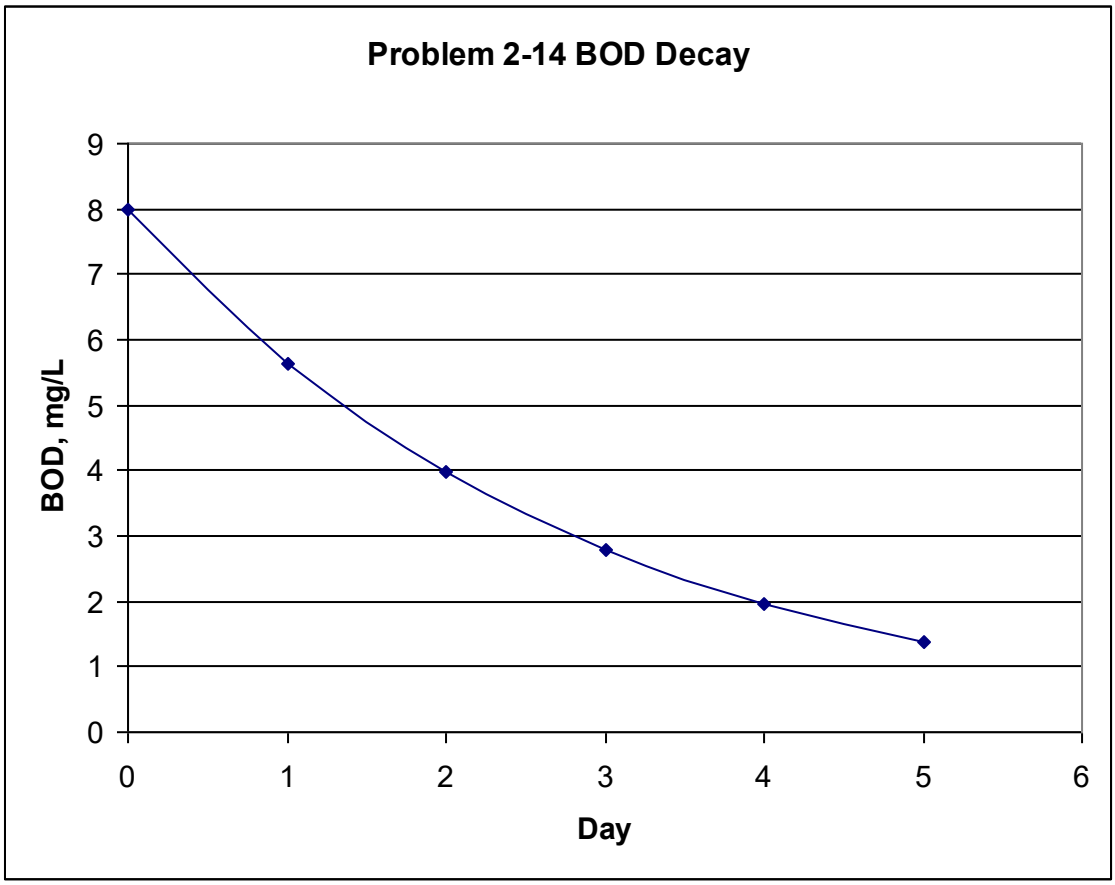


Figure S-2-14: BOD decay

2-15 Decay rate for anthrax die-off

Given: Die-off data points