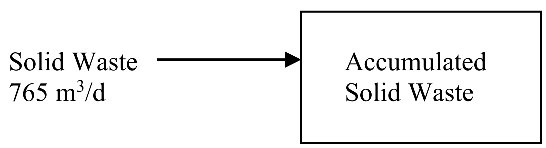
CHAPTER 2
SOLUTIONS

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

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

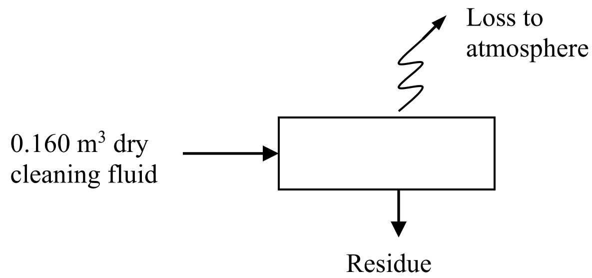
NOTE: the actual life will be somewhat less due to the need to cover the waste with soil each day.

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

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

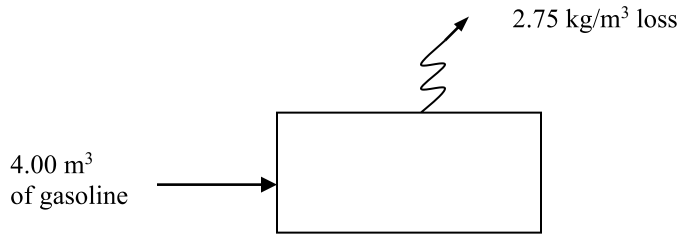
Savings = (0.1440 m^3/mo – 0.0240 m^3/mo)(12 mo/y) = 1.44 m^3/y

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)

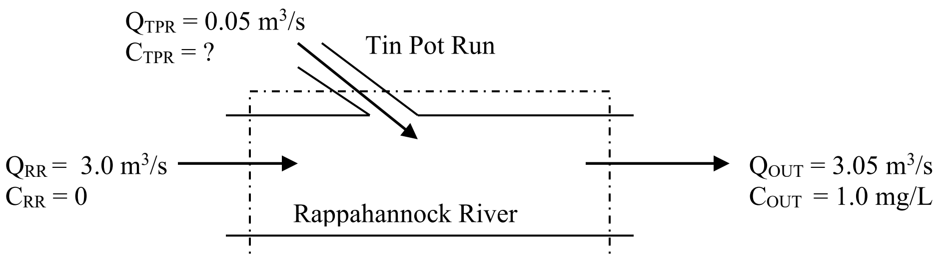
$$\frac{(552.24\,\text{kg/y})(1000\,\text{L/m}^3)}{800\,\text{kg/m}^3}(\$1.06/\text{L}) = \$731.72 \text{ or } \$732/\text{y}$$

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

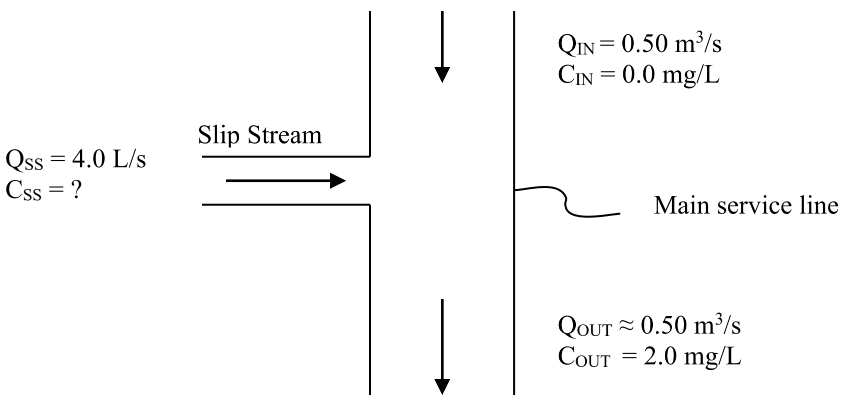
$$C_{TPR} = \frac{C_{TPR}Q_{TPR}}{Q_{TPR}} = \frac{(264\,\text{kg/d})(10^6\,\text{mg/kg})}{(0.05\,\text{m}^3/\text{s})(86400\,\text{s/d})(1000\,\text{L/m}^3)} = 61 \text{ or } 60\text{ mg/L}$$

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}

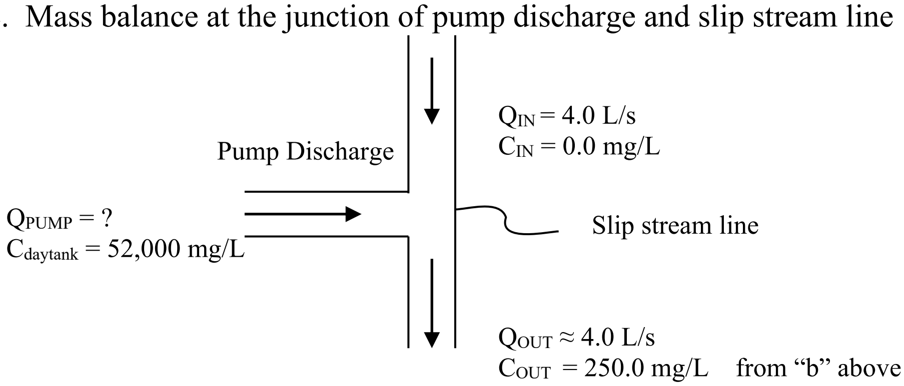
Mass out = Mass in

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

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

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

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



d. Calculate Q_{PUMP}

Mass in = Mass out

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

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

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

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

b. Volume of stock solution

$$\frac{2.88 \times 10^7 \text{ mg}}{52{,}000 \text{ mg/L}} = 5.54 \times 10^2 \text{ L} \text{ or } 0.554 \text{ m}^3$$

c. Volume of dilution water

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

d. Check

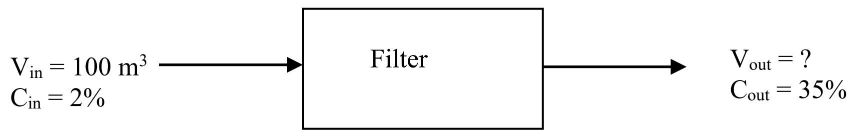
$28.8 \text{ m}^3 + 0.554 \text{ m}^3 = 29.4 \text{ m}^3 < 30 \text{ m}^3$

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 $\forall_{out}$

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

d. Substituting values

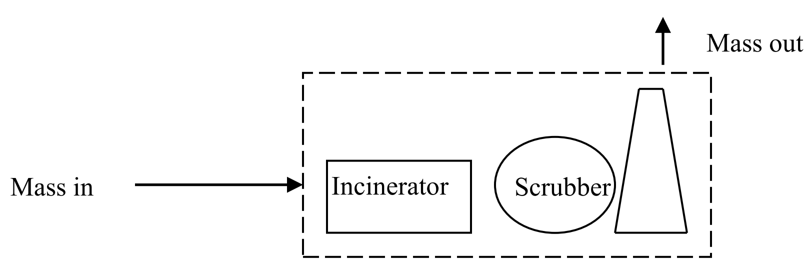
$$V_{out} = \frac{(0.02)(100\,m^3)}{0.35} = 5.71\,m^3$$

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

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

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 - 1941η

-1,941η = 63 – 1941 = -1,878

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

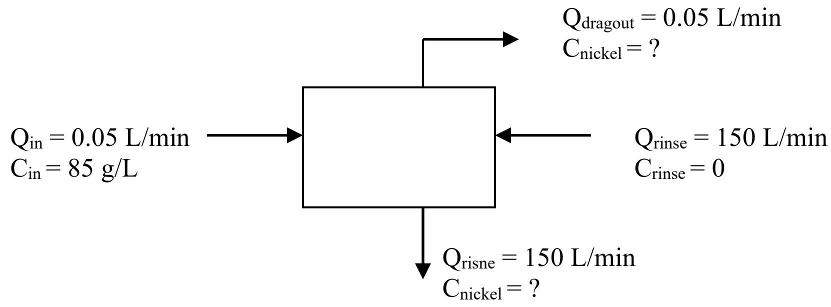
e. The efficiency of the sampling filters is 96.75%

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

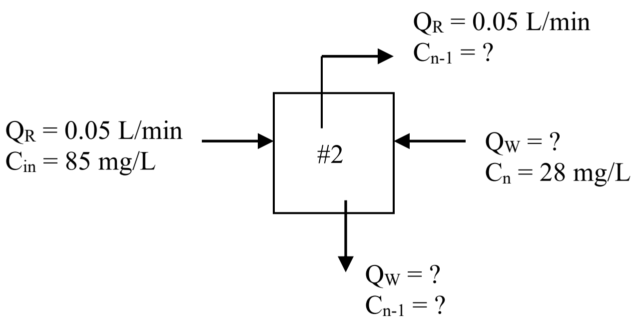
$$C_{nickel} = \frac{(0.05\ L/min)(85\ g/L)}{0.05\ L/min + 150\ L/min} = 28\ mg/L$$

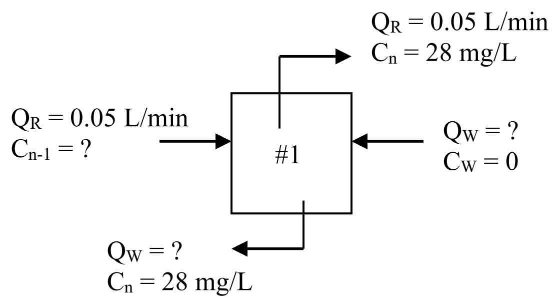
2-12 Counter-current rinse tanks

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

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

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

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

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

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

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:

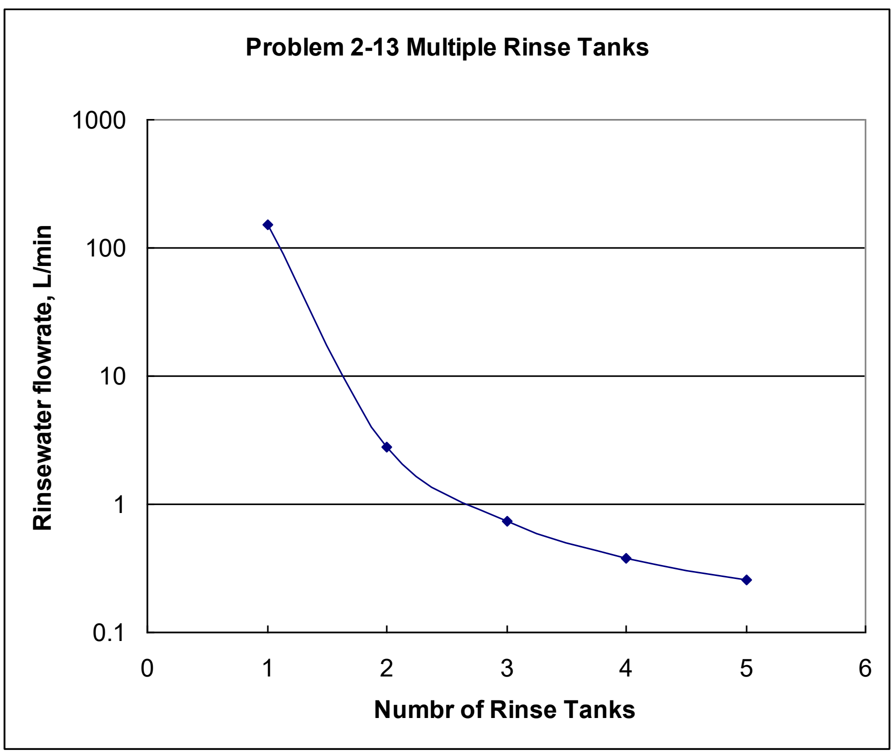


Figure S-2-13: Multiple rinse tanks

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

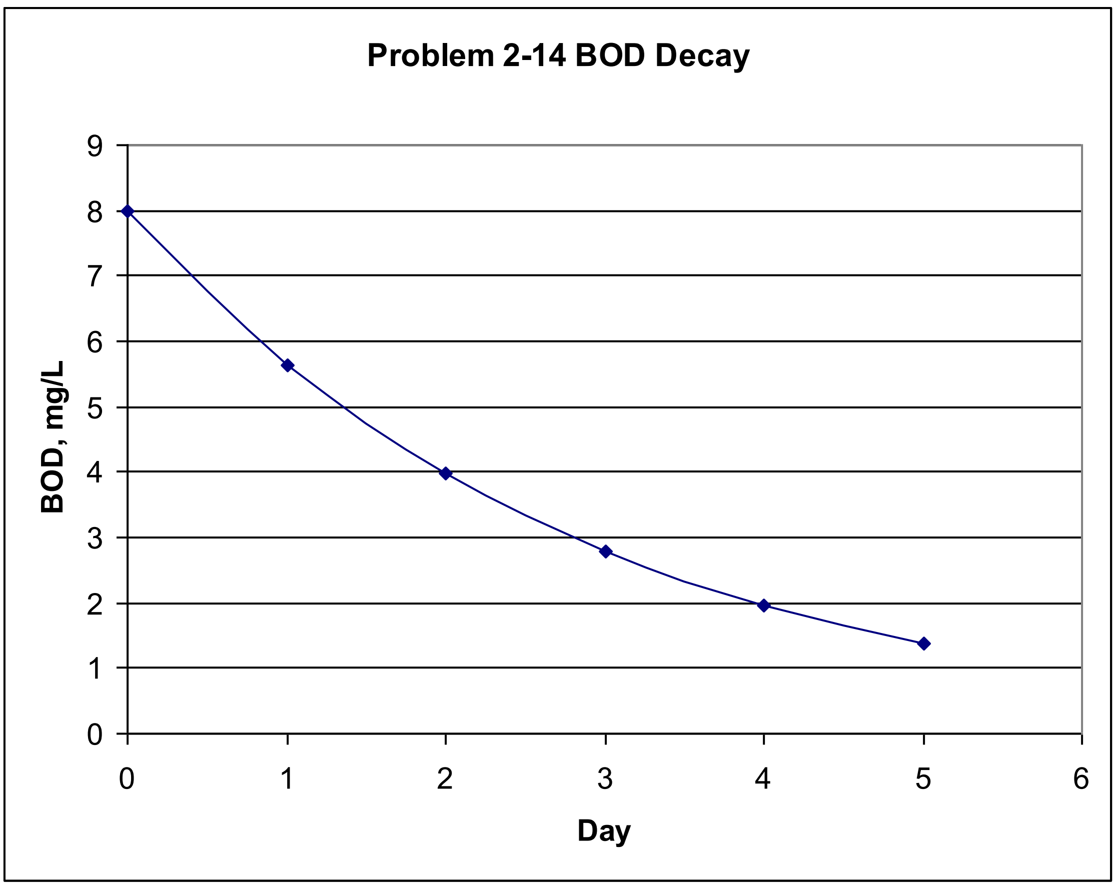


Figure S-2-14: BOD decay

2-15 Decay rate for anthrax die-off

Given: Die-off data points

no./mL	Time, min
398	0
251	30
158	60

Solution:

a. Assume this is 1st order decay (Eqn 2-28)

$C_t = C_o e^{-kt}$

b. Using two values (t = 0 and t = 60 min), set $C_o = C_{60}$ and solve for k

$158 = 398e^{-k(60\ \text{min})}$

$$\frac{158}{398} = e^{-k(60)}$$

$0.397 = e^{-k(60)}$

Take the natural log of both sides

$\ln(0.397) = \ln[e^{-k(60)}]$

$-0.924 = -k(60)$

$k = 0.0154\ \text{min}^{-1}$ (or $k = 22.18\ \text{d}^{-1}$)

c. Check at t = 30 min

$C_t = 398e^{-(0.0154)(30)} = 250.767$ or 251

2-16 Chlorine decay in water tower

Given: 4000 m^3 water tower
Initial chlorine concentration = 2.0 mg/L
$k = 0.2\ h^{-1}$
Shut down for 8h
Assume completely mixed batch reactor

Solution:

a. Because there is no influent or effluent, the concentration is described by Eqn 2-28.

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

b. Substituting values and solving for C_t

(Note: 8h = 0.33 d)

$C_t = 2.0 \exp[-(1.0\ d^{-1})(0.33\ d)]$

$C_t = 2.0(0.72) = 1.44$ mg/L

c. Mass of chlorine to raise concentration back to 2.0 mg/L

Concentration change required

2.0 mg/L – 1.44 mg/L = 0.56 mg/L

Mass required in kg

$$\frac{(0.56\,\text{mg/L})(4000\,\text{m}^3)(1000\,\text{L/m}^3)}{10^6\ \text{mg/kg}} = 2.25 \text{ or } 2.3\text{kg}$$

2-17 Expression for half-life

Given: Batch reactor

Solution:

a. Mass balance equation (Eqn 2-16)

$$\frac{dM}{dt} = \frac{d(\text{In})}{dt} - \frac{d(\text{Out})}{dt} - kC\forall$$

b. Since it is a batch reactor with no “in” or “out”, this reduces to

$$\frac{dM}{dt} = -kC\forall$$

c. Because the reactor volume is constant the change in mass may be written as

$$\frac{dM}{dt} = \forall\frac{dC}{dt}$$

so,

$$\not{V}\frac{dC}{dt} = -kC\not{V} \text{ or } \frac{dC}{dt} = -kC$$

d. Integrating

$$C_{out} = C_{in}e^{-kt}$$

e. For half the substance to decay

$$\frac{C_{out}}{C_{in}} = \frac{1}{2}$$

f. So the time for ½ the substance to decay is

$$\frac{1}{2} = e^{-kt}$$

Taking the natural log of both sides,

$$\ln(0.5) = \ln(e^{-kt})$$

$$-0.693 = -kt$$

$$t = \frac{0.693}{k}$$

2-18 Amount of substance remaining after half-life

Given: $k = 6\ \text{months}^{-1}$, 1, 2, 3, and 4 half-lives, initial amount = 100%

Solution:

a. Recognizing the half-life concept, then the amount remaining is by observation

Half Life	Amount Remaining, %
0	100
1	50
2	25
3	12.5
4	6.25

b. By equation

$$t_{1/2} = \frac{0.693}{6\text{mo}^{-1}} = 0.1155\,\text{months}$$

c. For one half life

$C_t = 100\%e^{-(6\text{ /months})(0.1155\text{ months})}$

$C_t = 50\%$

d. For two half lives (2*0.1155 = 0.231 months)

$C_t = 100\%e^{-(6\text{ /months})(0.231\text{ months})}$

$C_t = 25.01\%$ or 25%

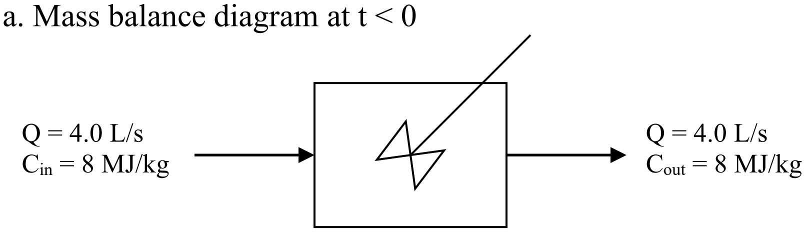
etc.

2-19 Mixing time to achieve desired energy content

Given: CMFR, current waste energy content = 8.0 MJ/kg, new waste energy content = 10.0 MJ/kg, volume of CMFR = 0.20 m^3, flow rate into and out of CMFR = 4.0 L/s, effluent energy content = 9 MJ/kg.

Solution:

a. Mass balance diagram at $t < 0$



b. Step change in influent concentration at $t \geq 0$

C_{in} = 8 MJ/kg increases to C_{in} = 10 MJ/kg

c. Assuming this is non-reactive then the behavior is as shown in Figure 2-8 and Eqn 2-30 applies. Using the given values:

$$9\frac{\text{MJ}}{\text{kg}} = 8\frac{\text{MJ}}{\text{kg}}e^{-t/\theta} + 10\frac{\text{MJ}}{\text{kg}}\left(1 - e^{-t/\theta}\right)$$

Compute theoretical detention time:

$$\theta = \frac{0.20\text{m}^3}{(4.0\,\text{L/s})(10^{-3}\ \text{m}^3/\text{L})} = 50\text{s}$$

Solving for the exponential term:

$$9 = 8e^{-t/50} + 10 - 10e^{-t/50}$$

$$-1 = (8 - 10)e^{-t/50}$$

$$0.50 = e^{-t/50}$$

Taking the natural log of both sides

$$-0.693 = \frac{-t}{50}$$

t = 34.66 or 35 s

2-20 Repeat Problem 2-19 with new waste at 12 MJ/kg

Given: Data in Problem 2-19

Solution:

a. See Problem 2-19 for initial steps

$$9 = 8e^{-t/50} + 12 - 12e^{-t/50}$$

$$0.75 = e^{-t/50}$$

Taking the natural log of both sides:

$$-0.288 = \frac{-t}{50}$$

t = 14.38 or 14 s

2-21 Time for sample to reach instrument

Given: 2.54 cm diameter sample line
Sample line is 20 m long
Flow rate = 1.0 L/min

Solution:

a. Calculate area of sample line

$$A = \frac{\pi(2.54\text{cm})^2}{4} = 5.07\text{cm}^2$$

In m^2

$$\frac{5.07\text{cm}^2}{10^4\ \text{cm}^2/\text{m}^2} = 5.07 \times 10^{-4}\ \text{m}^2$$

b. Speed of water in the pipe

$$u = \frac{(1.0\ \text{L/min})(10^{-3}\ \text{m}^3/\text{L})}{5.07 \times 10^{-4}\ \text{m}^2} = 1.97\ \text{m/min}$$

c. Time to reach sample

$$t = \frac{20\text{m}}{1.97\ \text{m/min}} = 10.13\ \text{ or } 10\ \text{min}$$

d. Volume of water (ignoring 10 mL sample size)

$$\forall = (1.0\ \text{L/min})(10\ \text{min}) = 10\ \text{L}$$

2-22 Brine pond dilution

Given: Pond volume = 20,000 m^3, salt concentration = 25,000 mg/L, Atlantic ocean salt concentration = 30,000 mg/L, final salt concentration = 500 mg/L, time to achieve final concentration = 1 year.

Solution:

a. Assuming the pond is completely mixed, treat as a step decrease in CMFR and use Eqn 2-33 and solve for θ.

$$500 = 25000 \exp\left(-\frac{1\text{year}}{\theta}\right)$$

$$0.020 = \exp\left(\frac{-1\text{y}}{\theta}\right)$$

Take the natural log of both sides

$$-3.912 = \left(\frac{-1\text{y}}{\theta}\right)$$

$$\theta = \frac{1}{3.912} = 0.2556\,\text{y}$$

b. Recognize that

$$\theta = \frac{\forall}{Q}$$

and solve for Q

$$0.2556\,\text{y} = \frac{20000\,\text{m}^3}{Q}$$

$$Q = \frac{20000\,\text{m}^3}{0.2556\,\text{y}} = 78{,}240\,\text{m}^3/\text{y}$$

c. Convert to units of m^3/s

$$78{,}240\,\text{m}^3/\text{y} \times \frac{1}{365\,\text{d/y}} \times \frac{1}{86400\,\text{s/d}} = 0.0025\,\text{m}^3/\text{s}$$

2-23 Venting water tower after disinfection

Given: Volume = 1,900 m^3, chlorine concentration = 15 mg/m^3, allowable concentration = 0.0015 mg/L, air flow = 2.35 m^3/s.

Solution:

a. Assume the water tower behaves as CMFR and apply Eqn 2-33

$$\theta = \frac{1900\,\text{m}^3}{2.35\,\text{m}^3/\text{s}} = 808.51\text{s}$$

Convert concentration to similar units

$(0.0015 \text{ mg/L})(1{,}000 \text{ L/m}^3) = 1.5 \text{ mg/m}^3$

Now solve Eqn 2-33

$$1.5\,\text{mg}/\text{m}^3 = 15\,\text{mg}/\text{m}^3 \exp\left(-\frac{t}{808.51\text{s}}\right)$$

$$0.10 = \exp\left(\frac{-t}{808.51\text{s}}\right)$$

Take the natural log of both sides

$$-2.303 = \left(\frac{-t}{808.51\text{s}}\right)$$

t = 1,861.66 s or 31 min or 30 min

2-24 Railroad car derailed and ruptured

Given: Volume of pesticide = 380 m^3
Mud Lake Drain: $\nu = 0.10$ m/s, Q = 0.10 m^3/s, L = 20 km
Mud Lake: $\forall = 40{,}000 m^3$
Assume pesticide is non-reactive, assume pulse injection and lake is CMFR, assume drain behaves like PFR

Solution:

a. Treat as two part problem: a PFR followed by a CMFR

b. Time for pulse to reach Mud Lake

$$t = \frac{L}{u} = \frac{(20\text{km})(1000\text{ m/km})}{0.10\text{ m/s}} = 200{,}000\text{s or } 2.31\text{ d}$$

c. Pulse injection into CMFR. If it is completely mixed, then the initial concentration as the pulse enters the lake is C_o. To achieve 99% removal, $C_t = (1-0.99)C_o = 0.01C_o$.

$$\frac{C_t}{C_o} = \frac{0.01C_o}{C_o} = 0.01$$

d. Using Eqn 2-33 with

$$\theta = \frac{\forall}{Q} = \frac{40000\,m^3}{0.10\,m^3/s} = 400{,}000s$$

$$0.01 = \exp\left(-\frac{t}{400{,}000}\right)$$

Taking the natural log of both sides

$$-4.605 = \frac{-t}{400{,}000}$$

t = 1,842,068 s or 30,701 min or 511 h or 21.3 d

2-25 Fluoride feeder failure

Given: Rapid mix tank, $\forall = 2.50\ m^3$
Find concentration = 0.01 mg/L, initial concentration = 1.0 mg/L, Q = 0.44 m^3/s
Pipe, L = 5 km, ν = 0.17 m/s

Solution:

a. Treat as two part problem: a CMFR followed by PFR

b. Use Eqn 2-27 to find θ and Eqn 2-33 to solve for t

$$\theta = \frac{\forall}{Q} = \frac{2.5m^3}{0.44\,m^3/s} = 5.68s$$

$$\frac{0.01}{1.0} = \exp\left(\frac{-t}{5.68s}\right)$$

t = 26.16 s

c. Assuming pipe behaves as PFR, the time for the last parcel at 0.01 mg/L to travel the length of the pipe is

$$\frac{L}{u} = \frac{(5km)(1000\,m/km)}{0.17\,m/s} = 29{,}411s$$

d. Total time

$t_{total} = 26.16 + 29{,}411.76 = 29{,}437.92$ s or 490.6 min or 8.17 h

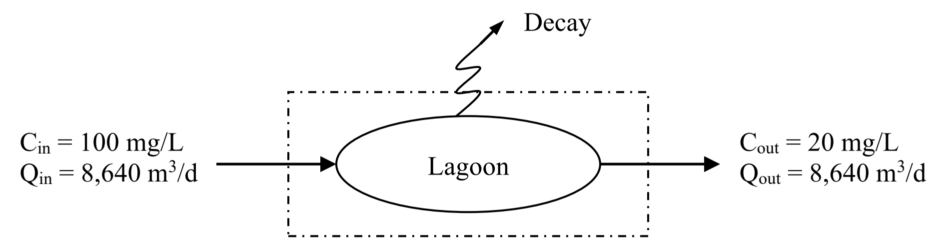
2-26 Rate constant for sewage lagoon

Given: Area = 10 ha, depth = 1 m, flow into lagoon = 8,640 m^3/d, biodegradable material = 100 mg/L, effluent must meet = 20 mg/L, assume 1st order reaction.

Solution:

a. There are two methods to solve this problem: (1) by using mass balance, (2) using equation from Table 2-2

b. First by mass balance



The mass balance equation is

$$\frac{dM}{dt} = C_{in}Q_{in} - C_{out}Q_{out} - kC_{lagoon}\forall$$

Assuming steady state, CMFR then

$$\frac{dM}{dt} = 0 \text{ and } C_{lagoon} = C_{out}$$

So,

$$C_{in}Q_{in} - C_{out}Q_{out} - kC_{out}\forall = 0$$

Solving for k

$$C_{in}Q_{in} - C_{out}Q_{out} = kC_{out}\forall$$

$$k = \frac{C_{in}Q_{in} - C_{out}Q_{out}}{C_{out}\forall}$$

Note that 1 mg/L = 1 g/m^3

$$k = \frac{(100\,g/m^3)(8640\,m^3/d) - (20\,g/m^3)(8640\,m^3/d)}{(20\,g/m^3)(10ha)(10000\,m^2/ha)(1m)}$$

$k = 0.3456\ d^{-1}$

c. Repeat using Table 2-2 equation for CMFR and 1st order reaction

$$C_t = \frac{C_o}{1 + k\theta}$$

$$\theta = \frac{\forall}{Q} = \frac{(10\text{ha})(10000\ \text{m}^2/\text{ha})(1\text{m})}{8640\ \text{m}^3/\text{d}} = 11.574\text{d}$$

$$20\ \text{mg/L} = \frac{100\ \text{mg/L}}{1 + k(11.574\text{d})}$$

Solve for k

$$0.20 = \frac{1}{1 + k(11.574\text{d})}$$

$5.00 = 1 + k(11.574\ d)$

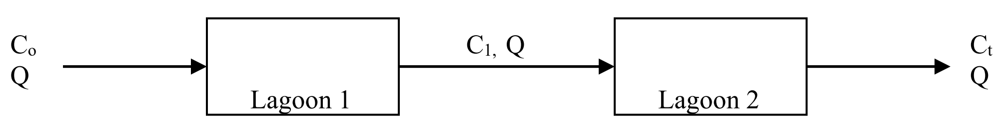
$$k = \frac{4.00}{11.574\text{d}} = 0.3456\text{d}^{-1}$$

2-27 Rate constant for two lagoons in series

Given: Data from Problem 2-26, two lagoons in series, area of each lagoon = 5 ha, depth = 1 m

Solution:

a. Mass balance diagram



Thus, the output from the 1st lagoon is the input to the 2nd lagoon. Solve the problem sequentially.

b. Calculate volume and hydraulic retention time

$\forall = (5\ \text{ha})(10{,}000\ \text{m}^2/\text{ha})(1\ \text{m}) = 5.0 \times 10^4\ \text{m}^3$

$$\theta = \frac{V}{Q} = \frac{5.0 \times 10^4 \, m^3}{8640 \, m^3/d} = 5.787 d$$

c. Using Table 2-2

$$C_1 = \frac{C_o}{1 + k\theta}$$

d. Because $C_1 = C_o$ for the second lagoon and the second lagoon has the same relationship

$$C_t = \frac{C_1}{1 + k\theta}$$

Substituting for C_1

$$C_t = \left(\frac{1}{1 + k\theta}\right)\left(\frac{C_o}{1 + k\theta}\right)$$

$$\frac{C_t}{C_o} = \left(\frac{1}{1 + k\theta}\right)^2$$

$$\left(\frac{C_t}{C_o}\right)^{1/2} = \frac{1}{1 + k\theta}$$

$$1 + k\theta = \left(\frac{C_o}{C_t}\right)^{1/2}$$

$k = 0.2136$ or $0.21 \, d^{-1}$

2-28 Plot concentration after shutdown

Given: Data from Problem 2-26, $C_o = 100$ mg/L, $k = 0.3478 \, d^{-1}$

Solution:

a. Using Eqn 2-40 set up parameters for spreadsheet

$$C_{out} = C_o \exp\left[-\left(\frac{1}{\theta} + k\right)t\right]$$

C_o is the effluent concentration at time t = 0 because the lagoon is assumed to be CMFR.

C_o = 20 mg/L

$$\theta = \frac{V}{Q} = \frac{(10\,\text{ha})(10000\ \text{m}^2/\text{ha})(1\text{m})}{8640\ \text{m}^3/\text{d}} = 11.574\,\text{d}$$

$$\frac{1}{\theta} = 0.0864$$

For spreadsheet

C_{out} = 20exp[- (0.0864 + 0.3478)t]

C_{out} = 20exp[- (0.4342)t]

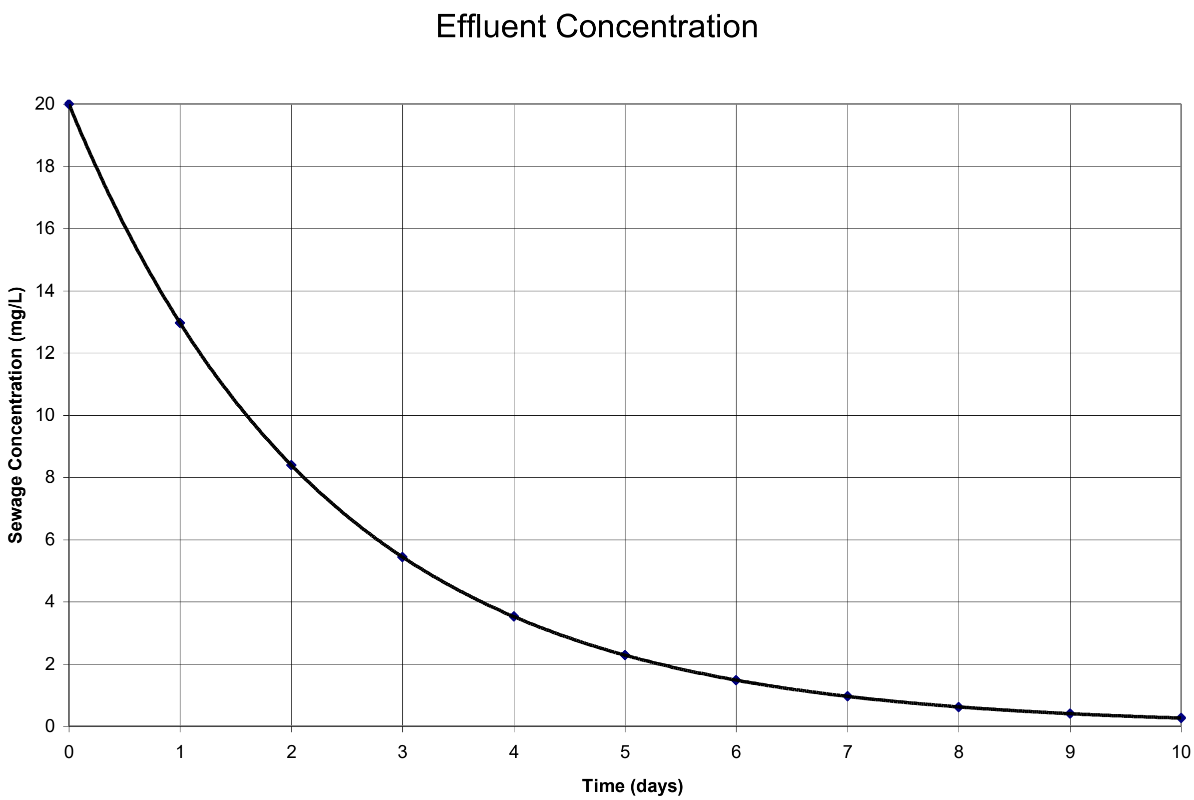

Effluent Concentration
Sewage Concentration (mg/L)
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
Time (days)

Figure S-2-28

2-29 Purging basement of radon

Given: $\forall$ = 90 m^3, radon = 1.5 Bq/L, radon decay rate constant = 2.09 x 10^{-6} s^{-1}, vent at 0.14 m^3/s, allowable radon = 0.15 Bq/L, assume CMFR.

Solution:

a. Using Eqn 2-40

$$C_{out} = C_o \exp\left[-\left(\frac{1}{\theta} + k\right)t\right]$$

$$\theta = \frac{\forall}{Q} = \frac{90 m^3}{0.14 m^3/s} = 642.857 s$$

$$\frac{0.15}{1.5} = \exp\left[-\left(\frac{1}{642.857 s} + 2.09 \times 10^{-6}\right)t\right]$$

$0.10 = \exp[-(1.558 \times 10^{-3})t]$

Take the natural log of both sides

$-2.303 = (-1.558 \times 10^{-3})t$

$t = 1.478 \times 10^3$ s or 24.64 min or 25 min

2-30 Decay of bacteria from ocean outfall

Given: 5000 m from outfall to beach
10^5 coliforms per mL
Discharge flow rate = 0.3 m^3/s
k = 0.3 h^{-1}
Current speed = 0.5 m/s
Assume current behaves as pipe carrying 600 m^3/s of seawater

Solution:

a. The concentration resulting from mixing with the seawater pipe

(10^5 coliforms/mL)(0.3 m^3/s) = ($C_{seawater}$)(600 m^3/s)

$$C_{seawater} = \frac{(10^5 \text{ coliforms / mL})(0.3 m^3/s)}{600 m^3/s} = 50 \text{ coliforms/mL}$$

b. Concentration of coliforms at beach