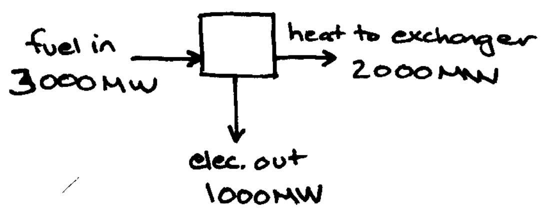
Problem 1

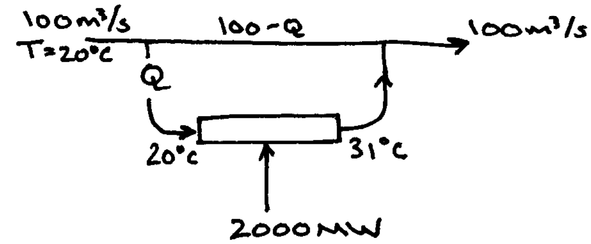
Two-thirds of the energy content of fuel entering a 1000 MW nuclear power plant is removed by a heat exchanger that uses cooling water that is withdrawn from a river. The river has an upstream flow of 100 m3/sec and a temperature of 20°C.

a) What flow rate of river water through the condenser is required of the temperature of the water is only allowed to rise 11°C?

b) What is the river temperature after the heated cooling water is returned to the river?

a)





$$E_{IN} - E_{OUT} = -HT_{IN}$$

$$3000 - 1000 = 2000\,MW$$

$$\rho Q c \Delta T = 2000 \cdot 10^6\ J/sec$$

$$(1000\,kg/m^3)\,Q\,(4.184 \cdot 10^3\ J/kg°C)(11°C) = 2000 \cdot 10^6\ J/sec$$

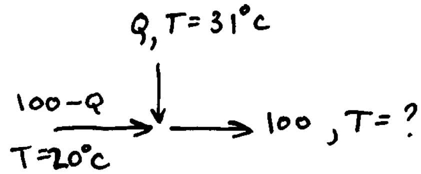
Solve for Q

$$Q = \frac{2000 \cdot 10^6\ J/sec}{(4.184 \cdot 10^3\ J/kg°C)(1000\,kg/m^3)(11°C)}$$

$$= \underline{43.4\ m^3/sec}$$

- units conversions
- energy equation(s)
- arithmetic
- answer
- sig figs

b)



Assume complete mixing

$$T_1 Q_1 + T_2 Q_2 = T_3 (Q_1 + Q_2)$$

$$T_3 = \frac{T_1 Q_1 + T_2 Q_2}{Q_1 + Q_2} = \frac{(20°C)(100-43.45) + (31°C)(43.45)}{100}$$

$$= 24.78°C \qquad \underline{24.8°C}$$

Problem 2

Assume the world energy consumption of fossil fuels of 3 x 10^{17} kJ/yr is obtained from the complete combustion of generic hydrocarbon with the approximate chemical formula C_2H_3. Combustion of this compound produces about 43 x 10^3 kJ/kg.

a) Estimate the annual emissions of CO_2.

b) What is the ratio of grams of C emitted per unit energy for generic hydrocarbon versus methane (methane produces 39 x 10^3 kJ/kg)?

a) $C_2H_3 + \frac{11}{4} O_2 \rightarrow 2CO_2 + \frac{6}{4} H_2O$

$\Rightarrow 4C_2H_3 + 11O_2 \rightarrow 8CO_2 + 6H_2O$

$C_2H_3 = 27 g/mol$
$O_2 = 32 g/mol$
$CO_2 = 44 g/mol$
$H_2O = 18 g/mol$

burn enough C_2H_3 to produce $3 \cdot 10^{17}$ kJ energy

$$3 \cdot 10^{17} \frac{kJ}{yr} \cdot \frac{kg}{43 \cdot 10^3 kJ} = 6.976 \cdot 10^{12} kg\text{-}C_2H_3/yr$$

CO_2 produced

$$6.976 \cdot 10^{12} \frac{kg\, C_2H_3}{yr} \cdot \frac{1 mol\, C_2H_3}{27 g\, C_2H_3} \cdot \frac{8 mol\, CO_2}{4 mol\, C_2H_3} \cdot \frac{44 g\, CO_2}{1 mol\, CO_2} = 2.274 \cdot 10^{13} kg\, CO_2/yr$$

CO_2 / kJ

$$\frac{1 kg\, C_2H_3}{43 \cdot 10^3 kJ} \cdot \frac{1 mol\, C_2H_3}{27 g\, C_2H_3} \cdot \frac{8 mol\, CO_2}{4 mol\, C_2H_3} \cdot \frac{44 g\, CO_2}{1 mol\, CO_2} = 7.579 \cdot 10^{-5} \; kg\, CO_2/kJ$$

b) Use methane CH_4

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$$\frac{1 kg\, CH_4}{39 \cdot 10^3 kJ} \cdot \frac{1 mol\, CH_4}{16 g\, CH_4} \cdot \frac{1 mol\, CO_2}{1 mol\, CH_4} \cdot \frac{44 g\, CO_2}{1 mol\, CO_2} = 7.051 \cdot 10^{-5} \; kg\, CO_2/kJ$$

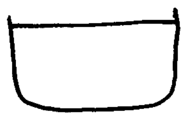
Ratio generic/methane $\frac{7.579 \cdot 10^{-5}}{7.051 \cdot 10^{-5}} = 1.0748$

$\therefore$ generic hydrocarbon produces 1.07 times CO_2 as does burning methane for the same energy output

Problem 3

Calculate the equilibrium concentration of dissolved oxygen in water at 15°C, 1 atm and at the same temperature at 2000m.

$P_o = 1\ atm$
$pO_2 = 0.21\ atm$



$z = 0m$

$[O_2] = K_H P_g$

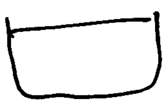
$[O_2] = (0.0015236)(0.21)$

$[O_2] = 3.1996 \cdot 10^{-4}\ mol/L$

$$3.1996 \cdot 10^{-4}\ mol/L \cdot \frac{32{,}000\ mg}{1\ mol\ O_2} = 10.239\ mg/L$$

$= 10.2\ mg/L$

$P = 0.77\ atm$ $\quad pO_2 = (.21)(.77)$



$P_{2000} = P_o - 1.15 \cdot 10^{-4} H$

$= 1atm - 1.15 \cdot 10^{-4}(2000)$

$= .77atm$

$pO_{2e_{2000}} = 0.77\ atm \times 0.21\% = 1.617 \cdot 10^{-1}\ atm$

$[O_2] = (0.0015236)(.1617\ atm)$

$= 2.4637 \cdot 10^{-4}\ mol/L$

$$2.4637 \cdot 10^{-4}\ \frac{mol}{L} \cdot \frac{32{,}000\ mg}{1\ mol\ O_2} = 7.88\ mg/L$$

$= 7.8\ mg/L$

Problem 4

Three lakes are connected in a series as sketched in Figure 1. The characteristics of each lake are listed in Table 1.

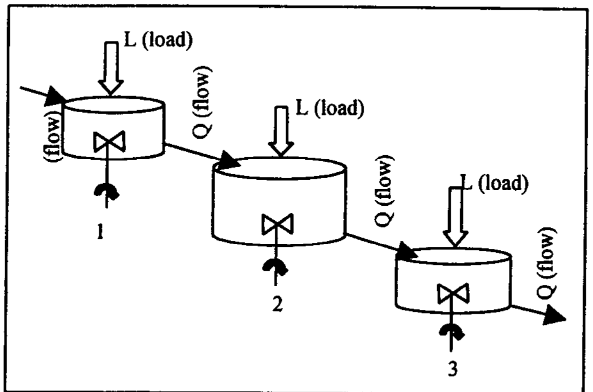


Figure 1. Schematic diagram of three lakes in series.

Table 1. Physical characteristics of three lakes

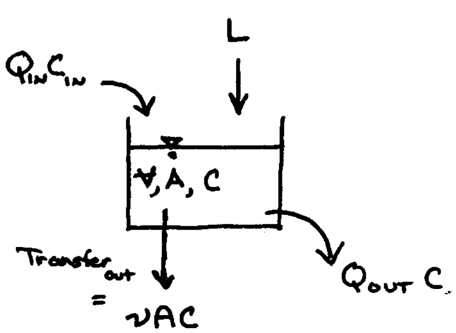
	Lake #1	Lake #2	Lake#3
Volume (m^3)	2×10^6	4×10^6	3×10^6
Mean depth (m)	3	7	3
Surface area (m^2)	667×10^3	571×10^3	1×10^6
Loading (kg/yr)	2000	4000	1000
Inflow (m^3/yr)	1×10^6	1×10^6	1×10^6
Outflow (m^3/yr)	1×10^6	1×10^6	1×10^6

The pollutant settles to each lake bottom at a rate of 10m/yr (use this value and the lake area to determine a volumetric flow rate for the pollutant, eg $Transfer_{out} = v_{settle} A_{lake} C_{lake}$)

a) Write a mass balance expression for each lake in terms of pollutant concentration, C, volumetric flow rate, Q, lake volume, V, lake area, A, and pollutant loading, L.

b) Solve the resulting system of equations to estimate the steady-state concentration of pollutant in each lake.

Sketch



GENERIC BALANCE

$$\forall_i \frac{dC_i}{dt} = Q_{IN} C_{IN} - Q_{OUT} C_i - \nu A_i C_i + L_i$$

Problem 4 (Continued)

FOR EACH LAKE

$$V_1 \frac{dC_1}{dt} = QC_0 - QC_1 - \nu A_1 C_1 + L_1$$

$$V_2 \frac{dC_2}{dt} = QC_1 - QC_2 - \nu A_2 C_2 + L_2$$

$$V_3 \frac{dC_3}{dt} = QC_2 - QC_3 - \nu A_3 C_3 + L_3$$

AT STEADY STATE $\frac{dC_i}{dt} = 0$; $C_0 = 0$

$\therefore$

$$-QC_1 - \nu A_1 C_1 + L_1 = 0$$

$$QC_1 - QC_2 - \nu A_2 C_2 + L_2 = 0$$

$$QC_2 - QC_3 - \nu A_3 C_3 + L_3 = 0$$

3 eqn. 3 unk (C_1, C_2, C_3)

SOLUTION

$$C_1 = \frac{L_1}{Q + \nu A_1} = \frac{2000\,kg/yr}{1 \cdot 10^6\,m^3/yr + (10\,m/yr)(667 \cdot 10^3\,m^2)} = 2.6076 \cdot 10^{-4}\,kg/m^3$$

$$C_2 = \frac{L_2 + QC_1}{Q + \nu A_2} = \frac{4000\,kg/yr + (1 \cdot 10^6\,m^3/yr)(2.607 \cdot 10^{-4}\,kg/m^3)}{1 \cdot 10^6\,m^3/yr + (10\,m/yr)(571 \cdot 10^3\,m^2)} = 6.3499 \cdot 10^{-4}\,\frac{kg}{m^3}$$

$$C_3 = \frac{L_3 + QC_2}{Q + \nu A_3} = \frac{1000\,kg/yr + (1 \cdot 10^6\,m^3/yr)(6.3499 \cdot 10^{-4}\,kg/m^3)}{1 \cdot 10^6\,m^3/yr + (10\,\frac{m}{yr})(1 \cdot 10^6\,m^2)} = 1.486 \cdot 10^{-4}\,\frac{kg}{m^3}$$

CONVERT TO USEFUL UNITS

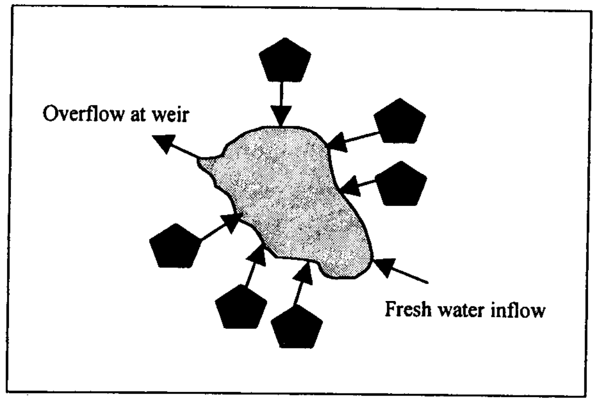
$$C_1 = 2.6076 \cdot 10^{-4}\,\frac{kg}{m^3} \cdot \frac{1\,m^3}{1000\,L} \cdot \frac{1000\,g}{1\,kg} \cdot \frac{1000\,mg}{g} = 0.261\ mg/L$$

$$C_2 = 0.635\ mg/L$$

$$C_3 = 0.148\ mg/L$$

Problem 5

A natural weir controls a lake with volume of 12,000 m^3 so that the volume of the lake remains constant regardless of inflow. There is a fresh water inflow of 400 m^3/d. Six communities are located on the shore of the lake, and each discharges its treated sewage into the lake. Each community is discharges 100 m^3/d. The two older communities have effluent permits to discharge 20 mg/L-BOD while the newer communities have effluent permits to discharge 10 mg/L-BOD. The BOD degrades at a first-order decay rate of 0.2/d in the lake.



a) Write a mass balance expression for the BOD concentration in the lake. Estimate the BOD concentration leaving the lake over the weir (outlet).

b) The acceptable in-stream standard for BOD is determined to be 2.0 mg/L. Are the current effluent permits protective of the environment?

Evaluate the two proposed strategies for addressing the in-stream standard.

(1) 30% reduction in concentration for the two older permits.

(2) 15% reduction in concentration for all the permits.

c) Which strategy will achieve the desired in-stream standard?

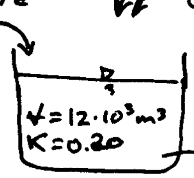
d) (Brief essay response) Which strategy do you think is more equitable (fair) and why?

a) $Q_1 = 400\, m^3/d$, $C_1 = 0$

$Q_2 \cdots Q_7 = 100\, m^3/d$ each

$C_2, C_3 = 20\, mg/L$

$C_4 - C_7 = 10\, mg/L$



$Q = \sum Q_i$, $C = ?$

$$V\frac{dC}{dt} = Q_1C_1 + Q_2C_2 + Q_3C_3 + Q_4C_4 + Q_5C_5 + Q_6C_6 + Q_7C_7 - KVC - C\sum_{i=1}^{7} Q_i$$

Problem 5 (Continued)

AT STEADY STATE $\frac{dC}{dt} = 0$, $C_1 = 0$

$\therefore$

$$C = \frac{C_2Q_2 + C_3Q_3 + C_4Q_4 + C_5Q_5 + C_6Q_6 + C_7Q_7}{Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + K\forall}$$

$C_2Q_2 = C_3Q_3 = 20\frac{mg}{L}\,100\,m^3/d$

$2 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d}$

$C_4Q_4 - C_7Q_7 = 10\frac{mg}{L}.\,100\,m^3/d$

$= 1 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d}$

$$\therefore C = \frac{(4 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d}) + (4 \cdot 10^3 \frac{mg}{L}.\frac{m^3}{d})}{1000\frac{m^3}{d} + 0.\frac{2}{d}(12{,}000\ m^3)}$$

$= 2.3529\ mg/L \qquad = \underline{\underline{2.35\ mg/L}}$

b) ~~Standards~~ Permit values do not ~~meet~~ meet in-stream requirement

c) 30% reduction in C_2 & C_3

$$C = \frac{(2.8 \cdot 10^3 \frac{m}{L}\frac{m^3}{d}) + (4 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d})}{1000\ m^3/d + 0.2/d\,(12{,}000\ m^3)} = 2.00\ mg/L$$

* meets standa

15% reduction all permits

$C_2Q_2 = C_3Q_3$

$$C = \frac{(3.4 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d}) + (3.4 \cdot 10^3 \frac{mg}{L}\frac{m^3}{d})}{1000\ m^3/d + 0.2/d\,(12{,}000)} = 2.00\ mg/L$$

* meets stan

d) ARGUMENTS for either case OK.
Should state (i) Both strategies work.

Strategy 1 places burden on biggest polluters, rewards smaller polluters, and can be considered fair because economic burden is placed on fewer people.

Strategy 2 is "flat-tax" approach and distributes burden evenly among all polluters, can be fair because economic burden is shared by all. Cleaner communites could generate revenue by treating neighbors waste.