CIVE 3331 Environmental Engineering
Spring 2003 Mid-Term Exam

Name: Solution

Problem 1 – (Concentration)

"Clean" air might have a sulfur dioxide (SO2) concentration of 0.01 ppm, while "polluted" air might have a concentration of 2 ppm. Convert these two concentrations to $\mu g/m^3$ at 298K.

(1) can use:

$$\frac{\mu g}{m^3} = ppm * MW * \frac{P V}{RT}$$

(2) OR:

$$X_{ppm_V} = \frac{X_{m^3 SO_2}}{1 \cdot 10^6 m^3 \text{ air}}$$

(A)

$$\frac{0.01 m^3 SO_2}{1 \cdot 10^6 m^3 air} \cdot \frac{P}{RT} = \frac{0.01 m^3 SO_2}{1 \cdot 10^6 m^3 air} \cdot \frac{1 atm}{8.205 \cdot 10^{-5} \left(\frac{m^3 atm}{K mol}\right)(298K)}$$

$$= \frac{4.089 \cdot 10^{-7} mol SO_2}{m^3 air} \cdot \frac{64 g}{1 mol SO_2} = 2.617 \cdot 10^{-5} \frac{g}{m^3}$$

$$2.617 \cdot 10^{-5} \frac{g}{m^3} * \frac{1 \cdot 10^6 \mu g}{g} = \underline{\underline{26.17 \frac{\mu g}{m^3}}} \longleftarrow \text{"Clean Air"}$$

"Dirty air" is F times more polluted

$$0.01 \cdot F = 2$$

$$F = \frac{2}{0.01} = 200$$

$$26.17(200) = \underline{\underline{5234 \frac{\mu g}{m^3}}} \longleftarrow \text{"Dirty air"}$$

also can get result by substituting 2 for 0.01 in equation "A"

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Problem 2 – (Chemical Equilibrium)

A water with a high concentration of Mg^{2+} can be treated by pH adjustment to precipitate $Mg(OH)_{2(s)}$. Determine the required pH to reduce a high concentration of dissolved Mg^{2+} to 43 mg/L. The equilibrium equation is

$$Mg(OH)_{2(s)} \Leftrightarrow Mg^{2+} + 2OH^- \qquad K_{sp} = 1 \times 10^{-11.16}$$

MW: $Mg^{2+} = 24g$

$$[Mg^{2+}] = 43mg/L \cdot \frac{g}{1000mg} \cdot \frac{1mol}{24g} = 0.0018 \frac{mol}{L} Mg^{2+}$$

Now law of mass action

$$\frac{[Mg^{2+}][OH^-]^2}{[Mg(OH)_{2(s)}]} = 1 \cdot 10^{-11.16}$$

Recall that $[Mg(OH_2)_{(s)}]$ is built into K_{sp}

$$\therefore [Mg^{2+}][OH^-]^2 = 1 \cdot 10^{-11.16}$$

Solve for $[OH^-]$

$$[OH^-] = \left\{ \frac{1 \cdot 10^{-11.16}}{[Mg^{2+}]} \right\}^{1/2} = \sqrt{\frac{1 \cdot 10^{-11.16}}{0.0018}} = 6.199 \cdot 10^{-5} M$$

Now use water equilibrium

$$[H^+][OH^-] = 10^{-14}$$

$$[H^+] = \frac{10^{-14}}{[OH^-]} = \frac{10^{-14}}{6.2 \cdot 10^{-5}} = 1.62 \cdot 10^{-10} M$$

Now convert to pH

$$pH = -\log[H^+] = \underline{\underline{9.79}}$$

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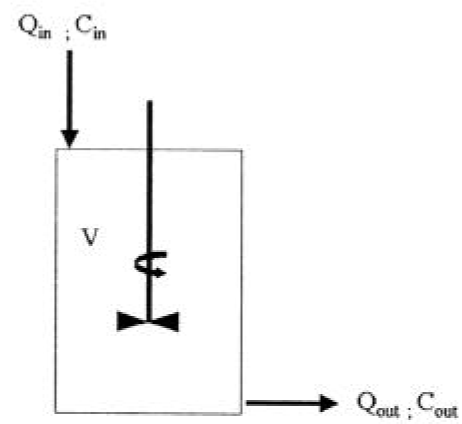
Problem 3 – (Mass Balance)

The reactor in the sketch below is used to treat an industrial waste product, using a reaction that destroys the pollutant according to first-order kinetics with k = 0.216/day. The reactor volume is 500 m^3, the volumetric flow rate of inlet and outlet is 50 m^3/day, and the inlet constituent concentration is 100 mg/L. Write the constituent mass balance equation and determine the outlet concentration?



Mass Balance

$$\frac{d}{dt}CV = C_{IN}Q_{IN} - C_{OUT}Q_{OUT} - C_{OUT}k\forall \qquad \text{complete mix} \Rightarrow C = C_{OUT}$$

$$\therefore \frac{dCV}{dt} = C_iQ - CQ - Ck\forall$$

Problem is equilibrium case $\therefore \frac{dCV}{dt} = 0$

$$0 = C_iQ - CQ - kC\forall$$

Rearrange and solve for C

$$C = \frac{C_iQ}{Q + k\forall} = C_i\left(\frac{1}{1 + k\frac{\forall}{Q}}\right) = 100\,mg/L \cdot \frac{1}{1 + (0.216/day)\frac{(500m^3)}{(50m^3/day)}} = \underline{\underline{32\,mg/L}}$$

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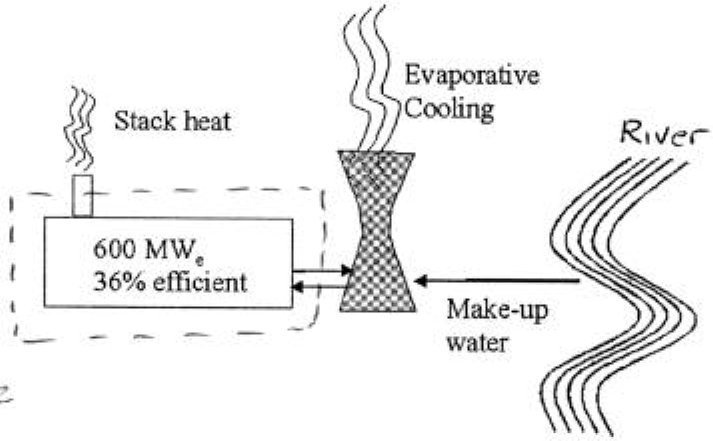
Problem 4 – Energy Balance

A 600 MW_e (electric output) power plant has an efficiency of 36 percent with 15 percent waste heat being released into the atmosphere as stack heat and the other 85% taken away by cooling water. Instead of drawing water from a river, heating it, and returning the heated water to the river, the plant uses an evaporative cooling tower to release heat to the atmosphere as water is evaporated. At what rate must 15°C makeup water be provided from the river to offset the water evaporated in the cooling tower?



Energy Balance

$$\frac{dE_{sys}}{dt} = \text{Rate Fuel IN} - \text{Rate Elect. Out} - \text{Stack Heat Out} - \text{Cooling Wat. Out}$$

Steady State

$$0 = Fuel_{IN} - Elec._{out} - Stack_{out} - Cooling_{out}$$

$$Fuel_{IN} = \frac{Elec._{out}}{0.36} = 1667 MW$$

$$Net(Stack + Cooling) = 1667MW - 600MW = 1067MW$$

$$Stack = 15\%(1067) = 160.05MW$$

$$Cooling = 85\%(1067) = 906.95MW$$ } This heat is "evaporated" using water

$$907 \cdot 10^3 kW \cdot \frac{1kJ/sec}{1kW} \cdot \frac{kg\text{-}H_2O}{2465 kJ} \cdot \frac{m^3}{10^3 kg} = \underline{\underline{0.37 m^3/sec}}$$ ← Make flow rate

latent heat evap. from 15°C to Vapor (Table 1.4 pg 19)

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Problem 5- (Oxygen Demand)

Suppose a solution of 100.0 mg/L of glycine [$CH_2(NH_2)COOH$] is oxidized biologically. Balance the following reactions, then estimate the theoretical carbonaceous oxygen demand and the total theoretical nitrogenous oxygen demand.

$$(2)\ 2\ \cancel{1}\ CH_2(NH_2)COOH + (3)\ \cancel{2}\ 8\ O_2 \Rightarrow (4)\ \cancel{2}\ CO_2 + (2)\ \cancel{1}\ H_2O + (2)\ \cancel{1}\ NH_3$$

$$1\ NH_3 + 2\ O_2 \Rightarrow 1\ NO_3^- + 1\ H^+ + 1\ H_2O$$

MW GLY

$$\underset{C}{2(12)} + \underset{H}{5(1)} + \underset{N}{1(14)} + \underset{O}{2(16)} = 75\,g/mol$$

$$CBOD = \frac{3\,mol\,O_2}{2\,mol\,GLY} \cdot \frac{32\,g\,O_2}{1\,mol\,O_2} \cdot \frac{1\,mol\,GLY}{75\,g\,GLY} \cdot \frac{100\,mg}{L} = 64\,mg/L$$

$$NBOD = \frac{2\,mol\,O_2}{1\,mol\,NH_3} \cdot \frac{2\,mol\,NH_3}{2\,mol\,GLY} \cdot \frac{32\,g\,mol\,O_2}{1\,mol\,O_2} \cdot \frac{1\,mol\,GLY}{75\,g\,GLY} \cdot \frac{100\,mg}{L} = 85\,mg/L$$

$$THOD_{Total} = CBOD + NBOD = 64 + 85 = 149\,mg/L$$