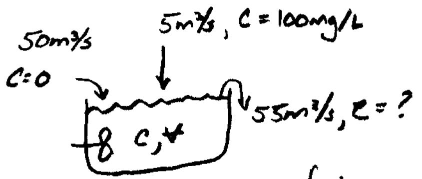
1) A lake with a constant volume of 10×10^6 m^3 is fed by a pollution free stream with flow rate 50 m^3/s. A factory discharges 5 m^3/s of a non-conservative waste with concentration 100 mg/L into the lake. The pollutant has a reaction rate coefficient K of 0.25/day. Assuming the pollutant is completely mixed in the lake, find the steady-state concentration of the pollutant in the lake.



$$K = 0.25/\text{day} \cdot \frac{1\ \text{day}}{86400\,\text{s}}$$

$$\underbrace{\frac{d\mathcal{C}}{dt}}_{\substack{=0 \\ \text{steady state}}} = \underbrace{C_0 Q_0}_{\substack{\text{clean} \\ \text{stream}}} + \overbrace{C_1 Q_1}^{\text{factory}} - \underbrace{C_2 Q_2}_{\text{overflow}} - \overbrace{K C_2 \forall}^{\text{decay}}$$

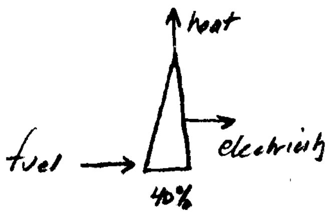
$$0 = (5\,\text{m}^3/\text{s})(100\,\text{mg/L}) - (55\,\text{m}^3/\text{s})(C_2) - K C_2 (10 \cdot 10^6\,\text{m}^3)$$

solve for C_2

$$(55\,\text{m}^3/\text{s})(C_2) + K C_2 (10 \cdot 10^6\,\text{m}^3) = (5\,\text{m}^3/\text{s})(100\,\text{mg/L})$$

$$C_2 = \frac{(5\,\text{m}^3/\text{s})(100\,\text{mg/L})}{(55\,\text{m}^3/\text{s}) + \left(\frac{0.25}{86400\,\text{s}} \cdot 10 \cdot 10^6\,\text{m}^3\right)} = 5.95\,\text{mg/L}$$

2) No. 6 fuel oil has a carbon content of 20 kg carbon per 10^9 J. If it is burned in a 40% efficient power plant, find the carbon emissions per kilowatt-hour of electricity produced, assuming all of the carbon in the fuel is released into the atmosphere. Current law requires oil-fired power plant emissions not to exceed 86 mg SO_2 per million joules of input energy and 130 mg NO_x/MJ. Estimate the maximum allowable SO_2 and NO_x emissions per kilowatt-hour for this power plant.



$\frac{20\ kg}{10^9 J}$

$1 W = 1 J/sec$

$1 kW = 1000 J/sec = 1 kJ/sec$

$1 kW\text{-}hr = 1 kJ/sec \cdot 1 hr$

① how much fuel to produce 1 kW?

$0.4\ fuel = electricity$

$\therefore\ fuel = \frac{1\ kW}{0.4} = 2.5 kW$

② 1 kW-hr uses how much fuel?

$2.5 kW\text{-}hr = 2.5\ kJ/sec \cdot 1 hr = \frac{2.5 kJ}{sec} \cdot 1 hr \cdot \frac{3600 sec}{1 hr} = 9000 kJ$

③ How much carbon up in smoke?

$9000 kJ \cdot \frac{20 kg}{10^6 kJ} = 0.18\ kg\ C/kw\text{-}hr$ produced ←

④ How much SO_2 allowed?

$9000\ kJ/Kw\text{-}hr\ produced * \frac{86 mg\ SO_2}{10^3 kJ} = 774 mg\ SO_2/kw\text{-}hr$ produced ←

⑤ How much NO_x allowed?

$\frac{9000 kJ}{kw\text{-}hr} \times \frac{130 mg\ NO_x}{10^3 kJ} = 1170\ mg\ NO_x/kw\text{-}hr$ produced ←

3) Trinitrotoluene (*TNT*), $C_7H_5N_3O_6$ combines explosively with oxygen to produce CO_2, H_2O, and N_2.

(a) Write a balanced chemical equation for the reaction.

(b) Calculate the number of grams of oxygen required for each *100*g of *TNT*.

$C_7H_5N_3O_6 + O_2 \rightarrow 7CO_2 + H_2O + N_2$

① balance C $\quad C_7H_5N_3O_6 + O_2 \rightarrow 7CO_2 + H_2O + N_2$

② balance H $\quad 2C_7H_5N_3O_6 + O_2 \rightarrow 14CO_2 + 5H_2O + N_2$

$\frac{21}{2} \quad 28 \quad 5$

③ balance O $\quad 2C_7H_5N_3O_6 + \frac{21}{2}O_2 \rightarrow 14CO_2 + 5H_2O + N_2$

④ balance N $\quad 2C_7H_5N_3O_6 + \frac{21}{2}O_2 \rightarrow 14CO_2 + 5H_2O + 3N_2$

Clean Up: $\quad 4C_7H_5N_3O_6 + 21O_2 \rightarrow 28CO_2 + 10H_2O + 6N_2$ ←

MW TNT: $7(12) + 5 + 3(14) + 6(16) = 227\,g/mol$

$$\frac{100g\ TNT}{227g/mol} \cdot \frac{21\,mol\,O_2}{4\,mol\,TNT} \cdot \frac{32g\ O_2}{mol\ O_2} = 74g\ O_2$$ ←

4) Hydrogen sulfide (H_2S) is an odorous gas that can be stripped from solution in a process similar to that described for ammonia stripping. The reaction is

$$H_2S \Leftrightarrow H^+ + HS^- \qquad K = 0.86 \times 10^{-7}$$

(a) Develop an equation to determine the fraction of hydrogen sulfide in the dissolved gas form (H_2S) as a function of *pH*.

(b) Determine the fraction of hydrogen sulfide in H_2S form at: *pH* 4, *pH* 5, *pH* 6, *pH* 7, *pH* 8, and *pH* 9.

$$\frac{[H^+][HS^-]}{[H_2S]} = 0.86 \cdot 10^{-7} \qquad [H^+][OH^-] = 10^{-14}$$

$$\frac{[HS^-]}{[H_2S]} = \frac{0.87 \cdot 10^{-7}}{[H^+]}$$

$$\frac{[H_2S]}{[HS^-]+[H_2S]} = \frac{\overset{1}{\overline{[H_2S]\ [H_2S]}}}{\frac{[HS^-]}{[H_2S]} + \frac{[H_2S]}{[H_2S]}} = \frac{1}{1 + \frac{[HS^-]}{[H_2S]}}$$

$$\therefore [H_2S]\text{fraction} = \frac{1}{1 + \frac{0.87 \cdot 10^{-7}}{[H^+]}}$$

pH	$[H^+]$	$\frac{0.87 \cdot 10^{-7}}{[H^+]}$	$1 + \frac{0.87 \cdot 10^{-7}}{[H^+]}$	$[H_2S]$ fraction	$[H_2S]\%$
4	10^{-4}	0.00087	1.00087	0.999	99.9
5	10^{-5}	0.0087	1.0087	0.991	99.1
6	10^{-6}	0.087	1.087	0.919	91.9
7	10^{-7}	0.87	1.87	0.534	53.4
8	10^{-8}	8.7	9.7	0.103	10.3
9	10^{-9}	87	88	0.011	1.1

5) A typical motorcycle emits about *20* g of carbon monoxide (*CO*) per mile.
   (a) What volume of CO would a *5*-mile trip produce after the gas cools to *25°C* (at 1 atm)?
   (b) Per meter of distance traveled, what volume of air could be polluted to the air quality standard of 9 ppm?

a) $5\text{mile} * \frac{20\text{g CO}}{\text{mile}} = 100\text{g CO} * \frac{1\text{mol CO}}{28\text{g}} = 3.571\text{mol CO}$

Ideal gas law

$$V = \frac{nRT}{P} = \frac{(3.571\text{mol})(0.082056 \frac{L\cdot atm}{K\cdot mol})(298.15°K)}{1atm} = 87.36\text{L CO}$$

b) $\frac{3.28\text{ft}}{1\text{meter}} \cdot \frac{1\text{mile}}{5280\text{ft}} \cdot \frac{20\text{g CO}}{\text{mile}} = 1.2424\cdot10^{-2} \frac{\text{g CO}}{\text{meter}} \times \frac{1\text{mol}}{28\text{g}} = 4.4373\cdot10^{-4}\text{mole}$

@ 25°C

$$\frac{(4.4373\cdot10^{-4}\text{mol CO})(0.082056 \frac{L\cdot atm}{K\,mol})(298.15°K)}{1atm} = 1.0855\cdot10^{-2}\text{L-CO}$$

$$1.0855\cdot10^{-2}\text{L CO} \cdot \underbrace{\frac{10^6\text{L-air}}{9\text{ L-CO}}}_{9\text{ppm}} = 1206\text{L} = 1.206\text{m}^3$$

$\therefore$ Motorcycle pollutes $\frac{1.2\text{m}^3\text{air}}{\text{m-travel}}$ ←