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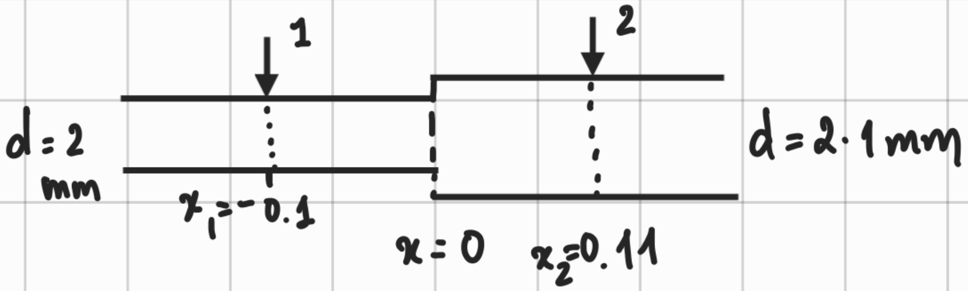
1.



$D_m = 10^{-9}\ m^2/s$

(a) $t = 200\ h = 720000\,s$

$$M_1 = \frac{0.1\,g}{\frac{\pi}{4}(0.002\,m)^2} = 31831\ g/m^2$$

$$M_2 = \frac{0.2\,g}{\frac{\pi}{4}(0.0021\,m)^2} = 57743\ g/m^2$$

$$C = C_1 + C_2$$

$$= \frac{M_1}{\sqrt{4\pi D_M t}}\, e^{-\frac{(x-x_1)^2}{4D_m t}} + \frac{M_2}{\sqrt{4\pi D_m t}}\, e^{-\frac{(x-x_2)^2}{4D_m t}}$$

$$C_1 = \frac{31831}{\sqrt{4\pi(10^{-9})(720000)}}\, e^{\frac{-(0+0.1)^2}{4(10^{-9})(720000)}} = 10390\ g/m^3$$

$$C_2 = \frac{57743}{\sqrt{4\pi(10^{-9})(720000)}}\, e^{\frac{-(0-0.11)^2}{4(10^{-9})(720000)}} = 9090\ g/m^3$$

$$C = C_1 + C_2$$

$$= 19480\ g/m^3$$

$$= 19.48\ kg/m^3$$

(b)

Concentration at $x = -0.1m$ due to Injection 1:

$$C_1(-0.1, 720000) = \frac{31831}{\sqrt{4\pi(10^{-9})(720000)}} = 334641 \ g/m^3$$

Diffusive flux due to the 1st injection at $x=0$:

$$\text{Mass flux} = -AD_m \frac{dc}{dx}$$

$$= -\left(\frac{\pi}{4}\times 0.002^2\right)(10^{-9}) \frac{10390 - 334641}{0.1}$$

$$= +1.019 \times 10^{-8} \ g/s$$

Flux direction: left to right

Concentration at $x = 0.11$ due to Injection 2:

$$C_2(0.11, 720000) = \frac{57743}{\sqrt{4\pi(10^{-9})(720000)}} = 607055 \ g/m^3$$

Diffusive flux due to Injection 2 at $x=0$:

$$\text{Mass flux} = -AD_m \frac{dc}{dx}$$

$$= -\left(\frac{\pi}{4}\times 0.0021^2\right)(10^{-9}) \frac{9090 - 607055}{0.11}$$

$$= 1.883 \times 10^{-8} \ g/s$$

Direction: right to left

Diffusive flux at $x = 0$:

Mass flux $= 1.883 \times 10^{-8} - 1.019 \times 10^{-8}$

$= 0.864 \times 10^{-8}$ g/s

$= 0.864 \times 10^{-5}$ mg/s

Direction : right to left

(from section 2 to section 1)

(c)

Assume injection 2 is performed for t seconds

Concentration at $x = 0$ and $x = 0.11$ m due to injection 2 :

$$x = 0: \quad C_2(0, t) = \frac{57743}{\sqrt{4\pi(10^{-9})\, t}} e^{\frac{-(0-0.11)^2}{4(10^{-9})\, t}}$$

$$= \frac{515.1 \times 10^6}{\sqrt{t}} e^{\frac{-3.025 \times 10^6}{t}}$$

$$x = 0.11: \quad C_2(0.11, t) = \frac{57743}{\sqrt{4\pi(10^{-9}) t}} = \frac{515.1 \times 10^6}{\sqrt{t}}$$

Diffusive flux due to Injection 2 at $x = 0$:

$$\text{Mass flux} = -AD_m \frac{dc}{dx}$$

$$= -\frac{\pi}{4}(0.0021^2)(10^{-9})\frac{515.1\times10^6}{\sqrt{t}}\left(e^{\frac{-3.025\times10^6}{t}}-1\right)\times\frac{1}{0.11}$$

$$= \frac{-1.622\times10^{-5}}{\sqrt{t}}\left(e^{\frac{-3.025\times10^6}{t}}-1\right)$$

Since there is no flux at $x=0$,
mass flux due to Injection 1 = mass flux due to Injection 2

$$\Rightarrow \frac{-1.622\times10^{-5}}{\sqrt{t}}\left(e^{\frac{-3.025\times10^6}{t}}-1\right) = 1.019\times10^{-8}$$

$\Rightarrow t = 1729176$ s $= 480$ hours

Injection 2 should be performed earlier

time difference $= 480 - 200 = 280$ hours

(d) The concentration at the location of injection 2 after 200 hours:

$$C(0.11, 720000) = c_1(0.11, 720000) + c_2(0.11, 720000)$$

2(a)

(i) At 25°C $k = 0.2$ per day

$\Rightarrow$ the reaction follows first order kinematics

$$\frac{dL}{dt} = kL \Rightarrow \ln L = kt + C$$

$$\Rightarrow L = e^{kt} \cdot e^{C} = A e^{kt}$$

(A, C = arbitrary const)

At $t = 0$, $L = L_0 = 500$ mg/L $\Rightarrow A = 500$

$\Rightarrow L = 500 e^{0.2t}$

At the end of day 1 ($t = 1$):

$$L_1 = 500 e^{0.2} = 611 \text{ mg/L}$$

At the end of day 5 ($t = 5$):

$$L_5 = 500 e^{0.2 \times 5} = 1359 \text{ mg/L}$$

(ii) At the end of day 2 ($t = 2$):

$$L_2 = 500 e^{0.2 \times 2} = 746 \text{ mg/L}$$

From day 3 to day 5, the rate of reaction:

$$\frac{k'}{k} = \beta^{(T' - T)}$$

$$k' = k \times \beta^{(T' - T)}$$

$$= 0.2 \times 1.078^{30 - 25}$$

$$= 0.291 \text{ per day}$$

$$L_5 = L_2 e^{0.291 \times 3}$$
$$= 746 e^{0.291 \times 3}$$
$$= 1786 \text{ mg/L}$$

(iii) $k' = 0.2 \times 1.078^{T' - 25}$

Temperature increases linearly to 30°C at the end of day 5 $\Rightarrow T' = 25 + t$

(t = number of days from t_0)

$\Rightarrow k' = 0.2 \times 1.078^{t}$

$$\Rightarrow L = 500 e^{k't}$$
$$= 500 e^{0.2 \times 1.078^{t} \times t}$$

BOD value at the end of Day 5:

$$L_5 = 500 e^{0.2 \times 1.078^5 \times 5}$$
$$= 2144 \text{ mg/L}$$

3.

(a) Wet scrubbers remove pollutants from gas stream

In a wet scrubber, the polluted gas stream is in contact with scrubbing liquid to remove gas-phase pollutants

(b) Chanelling of flow, short-circuiting, dead zones, restricted inlet or outlet effects, etc.

(c) The outbreak of Minamata Disease in Japan was due to the discharge of Hg-laden wastes into Minamata Bay. The elemental Hg that settled into the sediment was converted into methyl- or dimethyl-mercury. The methylated Hg is soluble and is easily transportable from the sediment to the water column. Hg was subsequently absorbed in fish and shellfish tissue and bioaccumulated in the food chain. The contaminated seafood poisoned local people whose diet consisted of substantially the caught from the Minamata Bay.

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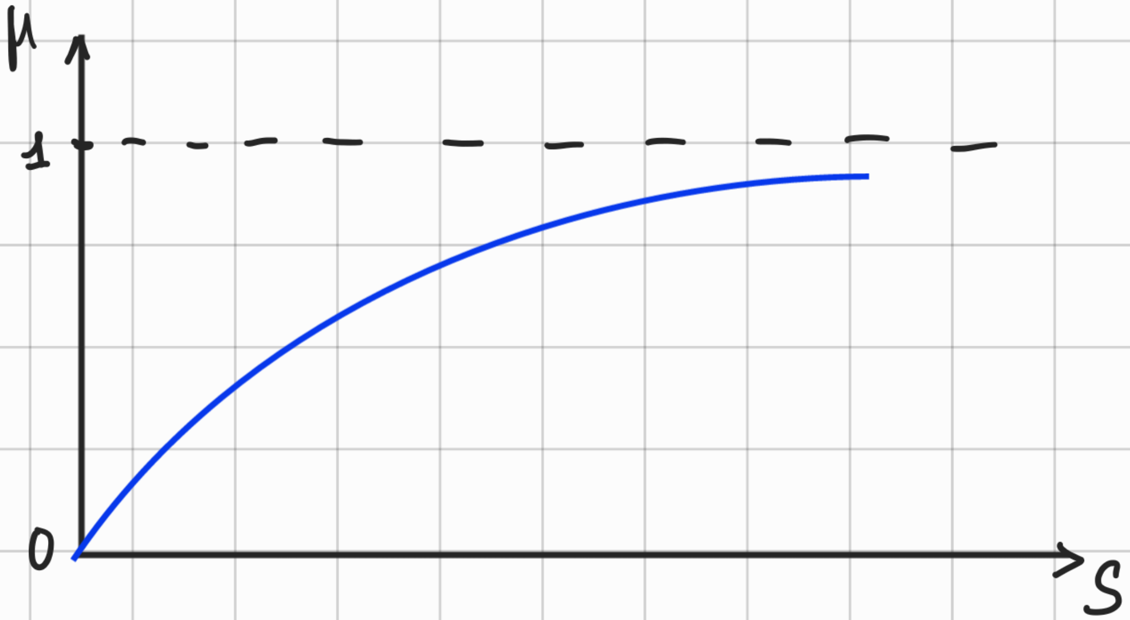
(b) When $S \to 0$, $\mu \to 0$

When $S \to \infty$, $\mu \to 1$



4.

$C_{TSS} = 10 \text{ mg/L}$
$C_w = 100 \text{ µg/L}$
$V = 2.0 \times 10^5 \text{ m}^3$
$H = 20 \text{ m}$
$K_d = 2 \times 10^4 \text{ L/kg}$
$v_s = 0.2 \text{ m/d}$

(a) Settling time $= \dfrac{20 \text{ m}}{0.2 \text{ m/d}} = 100 \text{ days}$

Mass of suspended solids $= (10 \text{ mg/L})(2.0 \times 10^5 \text{ m}^3)(10^3 \text{ L/m}^3)$
$= 2 \times 10^9 \text{ mg}$
$= 2000 \text{ kg}$

Settling rate $= \dfrac{2000 \text{ kg}}{100 \text{ days}} = 20 \text{ kg/d}$

(b) $S = K_d \cdot C_w = (2 \times 10^4 \text{ L/kg})(100 \text{ µg/L})$
$= 2 \times 10^6 \text{ µg/kg}$
$= 2000 \text{ mg/kg}$

Rate of X to sediment $= (2000 \text{ mg/kg})(20 \text{ kg/d})$
$= 40\,000 \text{ mg/d}$

Flux $= \dfrac{40000 \text{ mg/d}}{(2.0 \times 10^5 \text{ m}^3 \div 20 \text{ m})} = 4 \text{ mg/m}^2.\text{d}$

(c) Surface renewal
Intensive energy consumption

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(a) The atmospheric content of oxygen = 21%
Thus the partial pressure of oxygen = 0.21 atm

$$C_w = \frac{P_{O_2}}{H_{pc}} = \frac{0.21 \text{ atm}}{810 \text{atm-L/mol}} = 0.000259 \text{ mol/L}$$

$$C_{sat} = (0.000259 \text{ mol/L})(32 \text{ g/mol})$$
$$= 0.0083 \text{ g/L}$$
$$= 8.3 \text{ mg/L}$$

(b) $$k_L = \left(\frac{2.6\times10^{-5}}{2.6\times10^{-5}}\right)^{0.57}(0.0014\times3^2+0.014)$$
$$= 0.0266 \text{ m/h}$$

$$k_G = \left(\frac{0.178}{0.26}\right)^{2/3}(7\times3+11) = 24.9 \text{ m/h}$$

$$\frac{1}{K_{tot}} = \frac{1}{k_L} + \frac{1}{k_G H_{cc}}$$

$$H_{cc} = \frac{H_{pc}}{RT} = \frac{(810 \text{ atm-L/mol})(10^{-3} \text{ m}^3\text{/L})}{(82.08\times10^{-6} \text{ atm-m}^3\text{/mol-K})(298\text{K})}$$
$$= 33.1$$

$$K_{tot} = \frac{1}{\frac{1}{0.0266}+\frac{1}{24.9\times33.1}} = 0.0266 \text{ m/h}$$

$$\frac{R_L}{R_G} = \frac{k_G H_{cc}}{k_L} = \frac{24.9\times33.1}{0.0266} = 30985 \gg 1$$

$\Rightarrow$ liquid-phase resistance control

(c) Mass flux $J = K_{tot}\left(C^L_{bulk} - C^{L*}\right)$

$$\frac{dM^L}{dt} = K_{tot} A \left(C^L_{bulk} - C^{L*}\right)$$

$$\frac{dC^L_{bulk}}{dt} = K_{tot}\left(\frac{A}{V}\right)\left(C^L_{bulk} - C^{L*}\right) = \frac{K_{tot}}{H}\left(C^L_{bulk} - C^{L*}\right)$$

$$\int_{2.5}^{4.0} \frac{dC^L_{bulk}}{C^L_{bulk} - C^{L*}} = \int_0^t \frac{K_{tot}}{H}\,dt$$

$$-\ln\left(\frac{C^{L*} - 4.0}{C^{L*} - 2.5}\right) = \frac{K_{tot}}{H}\,t$$

$$C^{L*} = 8.3 \text{ mg/L}$$

$$\Rightarrow t = \frac{-\ln\left(\frac{8.3-4.0}{8.3-2.5}\right)}{\frac{0.0266}{30}} = 337.5 \text{ h} = 14 \text{ days}$$

(d)

$$V\frac{dC^L_{bulk}}{dt} = K_{tot}\left(C^L_{bulk} - C^{L*}\right) - K_d C^L_{bulk} V$$

6.

(a)

(i) $$V_a \frac{dC_{a,out}}{dt} = Q_a\left(C_{a,in} - C_{a,out}\right) + V_w k\left(C_{w,out} - \frac{C_{a,out}}{H_{cc}}\right)$$

(ii) At steady state: $\frac{dC_{a,out}}{dt} = 0$

$$\Rightarrow Q_a\left(C_{a,in} - C_{a,out}\right) + V_w k\left(C_{w,out} - \frac{C_{a,out}}{H_{cc}}\right) = 0$$

$$\Rightarrow Q_a (C_{a,out} - C_{a,in}) = V_w k \left(C_{w,out} - \frac{C_{a,out}}{H_{cc}} \right)$$

(b) $C_{a,in} = 0$

$$\Rightarrow Q_a C_{a,out} = V_w k \left(C_{w,out} - \frac{C_{a,out}}{H_{cc}} \right)$$

$$\Rightarrow \left(\frac{Q_a}{V_w k} + \frac{1}{H_{cc}} \right) C_{a,out} = C_{w,out}$$

$$\Rightarrow \frac{C_{a,out}}{C_{w,out}} = \left(\frac{Q_a}{V_w k} + \frac{1}{H_{cc}} \right)^{-1}$$