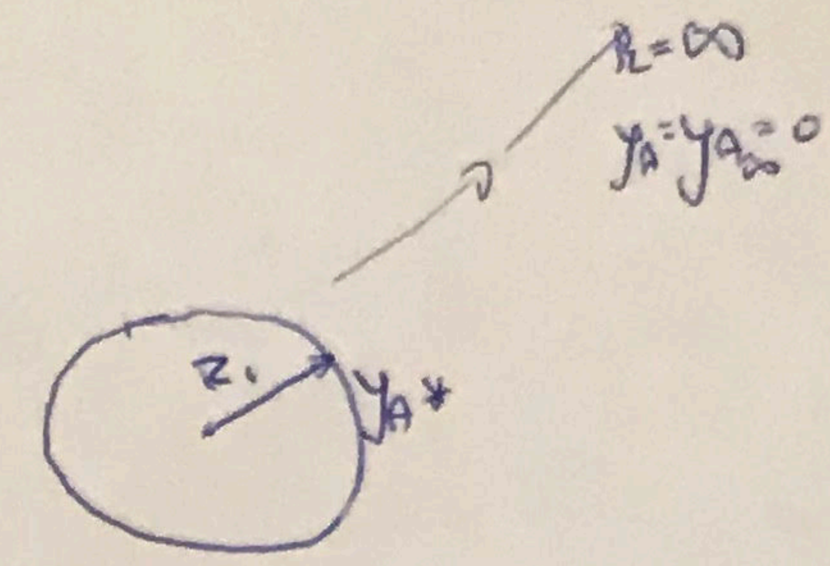
# Difusão em Estado Pseudo-estacionário

2.

Esfera de naftaleno ($C_{10}H_8$) → $M = 128$ g/mole




$\phi_i = 1$ cm $\Rightarrow R_1 = 5 \times 10^{-3}$ m

$T = 318$ K

ar estagnado ; $r \to \infty \Rightarrow y_{\text{Naftaleno}} = 0$

$P_v = 0{,}106$ atm $= 0{,}106 \times 1{,}013 \times 10^5$ Pa $= 1{,}0738 \times 10^4$ Pa → $y_A = 0{,}106$

$\rho = 1140$ kg/m$^3$

$D_{AB} = 6{,}9 \times 10^{-7}$ m$^2$/s

$$N_{A_r} = y_A(N_{A_r} + \cancel{N_{B_r}}^{0}) - \frac{P D_{AB}}{RT}\frac{dy_A}{dr}$$

$$N_{A_r}(1-y_A) = -\frac{P D_{AB}}{RT}\frac{dy_A}{dr}$$

Condições fronteira: $r = R_1 \quad y_A = y_A^*$ ; $r = \infty \quad y_A = 0$

$$N_{A_r}\, dr = -\frac{P D_{AB}}{RT}\frac{dy_A}{(1-y_A)}$$

Eq. de conservação: $N_{A_r} \times r^2 = N_{A_1} \times R_1^2$

$N_{A_r} = N_{A_1} \times R_1^2 \times \frac{1}{r^2}$

$$N_{A_1} R_1^2 \int_{r=R_1}^{r=\infty} \frac{dr}{r^2} = -\frac{P D_{AB}}{RT} \times \int_{y=y_A^*}^{y=0} \frac{dy_A}{1-y_A}$$

$$N_{A_1} \times R_1^2 \times \left[-\frac{1}{r}\right]_{R_1}^{\infty} = -\frac{P D_{AB}}{RT} \times (-1)\left[\ln(1-y_A)\right]_{y_A^*}^{0}$$

$$N_{A_1} \times R_1^2 \times \left(0 + \frac{1}{R_1}\right) = \frac{P D_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)$$

$$N_{A_1} \times R_1 = \frac{P D_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)$$

$$\boxed{Q_A = -C_{AL}\frac{dV}{dt}}$$

$$\frac{dV}{dt} = \frac{dV}{dr} \times \frac{dr}{dt}$$

$V = \frac{4}{3}\pi r^3 \Rightarrow \frac{dV}{dr} = 3 \times \frac{4}{3}\pi r^2 = 4\pi r^2$

$$\frac{dV}{dt} = 4\pi r^2 \frac{dr}{dt}$$

$$\boxed{Q_A = -C_{AL} \times 4\pi r^2 \frac{dr}{dt}}$$

Como $Q_A = N_A \times 4\pi r^2$

$$N_A 4\pi r^2 = -C_{AL} \times 4\pi r^2 \frac{dr}{dt}$$

$$\boxed{N_A = -C_{AL}\frac{dr}{dt}}$$

$$-C_{AL} \times R_1 \frac{dR_1}{dt} = \frac{P D_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)$$

Condições fronteira: $t = t_0 \quad R = R_{t_0}$ ; $t = t \quad R = R_t = 0$

$$\int_{R_{t_0}}^{R_t} R_1\, dR_1 = -\frac{P D_{AB}}{C_{AL} RT}\ln\left(\frac{1}{1-y_A^*}\right)\int_{t=t_0}^{t=t} dt$$

$$\left[\frac{R_1^2}{2}\right]_{R_{t_0}}^{R_t} = -\frac{P D_{AB}}{C_{AL} RT}\ln\left(\frac{1}{1-y_A^*}\right) \times t$$

$$t = -\frac{C_{AL} RT}{P D_{AB}} \times \left(\frac{R_t^2 - R_{t_0}^2}{2}\right) \Big/ \ln\left(\frac{1}{1-y_A^*}\right)$$

c/ $R_t = 0$ m e $R_{t_0} = 5 \times 10^{-3}$ m

c/ $C_{AL} = \frac{1\text{ m}^3 - 1140\text{ kg}}{8906{,}25\text{ mole/m}^3}$

$$t = -\frac{8906{,}25 \times 8{,}3145 \times 318}{1{,}013 \times 10^5 \times 6{,}9 \times 10^{-7}} \times \left(0 - \frac{(5\times10^{-3})^2}{2}\right) \Big/ \ln\left(\frac{1}{1-0{,}106}\right)$$

$$\boxed{t = 37583{,}7\,s = 10h\ 26min}$$

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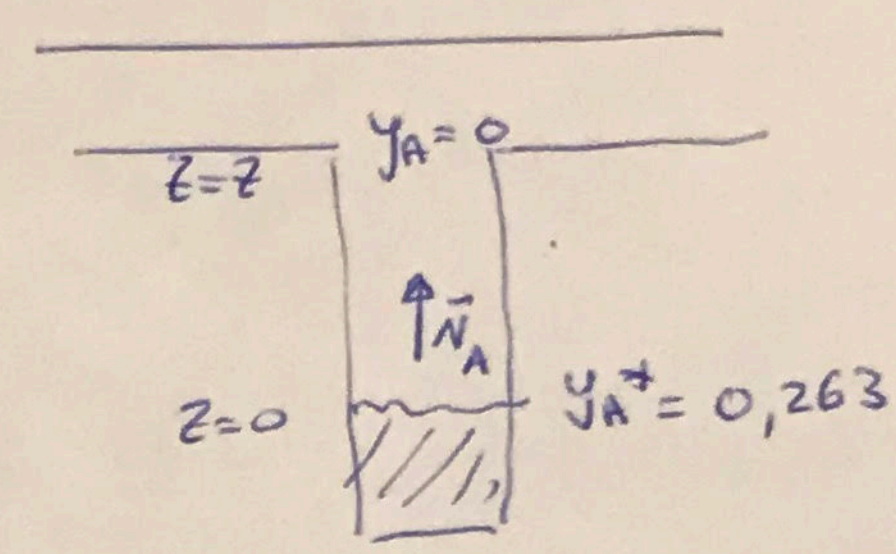
3. Difusão em Estado Pseudo-estacionário

Célula de Arnold




clorofórmio ($CHCl_3$) – $M = 119{,}38$ g/mol

$T = 25°C \Rightarrow T = 298K$

$P = 1\,atm \Rightarrow 1{,}013\times10^5\,Pa$

$\rho_{CHCl_3} = 1{,}485\ g/cm^3 = 1485\ kg/m^3$

$P_v = 200\ mmHg = p_A$ (pois $x_A = 1$ e $y_A = 1$)

$p_A = 200\,mmHg = \frac{200}{760}\,atm = \frac{200}{760} \times 1{,}013\times10^5\,Pa = 0{,}263 \times 1{,}013\times10^5\,Pa$  $y_A^* = \frac{p_A}{P}$

$y_A^* = 0{,}263$

$$N_{A_z} = y_A(N_A + \cancel{N_B}^{\,0}) - \frac{PD_{AB}}{RT}\frac{dy_A}{dz}$$

condições fronteira

$z=0 \quad y_A = y_A^*$

$z=z \quad y_A = 0$

$$N_{A_z}(1-y_A) = -\frac{PD_{AB}}{RT}\frac{dy_A}{dz}$$

$$N_{A_z}\,dz = -\frac{PD_{AB}}{RT}\frac{dy_A}{(1-y_A)}$$

$N_{A_z} = cte$

$$N_{A_z}\int_0^z dz = -\frac{PD_A}{RT}\int_{y_A=y_A^*}^{y_A=0}\frac{dy_A}{(1-y_A)}$$

$$N_{A_z}\cdot z = -\frac{PD_{AB}}{RT}\times(-1)\Big[\ln(1-y_A)\Big]_{y_A^*}^{0}$$

$$N_{A_z} = \frac{PD_{AB}}{RTz}\ln\left(\frac{1}{1-y_A^*}\right)$$

$Q = -C_{AL}\frac{dV}{dt}$

$\frac{dV}{dt} = -S\frac{dz}{dt}$

$Q = C_{AL}\times S\frac{dz}{dt}$

como $N_A = \frac{Q}{S}$

$\boxed{N_A = C_{AL}\frac{dz}{dt}}$

$$C_{AL}\frac{dz}{dt} = \frac{PD_{AB}}{RTz}\ln\left(\frac{1}{1-y_A^*}\right)$$

condições fronteira

$t=0 \quad z = z_{t0}$

$t=t \quad z = z_t$

$$C_{AL}\,z\,dz = \frac{PD_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)dt$$

$$C_{AL}\int_{z_{t0}}^{z_t} z\,dz = \frac{PD_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)\int_0^t dt$$

$$C_{AL}\left[\frac{z^2}{2}\right]_{z_{t_0}}^{z_t} = \frac{P D_{AB}}{RT}\ ln\left(\frac{1}{1-y_A^*}\right)\times t$$

$$C_{AL}\left(\frac{z_t^2 - z_{t_0}^2}{2}\right) = \frac{P D_{AB}}{RT}\ ln\left(\frac{1}{1-y_A^*}\right)\times t$$

$$D_{AB} = \frac{C_{AL} R T}{P}\times\left(\frac{z_t^2 - z_{t_0}^2}{2}\right) \Big/ \left[ ln\left(\frac{1}{1-y_A^*}\right)\times t\right]$$

cálculo de $C_{AL}$:

$1\ m^3\ CHCl_3 = 1485\ Kg$

como $M_{CHCl_3} = 119{,}38\ g/mol$

$n_{CHCl_3} = \frac{1485}{0{,}11938} = 12439{,}3\ mol\ \Rightarrow\ C_{AL} = 12439{,}3\ mol/m^3$

$R = 8{,}314\ m^3 . Pa . K^{-1} . mol^{-1}$

$t = 0 \qquad z_{t_0} = 7{,}4\times 10^{-2}\ m$

$t = 10h = 36000\ s \qquad z_t = 7{,}84\times 10^{-2}\ m$

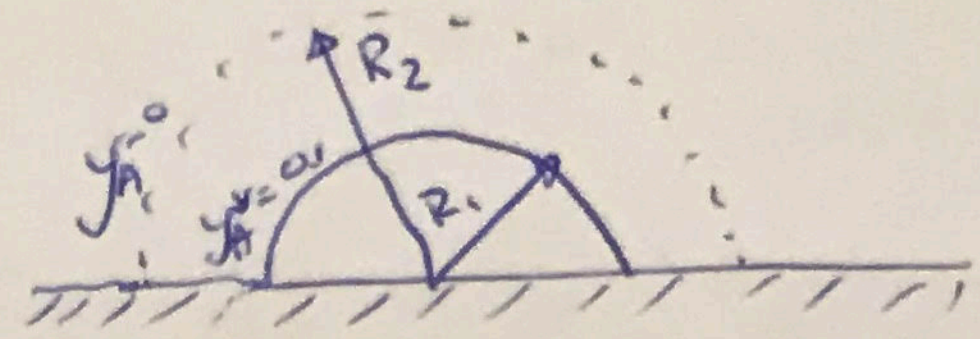
$$D_{AB} = \frac{12439{,}3\times 8{,}314\times 298}{1{,}013\times 10^5}\times\left(\frac{(7{,}84\times10^{-2})^2 - (7{,}4\times10^{-2})^2}{2}\right) \Big/ \left[\left(ln\frac{1}{1-0{,}263}\right)\times 36000\right]$$

$$D_{AB} = 9{,}285\times 10^{-6}\ m^2/s$$

Difusão em estado pseudo-estacionário

4.

$d_i = 6 \times 10^{-3}\,m \rightarrow r_i = 3 \times 10^{-3}\,m$




$R_1 = 3 \times 10^{-3}\,m$

$R_2 = (3+5) \times 10^{-3}\,m = 8 \times 10^{-3}\,m$

$y_A^* = \frac{p_A}{P} = \frac{1,013 \times 10^4\,Pa}{1,013 \times 10^5\,Pa} = 0,1$

$D_{AB} = 2,1 \times 10^{-5}\,m^2/s$

$T = 25°C \rightarrow T = 298\,K$ $\qquad \bar{N}_B = 0$

Condições fronteira:

$\begin{cases} r = R_1 & y_A = y_A^* \\ r = R_2 & y_A = 0 \end{cases}$

a) Abordagem de estado estacionário ($R_1$ = constante)

$$N_{Ar} = y_A (N_{Ar} + \cancel{N_{Br}}^{\,0}) - \frac{P D_{AB}}{RT} \frac{dy_A}{dr}$$

Eq. Conservação

$N_{Ar} \times r^2 = N_{A_1} \times R_1^2$

$N_{Ar} = N_{A_1} \times R_1^2 \times \frac{1}{r^2}$

$$N_{Ar}(1 - y_A) = -\frac{P D_{AB}}{RT} \frac{dy_A}{dr}$$

$$N_{A_1} \times R_1^2 \int_{r=R_1}^{r=R_2} \frac{dr}{r^2} = -\frac{P D_{AB}}{RT} \int_{y_A = y_A^*}^{y_A = 0} \frac{dy_A}{1 - y_A}$$

$$N_{A_1} \times R_1^2 \left[-\frac{1}{r}\right]_{R_1}^{R_2} = -\frac{P D_{AB}}{RT} \times (-1) \left[\ln(1 - y_A)\right]_{y_A^*}^{0}$$

$$\boxed{N_{A_1} \times R_1^2 \left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{P D_{AB}}{RT} \ln\left(\frac{1}{1 - y_A^*}\right)}$$

como

$N_{A_1} = \frac{Q}{2\pi R_1^2}$

$$\frac{Q}{2\pi R_1^2} \times R_1^2 \left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{P D_{AB}}{RT} \ln\left(\frac{1}{1 - y_A^*}\right)$$

$$Q = \frac{2\pi P D_{AB}}{RT} \times \ln\left(\frac{1}{1 - y_A^*}\right) \Big/ \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$Q = \frac{2 \times \pi \times 1,013 \times 10^5 \times 2,1 \times 10^{-5}}{8,314 \times 298} \times \ln\left(\frac{1}{1 - 0,1}\right) \Big/ \left(\frac{1}{3 \times 10^{-3}} - \frac{1}{8 \times 10^{-3}}\right)$$

$Q = \quad$ mole/s

$2,729 \times 10^{-6}$

## VARIAÇÃO DE volume DA hemisfera

$$V_{hemisfera} = \frac{1}{2} \times \frac{4}{3} \pi R^3 = \frac{2}{3} \pi R^3$$

$R_i$ e $R_f$

$$\Delta V = \frac{2}{3} \pi (R_i^3 - R_f^3)$$

$$\Delta V = \frac{2}{3} \pi \times \left( (3 \times 10^{-3})^3 - (6,25 \times 10^{-4})^3 \right)$$

$$= 5,604 \times 10^{-8} \ m^3$$

## Massa $H_2O$ evaporada

$$\rho = \frac{m}{V} \qquad m = \rho \times V \qquad \rho = 1000 \ Kg/m^3$$

$$m = 1000 \times 5,604 \times 10^{-8} \ Kg$$

$$m = 5,604 \times 10^{-5} \ Kg$$

## moles $H_2O$ evaporada

$$M_{H_2O} = 18 \ g/mole$$
$$= 18 \times 10^{-3} \ Kg/mole$$

$$n_{moles} = \frac{5,604 \times 10^{-5}}{18 \times 10^{-3}} = 3,113 \times 10^{-3} \ moles$$

Como $Q = \frac{moles}{t} \Rightarrow t = \frac{moles}{Q}$

$$t = \frac{3,113 \times 10^{-3}}{2,729 \times 10^{-6}} = 1141 \ s$$

$$t = 19 \ min \ 1 \ s$$

b) Repita o cálculo anterior admitindo que o filme de Azoto ocupa o espaço deixado livre pela água evaporada

$R_2 = \text{constante} = 8\times10^{-3}\,m$

$R_1$ variável: $R_{1t_0} = 3\times10^{-3}\,m$ ; $R_{1t} = 6{,}25\times10^{-4}\,m$

$$\begin{cases} t = t_0 & R_1 = R_{1t_0} \\ t = t & R_1 = R_{1t} \end{cases}$$

ou seja, consideramos que $R_2$ é constante e $R_1$ diminui desde o raio inicial da hemisfera de água até ao seu raio final

Partimos da expressão deduzida na alínea anterior

$$N_{A_1}\times R_1^2\left(\frac{1}{R_1}-\frac{1}{R_2}\right) = \frac{PD_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)$$

$$\boxed{Q_{AL} = -C_{AL}\frac{dV}{dt}}$$

$V = \frac{2}{3}\pi R^3$

$\frac{dV}{dt} = \frac{dV}{dR}\frac{dR}{dt}$

$\frac{dV}{dR} = 2\pi R^2$

$\frac{dV}{dt} = 2\pi R^2\frac{dR}{dt}$

$N_A = \frac{Q}{2\pi R^2}$

$$\boxed{N_A = -C_{AL}\frac{dR}{dt}}$$

$$-C_{AL}R_1^2\left(\frac{1}{R_1}-\frac{1}{R_2}\right)\frac{dR}{dt} = \frac{PD_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)$$

$$-C_{AL}\int_{R_1=R_{1t_0}}^{R_1=R_{1t}} R_1^2\left(\frac{1}{R_1}-\frac{1}{R_2}\right)dR = \frac{PD_{AB}}{RT}\ln\left(\frac{1}{1-y_A^*}\right)\int_{t=t_0}^{t=t} dt$$

Primitiva de $R_1^2\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

considerando $R_1$ como variável $(x)$ e $R_2$ como constante $(a)$

$$\int x^2\left(\frac{1}{x}-\frac{1}{a}\right)dx = \int\left(x-\frac{x^2}{a}\right)dx = \int x\,dx - \frac{1}{a}\int x^2\,dx$$

então

$$\left[\frac{R_1^2}{2}\right]_{R_{1t_0}}^{R_1t} - \frac{1}{R_2}\left[\frac{R_1^3}{3}\right]_{R_{1t_0}}^{R_1t} = -\frac{PD_{AB}}{RTC_{AL}}\times\ln\left(\frac{1}{1-y_A^*}\right)\times t$$

$$t = \frac{RTC_{AL}}{PD_{AB}}\times\left[\frac{1}{R_2}\left[\frac{R_1^3}{3}\right]_{R_{t_0}}^{R_t} - \left[\frac{R_1^2}{2}\right]_{R_{t_0}}^{R_t}\right] \Big/ \ln\left(\frac{1}{1-y_A^*}\right)$$

$t = 3{,}3\times10^5\,s \simeq t = 91\,h\ 41\,min$

5. $T = 1145\,K$  $d_i = 15\times10^{-3}\,cm = 15\times10^{-5}\,m$

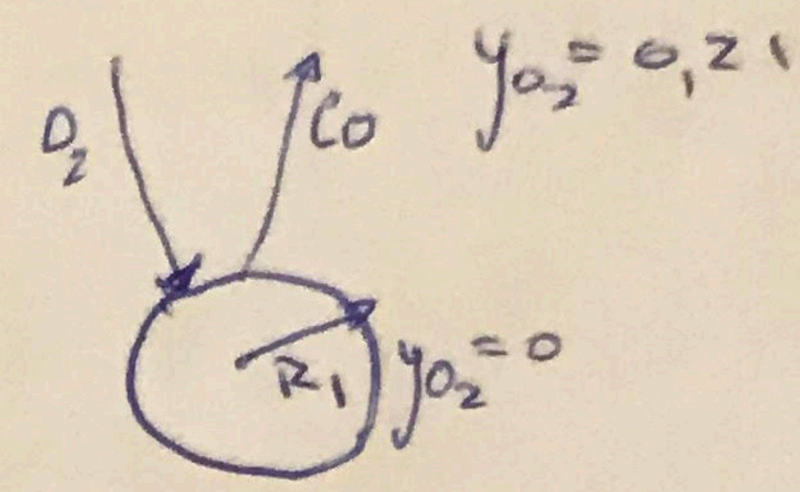
$P = 1\,Atm$  $r_{inicial} = 7{,}5\times10^{-5}\,m$

$D_{O_2-mist} = 1\times10^{-4}\,m^2/s$

$C_{(s)} + O_{2(g)} \longrightarrow 2CO_{(g)}$

$\rho = 1250\,kg/m^3$

$M_C = 12\,g/mol = 12\times10^{-3}\,kg/mol$




a) Considerem estado pseudo estacionário
e
$R = \infty$  $y_{O_2} = 0.21$ (composição de $O_2$ no Ar)

$$N_{CO} = -2N_{O_2}$$

(por cada molécula de $O_2$ que chega à superfície catalítica, formam-se e difundem 2 moléculas de CO)

$$N_{O_2} = y_{O_2}\left(N_{O_2} + N_{CO} + \cancel{N_{N_2}}^{\,0}\right) - \frac{PD_{AB}}{RT}\frac{dy_{O_2}}{dr}$$

Conservação:

$$N_{O_{2r}} \times r^2 = N_{O_{2R_1}} \times R_1^2$$

$$N_{O_2} = y_{O_2}\left(N_{O_2} - 2N_{O_2}\right) - \frac{PD_{AB}}{RT}\frac{dy_{O_2}}{dr}$$

$$N_{O_2} = -y_{O_2}N_{O_2} - \frac{PD_{AB}}{RT}\frac{dy_{O_2}}{dr}$$

$$N_{O_2}\left(1 + y_{O_2}\right) = -\frac{PD_{AB}}{RT}\frac{dy_{O_2}}{dr}$$

Condição fronteira

$$N_{O_2}\,dr = -\frac{PD_{AB}}{RT}\frac{dy_{O_2}}{1 + y_{O_2}}$$

$r = R_1$  $y_{O_2} = 0$

$r = \infty$  $y_{O_2} = 0{,}21$

Reacção instantânea

$$N_{O_{2R_1}} \times R_1^2 \int_{R_1}^{\infty}\frac{dr}{r^2} = -\frac{PD_{AB}}{RT}\int_0^{0,21}\frac{dy_{O_2}}{1 + y_{O_2}}$$

$$N_{O_{2R_1}} \times R_1^2 \left[-\frac{1}{R}\right]_{R_1}^{\infty} = -\frac{PD_{AB}}{RT}\left[\ln\left(1 + y_{O_2}\right)\right]_0^{0,21}$$

$$N_{O_{2R_1}} \times R_1^2 \times \frac{1}{R_1} = -\frac{PD_{AB}}{RT}\ln\left(1 + 0{,}21\right)$$

$$N_{O_{2R_1}} \times R_1 = -\frac{PD_{AB}}{RT}\ln\left(1 + 0{,}21\right)$$

Se quiser assumir estado estacionário, substituo agora os valores numéricos e faço o cálculo. $N_{O_{2R_1}}$ deverá dar negativo (ver coordenadas)

$$- C_{AL} \frac{dR}{dt} \times R = - \frac{P D_{AB}}{RT} \ln(1+0{,}21)$$

$N_A = - C_{AL} \frac{dV}{dt}$

para geometria esférica

$N_{AR} = - C_{AL} \frac{dR}{dt}$

$$\int_{R_{t_0}}^{R_t} R\, dR = + \frac{P D_{AB}}{C_{AL} RT} \ln(1+0{,}21) \int_0^t dt$$

$$\left[ \frac{R^2}{2} \right]_{R_{t_0}}^{R_t} = \frac{P D_{AB}}{C_{AL} RT} \ln(1+0{,}21) \times t$$

condições fronteira

$$\begin{cases} t=0 & R = R_{t_0} \\ t=t & R = R_t \end{cases}$$

$$\left( \frac{R_t^2}{2} - \frac{R_{t_0}^2}{2} \right) = \frac{P D_{AB}}{C_{AL} RT} \ln(1+0{,}21) \times t$$

$$t = \left[ \frac{C_{AL} RT}{P D_{AB}} \Big/ \ln(1+0{,}21) \right] \times \left( \frac{R_t^2 - R_{t_0}^2}{2} \right)$$

$1\ m^3\ e \longrightarrow 1280\ Kg$

$1280\ Kg_c \longrightarrow \frac{1280}{12 \times 10^{-3}}$

$= 1{,}067 \times 10^5\ mole/m^3$

$$t = \frac{1{,}067 \times 10^5 \times 8{,}314 \times 1145}{1{,}013 \times 10^5 \times 1 \times 10^{-4}} \times \left( 0 - \frac{(7{,}5 \times 10^{-5})^2}{2} \right) \Big/ \ln(1{,}21)$$

$t = 1{,}48\ s$

# Difusão em Estado Transiente

1

$C_{A_0} = 0{,}002\ (p/p)$

$D_{A\text{-}Aço} = 1 \times 10^{-11}\ m^2 s^{-1}$

a)

$t = 30 \times 60 = 1800\,s$

$z = 1 \times 10^{-4}\ m$

$C_A = 0{,}0055\ (p/p)$

$C_{AS} = ?$

$$\frac{C_{AS} - C_A}{C_{AS} - C_{A_0}} = \operatorname{erf}\left(\frac{z}{\sqrt{4Dt}}\right)$$

$$\operatorname{erf}\left(\frac{1 \times 10^{-4}}{\sqrt{4 \times 1 \times 10^{-11} \times 1800}}\right) =$$

$$= \operatorname{erf}(0{,}3727)$$

$$\simeq 0{,}4$$

$$\frac{C_{AS} - C_A}{C_{AS} - C_{A_0}} = 0{,}4$$

$$\frac{C_{AS} - 0{,}0055}{C_{AS} - 0{,}002} = 0{,}4 \quad (\Rightarrow) \quad C_{AS} - 0{,}0055 = 0{,}4\,C_{AS} - 0{,}4 \times 0{,}002$$

$$0{,}6\,C_{AS} = 0{,}0055 - 0{,}0008$$

$$C_{AS} = 0{,}0078$$

ou seja $\boxed{C_{AS} = 0{,}78\%\ (p/p)}$

b)

$C_{A_0} = 0{,}0020\ (p/p)$

$C_{AS} = 0{,}0078\ (p/p)$

$D = 1 \times 10^{-11}\ m^2 s^{-1}$

$t = 3600\,s$

$$\operatorname{erf}\left(\frac{1 \times 10^{-4}}{\sqrt{4 \times 1 \times 10^{-11} \times 3600}}\right)$$

$$\operatorname{erf}(0{,}2635) \simeq 0{,}29$$

$$\frac{C_{AS} - C_A}{C_{AS} - C_{A_0}} = 0{,}29$$

$$\frac{0{,}0078 - C_A}{0{,}0078 - 0{,}002} = 0{,}29 \Rightarrow C_A = 0{,}00612$$

$\boxed{C_A = 0{,}61\%\ (p/p)}$

**2.**

$C_{A0} = 1\ kg/m^3$ $\qquad D_{O_2\text{-}água} = 10^{-5}\ cm^2/s$

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

$C_{As} = 9\ kg/m^3$

a) Fluxo à superfície é $J_A^*\Big|_{z=0} = \sqrt{D/\pi \times t} \times (C_{As} - C_{A0})$

$$J_A^*\Big|_{z=0} = \sqrt{10^{-9}/(\pi \times 24 \times 3600)} \times (9-1)\ Kg\,m^{-2}s^{-1}$$

$$= 4{,}856 \times 10^{-7}\ Kg\,m^{-2}s^{-1}$$

em 24h a quantidade dissolvida por $m^2$ é

$$4{,}856 \times 10^{-7} \times 24 \times 3600 = 41{,}95 \times 10^{-3}\ Kg = 41{,}95\,g$$

b) Fluxo de transferência a 10 mm de profundidade

$$J_A^* = \sqrt{\frac{D}{\pi \times t}} \times e^{-z^2/(4Dt)} \times (C_{As} - C_{A0})$$

$$J_A^* = \sqrt{\frac{10^{-9}}{\pi \times 24 \times 3600}} \times e^{-(1 \times 10^{-2})^2/(4 \times 10^{-9} \times 24 \times 3600)} \times (9-1)\ Kg\,m^{-2}s^{-1}$$

$$= 3{,}636 \times 10^{-7}\ Kg/m^2.s$$

A percentagem que penetra além de 10 mm ao final desse tempo é

$$\frac{3{,}636 \times 10^{-7}}{4{,}856 \times 10^{-7}} \times 100 = 74{,}9\%$$

3.

$C_{A0} = ?$

$P = 14$ Atm

$t = 1h = 3600s$

$C_A = 0{,}1$ mol/l ; $z = 1\times10^{-2}$ m

$D_{CO_2-PEG} = 4\times10^{-9}\ m^2 s^{-1}$

$\mathcal{H} = 4\times10^{-2}$ mol . l$^{-1}$ . Atm$^{-1}$

$\mathcal{H} = \frac{C_A}{P_a}$ $\qquad C_A = \mathcal{H} P_a$ → na interface em equilíbrio logo $C_A$ é $C_{AS}$

$C_{AS} = 4\times10^{-2} \times 14 = 0{,}56$ mol l$^{-1}$

~~[illegible]~~

$$\frac{C_{AS} - C_A}{C_{AS} - C_{A0}} = erf\left(\frac{z}{\sqrt{4Dt}}\right)$$

$$erf\left(\frac{1\times10^{-2}}{\sqrt{4\times4\times10^{-9}\times3600}}\right)$$

$$\frac{0{,}56 - 0{,}1}{0{,}56 - C_{A0}} = 0{,}936 \qquad erf(1{,}318) \approx 0{,}936$$

$$\boxed{C_{A0} = 0{,}0685 \text{ mol} . l^{-1}}$$