Sheet No.(2)

Absorption

Q1) Drive the equation for the height of packed absorption column for the case of linear equilibrium and fresh solvent. Also find the height of the packed absorption tower for recovery 99.9% of solute from gaseous mixture using fresh solvent. The vapour pressure of the solute gas over the liquid can be considered negligible and the height of individual gas and liquid phases transfer units are 1 m and 0.5m respectively.

Z=?

$X_2=0$

$P_A^*=0$

hg HL

Answer: NOG = 6.91,   HOG = 1 m,   Z = 6.91 m

Q2) A sulphur burner gas contains 8 mol% SO_2 and 98% recovery of SO_2 is obtained by absorption in water at 15 ^{0}C and 1 atm in a packed tower. The height of the gas and liquid film transfer units are 0.6 each. Calculate the height of the packing for the production of a gaseous system 70 % saturated with SO_2. Equilibrium data can be given by Y*=0.72 X.

Z=?

m

Answer: NOG = 9.13,   HOG = 1.03 m,   Z = 9.4 m

P_T

Q3) A packed tower operating at 101 kPa, recovers 95% of solute gas initially is presented at low concentration in an inert gas. The inert gas rate is 0.16 kmol/m^2.s and the tower is supplied with solute free liquid at the rate of 0.23 kmol/m^2.s. Calculate the height of the tower given:

$X_2=0$ Z=?

$$y_A^* = 0.8 * x_A$$

$$KOG.a = 50 + KOL.a$$

Where KOG.a and KOL.a are in kmol/m^3.h

Answer: NOG = 5.08,   HOG = 2.304 m,   Z = 11.8 m

(X_2)

Q4) A relatively non-volatile hydrocarbon oil contains 4 mol % propane and being stripped by direct superheated steam in stripping tray tower to reduce the propane content to 0.2

mol %. The temperature is held constant at 422 k by internal heating in the tower at a pressure of $2.026 * 10^5$ pa. Twice the minimum of direct steam is used for 300 kmol of total interning liquid. The vapour liquid equilibrium can be given by $\boxed{y = 25 x}$ where x and y are mole fractions. Determine the number of theoretical trays.

$N_{th} = ?$

Answer: $N_{th} = 3.7 \approx 4$ trays

Q5) A gas stream contains 4 mol % NH_3 and this ammonia concentration is needs to be reduced to 0.5 mol % in a packed tower operating at 298 K and 101 kPa. The tower diameter is 750 mm.The inlet pure water flowerate is 68 kmol/h and the inlet gas flowrate is 57.8 kmol/h. The individual gas film mass transfer coefficient kg.a = 0.074 kmol/m^3.s and the individual liquid film mass transfer coefficient kl.a = 0.17 kmol/m^3.s. Calculate the height of tower if the equilibrium relationship is given as $P^*_A = 1.46\ C_A$

$X_2 = 0$

$Z = ?$

Answer: KOG.a = 198 kmol/m^3.s, HOG = 0.66 m, NOG = 3.67, Z = 2.42 m

$$G_s * dY = L_s * dx = N_A * A$$

$$N_A = G_s * Y - G_s\left(Y + \frac{dY}{dz}\partial z\right) = KOG * (a * S * \partial z) * (Y - Y^*)$$

$$\cancel{G_s * Y} - \cancel{G_s * Y} - G_s \frac{dY}{dz}\cancel{\partial z} = KOG(a * S * \cancel{\partial z}) * (Y - Y^*)$$

$$-G_s \frac{dY}{dz} = (KOG * a) * S * (Y - Y^*)$$

$$\frac{-G_s}{(KOG * a) * S} * \frac{dY}{(Y - Y^*)} = dz$$

$$\frac{-G_s}{(KOG * a) * S} \int_{Y_1}^{Y_2} \frac{dY}{(Y - Y^*)} = \int_0^Z dz$$

$$\frac{G_s}{(KOG * a) * S} \int_{Y_2}^{Y_1} \frac{dY}{(Y - Y^*)} = \int_0^Z dz$$

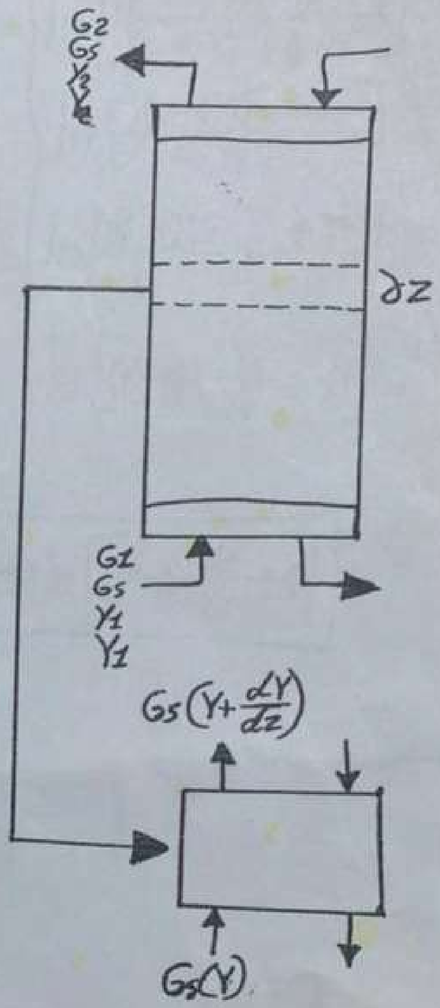
$$Z = \frac{G_s / S}{KOG * a} * \int_{Y_2}^{Y_1} \frac{dY}{(Y - Y^*)}$$

$$Z = \frac{\overline{G_s}}{KOG * a} * \int_{Y_2}^{Y_1} \frac{dY}{(Y - Y^*)}$$

$$HOG = \frac{\overline{G_s}}{KOG * a}$$

$$NOG = \int_{Y_2}^{Y_1} \frac{dY}{Y - Y^*}$$

$$\boxed{Z = HOG * NOG}$$



1.A

$$NOG=\int_{Y_2}^{Y_1}\frac{dY}{Y-Y^*}\ ---\ ①$$

For equilibrcim relationship ($Y^*=m*X$)---②

$$G_s(Y-Y_2)=L_s(X-X_2)$$

$$X=\frac{G_s}{L_s}(Y-Y_2)+X_2$$

*For pure liquid solvent ($X_2=0$)

$$X=\frac{G_s}{L_s}*(Y-Y_2)\ ---\ ③$$

sub eq.3 in eq.2 for X:-

$$Y^*=\frac{m*G_s}{L_s}(Y-Y_2)\ ---\ ⑤$$

sub eq.5 in eq.1 for Y^*:-

$$NOG=\int_{Y_2}^{Y_1}\frac{dY}{Y-\frac{mG_s}{L_s}(Y-Y_2)}$$

Let: $\frac{mG_s}{L_s}=\phi$

$$NOG=\int_{Y_2}^{Y_1}\frac{dY}{Y-\phi(Y-Y_2)}$$

$$NOG=\int_{Y_2}^{Y_1}\frac{dY}{Y-\phi Y+\phi Y_2}$$

$$NOG=\int_{Y_2}^{Y_1}\frac{dY}{(1-\phi)Y+\phi Y_2}*\frac{1-\phi}{1-\phi}$$

$$NOG=\frac{1}{1-\phi}*\ln\left[\frac{(1-\phi)Y_1+\phi Y_2}{(1-\phi)Y_2+\phi Y_2}\right]$$

Simplising:-

$$\ln\left[\frac{(1-\phi)Y_1+\phi Y_2}{(1-\phi)Y_2+\phi Y_2}\right]$$

$$\ln\left[\frac{(1-\phi)Y_1+\phi Y_2}{Y_2-\cancel{\phi Y_2}+\cancel{\phi Y_2}}\right]$$

$$\ln\left[\frac{(1-\phi)Y_1+\phi Y_2}{Y_2}\right]$$

$$\ln\left[\frac{(1-\phi)Y_1}{Y_2}+\frac{\phi\cancel{Y_2}}{\cancel{Y_2}}\right]$$

$$\ln\left[(1-\phi)\frac{Y_1}{Y_2}+\phi\right]$$

$$\boxed{NOG=\frac{1}{1-\phi}*\ln\left[(1-\phi)\frac{Y_1}{Y_2}+\phi\right]}$$

1.B

recovery = 99.9% $H_L = 0.5m$ $H_g = 1m$ $Z = ?$

Vapor pressure of solute gas over liquid negligible $\Rightarrow P_A^* = 0$

$$Y_2 = (1 - \text{recovery}) Y_1$$

$$Y_2 = (1 - 0.999) Y_1$$

$$\boxed{Y_2 = 0.001 Y_1}$$

$$Y^* = mX \rightarrow \frac{P_A^*}{P_T} = mx \rightarrow \frac{0}{P_T} = mx \rightarrow \boxed{m = 0}$$

$$\phi = \frac{m G_s}{L_s} = \frac{(0) * G_s}{L_s} \rightarrow \boxed{\phi = 0}$$

$$NOG = \frac{1}{1-\phi} * \ln\left[(1-\phi)\frac{Y_1}{Y_2} + \phi\right]$$

$$NOG = \frac{1}{1-0} * \ln\left[(1-0)\frac{\cancel{Y_1}}{0.001\cancel{Y_1}} + 0\right]$$

$$\boxed{NOG = 6.91}$$

$$HOG = H_g + \phi H_L$$

$$HOG = 1 + (0) * 0.5$$

$$\boxed{HOG = 1m}$$

Q1 (absorption)

$$Z = NOG * HOG$$

$$Z = 1 * 6.91$$

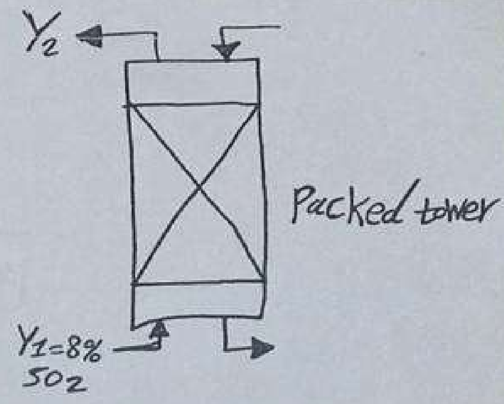
$$\boxed{Z = 6.91m}$$

1.C

Recovery = 98%   T = 15 C°   P = 1 atm

$H_g = 0.6m$ $H_L = 0.6m$ $Y^* = 0.72X$

Saturated = 70%   Z = ?



$Y_2 = (1 - \text{recovery}) Y_1$

$Y_2 = (1 - 0.98) * 0.08 \rightarrow \boxed{Y_2 = 0.0016}$

$$Y_1 = \frac{Y_1}{1 - Y_1} = \frac{0.08}{1 - 0.08} = 0.087$$

$$Y_2 = \frac{Y_2}{1 - Y_2} = \frac{0.0016}{1 - 0.0016} = 0.001602$$

$$\phi = \frac{m G_s}{L_s} \text{ ---- } (1)$$

$$G_s (Y_1 - Y_2) = L_s (X_1 - X_2)$$

$$\frac{G_s}{L_s} = \frac{X_1 - X_2}{Y_1 - Y_2} \text{ --- } (2)$$

sub eq.2 in eq.1 for $\frac{G_s}{L_s}$:-

$$\phi = m * \frac{X_1 - X_2}{Y_1 - Y_2}$$

Q2) absorption

$$Y_1 = m X_1^* \rightarrow X_1^* = \frac{Y_1}{m} \rightarrow X_1^* = \frac{0.087}{0.72} \rightarrow \boxed{X_1^* = 0.1208}$$

$$\text{Saturation} = \frac{X_1}{X_1^*} \rightarrow X_1 = \text{Saturation} * X_1^* \rightarrow X_1 = 0.7 * 0.1208 \rightarrow \boxed{X_1 = 0.08456}$$

$$\phi = m * \frac{X_1 - X_2}{Y_1 - Y_2}$$

$$\phi = 0.72 * \frac{0.08456 - 0}{0.087 - 0.001602}$$

$$\boxed{\phi = 0.713}$$

2.A

$$NOG = \frac{1}{1-\phi} * \ln\left[(1-\phi)\frac{Y_1}{Y_2} + \phi\right]$$

$$NOG = \frac{1}{1-0.713} * \ln\left[(1-0.713)\frac{0.087}{0.001602} + 0.713\right]$$

$$\boxed{NOG = 9.7}$$

$$HOG = Hg + \phi HL$$

$$HOG = 0.6 + (0.713)\,0.6$$

$$\boxed{HOG = 1.03\,m}$$

$$Z = NOG * HOG$$

$$Z = 9.7 * 1.03$$

$$\boxed{Z = 9.9\,m}$$

2.B

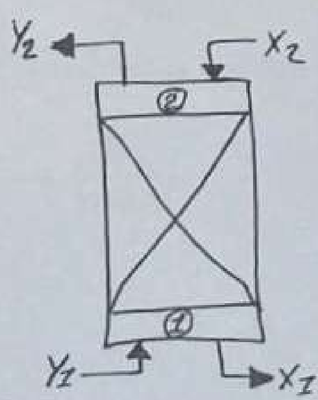
$P = 101\ kPa$ Recovery $= 95\%$

$\bar{G}_s = 0.16 \frac{kmol}{m^2.s} * \frac{3600 s}{1 hr} = 576 \frac{kmol}{m^2.hr}$

$\bar{L}_s = 0.23 \frac{kmol}{m^2.s} * \frac{3600 s}{1 hr} = 828 \frac{kmol}{m^2.hr}$

$K_{OG}.a = 50 + K_{OL}.a$ $\quad Y_A^* = mX_A \quad Z = ?$

wher $K_{OG}.a$ and $K_{OL}.a$ are in $\frac{kmol}{m^3.hr}$



$Y_2 = (1 - \text{recovery}) Y_1$

$Y_2 = (1 - 0.95) Y_1$

$\boxed{Y_2 = 0.05 Y_1}$

Q3 (absorption)

$\phi = \frac{m \bar{G}_s}{\bar{L}_s} = \frac{0.8 * 576}{828} = 0.556$

$NOG = \frac{1}{1-\phi} * \ln\left[(1-\phi)\frac{Y_1}{Y_2} + \phi\right]$

$NOG = \frac{1}{1-0.556} * \ln\left[(1-0.556)\frac{\cancel{Y_1}}{0.05 \cancel{Y_1}} + 0.556\right]$

$\boxed{NOG = 5.05}$

$HOG = Hg + \phi HL \rightarrow HL = \frac{HOG - Hg}{\phi}$ --- 1

$HOL = HL + \frac{Hg}{\phi} \rightarrow HL = HOL - \frac{Hg}{\phi}$ --- 2

sub eq.1 in eq.2 for HL:-

$HOL - \frac{Hg}{\phi} = \frac{HOG - Hg}{\phi}$

$HOL = \frac{HOG - Hg}{\phi} + \frac{Hg}{\phi}$

$HOL = \frac{HOG - \cancel{Hg} + \cancel{Hg}}{\phi}$

$\boxed{HOL = \frac{1}{\phi} HOG}$

3.A

While $H_{OL} = \frac{\bar{L}_s}{K_{OL} \cdot a}$, $H_{OG} = \frac{\bar{G}_s}{K_{OG} \cdot a}$ and $\phi = \frac{m\bar{G}_s}{\bar{L}_s}$ the equation written as:-

$$\frac{\bar{L}_s}{K_{OL} \cdot a} = \frac{1}{\frac{m\bar{G}_s}{\bar{L}_s}} * \frac{\bar{G}_s}{K_{OG} \cdot a} \longrightarrow \frac{\cancel{\bar{L}_s}}{K_{OL} \cdot a} = \frac{\cancel{\bar{L}_s}}{m * \cancel{\bar{G}_s}} * \frac{\cancel{\bar{G}_s}}{K_{OG} \cdot a}$$

$$\frac{1}{K_{OL} \cdot a} = \frac{1}{m} * \frac{1}{K_{OG} \cdot a} \longrightarrow$$

$$K_{OL} \cdot a = m * K_{OG} \cdot a \quad --- (3)$$

$$K_{OG} \cdot a = 50 + K_{OL} \cdot a$$

$$K_{OL} \cdot a = K_{OG} \cdot a - 50 \quad --- (4)$$

a 3) absorption

sub eq.3 in eq.4 for $K_{OL} \cdot a$:-

$$K_{OG} \cdot a - 50 = m * K_{OG} \cdot a$$

$$m * K_{OG} a - K_{OG} \cdot a = -50$$

$$K_{OG} \cdot a (m-1) = -50$$

$$K_{OG} \cdot a = \frac{-50}{m-1} = \frac{-50}{0.8-1} = 250 \frac{kmol}{m^3 \cdot hr}$$

$$H_{OG} = \frac{\bar{G}_s}{K_{OG} \cdot a} = \frac{576}{250}$$

$$\boxed{H_{OG} = 2.304\,m}$$

$$Z = N_{OG} * H_{OG}$$

$$Z = 5.05 * 2.304$$

$$\boxed{Z = 11.6\,m}$$

3.B

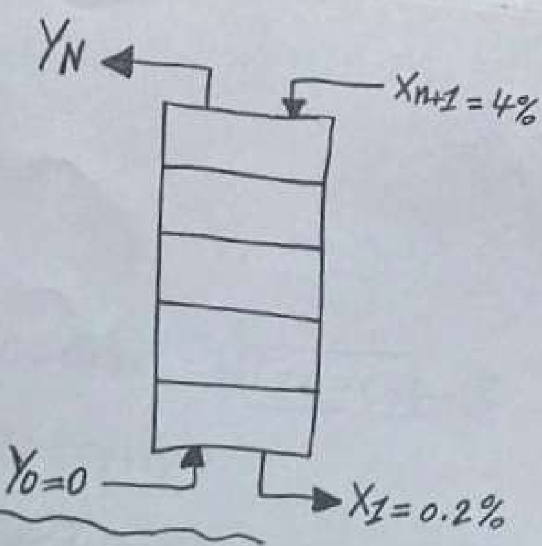
$T=422\,K \quad P=2.026\times10^{5}\,Pa$

$Y=25X$

Twice the minimum of direct steam (G)

$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{1}{2}\left(\frac{L_s}{G_s}\right)_{min}$

$N_{th}=?$



$$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{1}{2}\left(\frac{L_s}{G_s}\right)_{min}$$

$$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{1}{2}*\left[\frac{Y_0-Y_N^*}{X_1-X_{n+1}}\right]\quad ---(1)$$

$$Y_N^*=mX_{n+1}\quad ---(2)$$

absorPtion

sub eq.2 in eq.1 for Y_N^* :-

$$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{1}{2}*\left[\frac{Y_0-(mX_{n+1})}{X_1-X_{n+1}}\right]$$

$$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{1}{2}*\left[\frac{0-(25*0.04)}{0.002-0.04}\right]$$

$$\boxed{\left(\frac{L_s}{G_s}\right)_{actual}=13.2}$$

$$\left(\frac{L_s}{G_s}\right)_{actual}=\frac{Y_0-Y_N}{X_1-X_{n+1}}$$

$$13.2=\frac{0-Y_N}{0.002-0.04}$$

$$\boxed{Y_N=0.5}$$

$$\phi = \frac{mG_s}{L_s} = \frac{25}{13.2} \rightarrow \boxed{\phi = 1.9}$$

$$Y_n = C_1 + C_2\phi^n$$

B.C.(1) $n=0 \rightarrow Y_0 = C_1 + C_2\phi^0 \rightarrow 0 = C_1 + C_2 \rightarrow \boxed{C_1 = -C_2}$ --- ③

B.C.(2) $n=1 \rightarrow Y_1 = C_1 + C_2\phi^1 \rightarrow mX_1 = C_1 + C_2\phi$

$(25 * 0.002) = C_1 + 1.9C_2 \rightarrow \boxed{0.05 = C_1 + 1.9C_2}$ --- ④

sub eq.3 in eq.4 for C_1:-

$0.05 = -C_2 + 1.9C_2 \rightarrow 0.9C_2 = 0.05 \rightarrow C_2 = \frac{0.05}{0.9} \rightarrow \boxed{C_2 = 0.05}$

$C_1 = -C_2 \rightarrow \boxed{C_1 = -0.05}$

B.C.(3) $n=N \rightarrow Y_N = C_1 + C_2\phi^N \rightarrow C_2\phi^N = Y_N - C_1$

$\rightarrow \phi^N = \frac{Y_N - C_1}{C_2} \rightarrow \ln\phi^N = \ln\frac{Y_N - C_1}{C_2}$

$\rightarrow N\ln\phi = \ln\frac{Y_N - C_1}{C_2}$

Q4) absorPtion

$$N_{th} = \frac{\ln\left[\frac{Y_N - C_1}{C_2}\right]}{\ln\phi}$$

$$N_{th} = \frac{\ln\left[\frac{0.5-(-0.05)}{0.05}\right]}{\ln(1.9)}$$

$$\boxed{N_{th} = 3.7 \approx 4 \text{ trays}}$$

4.B

$T = 298\,K$ $\quad P = 101\,KPa$

$= 750\,mm * \frac{1m}{1000\,mm} = 0.75m$

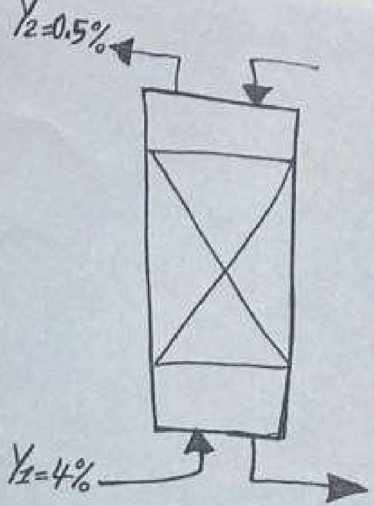
$L_s = 68 \frac{kmole}{hr} * \frac{1hr}{3600s} = 0.018\,kmole/s$

$G_s = 57.8 \frac{kmole}{hr} * \frac{1hr}{3600s} = 0.016\,kmol/s$

$k_g.a = 0.074\,kmol/m^3.s$

$k_L.a = 0.17\,kmol/m^3.s$

$P_A^* = 1.46\,C_A$ $\quad Z = ?$



$\boxed{P_A^* = 1.46 C_A} \div P_T \rightarrow \frac{P_A^*}{P_T} = 1.46 \frac{C_A}{P_T} \rightarrow Y = 1.46 \frac{C_A}{P_T}$ ---①

$X = \frac{C_A}{C_T} \rightarrow C_A = X * C_T$ ---②

Q5) absorption

sub eq.2 in eq.1 for C_A:-

$Y = 1.46 \frac{C_T}{P_T} X$

$C_T = \frac{n}{V} = \frac{\frac{\cancel{mass}}{M.Wt}}{\frac{\cancel{mass}}{\rho}} = \frac{\rho_{H_2O}}{M.Wt_{H_2O}} = \frac{1000\,\cancel{kg}/m^3}{18\,\cancel{kg}/kgmol} = 55.5\,Kmole/m^3$

$Y = 1.46 \frac{55.5}{101} X \rightarrow \boxed{Y = 0.8X}$ so the $\boxed{m = 0.8}$

$\phi = \frac{m\,G_s}{L_s} = \frac{0.8 * 0.016}{0.018} \rightarrow \boxed{\phi = 0.7}$

$NOG = \frac{1}{1-\phi} \ln\left[(1-\phi)\frac{Y_1}{Y_2} + \phi\right]$

$NOG = \frac{1}{1-0.7} \ln\left[(1-0.7)\frac{0.04}{0.005} + 0.7\right]$

$\boxed{NOG = 3.7}$

$m^2 \cdot s$ * 3600

$$A = \frac{\pi}{4} D^2 \rightarrow A = \frac{\pi}{4}(0.75)^2 \rightarrow \boxed{A = 0.442\, m^2}$$

$$\overline{G}_s = \frac{G_s}{A} \rightarrow \overline{G}_s = \frac{0.016}{0.442} \rightarrow \boxed{\overline{G}_s = 0.0362 \frac{kmol}{m^2 \cdot s}}$$

$$\frac{1}{K_{OG}.a} = \frac{1}{k_g.a} + \frac{m}{k_L.a} \rightarrow \frac{1}{K_{OG}a} = \frac{1}{0.074} + \frac{0.8}{0.17} \rightarrow \frac{1}{K_{OG}a} = 18.22$$

$$\rightarrow K_{OG}.a = \frac{1}{18.22} \rightarrow \boxed{K_{OG}.a = 0.0549 \frac{kmol}{m^3 \cdot s}}$$

$$HOG = \frac{\overline{G}_s}{K_{OG}.a}$$

$$HOG = \frac{0.0362\ kmol/m^2.s}{0.0549\ kmol/m^3.s}$$

$$\boxed{HOG = 0.66\, m}$$

$$Z = HOG * NOG$$

$$Z = 0.66 * 3.7$$

$$\boxed{Z = 2.4\, m}$$

gas absorption

5.B