1. Ravnotežje v dvofaznem sistemu

Gibsovo fazno pravilo: f + s = k + 2; Ravnotežje trdno – plin: $y_i = \frac{p_i}{p_{tot}}$

Ravnotežje plin – tekočina: p = He × x (Henryjev z.) Barometrska enačba: $\frac{dP}{dh} = -\rho \cdot g; \rho = \frac{MP}{RT}$

2. Prenos snovi v dvofaznih sistemih

Plini: $\nu = \frac{\eta}{\rho}; a; D \approx 10^{-5}$ pri deb. filma med 100 – 1000 µm;

Tekočine: $D \approx 10^{-9}$ pri deb. sloja 10 (hitra) – 100 (počasna) µm

Koeficient snovnega prenosa:

$10^{-5} < k_L < 10^{-4} m/s$ pri deb. sloja 10 – 100 µm $10^{-2} < k_G < 10^{-1} m/s$ pri 100 – 1000 µm

Snovni fluks na ravnotežju plin – tekoče: $\dot{w} = k_L (c_L - c_{L,i}) = k_G (c_{G,i} - c_G)$

$$\dot{w} = \frac{1}{\frac{1}{k_G} + \frac{K_H}{k_L}} (p - p_i) \quad \dot{w} = \frac{1}{\frac{1}{K_H k_G} + \frac{1}{k_L}} (c_i - c); \qquad K_H = \frac{He}{RTc_{sr}};\ c_G^i = K_H \cdot c_L^i;\ c_G = \frac{P}{RT}$$

3. Destilacija

Diferencialna destilacija

Rayleighova zveza: $\ln \frac{m}{m_0} = \int_{x_0}^{x} \frac{dc}{y - x}$ Masne bilance: $m_0 = m + m_D \quad m_0 \cdot x_0 = m \cdot x + m_D \cdot x_D$

Ravnotežna „Flash“ destilacija

relativna hlapnost: $\alpha = \frac{y_1 / x_1}{y_2 / x_2} = \frac{y_1 (1 - x_1)}{x_1 (1 - y_1)}$; $\log\alpha = 9{,}1 \frac{T_2 - T_1}{T_1 + T_2}$; ravnotežje: $y = \frac{\alpha x}{x(\alpha - 1) + 1}$

Masna bilanca: $F = L + V;\ F \cdot x_f = L \cdot x + V \cdot y$ Toplotna bilanca: $F \cdot c_{pF} (T_2 - T_1) = V \cdot \Delta H_{zmesi}$

Frakcija hlapov: $f = \frac{V}{F}$, frakcija tekočine: $1 - f = \frac{L}{F}$; obratovna črta: $y = -\frac{1 - f}{f} x + \frac{1}{f} x_f$

Tlak v adiabatni posodi: $P_i = P_0 \cdot \exp\left[10{,}58 \cdot \left(1 - {T_0}/{T}\right)\right]$

Desorpcija ali stripping

Masna bilanca: $L(x_{n-1} - x_n) = V(y_{n+1} - y_n)$; Učinkovitost: $E = \frac{n_t}{n_p} = \frac{\text{teoretično št. prekatov}}{\text{praktično št. prekatov}}$;

Št. teoretičnih prekatov: $n_t = \frac{\log\left(\frac{Kx_0 - y_1}{Kx_n - y_{n+1}}\right)}{\log\left(\frac{VK}{L}\right)}$; stripping faktor: $S = \frac{K}{L/V}$

Destilacija z vodno paro

a = LHK, b = THK, n = VP tekočina: $x_a = \frac{a}{a + b}$; para: $y_a = \frac{a}{a + n}$ Masna bilanca: $\frac{a}{n} = \frac{p_a}{P_{TOT} - p_a}$;

Izračun potrebne količine pare: $n = (a_1 - a_0) + (a_0 - a_1)\frac{P_{tot}}{\gamma_a E p_a} + \frac{P_{tot} b}{\gamma_a E p_a} \ln\left(\frac{a_0}{a_1}\right)$

Rektifikacija

Masna bilanca: F = D + B; Komponentna masna bilanca: $F \cdot x_F = D \cdot x_D + B \cdot x_B$

Toplotna bilanca: $\dot{Q}_{gr} + F \cdot \hat{h}_F = D \cdot \hat{h}_D + B \cdot \hat{h}_B + \dot{Q}_{izg} + \dot{Q}_{kond}$; $h_i = c_{pi}(T_i - T_{ref} = 0°C); i = D, F, B$

$\dot{Q}_{gr} = V' \cdot \Delta H_{izp}; \dot{Q}_{kond} = V \cdot \Delta H_{kond}$

Refluks. razm.: $R = \frac{L_0}{D} \rightarrow \infty \geq R$ naklon obrat. črte = 1; $\infty \geq R \Rightarrow n_t \geq n_{t,min}$; $R \geq R_{min} \Rightarrow n_t \leq \infty$

Optimalni R: $1{,}3 \cdot R_{min} < R_{opt} < 1{,}5 \cdot R_{min}$

Določitev števila prekatov v koloni:

- Izračun od prekata do prekata + enačba ravnotežja!

Zg. del: MB: V = L + D; KMB: $V \cdot y_{i,n+1} = L \cdot x_{i,n} + D \cdot x_{i,D}$;

Enačba zg. obrat. črte: $y_{i,n+1} = \frac{L}{L+D} x_{i,n} + \frac{D}{L+D} x_D = \frac{R}{R+1} x_{i,n} + \frac{1}{R+1} x_D$

Sp. del: MB: L' = V' + B; KMB: $L' \cdot x_{i,m-1} = V' \cdot y_{i,m} + B \cdot x_{i,B}$;

Enačba sp. obrat. črte: $y_{i,m} = \frac{L'}{V'} x_{i,n} - \frac{B}{V'} x_B$

E-črta: $y = \frac{e}{e-1} x - \frac{1}{e-1} x_F$; $e = \frac{H_f - h_F}{H_f - h_f}$; $V = V' \Rightarrow L' - L = e \cdot F$; $L = L' \Rightarrow V - V' = (1-e) \cdot F$

- Shorcut metoda (Fenske Underwood)

$n_{t,min} + 1 = \frac{\log \frac{x_D(1-x_B)}{x_B(1-x_D)}}{\log \alpha}$ + Robinson Gillilandov diagram $\frac{n_t - n_{t,min}}{n_t + 1}$ od $\frac{R - R_{min}}{R+1}$.

drug tlak: $\ln\left(\frac{P}{P_0}\right) = \frac{\Delta H}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right)$ lok. nap. prekata: $\log \frac{n}{m} = 0{,}2 \log\left[\frac{1-x_F}{x_F} \cdot \frac{B}{D} \cdot \left(\frac{x_B}{1-x_D}\right)^2\right]$

- Grafična (McCabe - Thiele)

Kolone: padec tlaka: $\Delta P = C \rho_{vapour} v_{vapour}^2; \Delta P_{max} = C \rho_{vapour} v_{vapour,max}^2$;

Obratovne hitrosti: 0,7 – 0,5 × v_{max}; Učinkovit.: $E = \frac{n_t}{n_p}$ (prekat.); $HETP = \frac{H}{n_t}$ (kolon.)

Šaržna destilacija

Bogartov int: $t = -\frac{m_{B,0}(x_D - x_{B,0})}{V} \cdot \int_{x_{B,0}}^{x_B} \frac{R(x_B)+1}{(x_D - x_B)^2} dx_B$; $V = \frac{\dot{Q}}{\Delta H_{izp}}; V = \frac{\pi D^2}{4} \cdot v \cdot \frac{\rho}{M}$

4. Sušenje

Masna bilanca: $L(X_{vst} - X_{izst}) = G(Y_{izst} - Y_{vst})$; $L = v \cdot S \cdot d \cdot \rho_{ss}$;

Vlažnost zraka Y: $Y = \frac{m_{vlage}}{m_{suhega\ zraka}}$; $Y = \frac{p}{P_{tot} - p} \cdot \frac{8}{29}; p = \varphi \cdot p_s$; X ... vlažnost materiala

Luikova zveza: $\ln \frac{\varphi}{\varphi_0} = \frac{1}{a}\left[\frac{1}{X_{max}} - \frac{1}{X}\right]$

Mollierov diagram (entalpija I vs. vlažnost): $I = c_{p,zr} \cdot (T - T_{ref}) + Y\left(2500 + c_{p,vlage} \cdot (T - T_{ref})\right)$

Snovni prenos: $\dot{w} = k_c(c_i - c); 10^{-2} < k_c < 10^{-1} m/s$; $\dot{w} = k_y(Y_i - Y); 10 < k_y < 100 g/m^2 s$;

$$\dot{w} = \frac{Y^* - Y}{1/k_y + K/k_x} \quad \dot{w} = \frac{X - X^*}{1/(K \cdot k_y) + 1/k_x}$$

Čas sušenja:

konvektivni način: $t_{kon} = \frac{\rho_{ss} \cdot d_{ss}(X_0 - X_{kr})}{k_y(Y_w - Y)}$ difuzivni način: $t_{dif} = \frac{4z^2}{\pi^2 D_{AB}} \ln\left[\frac{X_{kr} - X_i}{X - X_i}\right]$

Psihrometrija: adiabata: $Y_s - Y_g = \frac{c_{pzr}}{\Delta H}(T_g - T_s)$; črta T_w: $Y_w - Y_g = \frac{h}{k_y \cdot \Delta H}(T_g - T_w)$;

psihrometrijsko razmerje: $PR = \frac{h}{k_y \cdot c_p}$

Intenzivnost sušenja: $N = \frac{\dot{w}}{\rho X_0} \frac{d_{mat}}{D_{AB}}$; $N < 2 \Rightarrow X_{kr} = \frac{N}{3} \cdot X_0$; $N > 2 \Rightarrow X_{kr} = \left(1 - \frac{2}{3}N\right) \cdot X_0$

5. Ekstrakcija

Ekstrakcija tekočih zmesi: C... mat. kom rafinatne faze; S... mat kom ekstraktne faze; A... komp, ki prehaja; L... rafinatna faza; V... ekstraktna faza:

Kemijski tip ekstrakcije:

MB: $L(C_{in} - C_{out}) = V'(Y_{out} - Y_{in})$; $V = V'(1 + Y_{out})$

EB: $m \cdot g \cdot h_{org} = \frac{m \cdot v^2}{2} \Rightarrow \Delta\rho \cdot g \cdot h_{org} = \frac{\rho_{org} \cdot v_{org,jet}^2}{2}; \Delta\rho = f(h_{org})$

Baterija mešalnikov in ločevalnikov:

$t_{loč} = \frac{31 \cdot 10^3 \cdot \eta \cdot \gamma_i^{0,24}}{(\Delta\rho g)^{1,24} \cdot d_s^{1,48}} \frac{\phi_{disp}}{A} = c \cdot h \left(\frac{\Delta H_{disp}}{t_{loč}}\right)^{1/3}$; $\phi_{disp} = L = \phi_{org}$; $0,025 < c < 0,15$ $(m/s)^{2/3}$; $h = 0,5$;

$\phi_{tot} = L + V + V_R$

$v_{jet} = \alpha \sqrt{\frac{2\Delta\rho g h_0}{\rho_{org}}}$; $\phi_{org} = v_{jet} \cdot S_{lukenj}$; $R_z = \frac{L}{V}$; R_n notr. razmerje v mix: $V_R = \frac{L}{R_n}\left(1 - \frac{1}{R_z}\right)$

Masne bilance v ternarnih sistemih: določitev koordinat: $X_{iD} = \frac{L_n x_n - V_{n+1} \cdot y_{n+1}}{L_n - V_{n+1}}; n = 0, 1, 2...$

6. Absorpcija

Snovni fluks: $\dot{w} = \frac{1}{1/K \cdot k_{CI} + 1/k_{CII}}\left(C^*_{AII} - \overline{C}_{AII}\right)$ $10^{-2} < k_g < 10^{-1} m/s; 10^{-5} < k_l < 10^{-4} m/s$

Raulov zakon: $p = He \cdot x^* = He \cdot \frac{c^*}{c_{sr}}$; $K_{He} = \frac{He}{RT \cdot c_{sr}}$; $c_G^i = K_{He} \cdot c_L^i$

Načrtovanje: MB: $G(y_{in} - y_{out}) = L(x_{out} - x_{in})$

Snovni tok: $K_G \cdot P_{tot} \cdot a \cdot S \cdot (y - y^*)dz = Gdy = -K_L a \cdot S \cdot c_{sr} \cdot (x^* - x)dz = Ldx$

Višina naprave: $z = H_L \cdot n_L = \frac{L}{K_L aS \cdot c_{sr}} \int_{x_{vst}}^{x_{izst}} \frac{dx}{x^* - x}$ $\quad z = H_G \cdot n_G = \frac{G(RT)}{K_G aS \cdot P_{tot}} \int_{y_{izs}}^{y_{vst}} \frac{dy}{y - y^*}$

Število prestopnih enot: $n_t = \frac{\text{konc razlika}}{\text{sr. potencial}} = \frac{\Delta c}{\Delta c_{ln}}$; $\quad$ sr potencial: $\Delta c_{ln} = \frac{\Delta c_{dno} - \Delta c_{vrh}}{\ln \frac{\Delta c_{dno}}{\Delta c_{vrh}}}$

Moč kompresorja: $P = \frac{\kappa}{\kappa - 1} \cdot \phi_{zr} \left[\frac{m^3}{s}\right] \cdot P_{vrh} \left[\left(\frac{P_{dno}}{P_{vrh}} \right)^{\frac{\kappa - 1}{\kappa}} - 1 \right]$ $\quad n_L = \frac{(x_2 - x_1)}{\frac{(x_2^* - x_2) - (x_1^* - x_1)}{\ln \frac{(x_2^* - x_2)}{(x_1^* - x_1)}}}$

7. Uparjanje

Uparjanje v seriji: (f .... doba amortizacije)

$\Delta T_{bruto} - \Delta T_{ebulio} = \Delta T_{neto}$; cena C: $C = C_{inv} + C_{obr} = N \cdot C_{up} \cdot f + V \left(\frac{G}{V} \right)_{pr} \cdot \frac{1}{N} \cdot 24h \cdot D \cdot C_{pare} \cdot 10^3$;

$\left(\frac{G}{V} \right)_{pr} = 1{,}1$; optimalno št. uparjalnikov: $N_{opt} = \sqrt{\frac{K_{obr}}{K_{inv}}}; 0 = \frac{dC}{dN} = K_{inv} - K_{obr} \cdot \left(\frac{1}{N_{opt}} \right)^2$

Večstopenjska baterija: $\underline{\underline{\Delta T_{ebulio} = 0!!!}}$

prva st.: $x_1 \cdot \Delta H_1 + F \cdot c_p (T_F - T_2) = x_2 \cdot \Delta H_2$;

i-ta st.: $x_i \cdot \Delta H_i + \left(F - \sum_j^i x_j \right) \cdot c_p (T_i - T_{i+1}) = x_{i+1} \cdot \Delta H_{i+1}$

entalpija: $\Delta H_i = 2256 + 2{,}1 \cdot (100 - T_i) [kJ/kg]$; $\quad$ vsota vseh hlapov: $V = \sum_2^{n+1} x_i$; $V = F \left(1 - \frac{z_F}{z_L} \right)$

temperaturne razlike: $\Delta T_1 = \frac{T_1 - T_{n+1}}{\sum_{i=1}^{n} \frac{U_1}{U_i}}$; $\Delta T_i = \Delta T_1 \cdot \frac{U_1}{U_i}$; $\quad$ površina $A_i = \frac{x_i \cdot \Delta H_i}{U_i \cdot \Delta T_i}$, $\bar{A}_i = \frac{\sum_{i=1}^{n} A_i}{n}$

8. Kristalizacija

Zakon linearnega prirastka kristalov: $\frac{\Delta L}{\Delta t} = \frac{K_V}{\rho_{Kc}} \Delta C$

Kelvinova zveza: $\frac{4 V_m \sigma}{nRTD_C} = \ln s$; $s = \frac{c_e}{c_s}$; $\Delta s = \frac{\Delta c}{c_s}$

Hitrost nastajanja delcev: $\dot{N} = C \cdot \exp\left[\frac{A \cdot N_A}{RT} \right]$; $A = \frac{16 \pi \sigma^3 V_m^2}{3 (nRT \cdot \ln s)^2}$