Øving 4

1

In a heat exchanger with constant heat capacities and constant *UA*, we have the following simple formula for the total heat transfer from the hot to the cold stream [J/s]

$$Q = UA\Delta T_M$$

where $\Delta T_M = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$ is the log-mean temperature difference.

Countercurrent absorption is similar to a heat exchanger, but the driving force is the concentration difference between y in the gas phase and $y^*(x)$ in equilibrium with the liquid phase. With constant slopes for the equilibrim and operating lines (which is reasonable for dilute mixtures), the total mass transfer of A from the gas to liquid stream is [mol A/s] (as derived in the lecture)

$$\bar{N}_A = K_y(aSz)(y - y^*)_M$$

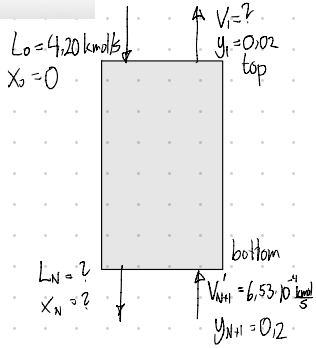
where (aSV) [m^2] is the total mass transfer area inside the column and $(y\text{-}y^*)M$ is the log mean vapor concentration difference between the phases, $(y-y^*)_M = \frac{(y-y)_1 - (y-y)_2}{\ln((y-y^*)_1/(y-y^*)_2)}$ (1=top of column, 2=btm of column).

*it should be easy to remember this formula at the exam and possibly for the rest of your life!

We want to apply this easy-to-remember formula to calculate the absorption of SO_2 using water. A tray tower is to be designed to absorb SO_2 (A) from an air stream by using pure water at 293 K (680F). The entering gas contains 20 mol % SO_2, and that leaving 2 mol % at a total pressure of 101.3 kPa. The inert air flow rate is 150 kg air/ h • m^2, and the entering water flow rate is 6000 kg water/h • m^2. Assuming an overall tray efficiency of 25%, ~~how many theoretical trays and actual trays are needed~~? Assume that the tower operates at 293 K (20^{0}C). It is not really a dilute mixture, so we expect some error.

Ikke nødvendig

Given data: The mole fraction of SO_2 drops from 0.2 (btm) to 0.02 (top) in air. The airflow (inert) is $6.53 \cdot 10^{-4}$ kmol/s. The entering liquid is $4.20 \cdot 10^{-2}$ kmol/s of pure water. The cross-sectional area of the column is 0.0929 m^2.



i)

Find the total mass transfer of A from the vapor to liquid,

$$\bar{N}_A = y_{btm}V_{btm} - y_{top}V_{top} \text{ [mol A/s]}$$

Oppgitt: ~~Column efficiency~~ $= \frac{N_t - 1}{N_a} = 0{,}25$

$A = 0{,}0929\ m^2$

$$V_{N+1} = \frac{V'_{N+1}}{1 - 0{,}2} = 8{,}1625 \cdot 10^{-4} \text{ kmol/s}$$

$$V_1 = \frac{V'_1}{1 - 0{,}02} = 6{,}6632 \cdot 10^{-4} \text{ kmol/s}$$

$$\Rightarrow N_A = 0{,}2 \cdot 8{,}1625 \cdot 10^{-4} - 0{,}02 \cdot 6{,}632 \cdot 10^{-4} \text{ kmol/s}$$

$$\underline{\underline{N_A = 1{,}499 \cdot 10^{-4} \text{ kmol/s}}}$$

ii) The column operates at 1 atm and 20C. Use the equilibrium data to find the slope *m* of the equilibrium line for the concentration range of interest.

A.3-19 Equilibrium Data for SO_2–Water System

Mole Fraction SO_2 in Liquid, x_A	Partial Pressure of SO_2 in Vapor, p_A (mm Hg) 20°C (293 K)	30°C (303 K)	Mole Fraction SO_2 in Vapor, y_A; P = 1 Atm 20°C	30°C
0	0	0	0	0
0.0000562	0.5	0.6	0.000658	0.000790
0.0001403	1.2	1.7	0.00158	0.00223
0.000280	3.2	4.7	0.00421	0.00619
0.000422	5.8	8.1	0.00763	0.01065
0.000564	8.5	11.8	0.01120	0.0155
0.000842	14.1	19.7	0.01855 ~0.02	0.0259
0.001403	26.0	36	0.0342	0.0473
0.001965	39.0	52	0.0513	0.0685
0.00279	59	79	0.0775	0.1040
0.00420	92	125	0.121	0.1645
0.00698	161	216	0.212 ~0.2	0.284
0.01385	336	452	0.443	0.594
0.0206	517	688	0.682	0.905
0.0273	698		0.917	

Source: T. K. Sherwood, *Ind. Eng. Chem.*, **17**, 745 (1925).

Linearregresjon av datoen gir.

$$y = 31{,}62 \cdot x - 0{,}01$$

$$\Rightarrow \underline{m = 31{,}62}$$

iii) Compute $K_y a$ using the data $k_x a = 0.85 \text{kmol/s,m}^3$ and $k_y a = 0.037 \text{kmol/s,m}^3$

$$\frac{1}{K_{ya}} = \frac{1}{k_{ya}} + \frac{m}{k_{xa}}$$

$$\Rightarrow K_{ya} = \frac{1}{\frac{1}{k_{ya}} + \frac{m}{k_{xa}}} = \frac{1}{\frac{1}{0{,}037} + \frac{31{,}62}{0{,}85}} = \underline{0{,}016 \text{ kmol/s,m}^3}$$

iv) Find the logarithmic mean driving force $(y - y^*)_M$

$$(y-y^*)_M = \frac{(y-y^*)_1 - (y-y^*)_2}{\ln \frac{(y-y^*)_1}{(y-y^*)_2}} = \frac{(0{,}02 - 0) - (0{,}2 - 0{,}1)}{\ln \frac{0{,}02}{0{,}1}} = \underline{0{,}05}$$

$y_1 = y_{top} = 0{,}02$

$y_2 = y_{bbm} = 0{,}2$

$X_1 = X_{top} = 0 \Rightarrow y_1^* = 0$

y_2^* finnes ved interpolasjon fra tabellen, trenger X_N, mbalanse SO_2:

$$X_N = \frac{N_A}{L_0 + N_A} = \underline{0{,}00356}$$

$$y_2^* = 0{,}0775 + (0{,}00356 - 0{,}00275)\frac{0{,}121 - 0{,}0775}{0{,}0042 - 0{,}00275}$$

$$y_2^* = 0{,}10$$

v) Use the easy-to-remember formula to find the packing height *z*.

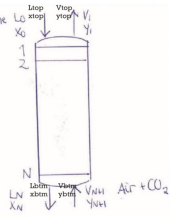
$$N_A = K_y a S z (y-y^*)_m \Rightarrow z = \frac{N_A}{K_{ya} S (y-y^*)_m} = \frac{1{,}499 \cdot 10^{-4} \text{ kmol/s}}{0{,}016 \text{ kmol/s,m}^3 \cdot 0{,}02 \text{ m}^2 \cdot 0{,}05}$$

$$\underline{\underline{z = 2{,}02 \text{ m}}}$$

2

Absorption of CO_2 in water-amine solution (part 2)

This continues the previous exercise, but now you should use the rate-based method (mass transfer) rather than equilibrium stages. Note that since we do not really have stages anymore, we choose to use a different notation with "top" and "btm", so x_0 is now x_{top}, etc. (see Figure).



Let us first repeat the basic data for the column:

$V_{btm} = 22$ kmol/s

$y_{btm} = 0.1176$ (CO2 mole fraction) (feed)

$y_{top} = 0.0116$

$x_{top} = 0.0219$ (feed)

$x_{btm} = 0.0532$

Assuming constant inert flows for air (V') and water-amine (L') through the column, we have

$$V' = V_{btm}(1 - y_{btm}) = 19.41 \text{ kmol/s}$$

$$L' = 69.80 \text{ kmol/s}$$

The operating line is not quite linear, but it goes through the points (x_{top},y_{top}) and (x_{btm},y_{btm}). To simplify, you may assume that the operating line is a straight line between these two points (which corresponds to using a constant $\frac{L'}{V'} = \frac{y_{top} - y_{btm}}{x_{top} - x_{btm}}$

Table: Equilibrium data for CO_2 and water-MEA at 1.2 bar and about 60C (inert air present).

x_{CO2}(%)	y_{CO2}(%)
2.227	1.162
3.001	2.917
3.339	3.783
4.101	6.057
4.700	8.448
5.324	11.60

$\Rightarrow p = 1{,}2$ bar, $T = 60°C$

The new part of the problem:

The overall mass transfer rate referred to the gas side is with pressure as the driving force (A=CO_2):

$$N_A = K_G \cdot a(p_A - p^*_A)$$

where p^*_A is the partial pressure of A that would result if we had gas in equilibrium with the liquid. The following data is given:

$$K_G \cdot a = 12.5 \text{ lbmol/(h} * \text{ft3} * \text{atm)}$$

a) Use the data to find $K_y a$ [kmol/(s*m3 packing)] as used in the book,

$$N_A = K_y a(y_A - y^*_A)$$

where y_A^* is the mole vapor mole fraction of a gas (imagined) in equilibrium with the liquid (which has mole fraction x_A).

a)

Setter $N_A = N_A \Rightarrow K_y a (y_A - y_A^*) = K_g a (p_A - p_A^*)$

$$K_y a = \frac{K_g a (P_A - P_A^*)}{(y_A - y_A)^*}, \quad P_A = P \cdot y_A$$

$$\Rightarrow K_y a = K_g a \frac{P(y_A - y_A^*)}{(y_A - y_A^*)}$$

$$K_y a = 12{,}5 \frac{\text{lb} \cdot \text{mol}}{\text{h} \cdot \text{ft}^3 \cdot \text{atm}} \cdot 1{,}2 \text{ bar}$$

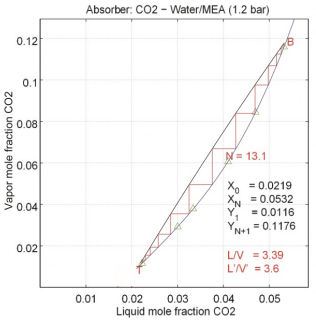
$$= 15 \cdot \frac{\text{lbmol} \cdot \text{bar}}{\text{h} \cdot \text{ft}^3 \cdot \text{atm}} \cdot 1{,}01325 \frac{\text{atm}}{\text{bar}} \cdot 0{,}45 \frac{\text{kmol}}{\text{lbmol}} \cdot \frac{1}{\frac{3600 \text{ s}}{\text{h}}} \cdot \frac{1}{(0{,}3048 \frac{\text{ft}}{\text{m}})^3}$$

$$K_y a = 0{,}067 \frac{\text{kmol}}{\text{s} \cdot \text{m}^3}$$

b) Find the required packing height when $S = 253.5\ m^2$ (cross-sectional area of column) and you can assume constant molar flows in the column.

Note from the McCabe-Thiele diagram from the previous exercise that the equilibrium line is far from linear, so we cannot use the simple method from Problem 1.

(Hint: Make a table of $1/(y_A - y_A^*)$ as a function of y_A; you can then integrate graphically, for example, by counting the number of squares on an mm-paper).



b) Massebalanse gir: $N_A dA = d(V y_A)$ $\quad V = \text{const}$

$$K_y a\,(y_A - y_A^*)\,S\,dz = V\,dy_A$$

$$\Rightarrow Z = \frac{V}{K_y a\, S}\int_{top}^{btm}\frac{dy}{y_A - y_A^*} = \frac{20{,}82\ kmol/s}{0{,}0687\ kmol/s\,m^2 \cdot 253{,}5\ m^2}\int_{top}^{btm}\frac{dy}{y_A - y_A^*}$$

La $V = \dfrac{V_{top} + V_{btm}}{2}$

$V = \dfrac{19{,}64 + 22}{2}\ kmol/s$

forrige øving

$V = 20{,}82\ kmol/s$

Operating line: (fra forrige øving)

$$y_{N+1} = \frac{L_N}{V_{N+1}}x_N + \frac{y_1 V_1 - x_0 L_0}{V_{N+1}}$$

$$y = \frac{L}{V}x + y_{top} - \frac{L}{V}x_{top}$$

$$y = \frac{L}{V}(x - x_{top}) + y_{top}, \quad \text{gitt: } \frac{L}{V} = \frac{y_{top} - y_{btm}}{x_{top} - x_{btm}} = \frac{0{,}0116 - 0{,}1176}{0{,}0219 - 0{,}0532}$$

$$\frac{L}{V} = 3{,}387$$

$$y = 3{,}387x - 0{,}0626$$

Får denne tabellen:

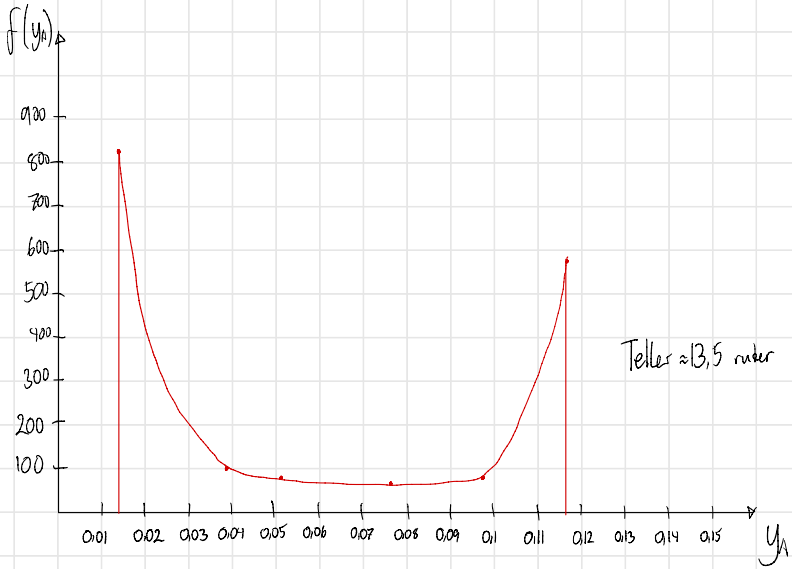
Gitt i oppgaven ↙ ↓ Operating line ↓

xA	yA*	yA	1/(yA - yA*)
0,02227	0,01162	0,01282849	827,47892
0,03001	0,02917	0,03904387	101,277412
0,03339	0,03783	0,05049193	78,97690163
0,04101	0,06057	0,07630087	63,56927494
0,047	0,08448	0,096589	82,58320258
0,05324	0,116	0,11772388	580,086781

$$Z = 1{,}226\int_{y_{A,top}=0{,}0116}^{y_{A,btm}=0{,}1176}\frac{dy_A}{y_A - y_A^*} = 1{,}226 \cdot 13{,}5$$

↑ diagram neste side

$$\underline{Z = 16{,}6\ m}$$


f(y_A)
900
800
700
600
500
400
300
200
100
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.11
0.12
0.13
0.14
0.15
y_A
Teller ≈ 13,5 meter