Eksamen 2013 — Sep-tele

Forslag fasit MB Hägg

<u>Oppgave 1</u>   Membran-separasjon   2.5% vekt

a) Beregning av min reject.
Using given information and eq. 13.4-12

$$X_{OM} = \frac{x_f \left[1 + (\alpha^* - 1) \frac{P_\ell}{P_h} (1 - x_f) \right]}{\alpha^* (1 - x_f) + x_f}$$
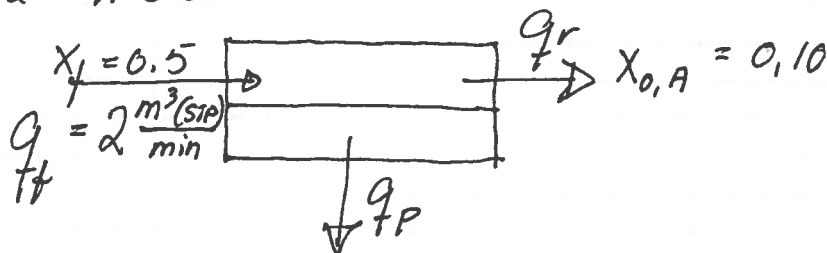
$$= \frac{0.5 \left[1 + (30 - 1) \frac{1}{10} (1 - 0.5) \right]}{30 (1 - 0.5) + 0.5}$$

$$\underline{X_{OM,A}} = 0.079 \approx \underline{0.08} \quad \text{for gas A}$$

$\Rightarrow$ Gass B is thus $X_{0,B} = \underline{0.92}$

b) assuming 20% higher $\Rightarrow \underline{X_{0,A} = 0.10}$

$\Rightarrow$ using this value to calculate
the stream:

$$q_f = q_r + q_P \qquad q_f \cdot x_f = q_r \cdot x_0 + q_P \, y_P$$

b)

$$\theta = \frac{q_P}{q_t} = 0,53 \Rightarrow q_P = 0,53 \cdot 2$$

$$= 1.06 \frac{m^3(STP)}{min}$$

Thus $\quad q_r = 0.94 \quad "$

Calculating composition y_P

using 13.4-8: $\quad y_P = \frac{x_f - x_o(1-\theta)}{\theta}$

$$= \frac{0.5 - 0.1(1-0.53)}{0,53}$$

$$= 0.855 \quad (Gas\ A)$$

How much of A are we loosing?

Gas A In : $2 \cdot 0.5 = 1\ m^3(STP)/min$

Hence, Gas B $= 1 \frac{m^3(STP)}{min}$

Gas B in permeate :

$$1,06 \cdot 0,145 = 0.154 \frac{m^3(STP)}{min}$$

which is $\frac{0.154}{1} \cdot 100\% = 15.4\%\ loss$

1c) Calculating membrane area:

eq. 13.4-9:

$$A_m = \frac{\Theta q_f Y_P}{\left(P'_A/t\right)\left(P_n \cdot x_0 - P_l Y_P\right)}$$

$$= \frac{0,53 \cdot 2 \frac{m^3}{min} \cdot 0,86}{\frac{400\,Barrer}{10^{-6}m}\left(10 \cdot bar \cdot 0,86 - 1\,bar\,0,86\right)} \quad \leftarrow \text{from given info}$$

$$\uparrow x_{0,A}$$

$$\underbrace{\qquad 1 - 0,86 = 0,14\,bar}$$

må gjøre om:

$$= \frac{0,53 \cdot (2 \cdot 10^6\,cm^3/60s) \cdot 0,86}{\frac{400 \cdot 10^{-10}}{10^{-4}} \cdot \frac{cm^3 \cdot cm}{cm \cdot s \cdot cm^2 \cdot cmH}} \bigg/ \cdot 0,14 \cdot 76\,cmHg$$

$$= \frac{0,53 \cdot 2 \cdot 0,86 \cdot 10^6 \cdot}{60 \cdot 400 \cdot 10^{-6} \cdot 0,14 \cdot 76} \cdot cm^2$$

$$= \frac{0.9116\,10^6}{0.14 \cdot 76 \cdot 24 \cdot 10^{-3}} = 357 \cdot 10^6\,cm^2$$

Membrane area $\Rightarrow \quad = \underline{357\ m^2}$

d) Reduce the loss of B by:
- Make a cascade solution or two steps with reduced stage cut (Θ)
- Change Pressure ratio
- Try to increase selectivity (new material)

Problem on Adsorption (4)

$H_T = 30\,cm$ $\rho_p = 712.8\ {}^{kg}/m^3$

Calculating $c/c_0 \Rightarrow$ Table $x/\cancel{0.02}\,926$

a)

Time, h	c/c_0	Time	c/c_0
0	$0 \cdot 10^{-2}$	10.8	0.45
9	$0.065 \cdot 10^{-2}$	11.25	0.68
		11.5	0.77
9.2	$0.129 \cdot 10^{-2}$	12.0	0.98
$t_b \rightarrow$ 9.6	0.027	12.8	1.00
1.0	0.098		
10.4	0.25		

$\Rightarrow$ curve can be drawn

$\rightarrow$ see Textbook page 767

$$t_u = \int_0^{t_b} \left(1 - \frac{c}{c_0}\right)dt \Rightarrow \text{from graph or Table,}$$

b) Break point : $\underline{t_b = 9.58\,h}$

$$\underline{H_{UNB}} = \left(1 - \frac{t_u}{t_b}\right)H_T$$

$$= \left(1 - \frac{9.58}{12.8}\right) 0.30\,m$$

$$= \underline{7.5\,cm} \quad \underline{unused\ bed}$$

c) The graph between $t = 9.58$ and $128h$ is 3.22 h.

$\Rightarrow$ additional bed in mass transfer zone is $\underline{1.61h}$

$\Rightarrow$ total capacity will be used after $9.58 + 1.61\,h = \underline{11.19\,h}$

which is / fraction used up to t_b

$\dfrac{t_u}{t_t} = \dfrac{9.58}{11.19} \doteq 0.86$

$\Rightarrow \underline{86\%}$

d) Determine the saturation capacity of the column for water up-take untill break-point

after 12.8 h the column is fully saturated

N_2-flow rate: $4052 \frac{kg\,N}{m^2\cdot h}$

Total water adsorbed:

$$\frac{926 \cdot 10^{-6}\,kg\,H_2O}{kg\,N_2}$$

$$926 \cdot 10^{-6} \cdot 4052 \cdot 9.58 \quad \frac{kg\,H_2O}{m^2 \cdot 0.225m}$$

$$= \frac{35.95}{0.225} \frac{kg\,H_2O}{m^3} \simeq 160 \frac{kg\,H_2O}{m^3}$$

or: $\dfrac{160\,kg\,H_2O}{712.8\,kg\,particle} = 0.22 \frac{kg\,H_2O}{kg\,particle}$

Solution Problem 1. Distillation

(a) Upper operating line: Mass balances over the top of the column give:

Total: $V = D + L$ (1)

Component: $Vy = D\, yD + L\, x$ (2)

Inserting $D=V-L$,(2) gives the top operation line

$y = (L/V)\, x + (1-L/V)\, yD$

Inserting $L/V=0.86$ and $yD=0{,}90$ this gives

$y = 0.86\, x + 0.126$.

This line goes through $(yD,yD)=(0.9,0.9)$ and the point $(0, 0.126)$ and is plotted on the xy-diagram.

Feed line. The feed is liquid, and the feed line is therefore a vertical line through the point $(xF,xF)=(0.5,0.5)$,

Lower operating line. The lower operating line starts from the intersection between the feed lina and the upper operating line and ends in (xB, xB), but we do not yet know xB.

To find xB, we need to do a "trial-and-error" approach, where we guess xB and keep changing it until we can fit in 7 stages in the McCabe-Thiele staircase; see the plot.

(i). With 2 plates above the feed, we find that the feed is about optimally located, and by trial and error we find xB=0.07.

We can now find D and B from the overall material balances

$F = D + B$

$FxF = DyD + BxB$

We get:

$10*0.5 = D*0.9 + (10-D)*0.07$

and $D = 5.18$ kmol/h and $B = 4.82$ kmol/h

(ii) With the feed moved down (three plates above the feed), the feed is no longer optimally located, so we get a slightly higher value for xB, maybe around xB=0.08 (see figure).

(b) Control.
Inputs for control (MVs): L, VB (QB), D, B, Lcw (Qc)
Controlled variables (CVs): L/V (said to fixed), yD, MD (level), MB (level), pressure

Main disturbances: F, xF

The pairing is not obvious, but one suggestion is given in the Figure:
First two rather obvious pairings:
L ↔ L/V (clearly the best option since V cannot be directly manipulated)
B ↔ MB
The other are less obvious, but one possibility is:
D ↔ p (since D is a vapor product it has a direct effect on pressure, but only an indirect effect on level, so this is why we do not use D for controlling MB)
Lcw (QC) ↔ MD (this is reasonable since the liquid that condenses increases the level)
VB (QB) ↔ yD (this is a bit by elimination; bu although VB seems a bit far away from yD its effect is very fast)

There are also other possibilities for the last three, for example, using vB(QB), to control pressure and D control composition, but this makes the composition control even more indirect.

Solution Problem 2. Absorption

Flows: We have a dilute mixtures so we assume V = V1 = V2 (throughout column) and L = L1 = L2.

Equilibrium: From p_{SO2} = Hx (which applies to dilute mixtures) we derive

y = (H/p) x = mx

where y is the vapor mole fraction of SO2. At p=1 bar and 25C, we get m=46bar/1bar = 46.

(a) The problem is that the liquid flow rate L is too low so that cannot absorb enough SO2 even with equilibrium at the bottom of the column. Note also that the absorption factor is less than 1: A = (L/V)/m = (90000/3000)/46 = 0.652.

Calculations: With equilibrium at the bottom (which requires an infinite number of stages) we have that x1 = x1* (approximately)
where x1* = y1/m = 0.002/46 = 0.0000435.

From the mass balance we can then compute y2:
In SO2 = Out SO2
V y1 + L x2 = V y2 + Lx1
Here x2=0 and x1=x1*=y1/m so we derive
y2 = y1 − (Ly1/(V*m) = y1 (1 − A) = 0.002 * 0.348 = 0.000696
 which is about 7 times too large.

(b) With another identical column we send y2 as the feed to the second column (so y1' = y2 = 0.000696). This helps a little, but still we have A=0.652 < 1 so it is not enough.

We get (similar to above):

y2' = y1' (1-A) = 0.000696*0.348 = 0.000242, which is still a factor 2.5 too large.

(c) Instead of building a second column, the following modifications for the original design have been suggested:

a. Increase the sea water flow by a factor 2
b. Decrease the temperature from 25C to 5C.
c. Increase the pressure from 1 bar to 2 bar

All of these increase A=(L/V)/m by a factor of 2 and will remove SO2 effectively (see detailed calculation below).

a. L is increased by a factor 2, so A=1.304
b. m is decreased by a factor 2.09, so A = 1.363
c. m = H/p is decreased by a factor 2, so A=1.304

Detailed calculation for case a (L=90000*2, A=1.304).

From the Kremser equation we have

$(y1-y1^*)/(y2-y2^*)=A^N = 1.304^{10} = 14.2$

In addition we have the mass balance

V y1 + L x2 = V y2 + Lx1

And equilibrium relationships, $y1^*=my1$, $y2^*=my2$.

We have given y1=0.002 and x2=0 so we have enough information to find y1 and x2.

From the mass balance we get since x2=0

x1 = (V/L) (y1 −y2) or $y1^* = (y1-y2)/A$

Putting this into the Kremser equation using $y2^*=0$ gives

$y1/y2 − (y1/y2-1)/A = A^N$

$y1/y2(1-1/A) = A^N-A$

and we derive

$y2 = y1 (1-1/A)/(A^N-A) = 0.002*(1-1/1.304)/(14.2-1.304) = 0.000036$

which is a factor 3 lower than the requirement of y2<0.000100, so we are OK

Which of the three modifications is the best?

All three give acceptavble SO2-removal so practical issues is probably the main reason for choosing one. Increasing the pressure is expensive as it requires compressing the

feed gas, so I would suggest one of the other alternatives. If there is no cold sea water, then the best alternativeis to increase the seawater flow,

(d) The Kremser equation (1)is on the form given in the lectures, but it is equivalent to what is given in the book.

    a. The assumptions are dilute muxtures with m constant (straight equilibrium line) and L/V constant (straight operating line).

    b. $y_1^* = mx1$ and $y_2^* = mx2$ are the "imaginary" vapor compositions in equilibrium with x1 and x2.

    c. From the diagram you see easily that (y2-y1)/(x2-x1) = L/V (operating line) and (y2*-y1*)/(x2-x1)=m)equilibrium line); and it follws that (y2-y1)/(y2*-y1*)=(L/V)/m = A; See also lecture notes (slide).

Solution.

We have dilute mixtures so we use V1=V2 =V and L1=L2=L

   (a)

(b) With another identical column we send y2 as the feed to the second column (so y1' = y2 = 0.000696). This helps a little, but still we have A=0.652 < 1 so it is not enough.

We get (similar to above):

y2' = y1' (1-A) = 0.000696*0.348 = 0.000242, which is still a factor 2.5 too large.

(c) Instead of building a second column, the following modifications for the original design have been suggested:

    a. Increase the sea water flow by a factor 2

    b. Decrease the temperature from 25C to 5C.

    c. Increase the pressure from 1 bar to 2 bar

All of these increase A=(L/V)/m by a factor of *about* 2 and will remove SO2 effectively (see detailed calculation below).

    a. L is increased by a factor 2, so A=1.304

    b. m is decreased by a factor 2.09, so A = 1.363

    c. m = H/p is decreased by a factor 2, so A=1.304

Detailed calculation for case a (L=90000*2, A=1.304).

From the Kremser equation we have

$(y1-y1^*)/(y2-y2^*)=A^N = 1.304^{10} = 14.2$

In addition we have the mass balance

$V\,y1 + L\,x2 = V\,y2 + Lx1$

And equilibrium relationships, $y1^*=my1, y2^*=my2$.

We have given y1=0.002 and x2=0 so we have enough information to find y1 and x2.

From the mass balance we get since x2=0

$x1 = (V/L)\,(y1 -y2)$ or $y1^* = (y1-y2)/A$

Putting this into the Kremser equation using $y2^*=0$ gives
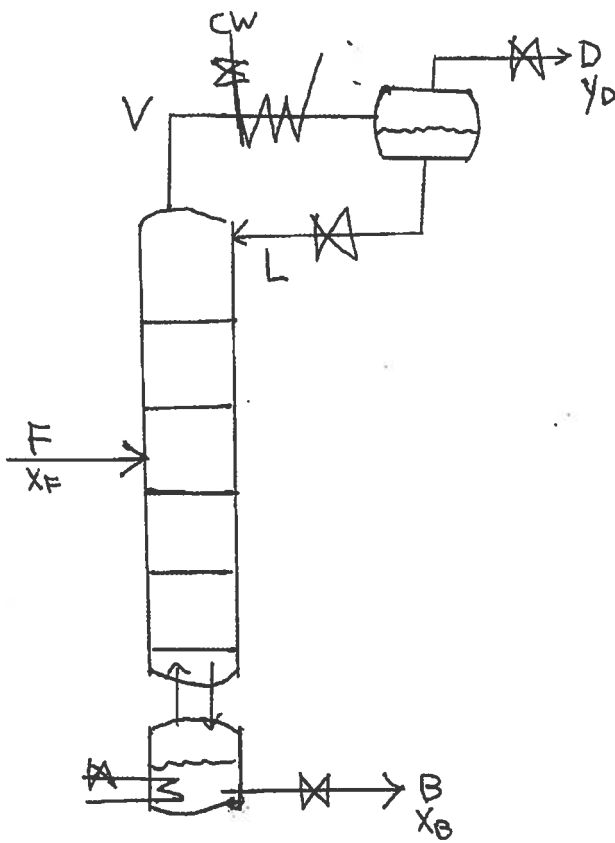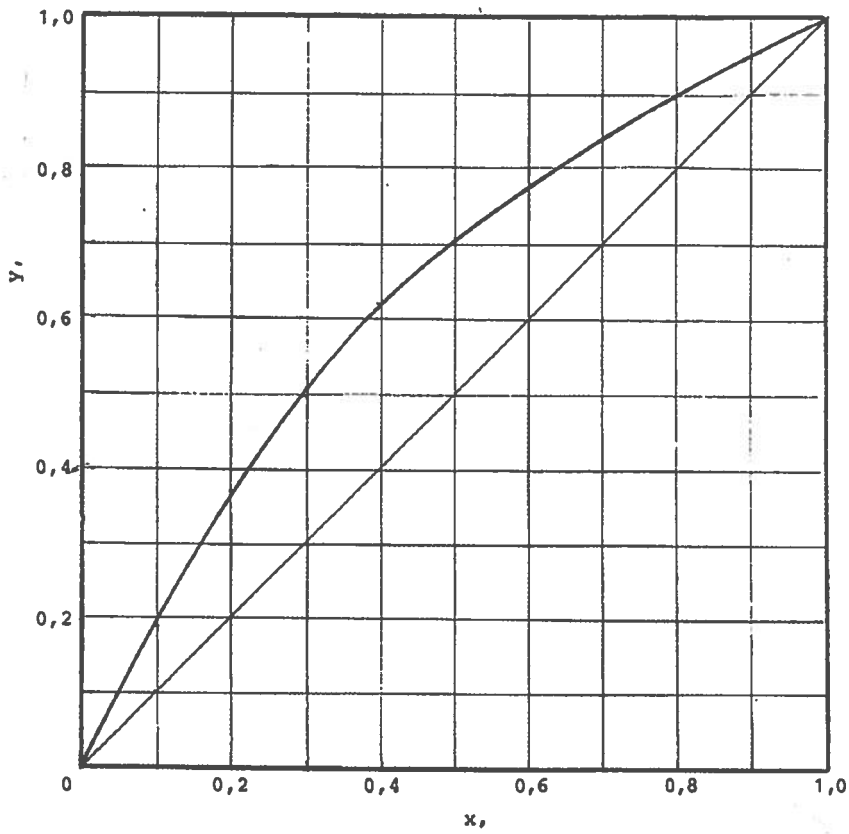
$y1/y2 - (y1/y2-1)/A = A^N$

$y1/y2(1-1/A) = A^N-A$

and we derive

$y2 = y1\,(1-1/A)/(A^N-A) = 0.002*(1-1/1.304)/(14.2-1.304) = 0.000036$

which is a factor 3 lower than the requirement of y2<0.000100, so we are OK

Which of the three modifications is the best?

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Figurer for oppgave 2

Oppgave 3 / Oppgåve 3 - Absorpsjon 25%

$$\frac{y_1 - y_1^*}{y_2 - y_2^*} = A^N \quad (1)$$

$$A = \frac{L/V}{m} \quad (2)$$

$$A = \frac{y_1 - y_2}{y_1^* - y_2^*} \quad (3)$$

Figur for oppgave 3

Forbrenningsgassen (V_1) fra et kullfyrt kraftverk er på 3000 mol/s (84 kg/s) ved 1 bar og inneholder 0.2 mol% SO2 (y_1=0.002). Vi ønsker å fjerne minst 95% av SO2'en (y_2<0.0001) ved absorpsjon med 90000 mol/s (1600 kg/s)sjøvann (x_2=0) ved 25 C; se figur.

Likevektsdata (Henry's konstant for SO_2 i vann; p_{SO2} = Hx der x er molfraksjon SO_2): H=115 bar (50°C), H=46 bar (25°C), H=22 bar (5°C).

(a) Selv med en stor kolonne (med et stort antall teoretiske trinn, N) oppnås ikke ønsket spesifikasjon på SO_2. Kan du forklare hvorfor? Hva er fraksjonen SO_2 (y_2) i utgassen dersom du antar en meget stor kolonne (N →∞)?

(b) For å fjerne mer SO_2 foreslå det å bygge en kolonne til, dvs. utgassen (y_2) sendes til en annen identisk absorpsjonskolonne (som også har 90000 mol/s med sjøvann og mange trinn). Lag et flytskjema av den foreslåtte prosessen med to kolonner. Hjelper dette? Hva er fraksjonen SO_2 (y_2') etter den andre absorpsjonskolonnen når du antar en meget stor kolonne (N →∞)?

(c) I stedet for å bygge en kolonne til, er følgende modifikasjoner av den opprinnelige designen med en kolonne foreslått:
   a. Øke sjøvannsmengden med en faktor 2.
   b. Redusere temperaturen fra 25°C til 5°C.
   c. Øke trykket fra 1 bar til 2 bar.

   Vil noen av disse endringene gi akseptabel SO_2-fjerning? Hvilken av endringene vil du anbefale?

(d) For beregningene i delspørsmål (c) kan du om ønskelig bruke Kremser-ligningen (1) gitt i figuren med N=10.
   a. Hvilke antagelser ligger bak ligning (1)?
   b. Hvordan er y_1^* og y_2^* definert?
   c. A is definert i (2), men er også gitt av (3). Bruk et y-diagram med inntegnet driftslinje og likevektskurve (McCabe-Thiele) til å bevise at (3) er riktig.