

Forslag løsning - EXAM TKP 4105 - Dec. 2014

2) Humidity Chart and definitions

4 a) From diagram, $H_p \approx 22\%$

7 b) Definitions: $H = \frac{P_A}{P - P_A} \cdot \frac{M_{H_2O}}{M_{luft}} = \frac{P_A}{1 - P_A} \cdot \frac{18}{29}$

$$H_s = \frac{P_{As}}{P - P_{As}} \cdot \frac{18}{24}$$

$$H_p = \frac{H}{H_s} \cdot 100 = \frac{P_A}{P_{As}} \cdot \frac{P - P_{As}}{P - P_A} \cdot 100$$

$$H_R = 100 \cdot \frac{P_A}{P_{As}} \quad (H_p \neq H_R)!$$

c) \Rightarrow søkes både P_A og P_{As}

From Table A.2-9 (given) $P_{As} = 17.8 \text{ kPa}$
 $1 \text{ bar} = 100 \text{ kPa}$ ∇

\Rightarrow

using $H = 0.03$ (given)

$$0,03 = \frac{P_A}{1 - P_A} \cdot \frac{18}{29}$$

NB! Must

use $1 \text{ bar} = 100 \text{ kPa}$

$$\Rightarrow 18 P_A = 0,03 \cdot 29 (100 - P_A)$$

$$18 P_A + 0,87 P_A = 0,87 \cdot 100$$

$$\Rightarrow P_A = 4,6 \text{ kPa}$$

$$\Rightarrow \underline{H_s} = \frac{17.8}{100 - 17.8} \cdot \frac{16}{29} = 0.134 \text{ kg H}_2\text{O/kg dry air}$$

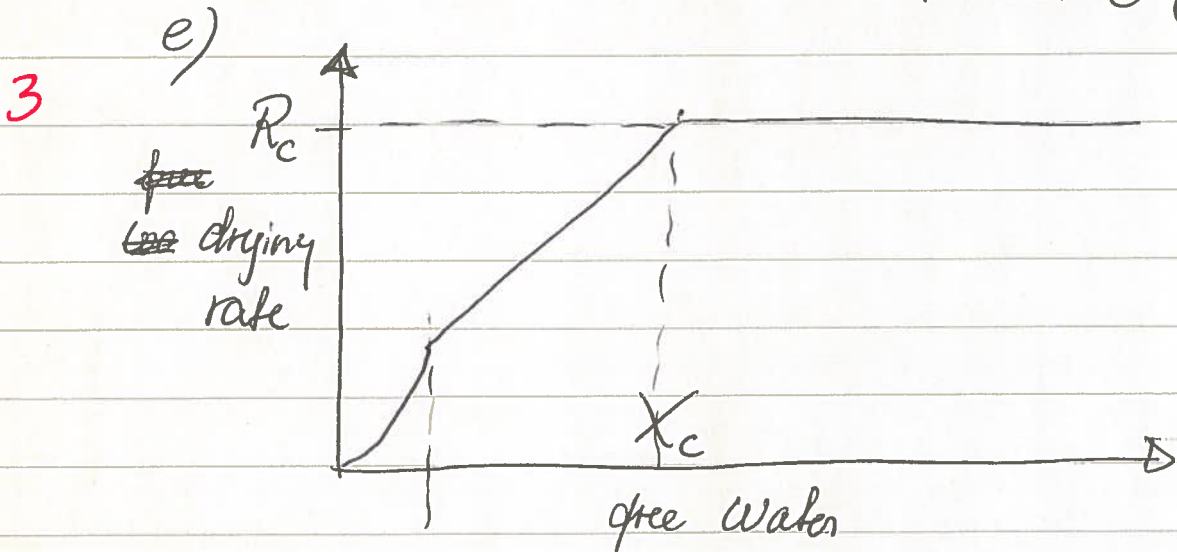
$$\Rightarrow \underline{H_p} = \frac{H}{H_s} \cdot 100 = \frac{0.03}{0.134} \cdot 100 = 22.4\%$$

$$\underline{H_R} = 100 \frac{P_A}{P_{A3}} = 100 \frac{4.6}{17.8} = 25.8\% \quad \left| \text{which is close to estimated} \right.$$

d) Dew point $\Rightarrow \underline{T = 30^\circ\text{C}}$ for this gas

In adiabatic chamber $\Rightarrow \sim \underline{T = 36^\circ\text{C}}$ (100%)

$\underline{T = 37.5^\circ\text{C}}$ (90%)



Solution, Problem 3 RO - Osmosis

a) see section 13.9, Figure 13.9-1

RO process, with flux indication; Figure 13.9-2

Advantage osmotic pressure \Rightarrow FO, PRO
for energy production

b) Calculating the osmotic pressure:

Using Van t'Hoff's eq: $\Pi = \left(\frac{n}{V_m}\right)RT$

Given 3.5w% NaCl in solution

\Rightarrow in 100 kg solution, 3.5 kg NaCl

$$\Rightarrow \frac{3.5 \text{ kg}}{58.45 \text{ kg/kmol}} = \underline{0.0599 \text{ kmol}}$$

Volume pure water; 96.5 kg / kg¹⁰⁰ solution

\Rightarrow From table A2-3; $\rho_{\text{water}} = 1000 \text{ kg/m}^3$

$$\underline{V_m} = \frac{96.5}{1000} = \underline{96.5 \cdot 10^{-3} \text{ m}^3}$$

From Table A1-1, $R = 82.057 \cdot 10^{-3} \text{ m}^3 \cdot \text{atm} / \text{kmol} \cdot \text{K}$

$$T = 273 + 4 = \underline{277 \text{ K}}$$

Calculating osmotic pressure:

$$\Delta \pi = \pi_1 - \pi_2 \quad \text{Here we neglect } \pi_2 \text{ due to dilute solution } (c_2 = 0,1 \text{ kg NaCl/m}^3)$$

$$\text{Hence: } \underline{\underline{\pi_1}} = \frac{2 \cdot 0,0599}{96,5 \cdot 10^{-3}} \cdot 82,057 \cdot 10^{-3} \cdot 277$$

$$= \underline{\underline{28,2 \text{ atm}}} \quad (\Rightarrow 28,6 \text{ bar})$$

$$[\text{if you are assuming } V_m = V_{\text{solution}} = \frac{100}{1000} = 0,1 \text{ m}^3$$

then

$$\underline{\underline{\pi_1}} = 27,2 \text{ atm}$$

$$(27,5 \text{ bar})$$

\rightarrow This is NOT a correct answer because a solution with 3,5 w% NaCl is NOT a dilute solution]

d) Water flux:

$$N_w = 3,04 \cdot 10^{-4} (55 - 28,6)$$

$$= \underline{\underline{80,26 \cdot 10^{-4} \text{ kg H}_2\text{O/s m}^2}}$$

e) Membrane area

15000 l in 24 hours \Rightarrow

$$\underline{\underline{A}} = \frac{15000}{24 \cdot 3600 \cdot 80,26 \cdot 10^{-4}} = \underline{\underline{21,6 \text{ m}^2}}$$

f) retention $R = \frac{c_1 - c_2}{c_1} = 1 - \frac{c_2}{c_1}$

$$c_2 = 0,1 \frac{\text{kg NaCl}}{\text{m}^3} = \frac{0,1}{58,45} \text{ kmol} = 1,71 \cdot 10^{-3} \text{ kmol}$$

$$\Rightarrow \underline{\underline{R}} = \frac{0,06 - 0,0077}{0,06} \cdot 100 = \underline{\underline{97\%}}$$

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Solution Problem Extraction.

Countercurrent process flow sheet

Water and paraffin may be treated as inerts (do not change phase), so this is similar to absorption (no need to use triangular diagrams).

Note that x and y are given on inert basis, that is, pr kg. water and pr. kg. paraffin, which is different from the "normal" case where x and are pr. kg total flow.

Therefore, we consider in the following the inert flows V' and L' , which we can assume constant:

$$L' = L'0 = L'1 = L'2 \text{ [kg water/h]}$$

$$V' = V'0 = V'1 = V'2 \text{ [kg paraffin/h]}$$

Given data: $L'0 = 1000$ kg water/h, $x0 = 0.03$ kg nicotine/kg water.

Comment: Strictly speaking, we are given that it is the total flow which is $L0 = 1000$ kg/h (but no students seemed to notice this....), so the amount $L'0$ of inert (water) is a bit smaller. We have:

Water in feed + nicotine in feed = Total feed

$$L'0 + x0 \cdot L'0 = L0 \text{ [kg/h]}$$

So we have the (more accurate) inert flow:

$$L'0 = L0 / (1 + x0) = 1000 / (1.03) = 971 \text{ kg water/h}$$

However, in the following I have used $L'0 = 1000$ kg water/h (which gives only a small error since we have a dilute solution).

(a) Minimum amount of V is when feed ($L0$) is in equilibrium with product ($V1$), which requires infinite number of stages ($N = \infty$). We then have

$$y1 = m \cdot x0$$

Furthermore from the requirement of removing 99% of the nicotine

$$V'1 \cdot y1 = 0.99 \cdot L'0 \cdot x0 \text{ [kg nicotine/h]}$$

The two equations give with $L'0 = 1000$ kg/h

$$V' = V'1 = 0.99 \cdot L'0 / m = 353.6 \text{ kg paraffin/h}$$

Comment: With the more accurate (smaller) value for $L'0$ we get $V' = 343$ kg/h

(b) We are given $N = 2$ and

$$V' = V'0 = 600 \text{ kg/h, } y0 = 0$$

In principle, this can be solved graphically (McCabe-Thiele) or analytically. Since the end compositions are not known and the number of stages is fixed, analytical is simplest (McCabe would require us to adjust the start point of the operating line to fit in $N = 2$ stages)

Material balances (In = Out) for nicotine give (Note that because x and y are given on inert basis, we should use the inert flows L' and V' in the balances!)

$$\text{Stage 1: } L'0x0 + V'2y2 = L'1x1 + V'1y1$$

$$\text{Stage 2: } L'1x1 + V'0y0 = L'2x2 + V'2y2$$

Equilibrium: $y1 = mx1, y2=mx2$

Constant inert flows: $L0=L1=L$

Putting in numbers then gives for the mass balances on stage 1 and 2:

$$1000*0.03 + 600*2.8*x2 = 1000*x1 + 600*2.8*x1$$

$$1000*x1 + 0 = 1000*x2 + 600*2.8*x2$$

This gives two linear equations with two unknowns. Solution:

$$x1 = 0.01461 \text{ (kg/kg)}$$

$$x2 = 0.00545 \text{ (kg/kg)}$$

The remaining compositions (in addition to $x0=0.03, y0=0$)

$$y1 = m*x1 = 0.04091, y2 = 0.01526$$

Amount extracted (in percentage):

$$100\%*V'1*y1/L'0*x0 = 100\%*600*0.04091/(1000*0.03) = 81.8\%$$

Comment: With the more accurate (smaller) value for $L'0$ we get the balances:

$$971*0.03 + 600*2.8*x2 = 971*x1 + 600*2.8*x1$$

$$971*x1 + 0 = 971*x2 + 600*2.8*x2$$

Solution:

$$x1 = 0.01431, x2 = 0.00524, y1 = 0.04001, y2 = 0.01467$$

Amount extracted:

$$100\%*V'1*y1/L'0*x0 = 100\%*600*0.04001/(971*0.03) = 82.3\%$$

Solution Problem Various

- (a) Disadvantage co-current: Less effective because of smaller driving forces (smaller concentration difference between liquid and vapor); can get at most one equilibrium stage even in a large column.
 Advantage co-current: The capacity is larger, for example, there is no problem with flooding.
- (b) Flooding usually occurs when the vapor rate is too large so that liquid follows the vapor upwards ("liquid entrainment").
- (c) Get
- Mass balance tank: $dm/dt = win - wout$ [kg/s].
 Assuming constant density ρ [kg/m³], $m = \rho*V$, $win = \rho*qin$, $wout = \rho*qout$ gives the desired result. $dV/dt = qin - qout$
 - See flowsheet with LC
 - Mass balance becomes $dV/dt = qin - Kc*V$.
 At steady-state $dV/dt=0$ so $V=qin/Kc$ where $Kc=0.1 \text{ min}^{-1}$.

So $q_{in}=1 \text{ m}^3/\text{min}$ gives $V = 10 \text{ m}^3$.

And $q_{in}=1.5 \text{ m}^3/\text{min}$ gives $V = 15 \text{ m}^3$.

With integral action in the controller, V would have remained constant at steady state (at its given setpoint, e.g. $V_s=10 \text{ m}^3$).

- Since $V=q_{out}/K_c$, the mass balance can be written as:

$$K_c \cdot dq_{out}/dt = -q_{in} + q_{out}$$

Which is on standard form with $\tau=1/K_c = 10 \text{ min}$ and $k=1$.

The response in q_{out} is then first-order with a time constant $\tau=10$ and gain $k=1$ (see figure). Since, $V = q_{out}/K_c$, the response in V is the same as q_{out} , except that V increases from 10 to 15 [m^3].

(e) Flash

- **Comment: The problem statement is a bit confusing since L means both “light component” (in equation for relative volatility) and “liquid product”.**

VLE: Let x and y be mole fraction of light component of products L and V .

x and y are in vapor-liquid equilibrium (VLE) and we assume constant relative volatility:

$$y_L/x_L = \alpha \cdot y_H/x_H$$

where $y_L=y$ and $x_L=x$ and for binary mixture $y_H=1-y$ and $x_H=1-x$. e . We get:

$$(y/x) = \alpha \cdot (1-y)/(1-x) \rightarrow y(1-x) = \alpha \cdot (1-y)x \rightarrow y = \alpha \cdot x / (1 + (\alpha-1) \cdot x)$$

Given $x=0.01$ we then have $y=280 \cdot 0.01 / (1+279 \cdot 0.01)=0.739$.

Balances:

Overall mass balance [mol/s]: $F = V+L$

Mass balance light component [mol/s]: $zF = yV + xL$

Solution: Inserting numbers into the mass balance for light component gives:

$$0.1 \cdot 10 = 0.739 \cdot V + 0.01 \cdot (10-V) \rightarrow V=0.9/0.729=1.24 \text{ mol/s}$$

- What is Q ? We assume that the feed is saturated liquid at 2 bar. The energy balance then gives, approximately, $Q = V \cdot dH_{vap} = 1.24 \text{ mol/s} \cdot 16 \text{ kJ/mol} = 19.8 \text{ kW}$.
- Flow sheet and control. We assume that the feed is a disturbance from a control point of view.
CVs: level, pressure, composition (x).
MVs: L, V, Q . The pairing is fairly obvious (see flowsheet), but we may use the process matrix to help:

	MV1=L	MV2=V	MV3=Q
CV1=level	-	0	-
CV2=p	(-) (indirect through level)	-	+
CV3=x (light)	0	0	-

Note that the suggested pairings along the diagonal avoid pairing on 0's.

Comment: We may make other assumptions for the disturbance and MVs. For example, (1) L may be given (disturbance) and then F is an MV (F is then used for level control instead of L). Or (2) V may be given (disturbance) and F is an MV (it not so clear what the best pairing is this case because F is not a good MV for pressure control).