Forslag løsning – EXAM TKP 4105 – Dec. 2014

2) Humidity Chart and definitions

4 a) From diagram, $H_P \simeq 22\%$

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

$$H_S = \frac{p_{AS}}{P - p_{AS}} \cdot \frac{18}{24}$$

$$H_P = \frac{H}{H_S} \cdot 100 = \frac{p_A}{p_{AS}} \cdot \frac{P - p_{AS}}{P - p_A} \cdot 100$$

$$H_R = 100 \cdot \frac{p_A}{p_{AS}} \qquad (H_P \neq H_R)!$$

c) ⇒ søker både p_A og p_{AS}

From Table A.2-9 (given) $p_{AS} = 17.8\,kPa$

1 bar = 100 kPa !

⇒

using $H = 0.03$ (given)

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

NB! Must use 1 bar = 100 kPa

$$\Rightarrow 18\,p_A = 0{,}03 \cdot 29\,(100 - p_A)$$

$$18\,p_A + 0{,}87\,p_A = 0{,}87 \cdot 100$$

$$\Rightarrow p_A = 4.6\,kPa$$

$$\Rightarrow \underline{\underline{H_S}} = \frac{17,8}{100-17,8} \cdot \frac{18}{29}$$

$$= \underline{\underline{0,134}} \; kg\,H_2O / kg \text{ dry air}$$

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$$\Rightarrow \underline{\underline{H_P}} = \frac{H}{H_S} \cdot 100 = \frac{0,03}{0,134} \cdot 100 = \underline{\underline{22,4\%}}$$

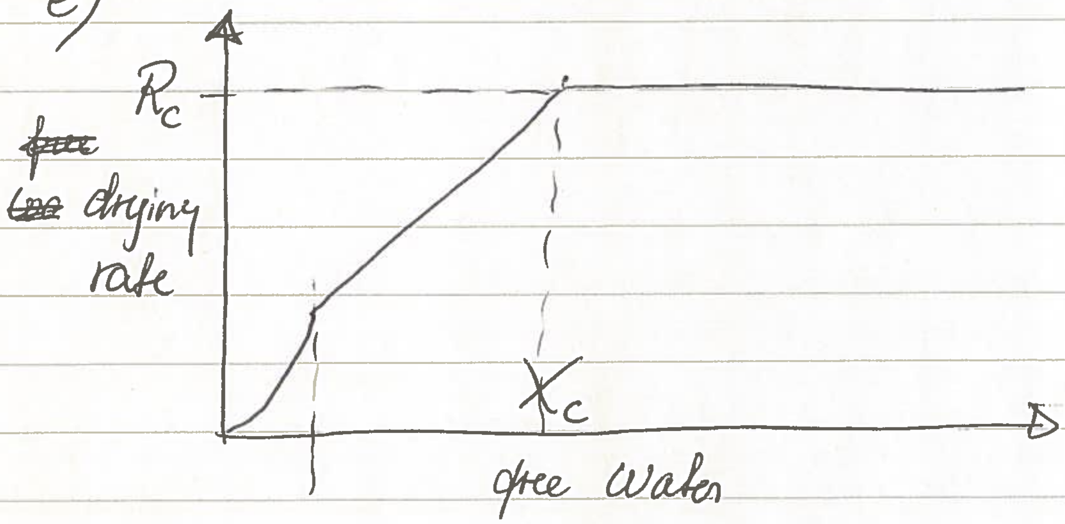
$$\underline{\underline{H_R}} = 100 \frac{P_A}{P_{AS}} = 100 \frac{4,6}{17,8} = \underline{25,8\%}$$ | which is close to estimated

4 d) Dew point $\Rightarrow$ $\underline{\underline{T = 30°C}}$ for this gas

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

$T = 37,5°C$ (90%)

3 e)



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 ⇒ 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 3.5 w% NaCl in solution

⇒ in 100 kg solution, 3,5 kg NaCl

$\Rightarrow \frac{3,5 \text{ kg}}{58,45 \text{ kg/kmol}} = \underline{0,0599 \text{ kmol}}$

Volum pure water; 96,5 kg / 100 kg solution

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

$V_m = \frac{96,5}{1000} = \underline{96,5 \cdot 10^{-3} \text{ m}^3}$

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

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

Calculating osmotic pressure:

$\Delta\Pi = \Pi_1 - \Pi_2$ Here we neglect Π_2 due to dilute solution ($C_2 = 0{,}1\ kg\ NaCl/m^3$)

Hence: $\underline{\underline{\Pi_1}} = \frac{2 \cdot 0{,}0599}{96{,}5 \cdot 10^{-3}} \cdot 82{,}057 \cdot 10^{-3} \cdot 277$

$= \underline{28{,}2\ atm}$ ($\Rightarrow$ 28.6 bar)

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

then $\underline{\Pi_1 = 27{,}\ 2\ atm}$ → This is NOT a correct answer because a solution with 3,5 w% NaCl is NOT a dilute solution]

(27.5 bar)

d) <u>Water flux</u>:

$N_w = 3.04 \cdot 10^{-4}(55 - 28{,}6)$

$= \underline{80{,}26 \cdot 10^{-4}\ kg\ H_2O/s\ m^2}$

e) <u>Membrane area</u>

15000 l in 24 hours ⇒

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

c) <u>retension</u> $R = \frac{C_1 - C_2}{C_1} = 1 - \frac{C_2}{C_1}$

$C_2 = 0{,}1\ \frac{kg\ NaCl}{m^3} = \frac{0{,}1}{58.45}\ kmol = 1{,}71 \cdot 10^{-3}\ kmol$

$\Rightarrow \underline{R} = \frac{0{,}06 - 0{,}0017}{0{,}06} \cdot 100 = \underline{\underline{97\%}}$

Forslag fasit

Problem I. Solution Sigurd

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).

To simplify, we assume that V and L are constant (V0=V1=V2, L0=L1=L2) which is an acceptable assumption because of dilute solution.

Given data: L0= 1000 kg/h, x0 = 0.03 kg/kg

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

y1 = m * x0

Furthermore from the requirement of removing 99% of the nicotine

V1*y1 = 0.99*L0*x0 [kg nicotine/h]

The two equations give

V1 = 0.99*L0/m = 353.6 kg/h

(b) We are given N=2 and

V=V0= 600 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.

Stage 1: L0x0 + V2y2 = L1x1 + V1y1

Stage 2: L1x1 + V0y0 = L2x2 + V2y2

Equilibrium: y1 = mx1, y2=mx2

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

30 + 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 (kg/kg)

X2 = 0.00545 (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%*V1*y1/L0*x0 = 100%*600*0.04091/(1000*0.03) = 81.8%

Solution Problem III Sigurd

(a) Disadvantage co-current: Less effective, 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 costant density rho [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 min-1.
  So qin=1 m3/min gives V = 10 m3.
  And qin=1.5 m3/min gives V = 15 m3.
  With integral action in the controller, V would have remained constant at steady state (at its given setpoint, e.g. Vs=10 m3).
- Since V=qout/Kc, the mass balance can be written as:
  Kc*dqout/dt = - qin + qout
  Which is on standard form with tau=1/Kc = 10 min and k=1. The response in qout is then first-order with a time constant tau=10 and gain k=1 (see figure).

(e) Flash

- Write VLE in terms of the component: (y/x) = alpha*(1-y)/(1-x)

Given x=0.01, Get y=0.739

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

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

Mass balance light component gives:

0.1*10 = 0.739*V + 0.01*(10-V) -> V=0.9/0.738=3.51 mol/s

- What is Q? We assume that the feed is saturated liquid at 2 bar.

The energy balance then gives, approximately, Q = V*dHvap = 3.51 mol/s*16 kJ/mol = 56.2 kW.

- Flow sheet and control. We assume that the feed is a disturbance from a control point of view. CVs: level, pressure, composition. Pair these with the following MVs: L, V, Q