2) **Humidity Chart and definitions**

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

7 b) Definitions:

\[
H = \frac{P_A}{P - P_A} \cdot M_{H_2O} = \frac{P_A}{P - P_A} \cdot \frac{18}{1 - P_A} \\
H = \frac{P_A}{P - P_A} \cdot \frac{18}{24} \cdot \frac{1}{1 - P_A} \\
H_s = \frac{P_A}{P - P_A} \cdot \frac{18}{24} \\
H_p = \frac{H}{H_s} \cdot 100 = \frac{P_A}{P - P_A} \cdot \frac{P - P_A}{P_s} \cdot 100 \\
H_r = 100 \cdot \frac{P_A}{P_s} = (H_p + H_r)!
\]

c) \( \Rightarrow \) søger både \( P_A \) og \( P_s \)

From Table A.2-9 (given) \( P_{s} = 17.8 \text{kPa} \)

\( 1 \text{bar} = 100 \text{kPa} \)

\( \Rightarrow \) using \( H = 0.03 \) (given)

\[
0.03 = \frac{P_A}{1 - P_A} \cdot \frac{18}{24} \\
0.03 = \frac{P_A}{1 - P_A} \cdot \frac{18}{24} \cdot \frac{1}{100 \text{kPa}} \\
\Rightarrow \frac{18P_A}{24} = 0.03 \cdot 29 (100 - P_A) \\
18P_A + 0.87P_A = 0.87 \cdot 100 \\
\Rightarrow P_A = 4.6 \text{kPa}
\]
\[
\Rightarrow \frac{H_0}{100-17.8} = \frac{17.8}{29} = 0.134 \frac{\text{kg H}_2\text{O}}{\text{kg dry air}}
\]

\[
\Rightarrow \frac{H_p}{H_0} = \frac{H}{H_0} \cdot 100 = \frac{0.03}{0.134} \cdot 100 = 22.4\%
\]

\[
\frac{H_p}{H_0} = 100 \cdot \frac{P_A}{P_{A_0}} = 100 \cdot \frac{4.6}{17.8} = 25.8\%
\]

Which is close to estimated.

4)

Dew point \( \Rightarrow T = 30^\circ\text{C} \) for this gas.

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

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

3)

\[
\begin{align*}
R_c & \\
\text{free drying rate} & \\
X_c & \text{free Water}
\end{align*}
\]
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 3.50% NaCl in solution
⇒ in 100 kg solution, 3.5 kg NaCl
⇒ \( \frac{3.5 \text{ kg}}{58.45 \text{ kg/kmol}} = 0.0599 \text{ kmol} \)

Volume pure water; 96.5 kg / 100 kg solution
⇒ From Table A2-3; \( C_{\text{wara}} = 1000 \text{ kg/m}^3 \)

\[ V_m = \frac{96.5}{1000} = 96.5 \times 10^{-3} \text{ m}^3 \]

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

\[ T = 273 + 4 = 277 \text{ K} \]
Calculating osmotic pressure:

\[ \Delta \Pi = \Pi_1 - \Pi_2 \]  
Here we neglect \( \Pi_2 \) due to dilute solution \( (C_2 = 0.1 \text{ kg NaCl/m}^3) \)

Hence:

\[ \Pi_1 = \frac{2 \times 0.0599}{96.5 \times 10^{-3}} \times 82.057 \times 10^{-3} \times 277 \]

\[ = 28.2 \text{ atm} \quad (\Rightarrow 28.6 \text{ bar}) \]

If you are assuming \( V_m = V_{\text{solution}} = \frac{100}{1000} = 0.1 \text{ m}^3 \)

then \( \Pi_1 = 27.2 \text{ atm} \quad \Rightarrow \text{This is NOT a correct answer} \]

\( \text{because a solution with 3.5 w\% NaCl is NOT a dilute solution} \]

d) Water flux:

\[ N_w = 3.04 \times 10^{-4} (55 - 28.6) \]

\[ = 80.26 \times 10^{-4} \text{ kg H}_2\text{O/5 m}^2 \text{ } \text{ h} \]

e) Membrane area

15000 l in 24 hours \( \Rightarrow \)

\[ A = \frac{15000}{24 \times 3600 \times 80.26 \times 10^{-4}} = 21.6 \text{ m}^2 \]

g) Retention

\[ R = 1 - \frac{C_2}{C_1} = 1 - \frac{0.1}{0.05845} \text{ kmol} = 1.71 \times 10^{-3} \text{ kmol} \]

\[ \Rightarrow R = 0.06 - 0.0077 \times 100 = 97\% \]
Problem I. Solution

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 (\(V_0=V_1=V_2, L_0=L_1=L_2\)) which is an acceptable assumption because of dilute solution.

Given data: \(L_0 = 1000\) kg/h, \(x_0 = 0.03\) kg/kg

(a) Minimum amount of \(V\) is when feed (\(L_0\)) is in equilibrium with product (\(V_1\)), which requires infinite number of stages (\(N=\infty\)). We then have
\[
y_1 = m \cdot x_0
\]
Furthermore from the requirement of removing 99% of the nicotine
\[
V_1 \cdot y_1 = 0.99 \cdot L_0 \cdot x_0 \quad [\text{kg nicotine/h}]
\]
The two equations give
\[
V_1 = 0.99 \cdot L_0 / m = 353.6 \text{ kg/h}
\]
(b) We are given \(N=2\) and
\[
V = V_0 = 600 \text{ kg/h, } y_0 = 0
\]

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: \(L_0 x_0 + V_2 y_2 = L_1 x_1 + V_1 y_1\)
Stage 2: \(L_1 x_1 + V_0 y_0 = L_2 x_2 + V_2 y_2\)

Equilibrium: \(y_1 = m x_1, y_2 = m x_2\)

Putting in numbers then gives for the mass balances on stage 1 and 2:
\[
30 + 600 \cdot 2.8 \cdot x_2 = 1000 \cdot x_1 + 600 \cdot 2.8 \cdot x_1
1000 \cdot x_1 + 0 = 1000 \cdot x_2 + 600 \cdot 2.8 \cdot x_2
\]

This gives two linear equations with two unknowns. Solution:
\[
X_1 = 0.01461 \text{ (kg/kg)}
X_2 = 0.00545 \text{ (kg/kg)}
\]

The remaining compositions (in addition to \(x_0=0.03, y_0=0\))
\[
Y_1 = m \cdot x_1 = 0.04091, y_2 = 0.01526
\]

Amount extracted (in percentage):
\[
100% \cdot V_1 \cdot y_1 / L_0 \cdot x_0 = 100% \cdot 600 \cdot 0.04091 / (1000 \cdot 0.03) = 81.8%
\]
Solution Problem III

(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: \( \frac{dm}{dt} = \text{win} - \text{wout} \, [\text{kg/s}] \).
     Assuming constant density \( \rho \, [\text{kg/m}^3] \), \( m = \rho \cdot V \), \( \text{win}=\rho \cdot \text{qin} \), \( \text{wout}=\rho \cdot \text{qout} \)
gives the desired result. \( \frac{dV}{dt} = \text{qin} - \text{qout} \)
   - See flowsheet with LC
   - Mass balance becomes \( \frac{dV}{dt} = \text{qin} - Kc \cdot V \).
     At steady-state \( \frac{dV}{dt}=0 \) so \( V = \frac{\text{qin}}{Kc} \) where \( Kc=0.1 \, \text{min}^{-1} \).
     So \( \text{qin} = 1 \, \text{m}^3/\text{min} \) gives \( V = 10 \, \text{m}^3 \).
     And \( \text{qin} = 1.5 \, \text{m}^3/\text{min} \) 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 \( V = qout/Kc \), the mass balance can be written as:
     \[ Kc \cdot \frac{dqout}{dt} = - \text{qin} + \text{qout} \]
     Which is on standard form with \( \tau = \frac{1}{Kc} = 10 \, \text{min} \) and \( k = 1 \). The response in \( \text{qout} \) 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: \( \frac{y}{x} = \alpha \cdot (1-y)/(1-x) \)
   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:
   \[ 0.1 \times 10 = 0.739 \times V + 0.01 \times (10-V) \implies V = 0.9/0.738 = 3.51 \, \text{mol/s} \]
   - What is \( Q \)? We assume that the feed is saturated liquid at 2 bar.

The energy balance then gives, approximately, \( Q = V \cdot dVap = 3.51 \, \text{mol/s} \times 16 \, \text{kJ/mol} = 56.2 \, \text{kW} \).

   - 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: \( L, V, Q \)