

Solution Exam TKP4105 2016 – May-Britt Hägg

Problem 2 Drying Max 30 p

- a) (Max 4 p) See text book Figures 9.3-3 and 9.3-4 (attached page)
- b) (Max 4 p) See text book Chapter 9.5. It is expected that the student explain B-C as constant rate with evaporation (by convection) from a water film, C-D at falling rate when water is drawn out of the material by capillary forces, D-E when water is drawn out of the pores in the material by diffusion
- c) (Max 4p) Constant rate period, see text book chp.9.6A:

$$t = \frac{L_s}{AR_c} (X_1 - X_2)$$

(Max 4 p) Falling rate period, see text book chp 9.7A and B, note the special case when C-D goes through origo

$$t = \frac{L_s}{aA} \ln \frac{R_1}{R_2}$$

- d) (Max 4 p) Content water at start: 0,029 kg H₂O/kg dry air. Percent humidity = 15% H
The answer may differ a bit here, but the student is expected to show on the graph how they find the values.
- e) (Max 4 p) Adiabatic drying to 90% H at outlet: Temperature of air is about 39°C. The answer may differ a bit here, but the student is expected to show on the graph how they find the value.
- f) (Max 6 p (3+3)) Calculating drying time:

In constant rate period:

From the given figure, we find $R_c = 1,5 \text{ kg H}_2\text{O/h.m}^2$

$$t = \frac{L_s}{AR_c} (X_1 - X_2) = (10/2.1,5)(0,4-0,18) = 0,733 \text{ h}$$

Calculating drying time in falling rate period:

$$t = \frac{L_s}{aA} \ln \frac{R_1}{R_2} = (10.0,18)/2.1,5 \ln(0,18/0,05) = 0,6.1,28 = 0,768 \text{ h}$$

Total drying time is thus $0,733 + 0,768 = 1,5 \text{ h} = \mathbf{1 \text{ hour } 30 \text{ minutes}}$

Problem 3 Membrane Gas separation Max 20 p

- a) (Max 5 p) See text book, figure 13.4-1
- b) (Max 10 p) Two equations were given:

$$\text{Flux: } \frac{q_A}{A_m} = \frac{q_p \cdot y_p}{A_m} = \left(\frac{P_A}{l} \right) p_h x_0 - p_l y_p \quad [m^3(STP) / (m^2 h)] \quad (1)$$

$$\text{Permeate cut: } (\theta = q_p / q_f) = 0,1 \quad (2)$$

Additional mass balances can be put up:

Total mass balance: $q_f = q_p + q_r$ (3)

Component balance: $q_f x_f = q_p y_p + q_r x_0$ (4)

From (2): $q_f = 2 / 0,1 = 20 \text{ m}^3(\text{STP})/\text{h}$

Hence (3) $q_r = 20 - 2 = 18 \text{ m}^3(\text{TP})/\text{h}$

From (4) $x_0 = (0,21 \cdot 20 - 2 \cdot 0,45) / 18 = \mathbf{0,183}$ giving the retentate composition

Solving equation (1) for one unknown (A_m) gives:

$$(4) \quad \frac{0,45 \cdot 2}{A_m} = \frac{1,109 \cdot 10^{-6}}{1 \cdot 10^{-6}} 2 \cdot 0,183 - 0,2 \cdot 0,45$$

solving for A_m gives: $A_m = \mathbf{2,94 \text{ m}^2}$

Comments: Above calculations are using the complete mixing model, with $x_r = x_0$

If the logarithmic mean values was used:

$$X_{\text{mean}} = (0,21 - 0,183) / \ln (0,21/0,183) = 0,196$$

Inserting this value for calculation of area in (4) gives: $A_m = 2,69 \text{ m}^2$

- b) (Max 5 p) For producing high purity nitrogen (95vol%), a compressor on feed side should be used, and permeate to atmospheric pressure. A feed side pressure of 10 bar would give the same ratio when permeating to 1 bar as 2 bar to 0,2 bar. Permeate cut should be higher and membrane area as well. Calculations would have to be performed over two stages. (x_0 from 0,21 \rightarrow 0,10 \rightarrow 0,05)

Problem 1, a – more details

- a) Adiabatic drying process. It is expected to sketch this figure, or at least be clear on that there is no heat exchange with the surroundings, thus the temperature of the gas goes down and (T_s) and humidity of the gas increases (here to H_s). Adiabatic saturation temperature is the steady-state temperature attained when a large amount of water is contacted with the entering gas.

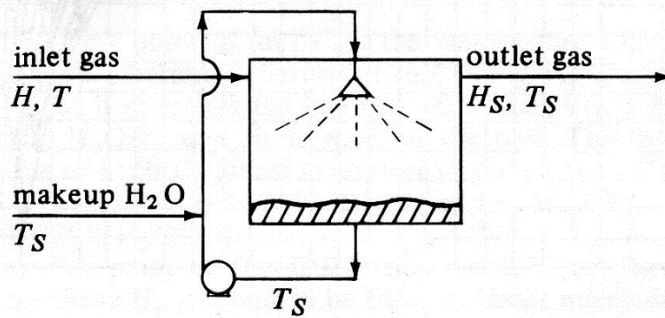


FIGURE 9.3-3. *Adiabatic air–water vapor saturator.*

Wet bulb temperature is the steady state nonequilibrium temperature reached when a small amount of water is contacted under adiabatic conditions by a continuous stream of gas. Since the amount of liquid is small, the temperature and humidity of the gas are not changed.

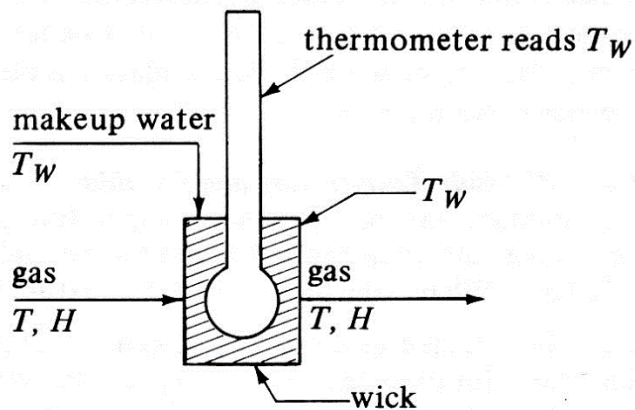


FIGURE 9.3-4. *Measurement of wet bulb temperature.*