

You may find additional useful information in the following:

(Questions start from page 4.)

The general continuity equations for component A and also for constant density and diffusivity are as follows:

NOTE: In the following equations, R_A is the rate of **generation** of A in the system [moles/(Volume.time)].

Rectangular Coordinate:

$$\frac{\partial c_i}{\partial t} + \left(\frac{\partial N_{i,x}}{\partial x} + \frac{\partial N_{i,y}}{\partial y} + \frac{\partial N_{i,z}}{\partial z} \right) = R_i \quad i=1,2,\dots,n$$

$$\frac{\partial C_A}{\partial t} + \left(v_x \frac{\partial C_A}{\partial x} + v_y \frac{\partial C_A}{\partial y} + v_z \frac{\partial C_A}{\partial z} \right) = D_{AB} \left(\frac{\partial^2 C_A}{\partial x^2} + \frac{\partial^2 C_A}{\partial y^2} + \frac{\partial^2 C_A}{\partial z^2} \right) + R_A$$

Cylindrical Coordinate:

$$\frac{\partial c_i}{\partial t} + \left(\frac{1}{r} \frac{\partial}{\partial r} (r N_{i,r}) + \frac{1}{r} \frac{\partial N_{i,\theta}}{\partial \theta} + \frac{\partial N_{i,z}}{\partial z} \right) = R_i \quad i=1,2,\dots,n$$

$$\frac{\partial C_A}{\partial t} + \left(v_r \frac{\partial C_A}{\partial r} + v_\theta \frac{1}{r} \frac{\partial C_A}{\partial \theta} + v_z \frac{\partial C_A}{\partial z} \right) = D_{AB} \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial C_A}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 C_A}{\partial \theta^2} + \frac{\partial^2 C_A}{\partial z^2} \right) + R_A$$

Spherical Coordinate:

$$\frac{\partial c_i}{\partial t} + \left(\frac{1}{r^2} \frac{\partial}{\partial r} (r^2 N_{i,r}) + \frac{1}{r \sin \theta} \frac{\partial}{\partial \theta} (N_{i,\theta} \sin \theta) + \frac{1}{r \sin \theta} \frac{\partial N_{i,\phi}}{\partial \phi} \right) = R_i$$

$$i=1,2,\dots,n$$

$$\frac{\partial C_A}{\partial t} + \left(v_r \frac{\partial C_A}{\partial r} + v_\theta \frac{1}{r} \frac{\partial C_A}{\partial \theta} + v_\phi \frac{1}{r \sin \theta} \frac{\partial C_A}{\partial \phi} \right) =$$

$$D_{AB} \left(\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial C_A}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial C_A}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 C_A}{\partial \phi^2} \right) + R_A$$

The diffusivity of gases in a binary system at low to moderate pressures (cm²/s):

$$D_{AB} = \frac{0.00226T^{1.5}}{PM_{AB}^{1/2} \sigma_{AB}^2 \Omega_D}$$

where: P=[bar]; T=[°K]; σ_{AB} = "collision diameter", a Leonard-Jones parameter, Å

Ω_D = diffusion collision integral, dimensionless

and:

$$M_{AB} = \frac{2}{(1/M_A) + (1/M_B)}$$

in which M_i is the molecular weight of component i.

The diffusivity of liquids in a binary system for dilute solutions (cm^2/s):

$$D_{AB} = \frac{7.4 \times 10^{-8} (\varphi_B M_B)^{1/2} T}{\mu_B V_A^{0.6}} \quad \text{Where } T \text{ is temperature } [^\circ\text{K}].$$

Dimensionless Numbers (*where l is the characteristic dimension*):

$$j_D = \frac{\text{Sh}}{\text{Re} \cdot \text{Sc}^{1/3}} \quad (\text{j-Factor}) \quad \& \quad \text{Sh} = \frac{kl}{D_{AB}} \quad (\text{Sherwood No.})$$

$$\text{Sc} = \frac{\mu}{\rho D_{AB}} \quad (\text{Schmidt No.}) \quad \& \quad \text{Re} = \frac{\rho ul}{\mu} \quad (\text{Reynolds No.})$$

$$\text{Pe} = \text{Re} \cdot \text{Sc} \quad (\text{Peclet No.})$$

$$\text{Nu} = \frac{hl}{k} \quad (\text{Nusselt No.})$$

R = Gas Constant = 82.06 ($\text{atm} \cdot \text{cm}^3$)/(mole \cdot $^\circ\text{K}$)**FACTORS FOR UNIT CONVERSIONS**

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb _m = 35.27392 oz 1 lb _m = 16 oz = 5 × 10 ⁻⁴ ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10 ⁶ microns (μm) = 10 ¹⁰ angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m ³ = 1000 L = 10 ⁶ cm ³ = 10 ⁶ mL = 35.3145 ft ³ = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft ³ = 1728 in. ³ = 7.4805 gal = 0.028317 m ³ = 28.317 L = 28,317 cm ³
Force	1 N = 1 kg·m/s ² = 10 ⁵ dynes = 10 ⁵ g·cm/s ² = 0.22481 lb _f 1 lb _f = 32.174 lb _m ·ft/s ² = 4.4482 N = 4.4482 × 10 ⁵ dynes
Pressure	1 atm = 1.01325 × 10 ⁵ N/m ² (Pa) = 101.325 kPa = 1.01325 bar = 1.01325 × 10 ⁶ dynes/cm ² = 760 mm Hg at 0°C (torr) = 10.333 m H ₂ O at 4°C = 14.696 lb _f /in. ² (psi) = 33.9 ft H ₂ O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10 ⁷ ergs = 10 ⁷ dyne·cm = 2.778 × 10 ⁻⁷ kW·h = 0.23901 cal = 0.7376 ft·lb _f = 9.486 × 10 ⁻⁴ Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb _f /s = 9.486 × 10 ⁻⁴ Btu/s = 1.341 × 10 ⁻³ hp

1. (35 points total)

A beaker filled with an equimolar liquid mixture of ethyl alcohol and ethyl acetate evaporates at 0°C into still air at 101 kPa total pressure. Assuming Raoult's law applies, what will be the composition of the liquid remaining when half the original ethyl alcohol has evaporated, assuming that each component evaporates independently of the other? Also assume that the liquid is always well mixed. The following data are available:

Vapor Pressure (kPa @ 0°C):

Ethyl acetate (AC) = 3.23

Ethyl alcohol (AL) = 1.62

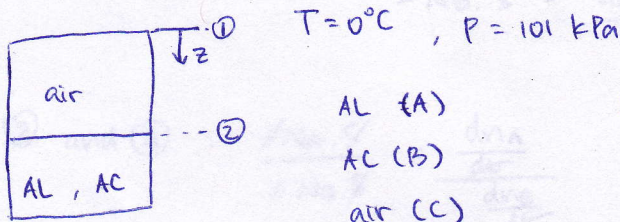
Diffusivity (m²/s):

Ethyl acetate (AC) in Air = 6.45 × 10⁻⁶

Ethyl alcohol (AL) in Air = 9.29 × 10⁻⁶

32

35



AL (A)

$$P_A^* = 1.62 \text{ kPa}$$

AC (B)

$$P_B^* = 3.23 \text{ kPa}$$

air (C)

$$D_{AC} = 9.29 \times 10^{-6} \text{ m}^2/\text{s}$$

$$D_{BC} = 6.45 \times 10^{-6} \text{ m}^2/\text{s}$$

$$y_{A1} = y_{B1} = 0$$

$$n_{Ai} = n_{Bi} \quad i = \text{initial}$$

$$n_{Af} = 0.5 n_{Ai} \quad f = \text{final}$$

Assume liquid is always well-mixed and evaporates independently of the other.

Raoult's law: $y_i P = x_i P_i^* \rightarrow \text{at point 2}$ ✓

For component A:

$$N_A = J_A + y_A (N_A + N_C)$$

assume no bulk flow.

- steady-state, one-D, no reaction.

$$N_A = -C D_{AC} \frac{dy_A}{dz}$$

Continuity equation: $\frac{\partial C}{\partial t} + \frac{\partial N_A}{\partial z} = R_A \rightarrow \frac{\partial N_A}{\partial t} = 0$ ✓

$$\int_0^z dz = -\frac{C D_{AC}}{N_A} \int_{y_{A1}=0}^{y_A} dy_A \rightarrow z = -\frac{C D_{AC}}{N_A} (y_A - 0) \rightarrow N_A = -\frac{C D_{AC}}{z} y_A$$

∴ N_A = constant
< similarly for N_B, N_B = const >

Similarly for component B:

$$N_B = J_B + y_B (N_B + N_C)$$

$$N_B = -C D_{BC} \frac{dy_B}{dz} \rightarrow N_B = -\frac{C D_{BC}}{z} y_B$$

① and ②: $\frac{N_A}{N_B} = \frac{-C D_{AC} \frac{y_A}{z}}{-C D_{BC} \frac{y_B}{z}} = \frac{D_{AC} \cdot y_A}{D_{BC} \cdot y_B}$ (*) ✓

Material balance for A:

$$\cancel{\text{in}} - \text{out} = \text{acc.}$$

$$-N_A \cdot S = \frac{dn_A}{dt} \quad \text{--- (3)} \quad \checkmark$$

Material balance for B:

$$\cancel{\text{in}} - \text{out} = \text{acc.}$$

$$-N_B \cdot S = \frac{dn_B}{dt} \quad \text{--- (4)} \quad \checkmark$$

$$\text{(3) and (4)} : \frac{-N_A \cdot S}{-N_B \cdot S} = \frac{\frac{dn_A}{dt}}{\frac{dn_B}{dt}} \Rightarrow \frac{N_A}{N_B} = \frac{dn_A}{dn_B} \quad \text{--- (**)} \quad \checkmark$$

Raoult's Law : $y_A P = P_A^* X_A$

$$y_A = X_A \cdot \frac{P_A^*}{P} = \frac{N_A}{N_A + N_B} \cdot \frac{P_A^*}{P}$$

$$\text{similarly for B, } y_B = X_B \cdot \frac{P_B^*}{P} = \frac{N_B}{N_A + N_B} \cdot \frac{P_B^*}{P} \quad \text{--- (***)}$$

Combining equation (*), (**), and (***) :

$$\frac{dn_A}{dn_B} = \frac{D_{AC} \cdot \frac{N_A}{N_A + N_B} \cdot \frac{P_A^*}{P}}{D_{BC} \cdot \frac{N_B}{N_A + N_B} \cdot \frac{P_B^*}{P}} = \frac{D_{AC} \cdot N_A \cdot \frac{P_A^*}{P}}{D_{BC} \cdot N_B \cdot \frac{P_B^*}{P}}$$

$$\int_{n_{A1}}^{n_{A2}} \frac{dn_A}{N_A} = \frac{D_{AC} \cdot \frac{P_A^*}{P}}{D_{BC} \cdot \frac{P_B^*}{P}} \int_{n_{B1}}^{n_{B2}} \frac{dn_B}{N_B}, \quad n_{A1} = n_{B1}$$

$$n_{A2} = 0.5 n_{A1}$$

$$\int_{n_{A1}}^{0.5 n_{A1}} \frac{dn_A}{N_A} = \frac{D_{AC} \cdot \frac{P_A^*}{P}}{D_{BC} \cdot \frac{P_B^*}{P}} \int_{n_{A1}}^{n_{B2}} \frac{dn_B}{N_B}$$

$$\ln\left(\frac{0.5 n_{A1}}{n_{A1}}\right) = \frac{D_{AC}}{D_{BC}} \cdot \ln\left(\frac{n_{B2}}{n_{A1}}\right) \cdot \frac{P_A^*}{P_B^*}$$

$$-0.693 = \frac{9.29 \times 10^{-6} \text{ m}^2/\text{s}}{6.45 \times 10^{-6} \text{ m}^2/\text{s}} \cdot \ln\left(\frac{n_{B2}}{n_{A1}}\right) \cdot \frac{1.62 \text{ kPa}}{3.23 \text{ kPa}}$$

2. (35 points) Air at 1 atm and 25°C flows through a 5 cm diameter, circular tube, cast from naphthalene, at a Reynolds number of 100. Air entering the tube has an established laminar-flow velocity profile. Properties are given as follows:

- Vapor pressure of naphthalene = 10 torr
- Viscosity of air = 0.0215 cP Where 1 poise = 1 g/(cm.s)
- Molar density of air = 0.0327 kmol/m³
- Diffusivity of naphthalene in air = 0.94 × 10⁻⁵ m²/s

If pressure drop through the tube is negligible, calculate the average mole fraction of naphthalene in the exiting air. The total length of the naphthalene tube is 3.73 m.

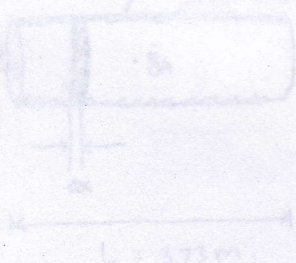
$$\ln \left(\frac{n_{Bf}}{n_{Ai}} \right) = -0.4812 \quad -0.9593$$

$$\frac{n_{Bf}}{n_{Ai}} = e^{-0.4812} = 0.618 \quad 0.383$$

$$X_{Af} = \frac{n_{Af}}{n_{Af} + n_{Bf}} = \frac{0.5 n_{Ai}}{0.5 n_{Ai} + 0.618 n_{Ai}} = \boxed{0.447}$$

$$X_{Bf} = 1 - X_{Af} = 1 - 0.447 = \boxed{0.553}$$

3



$$X_{Af} = \frac{0.5 n_{Ai}}{0.5 n_{Ai} + 0.383 n_{Ai}} = \underline{\underline{0.566}}$$

$$X_{Bf} = 1 - X_{Af} = \underline{\underline{0.434}}$$

~~Result's law: $Y_{Ae} = x_A \frac{P^*}{P} \rightarrow (1) \left(\frac{10 \text{ torr}}{760 \text{ torr}} \right) = 0.01316$~~
 Material balance for A:
 $m_{in} - \text{out} = \text{acc}$
 $m_{in} = \text{out}$
 $C_A u_s |_{in} + N_A A = C_A u_s |_{out} + N_A A$
 $C_A u_s |_{in} - C_A u_s |_{out} = N_A A$
 $C_A u_s \left(\frac{4R}{D} \right) |_{in} - C_A u_s \left(\frac{4R}{D} \right) |_{out} = N_A A$
 divide by $4R$ and taking $4R \rightarrow 0$

~~Result's law constant
 is used for solid & gas.
 It is only used for
 vapor & liquid in eqn.~~

2. (35 points total)

Air at 1 atm and 100°C flows through a straight, 5-cm-diameter, circular tube, cast from naphthalene, at a Reynolds number of 1500. Air entering the tube has an established laminar-flow velocity profile. Properties are given as follows:

- Vapor pressure of naphthalene = 10 torr
- Viscosity of air = 0.0215 cP Where 1 poise = 1 g/(cm.s)
- Molar density of air = 0.0327 kmol/m³
- Diffusivity of naphthalene (A) in air (B) = 0.94 × 10⁻⁵ m²/s.

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If pressure drop through the tube is negligible, calculate the average mole fraction of naphthalene in the exiting air. The total length of the naphthalene tube is 3.73 m.

Over a length of a tube (x) where mass transfer occurs from the inside surface area to the fluid, average Sherwood number for a fully developed flow is as follows:

$$Sh_{avg} = 3.66 + \frac{0.0668 \left[\frac{Pe}{x/D} \right]}{1 + 0.04 \left[\frac{Pe}{x/D} \right]^{2/3}}$$

$$Pe = Re_x \cdot Sc$$

$$Re_x = \frac{\rho_{air} u L}{\mu_{air}}$$

$$Sc = \frac{\mu_{air}}{\rho_{air} \cdot D_{AB}}$$

$$D = 5 \text{ cm.}$$

$$Re_x = 1500$$

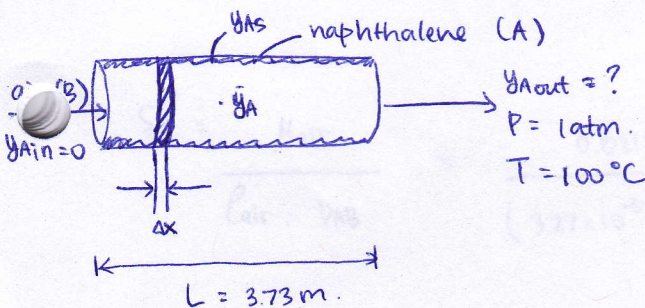
$$P_A^* = 10 \text{ torr} = 10 \text{ mmHg.}$$

$$\mu_{air} = 0.0215 \text{ cP} = 0.0215 \times 10^{-2} \frac{\text{g}}{\text{cm}\cdot\text{s}}$$

$$\rho_{air} = 0.0327 \text{ kmol/m}^3 = 3.27 \times 10^{-5} \text{ mol/cm}^3$$

$$D_{AB} = 0.94 \times 10^{-5} \text{ m}^2/\text{s} = 0.094 \text{ cm}^2/\text{s}$$

$\frac{\text{g}}{\text{cm}\cdot\text{s}}$
 $= 0.0215 \times 10^{-2} \frac{\text{g}}{\text{cm}\cdot\text{s}}$
 $= 0.000215 \frac{\text{g}}{\text{cm}\cdot\text{s}}$



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Raoult's law: $y_{As} = x_A \cdot \frac{P_A^*}{P} = (1) \left(\frac{10 \text{ mmHg}}{760 \text{ mmHg}} \right) = 0.01316$

Material balance for A:

$$in - out = acc. \quad \rightarrow \text{steady-state}$$

$$in = out$$

$$C_A \cdot u \cdot S|_x + N_A \cdot A = C_A \cdot u \cdot S|_{x+\Delta x}$$

$$C_A \cdot u \cdot S|_{x+\Delta x} - C_A \cdot u \cdot S|_x = N_A \cdot A$$

$$C_A \cdot u \cdot \left(\frac{\pi}{4} D^2 \right) |_{x+\Delta x} - C_A \cdot u \cdot \left(\frac{\pi}{4} D^2 \right) |_x = N_A \cdot \pi D \cdot \Delta x$$

Divide by Δx and taking $\Delta x \rightarrow 0$.

Raoult's law CANNOT be used for solid & gas. It is ONLY used for vapor & liq. in equilibrium.

$$\frac{u \cdot D}{4} \frac{dC_A}{dx} = k_y (y_{A_s} - y_A) \quad C_A = y_A C$$

$$\frac{u \cdot D \cdot C}{4} \frac{dy_A}{dx} = k_y (y_{A_s} - y_A)$$

$$\frac{u \cdot D \cdot C}{4 k_y} \int_{y_{A_{in}}=0}^{y_{A_{out}}} \frac{dy_A}{y_{A_s} - y_A} = \int_0^L dx$$

$$L = - \frac{u \cdot D \cdot C}{4 k_y} \cdot \ln \left(\frac{y_{A_s} - y_{A_{out}}}{y_{A_s}} \right) = \frac{u \cdot D \cdot C}{4 k_y} \ln \left(\frac{y_{A_s}}{y_{A_s} - y_{A_{out}}} \right) \quad \text{--- ①}$$

$$Re_x = \frac{\rho_{air} \cdot u \cdot L}{\mu_{air}} \rightarrow u = \frac{Re_x \cdot \mu_{air}}{\rho_{air} \cdot L} = \frac{(1500)(0.0215 \text{ g/cm} \cdot \text{s})}{(3.27 \times 10^{-5} \text{ mol/cm}^2)(373 \text{ cm})(29 \text{ g/mol})}$$

$$= 91.175 \text{ cm/s.}$$

$$Sc = \frac{\mu_{air}}{\rho_{air} \cdot D_{AB}} = \frac{0.0215 \text{ g/cm} \cdot \text{s}}{(3.27 \times 10^{-5} \text{ mol/cm}^2)(29 \text{ g/mol})(0.094 \text{ cm}^2/\text{s})} = 241.193$$

$$Pe = Re_x \cdot Sc$$

$$= (1500)(241.193) = 3.618 \times 10^5$$

$$Sh_{avg} = 3.66 + \frac{0.0668 \left[\frac{Pe}{L/D} \right]}{1 + 0.04 \left[\frac{Pe}{L/D} \right]^{1/3}}$$

$$= 3.66 + \frac{0.0668 \left[\frac{(3.618 \times 10^5)(5 \text{ cm})}{373 \text{ cm}} \right]}{1 + 0.04 \left[\frac{(3.618 \times 10^5)(5 \text{ cm})}{373 \text{ cm}} \right]^{1/3}} = 29.659$$

$$Sh_{avg} = \frac{k_c \cdot L}{D_{AB}} = \frac{k_y \cdot L}{C \cdot D_{AB}} \rightarrow k_y = \frac{Sh_{avg} \cdot C \cdot D_{AB}}{L}$$

3. (30 points total)

Air in a 600-L container (25°C & 1 atm) = 0.0326 kmol/m³ = 3.26 x 10⁻⁵ mol/cm³.
 In that container, 4.5 g dry silica gel is the only transferring component. Y is the ratio of the mass of water to the mass of dry air in the air phase, while X is the ratio of the mass of water to the mass of dry silica gel (dry solid) in the solid phase. Calculate the initial and final partial pressure of water in the air and the final amount of water in the silica gel.

$$C = \frac{P}{RT} = \frac{101 \text{ kPa}}{(8.314 \text{ kJ/kmol} \cdot \text{K})(100 + 273) \text{ K}} = 0.0326 \text{ kmol/m}^3 = 3.26 \times 10^{-5} \text{ mol/cm}^3$$

$$k_y = \frac{(29.659) (3.26 \times 10^{-5} \frac{\text{mol}}{\text{cm}^3}) (0.094 \text{ cm}^2/\text{s})}{373 \text{ cm}} = 2.43 \times 10^{-7} \text{ mol/cm}^2 \cdot \text{s}$$

Equation ① :

$$L = \frac{u \cdot D \cdot C}{4 k_y} \ln \left(\frac{y_{As}}{y_{As} - y_{Aout}} \right)$$

$$373 \text{ cm} = \frac{(91.175 \text{ cm}^2/\text{s})(5 \text{ cm})(3.26 \times 10^{-5} \text{ mol/cm}^3)}{4 (2.43 \times 10^{-7} \text{ mol/cm}^2 \cdot \text{s})} \ln \left(\frac{y_{As}}{y_{As} - y_{Aout}} \right)$$

$$\ln \left(\frac{y_{As}}{y_{As} - y_{Aout}} \right) = 0.0244$$

$$\frac{y_{As}}{y_{As} - y_{Aout}} = e^{0.0244} = 1.02474$$

$$y_{As} - y_{Aout} = \frac{y_{As}}{1.02474} = \frac{0.01316}{1.02474} = 0.01284$$

$$y_{Aout} = 0.01316 - 0.01284$$

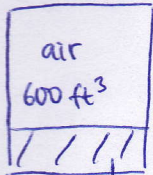
$$y_{Aout} = 0.00032$$

-5

25
30

3. (30 points total)

Air in a 600-ft³ container is at ambient condition (25°C & 1 atm) with the initial mole fraction of water 0.06. In that container, 4.5 lbm dry silica gel are placed. The equilibrium curve for the Air-Silica gel system is $Y=0.45X$. Silica gel adsorbs water, therefore water is the only transferring component. Y is the ratio of the mass of water to the mass of dry air in the air phase, while X is the ratio of the mass of water to the mass of dry silica gel (dry solid) in the solid phase. Calculate the initial and final partial pressure of water in the air and the final moisture content of the solid phase in terms of weight fraction.



$$P = 1 \text{ atm}$$

$$T = 25^\circ\text{C} = 298 \text{ K}$$

$$y_{A1} = 0.06 = y_1$$

(mole fraction)

$$4.5 \text{ lbm dry silica gel} = R_s$$

$$X_1 = 0$$

water (A)

$$\text{Equilibrium curve} = Y = 0.45 X$$

$$Y \left[\frac{\text{mass A}}{\text{mass dry air}} \right]$$

$$X \left[\frac{\text{mass A}}{\text{mass dry solid}} \right]$$

Initial partial pressure of water in air : $P_{A1} = y_1 P = 0.06 (1 \text{ atm})$

$$P_{A1} = 0.06 \text{ atm}$$

$$Y_1 = \frac{y_1}{1-y_1} \left(\frac{29}{18} \right) = \frac{0.06}{1-0.06} \cdot \frac{29}{18} = 0.10284 \frac{\text{lbm water}}{\text{lbm dry air}}$$

$$E_s = (1-y_1) \frac{PV}{RT} = \frac{(1-0.06)(1 \text{ atm})(600 \text{ ft}^3) \left(\frac{100 \text{ cm}^3}{3.2808 \text{ ft}} \right)^3}{(82.06 \text{ atm}\cdot\text{cm}^3/\text{mol}\cdot\text{K})(298 \text{ K})} \cdot 29 \text{ g/mol}$$

$$= 653.12 \text{ g} = 1.4399 \text{ lbm}$$

Material balance of A:

$$R_s X_1 + E_s Y_1 = R_s X_2 + E_s Y_2$$

$$-\frac{R_s}{E_s} = \frac{Y_2 - Y_1}{X_2}$$

X_2 and Y_2 are at equilibrium.

$$Y_2 = 0.45 X_2 \rightarrow \text{from equilibrium curve}$$

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$$\frac{-B_5}{E_5} = \frac{0.45 X_2 - Y_1}{X_2}$$

$$-\frac{4.5 \text{ lbm}^{\text{dry}} \text{ solid}}{1.4399 \text{ lbm dry air}} = \frac{0.45 X_2 - 0.10284}{X_2}$$

$$-3.125 X_2 = 0.45 X_2 - 0.10284$$

$$3.575 X_2 = 0.10284$$

$$X_2 = 0.02877 \frac{\text{lbm water}}{\text{lbm dry solid}}$$

$$x_2 = \frac{X_2}{1 + X_2} = \frac{0.02877}{1 + 0.02877} = 0.02796 \frac{\text{lbm water}}{\text{lbm solid}}$$

$$X_2 = 2.796 \text{ wt } \%$$

$$Y_2 = 0.45 X_2 = 0.45 (0.02877) = 0.01295 \frac{\text{lbm water}}{\text{lbm dry air}} \cdot \frac{29 \text{ lbm dry air}}{\text{lb-mol dry air}} = 0.02086 \frac{\text{mol water}}{\text{mol dry air}}$$

$$y_2 = \frac{Y_2}{1 + Y_2} = \frac{0.02086}{1 + 0.02086} = 0.02043 \frac{\text{mol water}}{\text{mol air}}$$

$$P_{A_2} = y_2 \cdot P = (0.02043)(1 \text{ atm})$$

$$P_{A_2} = 0.02043 \text{ atm}$$