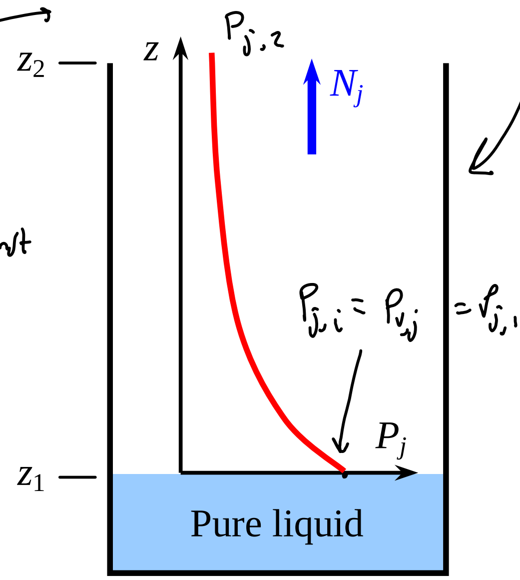
Today, we will:

- Continue our discussion about **evaporation of pure liquids in stagnant air** in **Section 4.5.4**
- Do some example problems – evaporation of pure liquids in stagnant air
- Discuss **evaporation of pure liquids with blowing air** in **Section 4.5.4**
- Do some example problems – evaporation of pure liquids with blowing air
- Discuss **evaporation of multi-component liquids** in **Section 4.5.6 and 4.5.7**

See book for derivations

$\boxed{P = P_{atm}}$

assume $T =$ const



Summary of results:

$$\boxed{N_j = k_G \left(P_{j,1} - P_{j,2}\right)}$$

mass transfer coefficient

k_G is a fnc. of D_{aj}, $(z_2 - z_1)$, etc.

$$\boxed{k_G = \frac{P\, D_{aj}}{R_u T (z_2 - z_1) P_{am}}} \quad \text{or} \quad \boxed{k_G = \frac{D_{aj}}{R_u T (z_2 - z_1)\, y_{am}}}$$

$$\boxed{y_{am} = \frac{P_{am}}{P}}$$

P_{am} = log mean partial pressure ratio

$$\boxed{P_{am} = \frac{P_{a,2} - P_{a,1}}{\ln\left(\frac{P_{a,2}}{P_{a,1}}\right)}}$$

These are partial pressures of the air, not species j

y_{am} = log mean mol fraction

$$\boxed{y_{am} = \frac{y_{a,2} - y_{a,1}}{\ln\left(\frac{y_{a,2}}{y_{a,1}}\right)}}$$

VERY ANALOGOUS TO LOG MEAN TEMPERATURE IN HEAT TRANSFER APPLICATIONS

The emission rate or source strength S, or evaporation rate

$\dot{m}$

is

surface area of evaporation

$$\boxed{\dot{m}_j = N_j\, A\, M_j}$$

$$\frac{\cancel{kmol}}{\cancel{m^2}\cdot s}\;\cancel{m^2}\;\frac{kg}{\cancel{kmol}} = \frac{kg}{s} \quad \checkmark$$

Putting it all together

$$\boxed{\dot{m}_j = \frac{P\, D_{aj}\,(P_{j,1} - P_{j,2})\, A\, M_j}{R_u T\,(z_2 - z_1)\, P_{am}}}$$

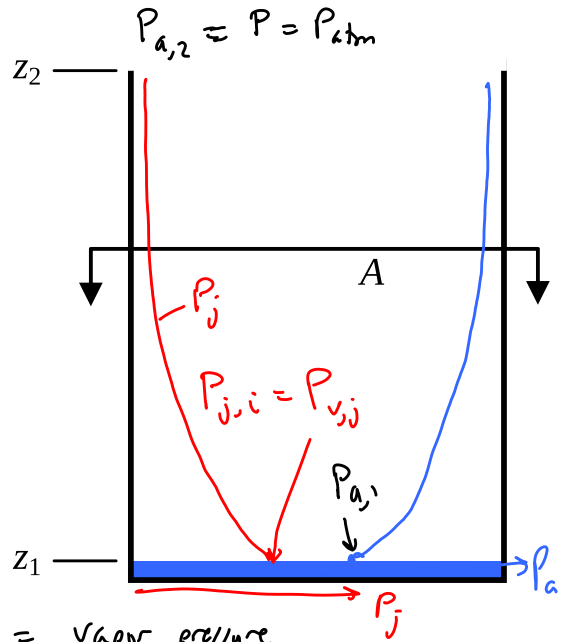
☆ Evaporation rate of a pure liquid into stagnant air

Example

Given: A standard 55-gallon drum (cross-sectional area is $A = 0.25\ \text{m}^2$ and height from bottom to top of drum is $z_2 - z_1 = 0.813$ m) contains a small amount of liquid perchloroethylene (PERC) at the bottom. The top is open, where the air in the room is nearly stagnant, and $T = 20^\circ\text{C} = 293.15$ K.

To do: Calculate the emission rate of PERC into the room. $(\dot{m}_j)$

Solution:



Properties of PERC

MSDS → @ 20°C, MSDS lists "VP" = vapor pressure

$\underline{VP = 14.0 \text{ mm Hg}} = P_{v,j}$

At other temperatures, use App. A.8 & interpolate as necessary

$\underline{M = 165.8}$

Table A-9 → $\underline{D_{aj} = 0.74 \times 10^{-5}\ \text{m}^2/\text{s}}$

$$\boxed{P_{am} = \frac{P_{a,2} - P_{a,1}}{\ln\left(\frac{P_{a,2}}{P_{a,1}}\right)}}$$

@ interface (z_1), $P_j = P_{v,j} = 14.$ mm Hg

Dalton's Law: $P_j + P_a = P$

$\therefore P_{a,1} = P - P_{j,1}$

$= (760 - 14)$ mm Hg

$\underline{P_{a,1} = 746. \text{ mm Hg}}$

$\underline{P_{a,2} \approx 760 \text{ mm Hg} = \text{atm. pressure}}$

$$\boxed{P_{am} = 753.\ \text{mm Hg}}$$

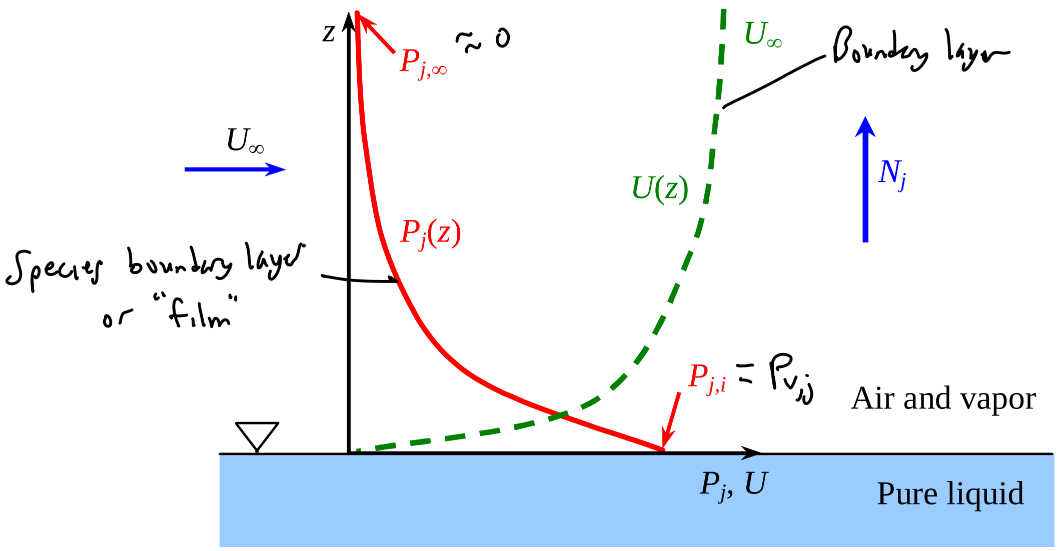
14 mm Hg   ≈ 0

$$\dot{m} = \frac{P D_{aj} (P_{j,1} - P_{j,2}) A M_j}{R_u T (z_2 - z_1) P_{am}} = \boxed{2.9 \times 10^{-7}\ \frac{\text{kg}}{\text{s}}}$$

Section 4.5.5 – Evaporation of a pure liquid with air blowing over it

VERY ANALOGOUS TO HEAT TRANSFER

[$\dot{m}_j$ analogous to $\dot{Q}$]



☆ We use Reynolds Analogy

See text for details & eq's (see Nusselt #'s, Reynolds #'s, Prandtl #'s, etc.)

$\dot{m}_j \uparrow$ as $U_\infty \uparrow$, as expect.

Same as previously:

$$\boxed{N_j = k_G \left(P_{j,i} - P_{j,\infty}\right)}, \qquad \boxed{\dot{m}_j = N_j A M_j}$$

k_G: see text, more complicated eq., fnc. of Nu, Pr, Sc, Re, etc.

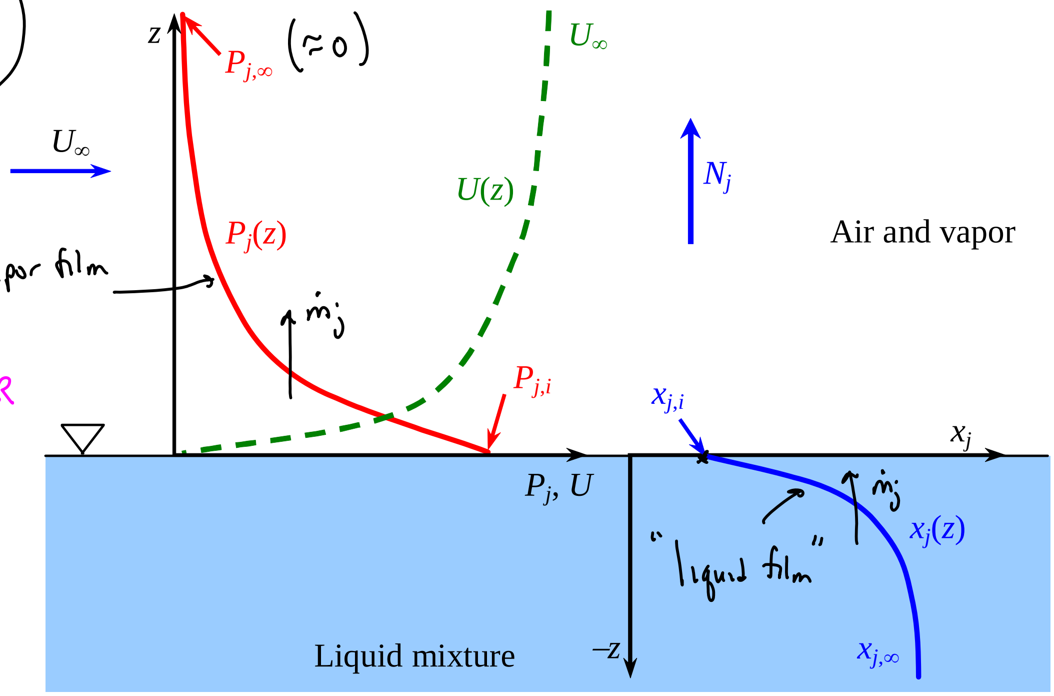
[See E.g. 4-12 in text] ☆

Sections 4.5.6 and 4.5.7 – Evaporation of multi-component liquids

"Single film evaporation"

"two film" evaporation vapor film

VERY ANALOGOUS TO HEAT TRANSFER



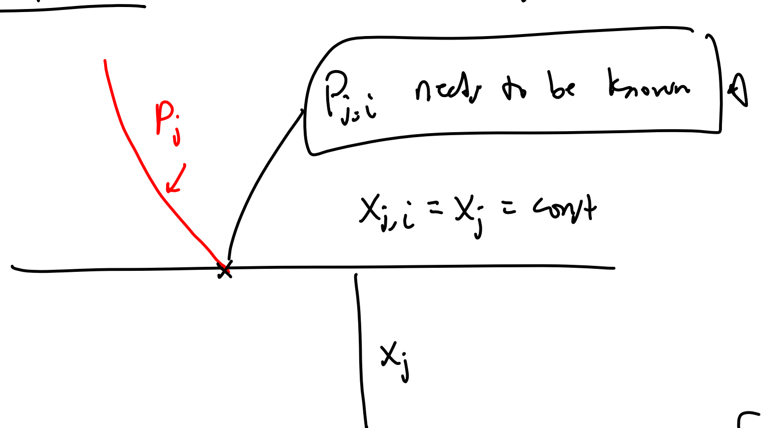
What is the value of $P_{j,i}$?

For most contaminants, there is a maximum solubility in water

So, x_j has a limit (chemical in water)

Just as P_j ...... (.... . air)

Single film evaporation → we assume x_j = constant [liquid is well mixed]



Two-film evaporation → x_j varies with depth [see fig. above]

In either case, we need to calculate $P_{j,i}$ & then all the previous eq's are still valid

Note: $P_{j,i}$ will be **less than** $P_{v,j}$ here since $x_j < 1$

$\boxed{0 < x_j < 1}$

Two extreme cases:

- **Raoult's Law** → $\boxed{P_{j,i} = x_{j,i} P_{v,j}}$ → valid at large values of x_j
- **Henry's Law** → $\boxed{P_{j,i} = x_{j,i} H'}$ → valid at small values of x_j

Henry's Law constant

See A-9 for H'

Equilibrium Isotherms: (see Fig. 4.16)