CHE 318 Lecture 22

Interface Mass Transfer

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Learning outcomes

After this lecture, you will be able to:

- **Recall** the equilibrium conditions that apply at phase interfaces.
- **Describe** equilibrium diagrams for two-phase mass transfer systems.
- **Apply** coupled flux and equilibrium relations to determine interfacial compositions.

What systems have we studies so far?

The most complex case is probably a packed-bed column.

- We we have focused on?
  - Mass transfer in **1 phase** – gas flow over solid spheres
  - Solve mass balance equation in flow direction – get **outlet** concentration
  - Solve mass transfer to beds – get concentration profiles using **fixed interfacial concentration**
- What we may miss?
  - Real-world applications are mass transfer between 2 phases
  - Mass transfer may occur across 2 phase interfaces
  - Equilibrium concentration at interfaces are usually not fixed

Examples of 2-phase mass transfer (1)

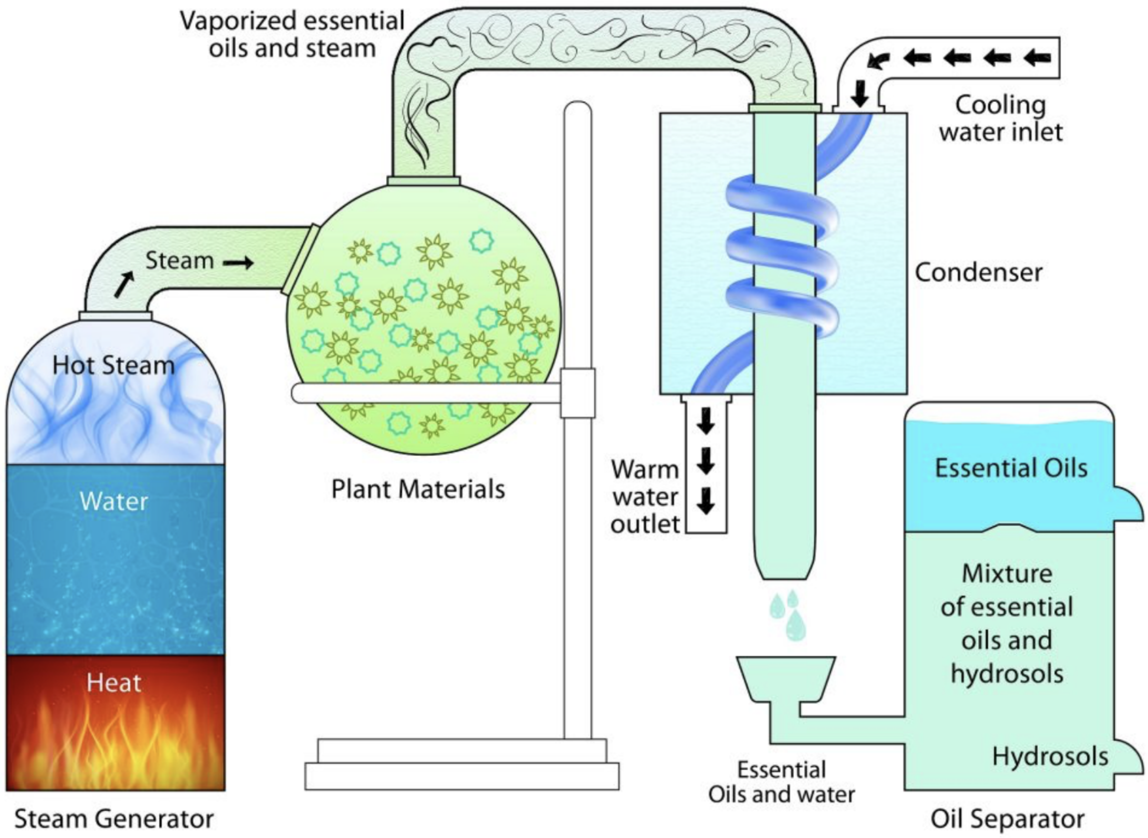
Absorption tower

- Water-soluble gases from industrial reaction mixture is transferred into aqueous solution
- Examples:
  - ammonia (NH_3) from Haber-Bosch process
  - CO_2 capture (a hot topic!)

Examples of 2-phase mass transfer (2)

Extraction apparatus (liquid-gas)

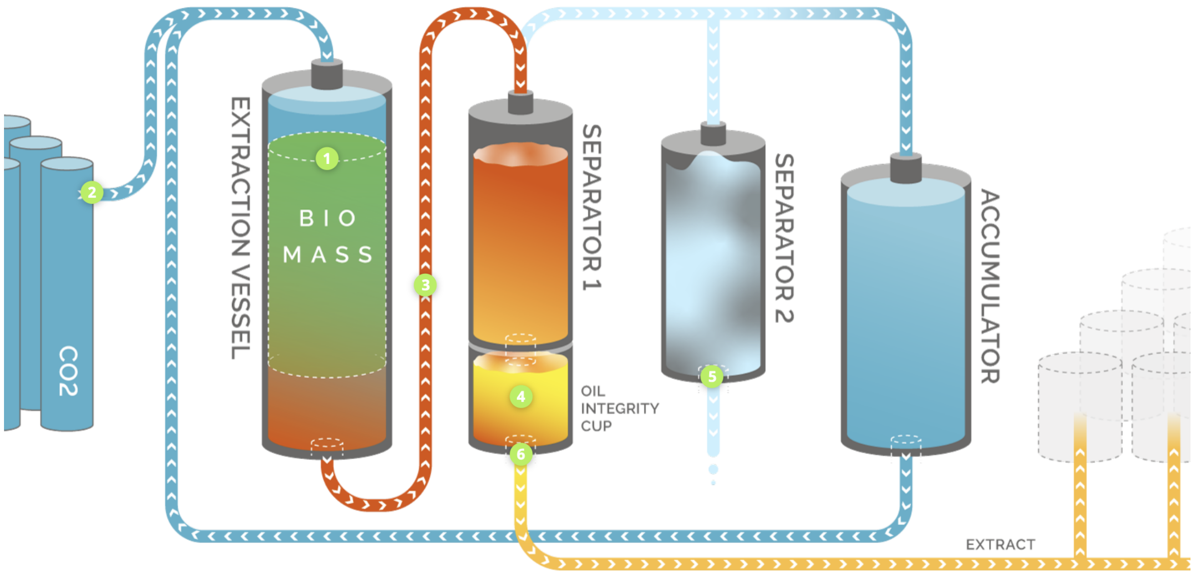
- Volatile chemical compounds originally mixed with water are extracted to vapour phase
- Examples:
  - Essence oil extraction



Examples of 2-phase mass transfer (3)

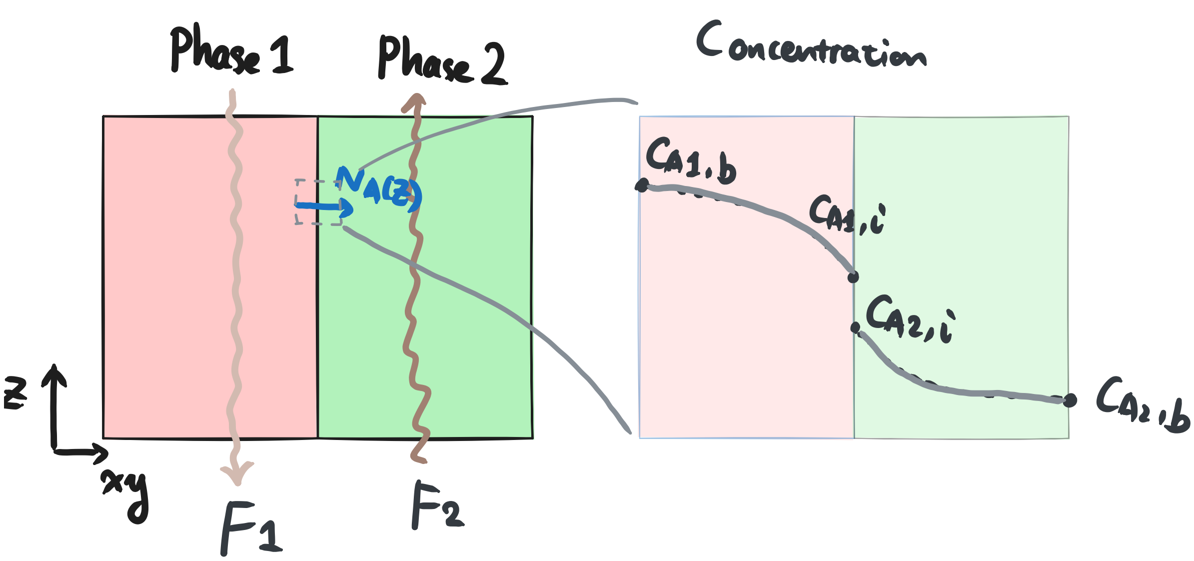
Extraction apparatus (liquid-liquid)

- Chemical compound in low solubility liquid is transferred to high solubility liquid
- Examples:
  - Supercritical CO_2 extraction of bioactive compounds



Common feature of 2-phase mass transfer

- Flow rate and interface transfer are usually orthogonal
- Interface concentration has discontinuity



Mass balance equation in 2-phase M.T.

Overall mass balance between liquid and gas

$$\mathrm{In}_{\mathrm{liq}} + \mathrm{In}_{\mathrm{gas}} = \mathrm{Out}_{\mathrm{liq}} + \mathrm{Out}_{\mathrm{gas}} \tag{1}$$

- In and outlet usually can be described by [Flow rate] $\times$ [Concentration]
- Depends on the direction of flow and control volume!

Mass balance equation in single phase

In each phase, we can use our knowledge from packed bed lecture, e.g.

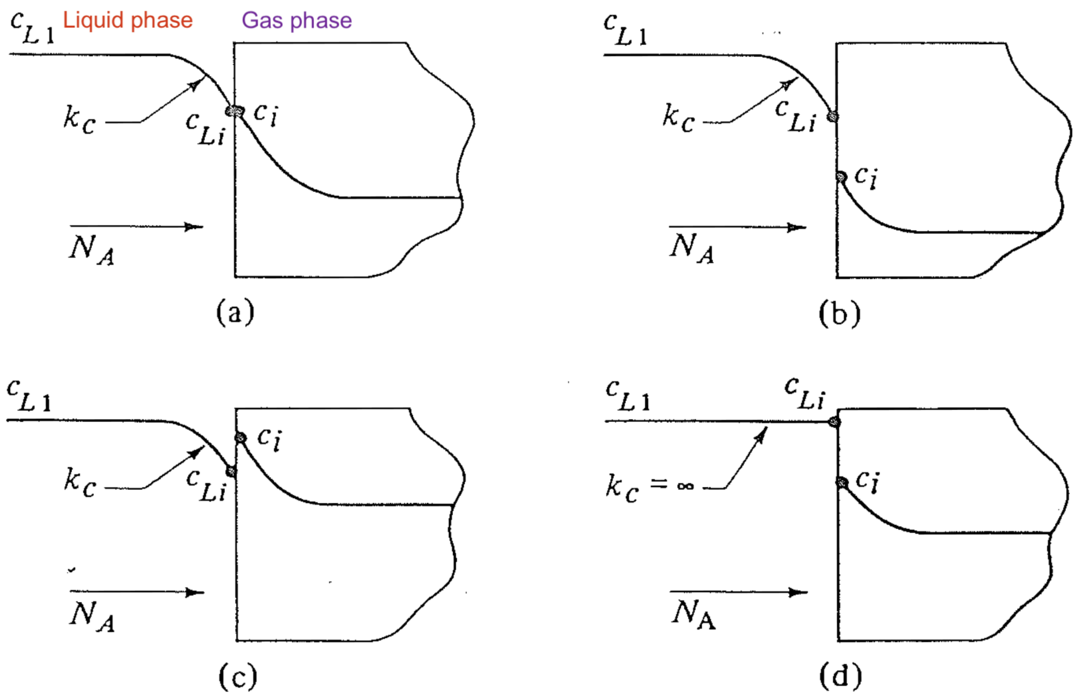
$$\mathrm{In}_{\mathrm{gas}} - \mathrm{Out}_{\mathrm{gas}} + \mathrm{Gen}_{\mathrm{gas}} = 0 \tag{2}$$

$$Q(c_1 - c_2) + A_{\mathrm{eff}}\hat{N}_{\mathrm{eff}} = 0 \tag{3}$$

- $\hat{N}_{\mathrm{eff}}$ is the average molar inter-phase flux, and A_{eff} is the effective contact area
- Cannot use packed-bed solution for $\hat{N}_{\mathrm{eff}}$ because interfacial concentration can vary!

How can we describe the interfacial transport?

In Lecture 14 we discussed the interfacial concentration and mass balance. We need to know 1) The equilibrium constant K at the interface 2) The ratio between k_c' in two phases

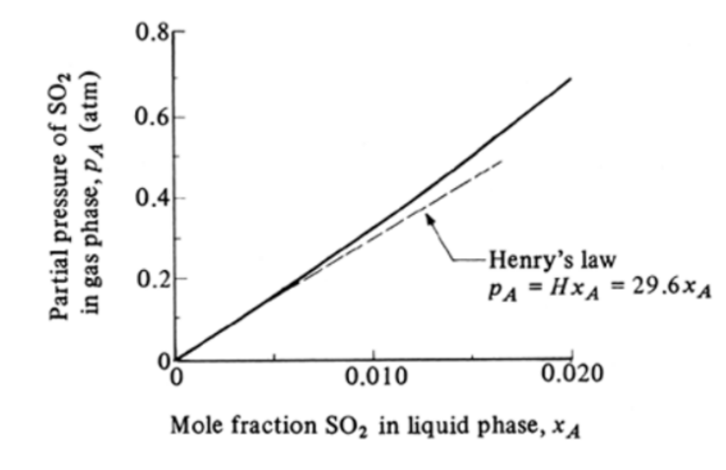


The equilibrium plot for gas-liquid interface

Most commonly in industry we can use the equilibrium plot between A's molar fractions in gas y_A (or p_A) and liquid x_A, respectively.

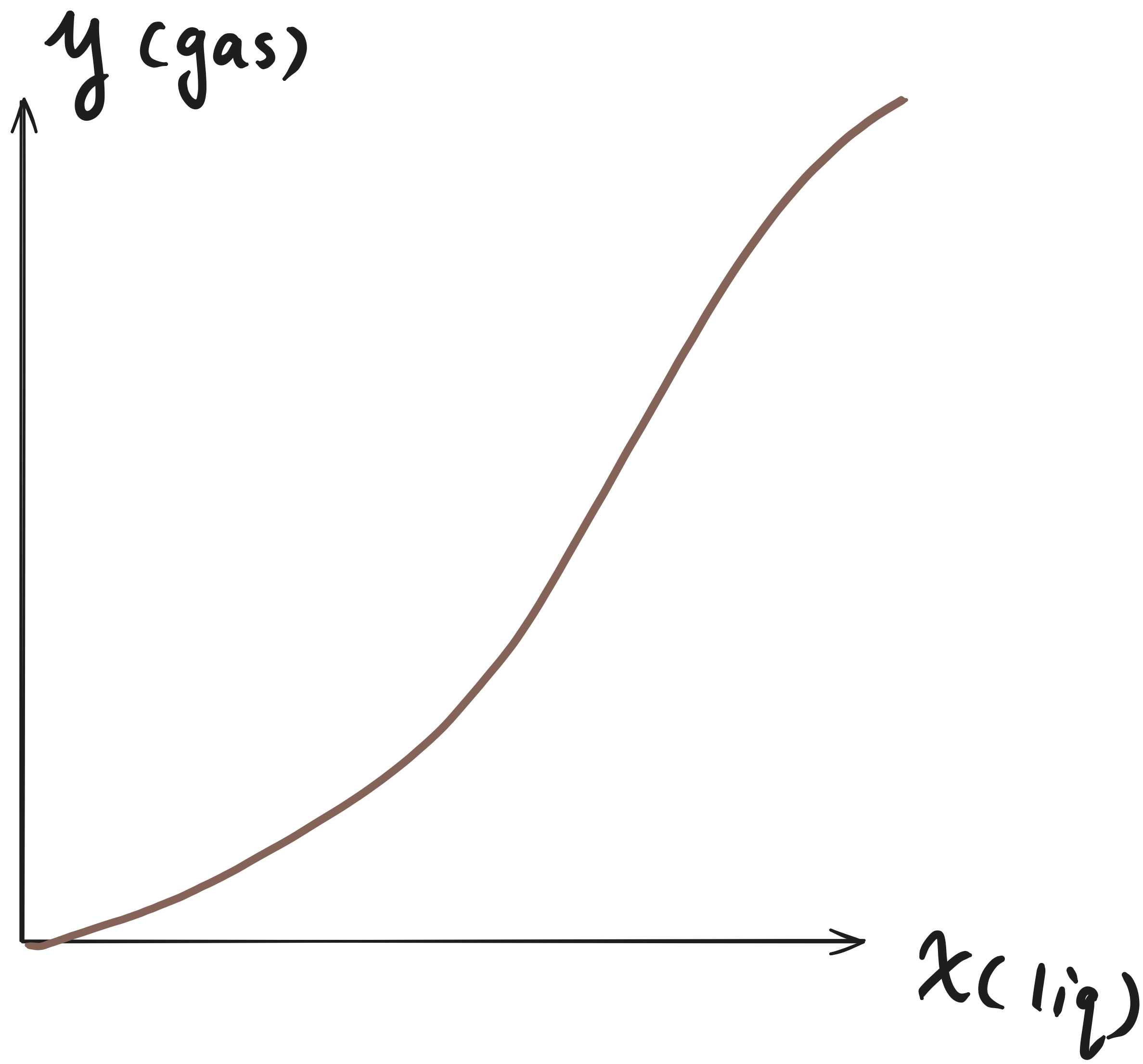
Simpliest situation is Henry's law

$$p_A = Hx_A$$



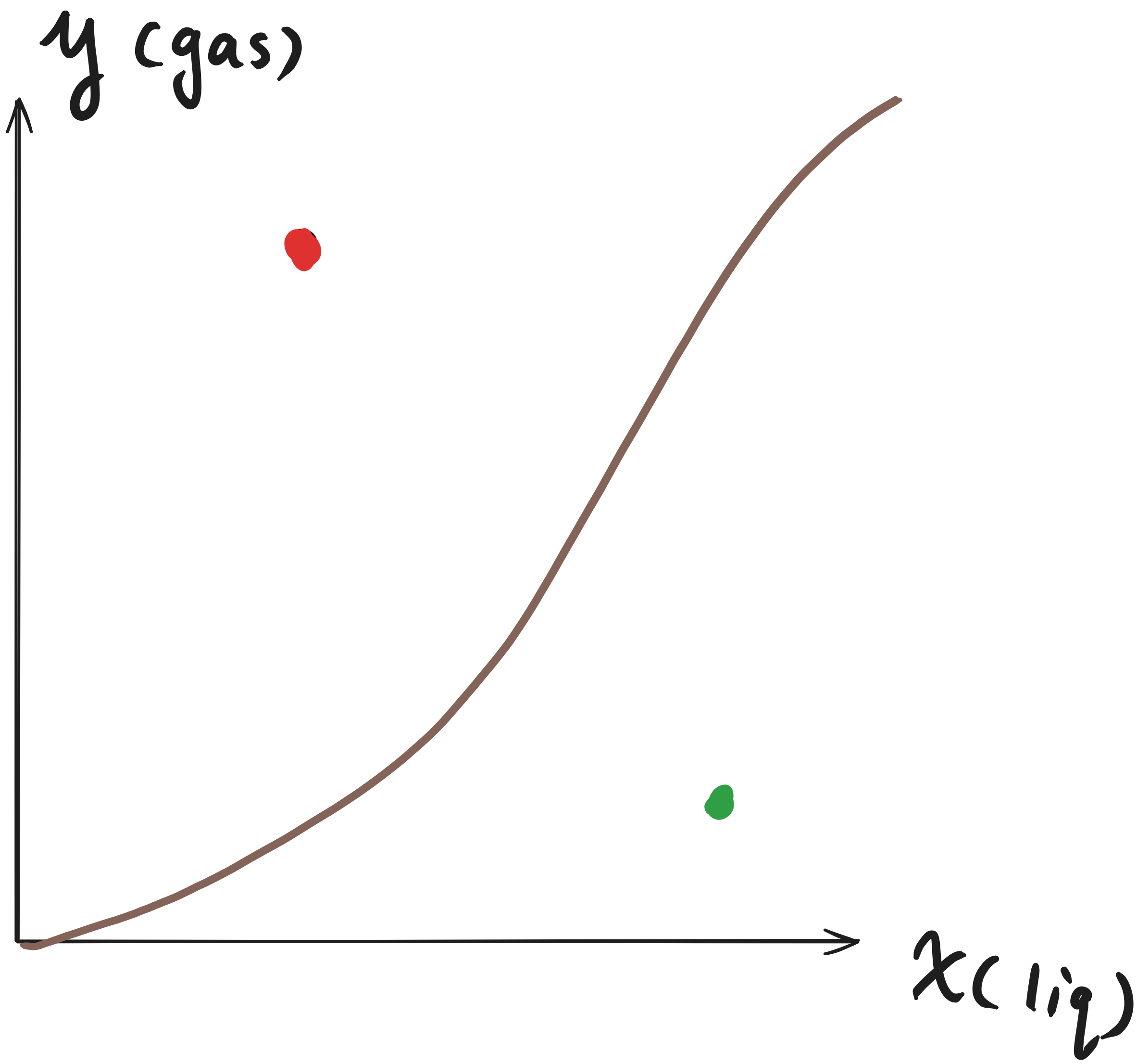
Reading an equilibrium plot (1)

Meaning of points on the equilibrium curve – interfacial concentraion



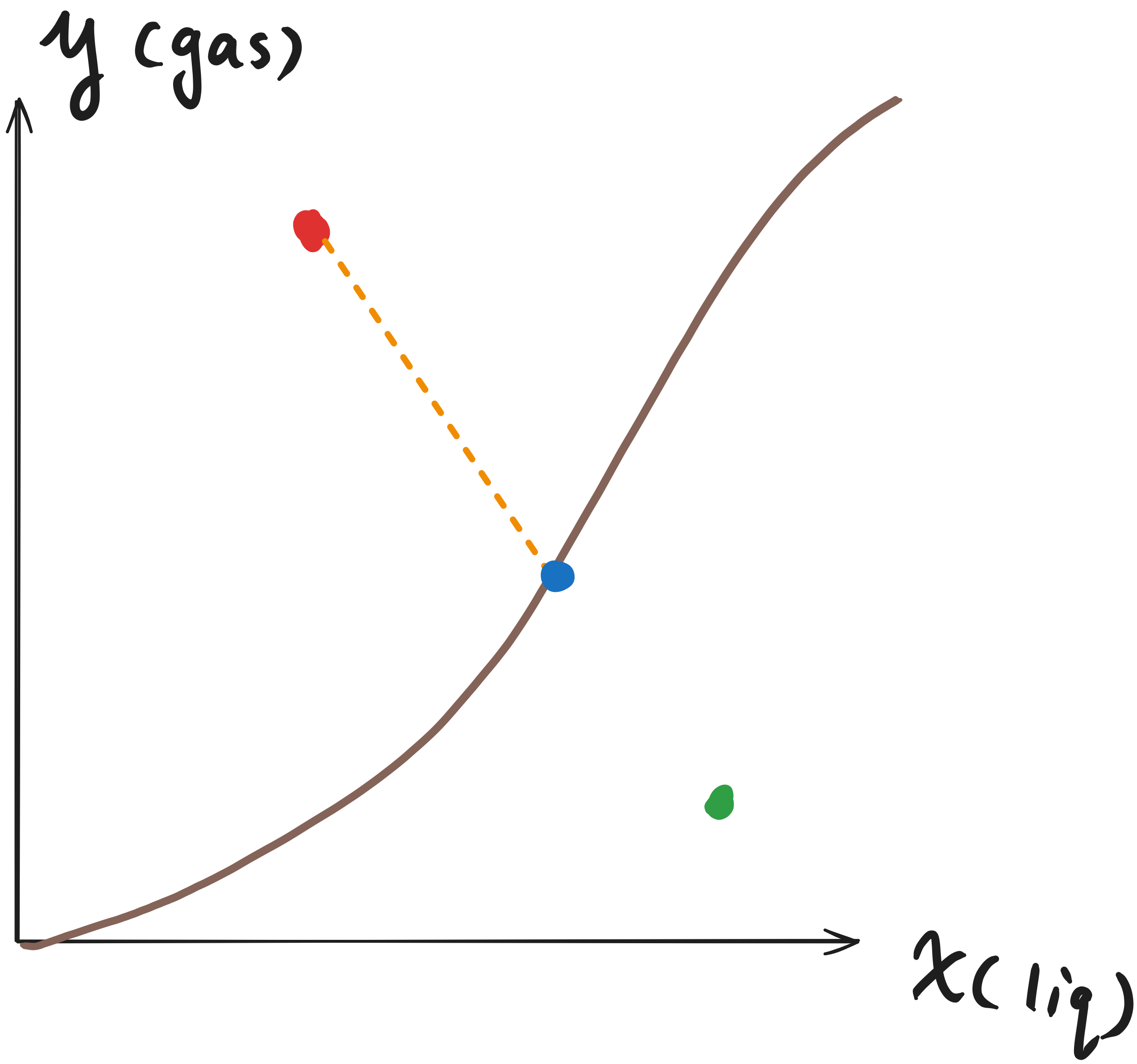
Reading an equilibrium plot (2)

- Points above the equilibrium curve N_A: gas → liquid (vice versa)



Reading an equilibrium plot (3)

- Non-equilibrium point + line with slope $-k_x/k_y$ interfacial concentration



Equilibrium phase: flux balance

- The slope + intercept method stems from the flux balance between phases

$$N_A(g) = N_A(l) \tag{4}$$
$$k_y(y_{AG} - y_{Ai}) = k_x(x_{Ai} - x_{AL}) \tag{5}$$

- We have

$$\text{Slope} = \frac{y_{AG} - y_{Ai}}{x_{AL} - x_{Ai}} \tag{6}$$

$$= -\frac{k_x}{k_y} \tag{7}$$

Example 1: finding equilibrium interface concentrations

A solute is being absorbed from a gas mixture of A and B in a wetted-wall tower, with the liquid flowing downwards. At a certain point in the tower, the bulk gas concentration of A is $y_{AG} = 0.380$ and the bulk liquid fraction is $x_{AL} = 0.100$. The film transfer coefficients for A in gas and liquid phases are: $k'_y = 1.465 \times 10^{-3}$ kg mol/m^2/s and $k'_x = 1.967 \times 10^{-3}$ kg mol/m^2/s. You can assume the $k'_x \approx k_x$ and $k'_y \approx k_y$. The following pairs of equilibrium $(x_A i, y_A i)$ data were measured:

$(0.0, 0.0), (0.05, 0.022), (0.10, 0.052)(0.15, 0.087)$

$(0.20, 0.131), (0.25, 0.187), (0.30, 0.265), (0.35, 0.385)$

1) Find the interface concentrations y_{Ai} and x_{Ai}
2) Calculate the N_A at this point

Solution steps:

1) Draw the equilbirum plot with interpolation
2) Draw the current (x_{AL}, y_{AG}) point on graph, which direction of mass transfer?
3) Draw line with slow of $-k_x/k_y$
4) Read the intersect with equilibrium curve as (x_{Ai}, y_{Ai})
5) Calculate $N_A = k_y(y_{AG} - y_{Ai})$

Example 1: solution plot

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Interface concentrations: x_Ai = 0.246589, y_Ai = 0.183180
N_A from gas film:    2.883412e-04 (same units as k_y)
N_A from liquid film: 2.883412e-04 (same units as k_x)
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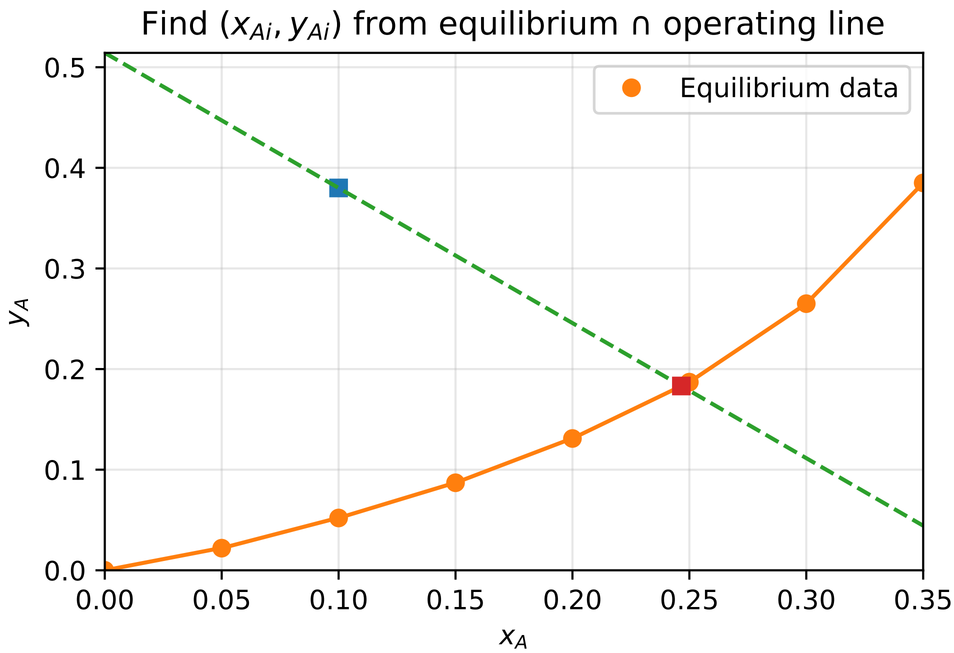

Example 1: answers

- Slope of curve $-k_x/k_y = -1.343$
- Interfacial concentration $(x_{Ai}, y_{Ai}) = (0.246, 0.180)$
- Flux: $N_A = 0.29 \times 10^{-3}$ kg mol/m^2/s
- Direction of flux: gas to liquid

Summary

- Real industrial applications involve mass transfer between 2 phases
- Equilibrium plots are extremely useful for elucidating the interfacial balance
- Describe driving force and interfacial concentrations from the equilibrium plot