Mass transfer

Lecture 15: *Gas absorption*

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Learning objectives

- **Apply the appropriate rate law in analyzing the absorption (or desorption) process, mainly with respect to column height and number of plates.**

- **Predict how temperature, pressure variations can affect the operation in a semi-quantitative manner based on graphs.**

Today's outline

- **Gas absorption**
  - ✓ Rate of absorption
  - ✓ Tower height
  - ✓ Number of transfer units
  - ✓ Film coefficients
  - ✓ Effects of pressure
  - ✓ Temperature variations
  - ✓ Multicomponent case
  - ✓ Desorption

18.3 Rate of absorption

- **Volumetric coefficients are often used. For lean gases (y < 0.1), neglecting changes in flow rates results in:**

$$r = k_y a(y - y_i) = k_x a(x_i - x) = K_y a(y - y^*) = K_x a(x^* - x)$$

where *a* is the interfacial area per unit volume

✓ The overall coefficients can be obtained using the following relations:

$$\frac{1}{K_y a} = \frac{1}{k_y a} + \frac{m}{k_x a}, \quad \frac{1}{K_x a} = \frac{1}{k_x a} + \frac{1}{m\, k_y a}$$

where *m* is the local slope of the equilibrium curve.

✓ For similar magnitudes of $k_y a$ and $k_x a$, either liquid or gas film can be the source of *controlling resistance*. (e.g., m = 0.1 vs 100)

18.3 Tower height

- **While any of the four eqn.s can be used, the gas-film coefficients are often used.**
  - ✓ For the cross-sectional area of *S*, the amount absorbed in section d*Z* is as follows if the change in flow rates can be neglected:

$$-V\,\mathrm{d}y = K_y a (y - y^*)\, S\, \mathrm{d}Z$$

  - ✓ Integration can be done as follows:

$$\frac{K_y a\, S}{V} \int_b^a \mathrm{d}Z = \frac{K_y a\, S\, Z_T}{V} = \int_a^b \frac{\mathrm{d}y}{(y - y^*)}$$

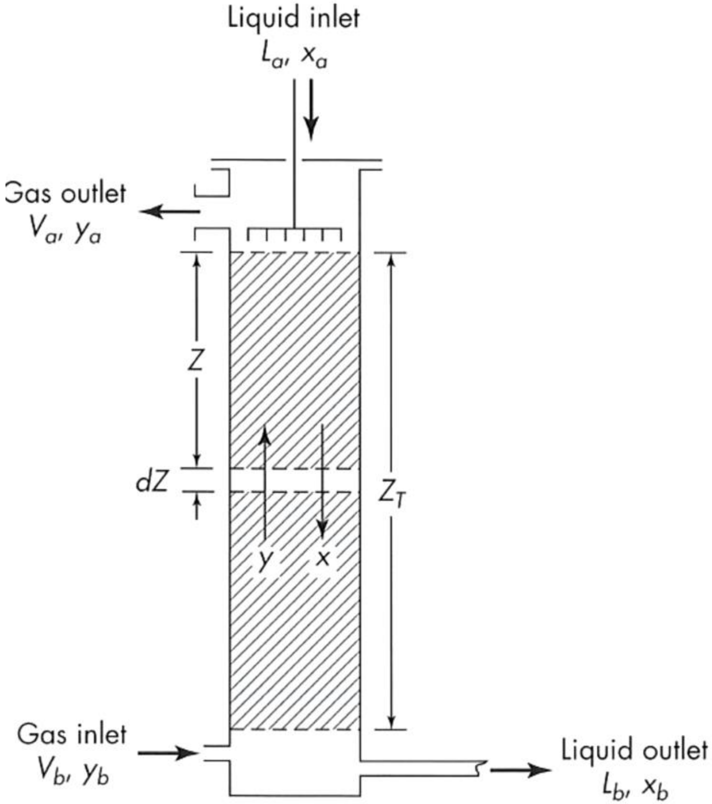
  - ✓ Tower height, Z_T, then becomes

$$Z_T = \frac{V}{K_y a\, S} \int_a^b \frac{\mathrm{d}y}{(y - y^*)} \; [=] \; \frac{mol/s}{\frac{mol}{s\, m^3} m^2} = m$$

$$= H_{Oy}\, N_{Oy}$$

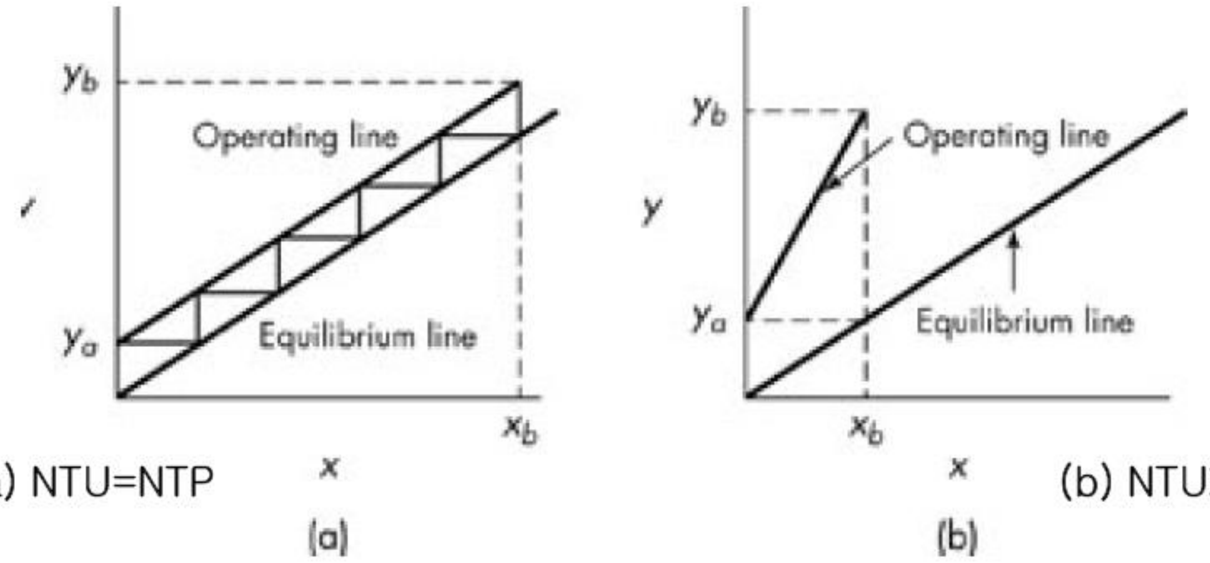
where H_{Oy} is the height of transfer unit and N_{Oy} the number of transfer units.

  - ✓ H_{ox} & N_{ox}, H_x & N_x, H_y & N_y?



18.3 Number of transfer units

- **When the operating and equilibrium line are straight,**
  - ✓ The number of transfer units (NTU) is the change in conc. across the tower divided by the logarithmic mean driving force.
  - ✓ Unless both lines are also parallel, more units are needed than the number of theoretical plates (NTP).



(a) NTU=NTP

(b) NTU>NTP

18.3 Film coefficients

- **In literature, $k_L a$ or $K_g a$ are often used instead.**
  - ✓ The following relations hold between $k_g a$ and $k_y a$:

$$K_g a = \frac{K_y a}{P}, \ k_g a = \frac{k_y a}{P} [=] \ ?$$

where P is the total pressure.

  - ✓ A similar relationship holds between $k_L a$ and $k_x a$:

$$K_L a = \frac{K_x a}{\rho}, \ k_L a = \frac{k_x a}{\rho} [=] \ ?$$

where ρ is the density of liquid.

- **Mass velocities can also be used in place of V or L.**
  - ✓ $G_M = G_y/M = \frac{u_0 \rho_y}{M} [=] \frac{\frac{m}{s}\frac{g}{m^3}}{\frac{g}{mol}} = \frac{mol}{s\, m^2} [=] \frac{V}{S}$

where M is the average molecular weight of the gas

  - ✓ $H_{Oy} = \frac{V}{K_y a\, S} = \frac{G_M}{K_g a\, P}$

18.3 Effects of pressure

- **Absorption columns are often operated under high pressure to increase mass transfer rates and capacity.**
  - ✓ y^* varies inversely with the total pressure:

$$y_A = \frac{p_A}{P}$$

where P is the total pressure.

(1) Why do slopes decrease?

(2) What happens to the overall mass transfer coefficient $K_y a$?

(3) Does mass transfer become better or worse?

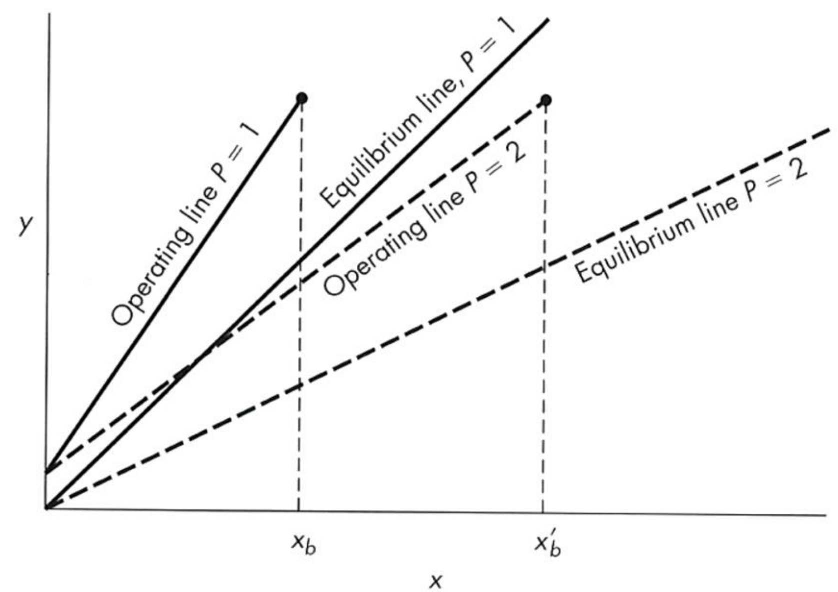


FIGURE 18.14
Effect of pressure on absorption.

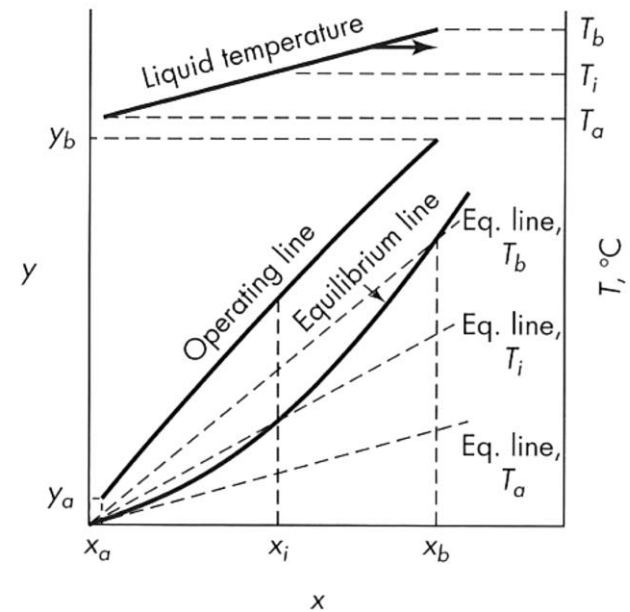
18.3 Temperature variations

- **Two phenomena affects temperature.**
  - ✓ Heat of absorption raises the liquid phase temperature while evaporation tends to lower temperature.
  - ✓ Temperature profile is thus a function of absorption, evaporation and possibly condensation rates across the tower.

- **Exact calculation is computationally heavy.**
  - ✓ To simplify, assume the gas inlet *T* is comparable to liquid outlet *T*.

(1) Why is the eq. line curved up?

(2) How will this graph change if there is evaporation near the bottom?



- Operation of an absorption column

https://www.youtube.com/watch?v=NhPqSWUrGsg

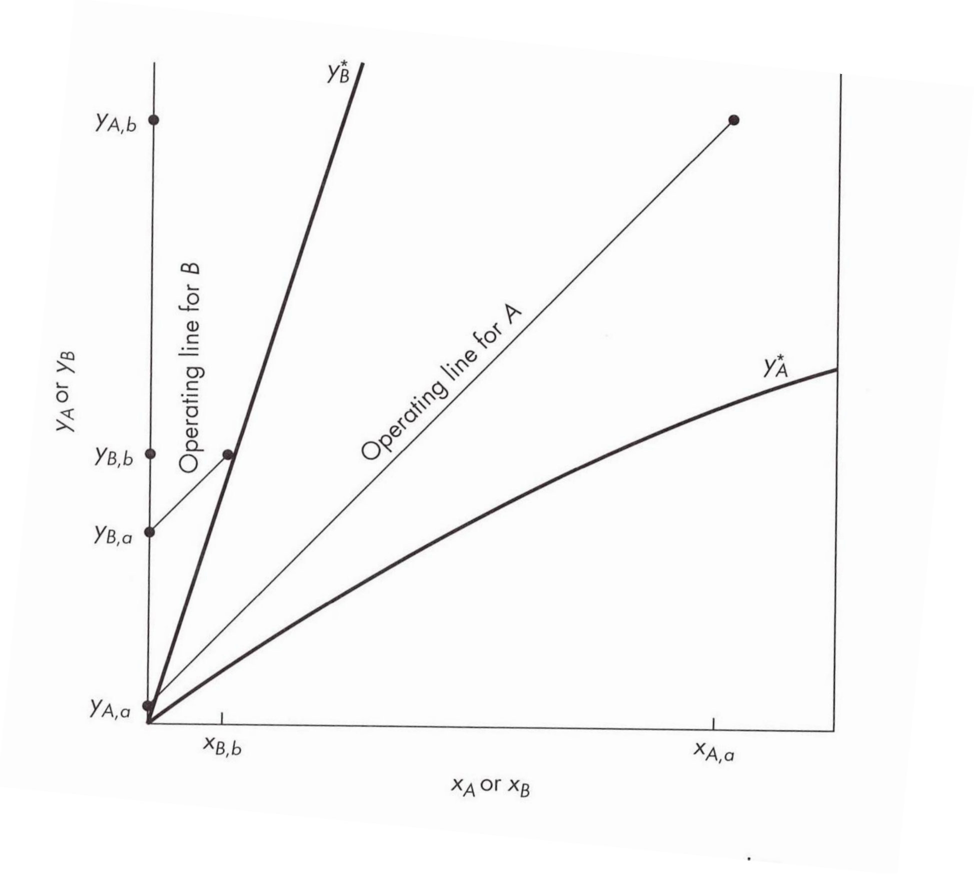
18.4 Multicomponent case

- **When more than one solute is absorbed from the gas,**
  - ✓ separate equilibrium and operating lines are needed for each solute.

(1) How are the slopes of the operating lines?

(2) How many transfer units are required for A vs B?

✓ The analysis can be complex especially if the equilibrium of A Is affected by B (or vice versa), or the molar flow rates vary throughout the tower.



18.4 Desorption

- **The solutes in the liquid are often desorbed afterwards.**
  - ✓ This produces concentrated solute, as well as regenerated solution for future use.
  - ✓ Desorption can be done by simply (1) lowering ??, (2) raising the ?? or doing both.
  - ✓ The height of a stripping column can be calculated similarly:

$$Z_T = \frac{L}{K_x a\ S} \int_a^b \frac{\mathrm{d}x}{(x^* - x)} \ [=] \ \frac{mol/s}{\frac{mol}{s\ m^3}\ m^2} = m$$

$$= H_{Ox}\ N_{Ox}$$