Absorption 3

Includes material adapted from slides
by Karl Johnson at U. Pittsburgh

Perspective

- Examined two methods for analysis of dilute absorption/stripping systems where the liquid and gas rates do not change appreciably (~1% or lower)

- Permits straight operating lines and McCabe Thiele analysis

- Analytical solution (Kremser) for straight operating lines and straight equilibrium line

Absorption Systems – Physical

- Examples:

CO_2 and water	Acetylene and acetic acid
CO and water	NH_3 and acetone
H_2S and water	Ethane and carbon disulfide
NH_3 and water	N_2 and methyl acetate
NO_2 and water	NO and ethanol

- Physical absorption relies on the solubility of a particular gas in a liquid.

- This solubility is often quite low; consequently, a relatively large amount of liquid solvent is needed to obtain the required separation.

- This liquid solvent containing the solute is typically regenerated by heating or stripping to drive the solute back out.

Absorber/Stripper Cycle
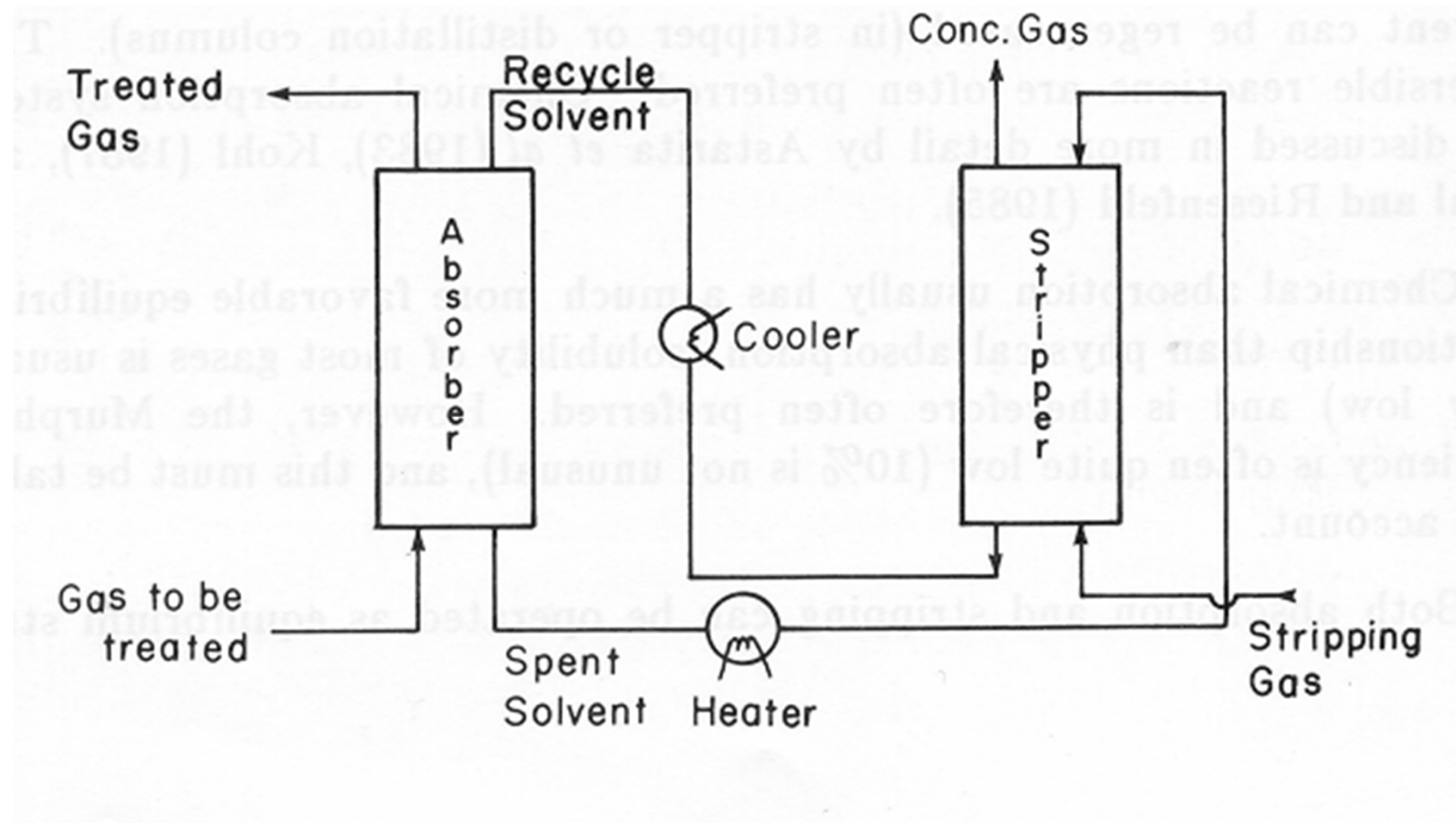
Is there something that we can do to get straight operating lines when the total flow rate changes due to transfer from one phase to another?

Absorption and Stripping –
Straight Operating Lines for More Concentrated Systems

- While the total gas and liquid streams can change in absorption, the flow rate of the carrier gas, which we assume to be insoluble in the solvent, does not change.

- Similarly, the flow rate of the solvent, which we assume to be nonvolatile, does not change.

- Consequently, we can define our equilibrium curve and operating line in terms of mole ratios with respect to the carrier gas and solvent, instead of mole fractions as we did in distillation.

- Doing so circumvents the problem of the changing total gas and liquid stream amounts or flow rates in absorption and stripping.

Absorption – Variable Specification
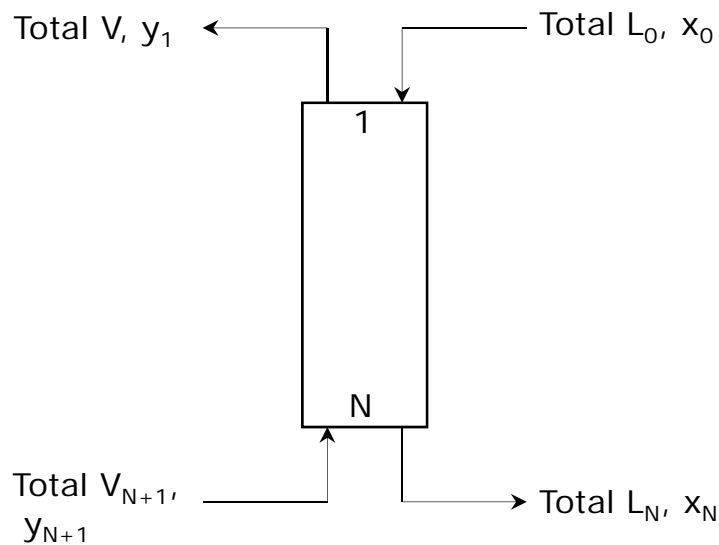
Total Vapor (V) and Total Liquid (L)
Flows Rates and Mole Fractions
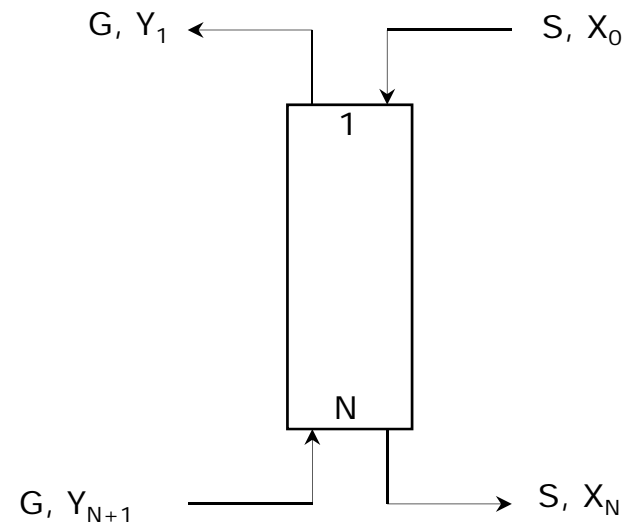
Carrier Gas (G) and Solvent (S)
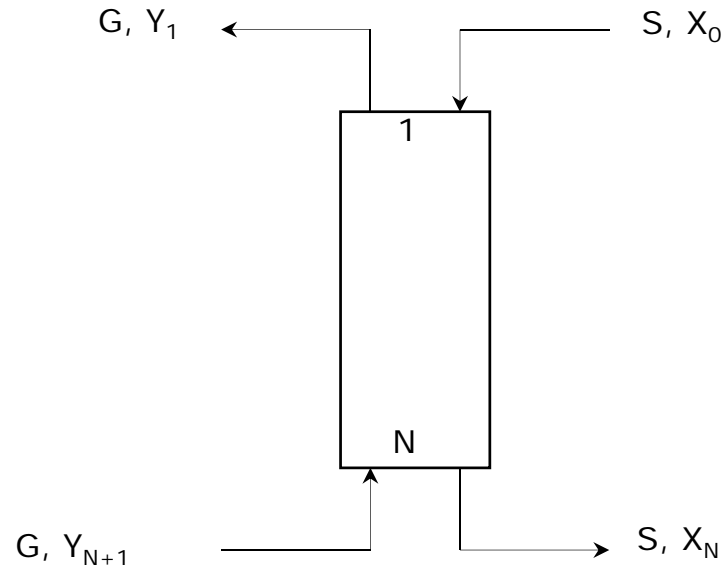Flow Rates and Mole Ratios

Mole Ratios

We can then define the gas and liquid molar ratios as

$$Y = \frac{\text{moles solute in gas}}{\text{moles solute free carier gas}} \qquad X = \frac{\text{moles solute in liquid}}{\text{moles solute free absorbent}} \qquad \text{Eq. (12-38a)}$$

The molar ratios are related to the mole fractions for solute i by

$$Y_i = \frac{y_i}{1 - y_i} \qquad\qquad X_i = \frac{x_i}{1 - x_i} \qquad\qquad \text{Eq. (12-38b)}$$

Absorber Operating Line

$$Y_{j+1} = \frac{S}{G}X_j + \left[Y_1 - \frac{S}{G}X_0 \right]$$

Eq. 12-40

Basically, a variable transformation that permits straight operating lines based on the carrier gas and solvent flows that do not change

Henry's Law – Mole Fraction Relationship

- Absorption data is typically available in the form of solute mole fractions, y_i vs. x_i, or in terms of the Henry's constant, H.

- Henry's Law, in terms of the mole fractions of solute i and the total pressure, is:

$$y_i = \frac{H_i}{P_{Tot}} x_i \qquad \frac{H_i}{P_{Tot}} = \frac{y_i}{x_i}$$

- Henry's Law is valid at low concentrations of solute i, approximately less than 10%.

Henry's Law – Mole Ratio Relationship

We can rewrite Henry's Law for solute i,

$$y_i = \frac{H_i}{P_{Tot}} x_i$$

in mole ratios, using the mole fraction relationships,

$$Y_i = \frac{y_i}{1 - y_i} \qquad\qquad X_i = \frac{x_i}{1 - x_i}$$

to yield Henry's Law in terms of the molar ratios, Y_i and X_i, or

$$\frac{Y_i}{1 + Y_i} = \frac{H_i}{P_{Tot}} \frac{X_i}{1 + X_i}$$
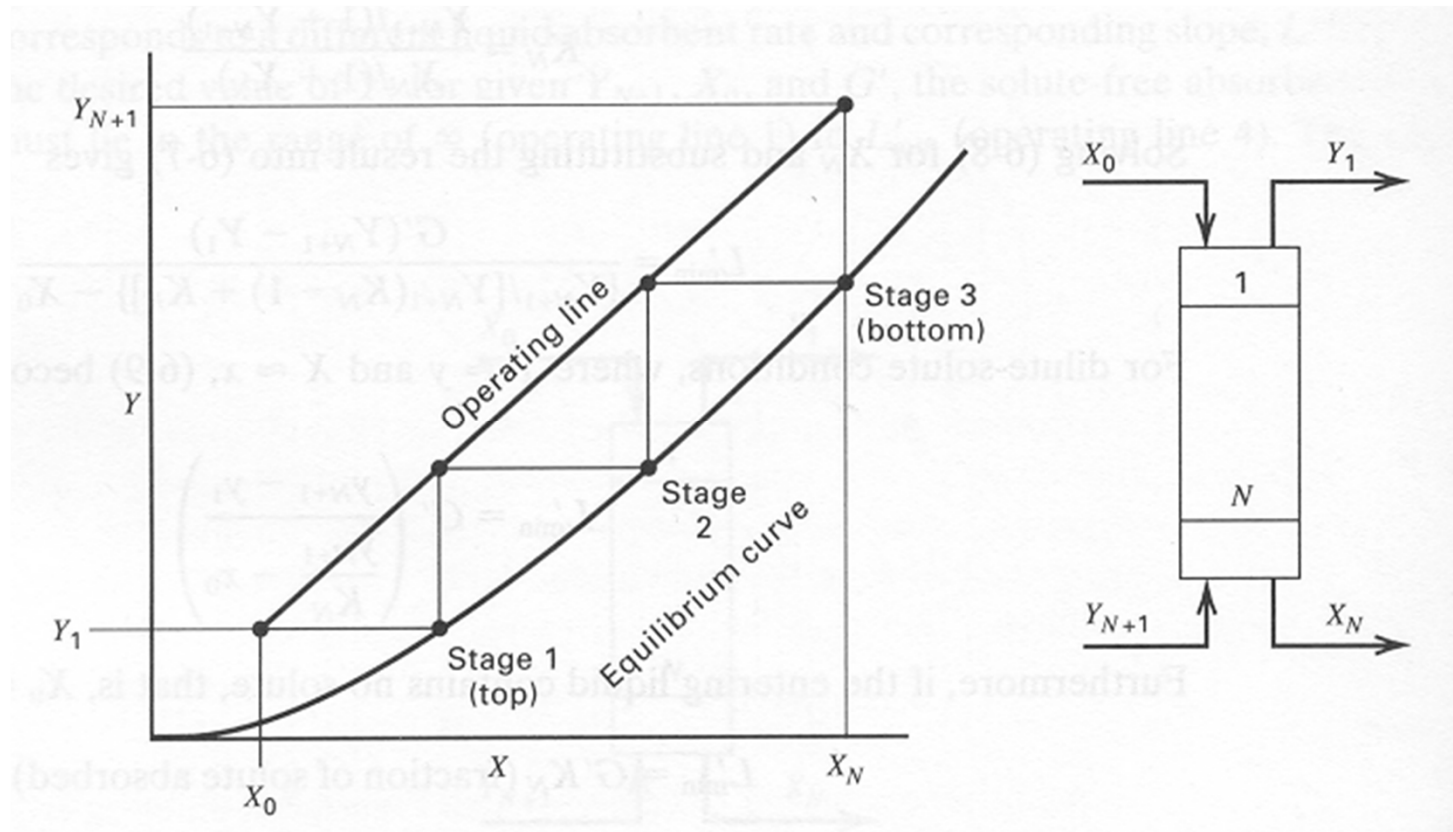
Equilibrium Curve – Mole Ratios

Therefore, for an equilibrium curve of the form:

$$y_i = mx_i$$

In terms of mole ratios:

$$Y_i = \frac{mX_i}{1 + (1-m)X_i}$$

McCabe-Thiele Plot – Absorber

Example (see 12-3 of your text)

A gas stream is 90 mol% nitrogen and 10 mol% carbon dioxide. The inlet water is pure and is at 5 C. Because of cooling coils, operation can be assumed to be isothermal. Operation is at 10 atm. If the liquid flow rate is 1.5 times the minimum, how many equilibrium stages are required to absorb 92% of the CO_2? Assume a gas flow rate of 100 kmol/h.

Draw diagram here

Example: Plan

1. Draw a sketch to define streams and variables
2. Use analysis for more concentrated systems
3. Equilibrium data- assume Henry's Law, convert to molar ratios
4. Calculate inlet and outlet molar ratios for gas, and inlet for liquid
5. Calculate G (carrier gas flow rate)
6. Calculate X in equilibrium with inlet Y from equilibrium data
7. Calculate minimum slope of operating line
8. Use minimum slope to determine S and S/G under desired operating conditions
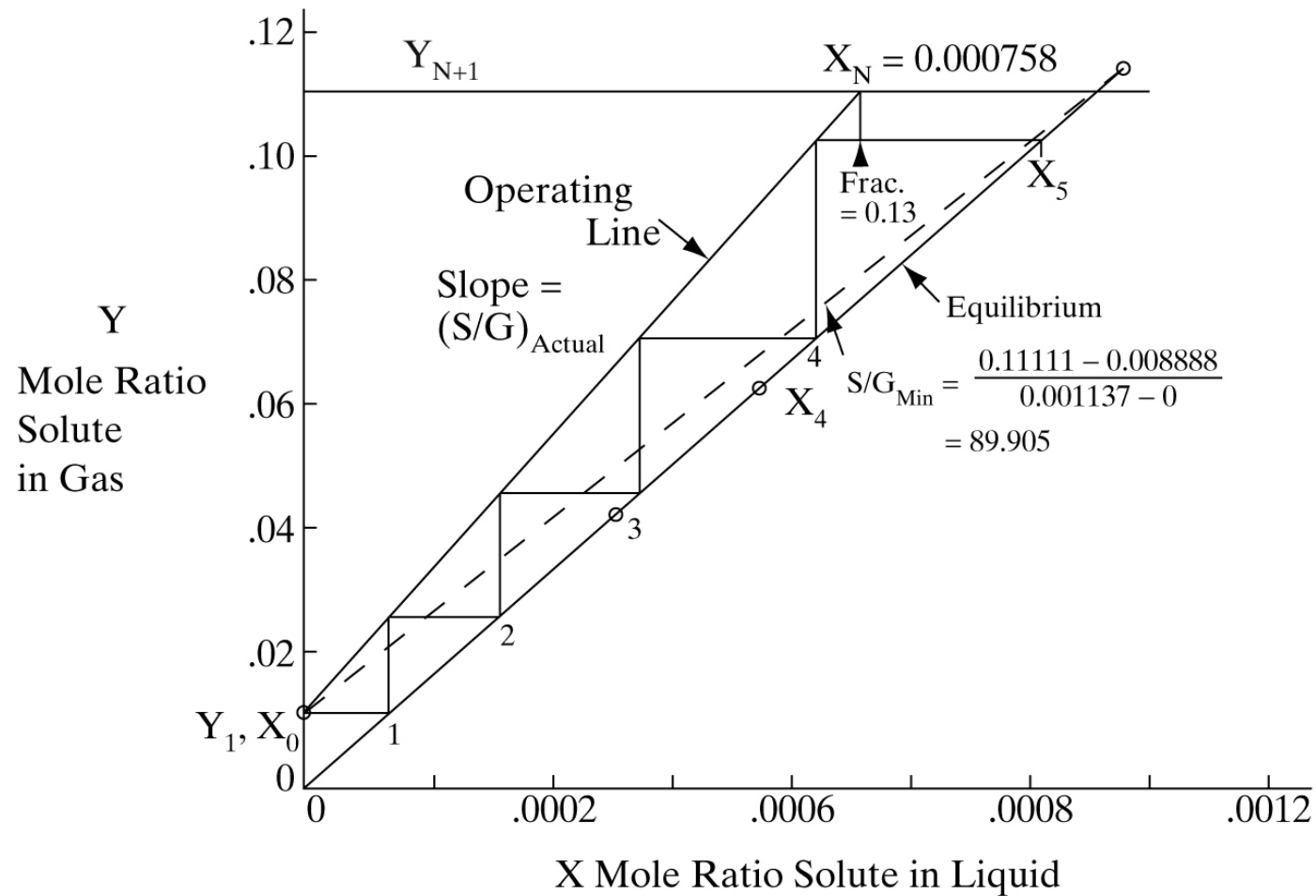9. Plot operating line and step off trays

Figure 12-9 McCabe-Thiele diagram for absorption, Example 12-3

Physical Absorption Summary

- Have methods for dilute systems
  - Simple
  - Illustrate basic function of units
- Methods can be extended to more concentrated systems
- Use simulation tools for more complicated analysis
  - Calculate tray-by-tray flows
  - Include heat effects
  - Use of thermodynamic models/data fitting

Question

- What would you do if you wanted to maximize the amount of a substance that you could remove, for example, from a gas?

Absorption Systems – Chemical

- Chemical absorption relies on reaction of a particular gas with a reagent in a liquid.
- Examples:

  CO_2 / H_2S and aqueous ethanolamines

  CO_2 / H_2S and aqueous hydroxides

  CO and aqueous Cu ammonium salt

  SO_2 and aqueous dimethyl aniline

  HCN and aqueous NaOH

  HCl / HF and aqueous NaOH

- This absorption can often be quite high; consequently, a smaller amount of liquid solvent/reagent is needed to obtain the required separation.

- However, the reagent may be relatively expensive, and it is often desirable to regenerate when possible.