Mass transfer

Lecture 09: *Liquid extraction*

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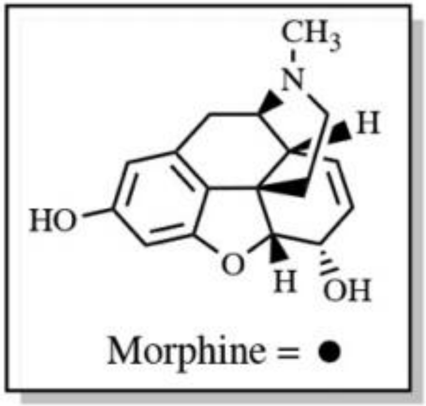
Learning objectives

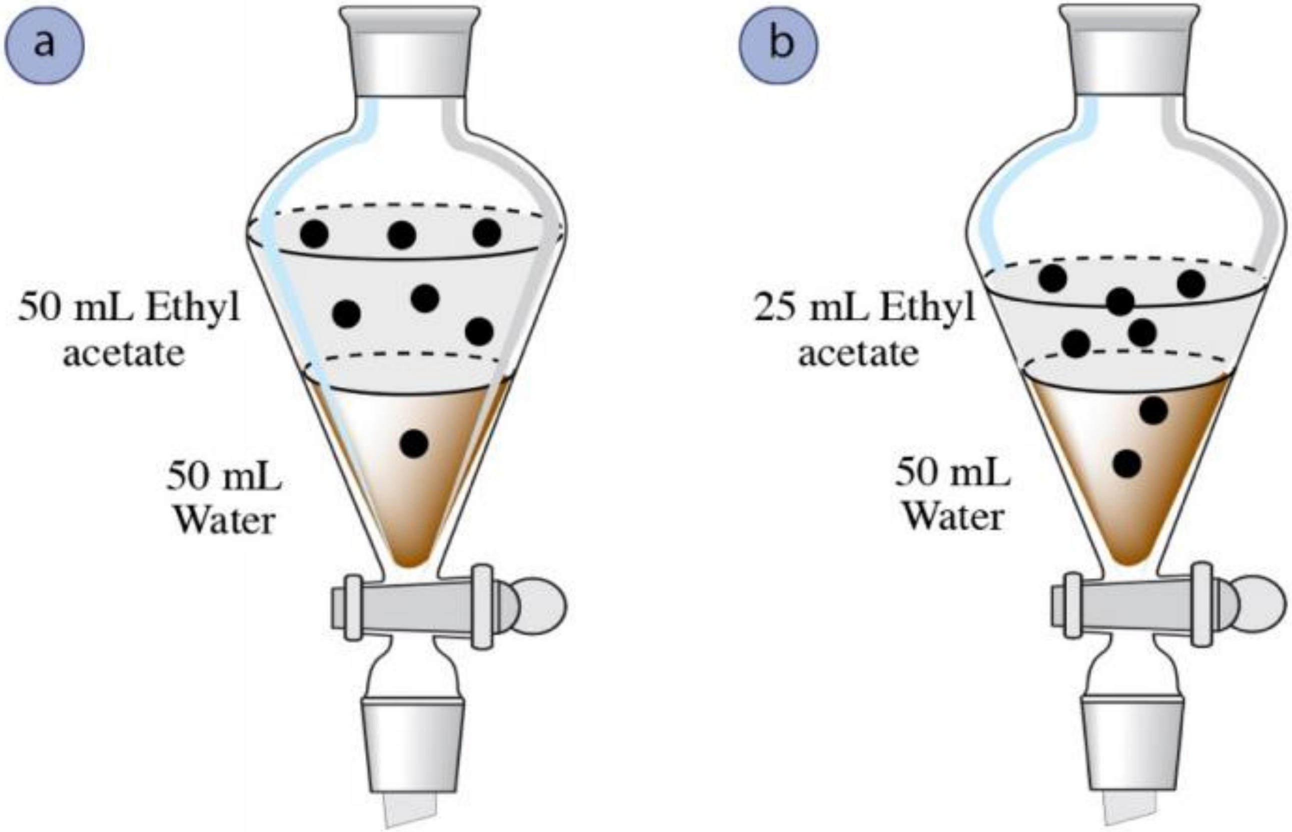
- **Analyze liquid-liquid extraction using mass balance equations, and the modified McCabe-Thiele method.**
- **Understand and be able to interpret the three-phase equilibria diagram.**
- **Apply the Hunter-Nash method in calculating the number of ideal stages needed for the Type I system without reflux.**

Today's outline

- **Analysis of liquid extraction**
  - ✓ Principles
  - ✓ Ex. 23.2
  - ✓ Phase equilibria, equilibrium diagram
  - ✓ McCabe-Thiele Method
  - ✓ Ex. 23.3
  - ✓ Extraction using reflux

- **Hunter-Nash method**
  - ✓ Application to acetone, water, MIK system (Type I)





$$K = \frac{[\text{Morphine}]_{\text{ethyl acetate}} = 0.0600\ \text{M}}{[\text{Morphine}]_{\text{water}} = 0.0101\ \text{M}} = \mathbf{5.95}$$

$$K = \frac{0.105\ \text{M}}{0.0177\ \text{M}} = \mathbf{5.93}$$

- ✓ Why is *K* different between a and b?
- ✓ Why is *K* much larger than 1 (Hint: chemical structure of ethyl acetate)?

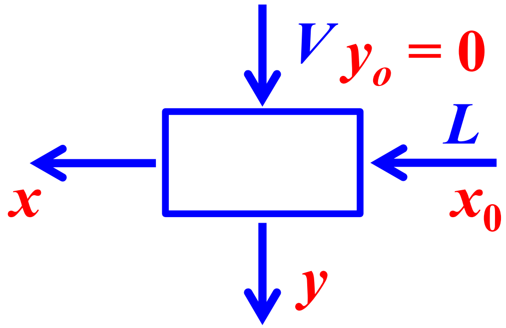
23.3 Principles of extraction

- **For extraction of dilute solutions where changes in flow rate and K_D can be neglected,**
  - ✓ an **extraction factor *E*** is defined by

$$E \equiv \frac{K_D V}{L}$$

where the *distribution coefficient* $K_D = y_e/x_e$

  - ✓ For a single-stage extraction with pure solvent (V), the fraction of solute remaining is calculated by:



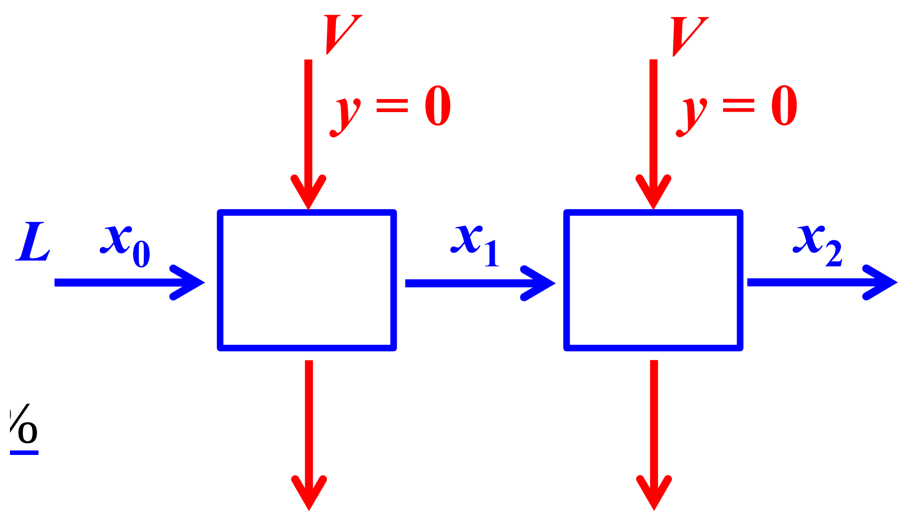
$x/x_0 = ?$

$1 - x/x_0 = ?$ (fraction of recovery)

23.3 Recovery of Penicillin F

Ex. 23.2. Penicillin F is recovered from a dilute aqueous fermentation broth by extraction with amyl acetate, using 6 volumes of solvent per 100 volumes of the aqueous phase. At pH = 3.2, K_D is 80. (**In-class**)

(a) What fraction of the penicillin would be recovered in a single ideal stage? (b) What would be the recovery with two-stage extraction using fresh solvent in both stages? (c) How many ideal stages would be needed to give the same recovery as in part (b) if a counterflow cascade were used with V/L = 0.06?



23.3 Phase equilibria

- **For extraction of concentrated solutions,**
  - ✓ the equilibrium data are often presented in a triangular diagram as shown in below: (**Type I**)

✓ *solute* (a), *diluent* (b), and *solvent* (s)

✓ *plait point* **E**

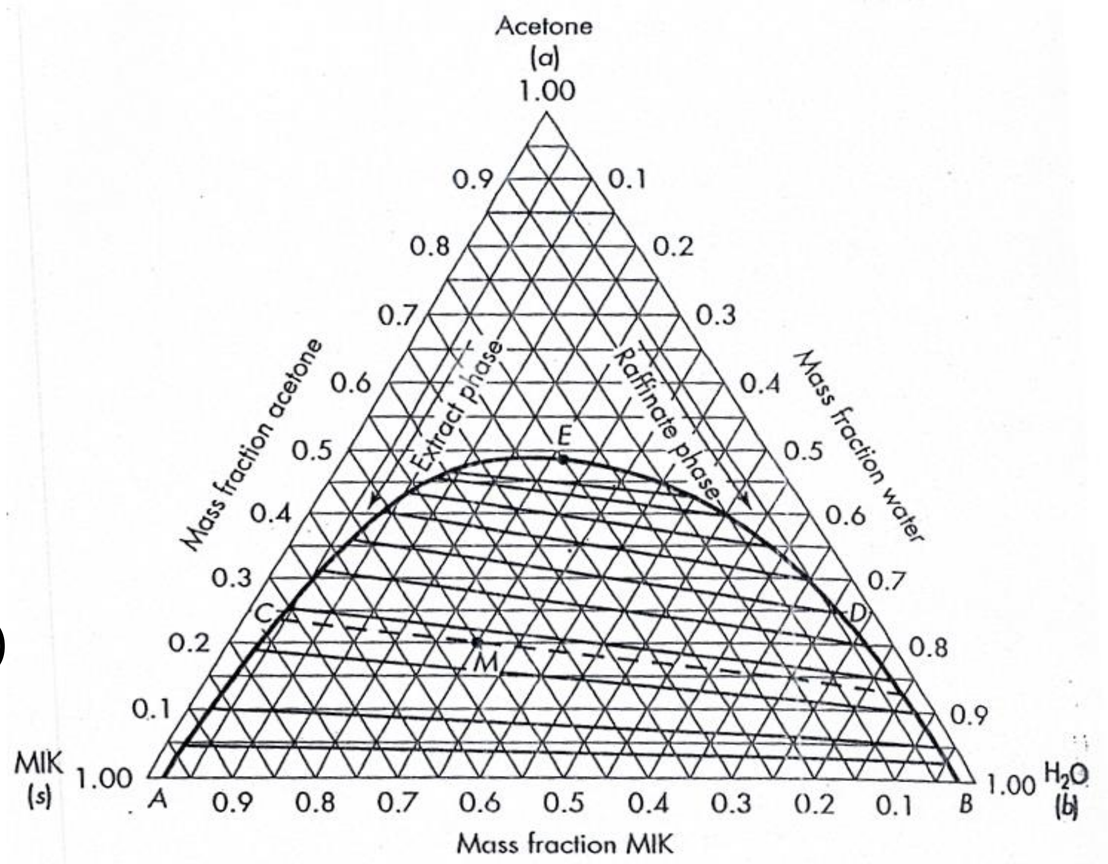
✓ line **ACE** vs **BDE**

✓ tie lines and slope

✓ Concentrations of each component at M

Extract (0,23, 0.73, 0.04)

Raffinate (0.13, 0.02, 0.85)



23.3 Equilibrium diagram

- **For extraction of concentrated solutions,**
  - ✓ There are cases where the solvent is only partially miscible with both the other components (**Type II**)

✓ tie lines and slope

✓ Concentrations of each component at M

Extract (?, ?, ?)

Raffinate (?, ?, ?)

✓ Is separation easier?

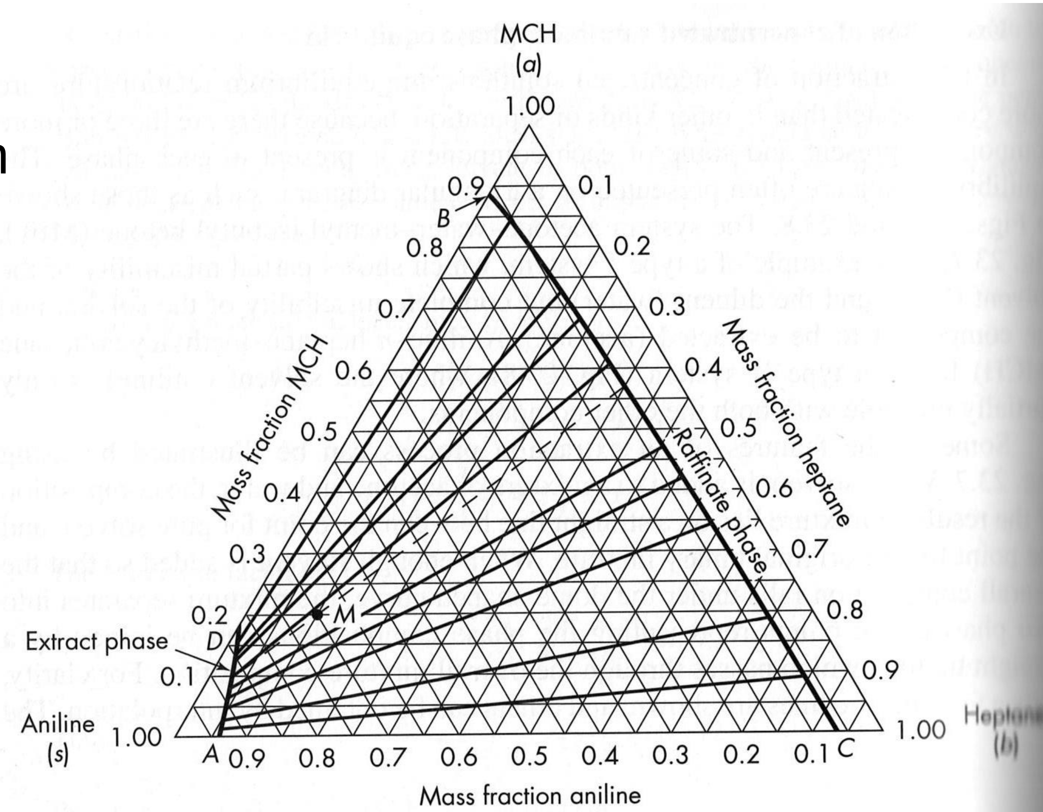
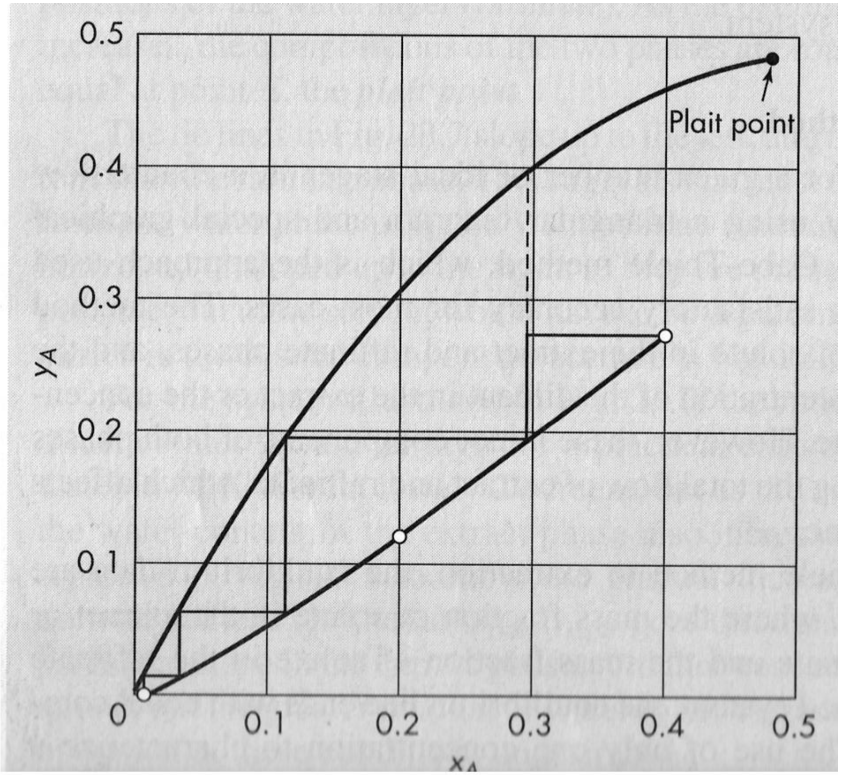


FIGURE 23.8
System aniline–*n*-heptane–MCH at 25°C: *a*, solute MCH; *b*, diluent, *n*-heptane; *s*, solvent, aniline. (*After Varteressian and Fenske.*[18])

23.3 McCabe-Thiele Method

- **For cascade-like extraction, the number of ideal stages can be determined by using the graphical method.**
  - ✓ The equilibrium data are shown on a rectangular graph, which ends at the plait point.

1) Draw the eq. line
2) Determine the terminal points (x_a, y_a), (x_b, y_b)
3) Determine one or more intermediate points using MB equations.
4) Use triangular drawing to figure out the number of ideal stages.



23.3 Acetone recovery

Ex. 23.3. A countercurrent extraction plant is used to extract acetone (A) from its mixture with water by means of methyl isobutyl ketone (MIK) at a temperature of 25 °C. The feed consists of 40% acetone and water. Pure solvent equal in mass to the feed is used as the extracting liquid. How many ideal stages are needed to extract 99% of the acetone fed? What is the extract composition after removal of the solvent? (**Homework**)

반류 추출 공장에서 물과 아세톤의 혼합물로부터 아세톤을 추출하는데 25°C의 MIK를 이용한다. 원료는 40%의 아세톤과 60%의 물로 구성되어 있고, 원료와 같은 질량의 순수 용매를 추출에 쓰고 있다. 다음 쪽에 첨부된 3상도를 이용하여 99%의 순도가 되도록 아세톤을 추출하는데 필요한 이상단 수를 계산하여라. 또한 용매를 제거한 후의 추출물의 조성을 계산하여라.

23.3 Extraction using reflux

- **Reflux can be used to improve recovery.**
  - ✓ Type II systems can especially benefit from using reflux.

TABLE 23.3
Comparison of extraction with distillation, both using reflux

Distillation	Extraction
Vapor flow in cascade V	Extract flow in cascade V
Liquid flow in cascade L	Raffinate flow in cascade L
Overhead product D	Extract product D
Bottom product B	Raffinate product B
Condenser	Solvent separator
Bottom-product cooler	Raffinate solvent stripper
Overhead-product cooler	Extract solvent stripper
Heat to reboiler q_r	Solvent to cascade s_B
Heat removal in condenser q_c	Solvent removal in separator s_D
Reflux ratio $R_D = L_a/D$	Reflux ratio $R_D = L_a/D$
Rectifying section	Extract-enriching section
Stripping section	Raffinate-stripping section

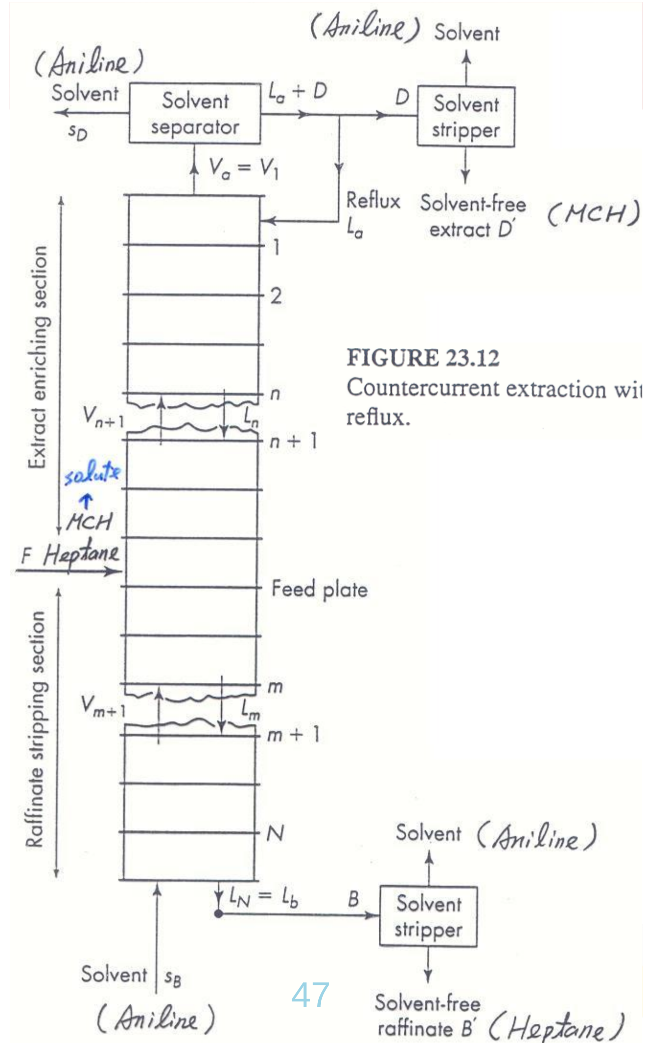


FIGURE 23.12
Countercurrent extraction wi
reflux.

23.3 Reflux ratio & number of p

- **The same relationship holds between the reflux ratio and the number of stages needed.**
  - ✓ At the minimum reflux ratio, ?? stages are needed whereas ?? stages are needed at the total reflux.