Mass transfer

Lecture 08: *Leaching and extraction*

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Learning objectives

- **Understand when leaching would be a more preferred, effective separation method.**
- **Analyze cascades leaching using the material balance equation and associated graphs.**
- **Determine when liquid extraction will be preferred versus distillation.**

Today's outline

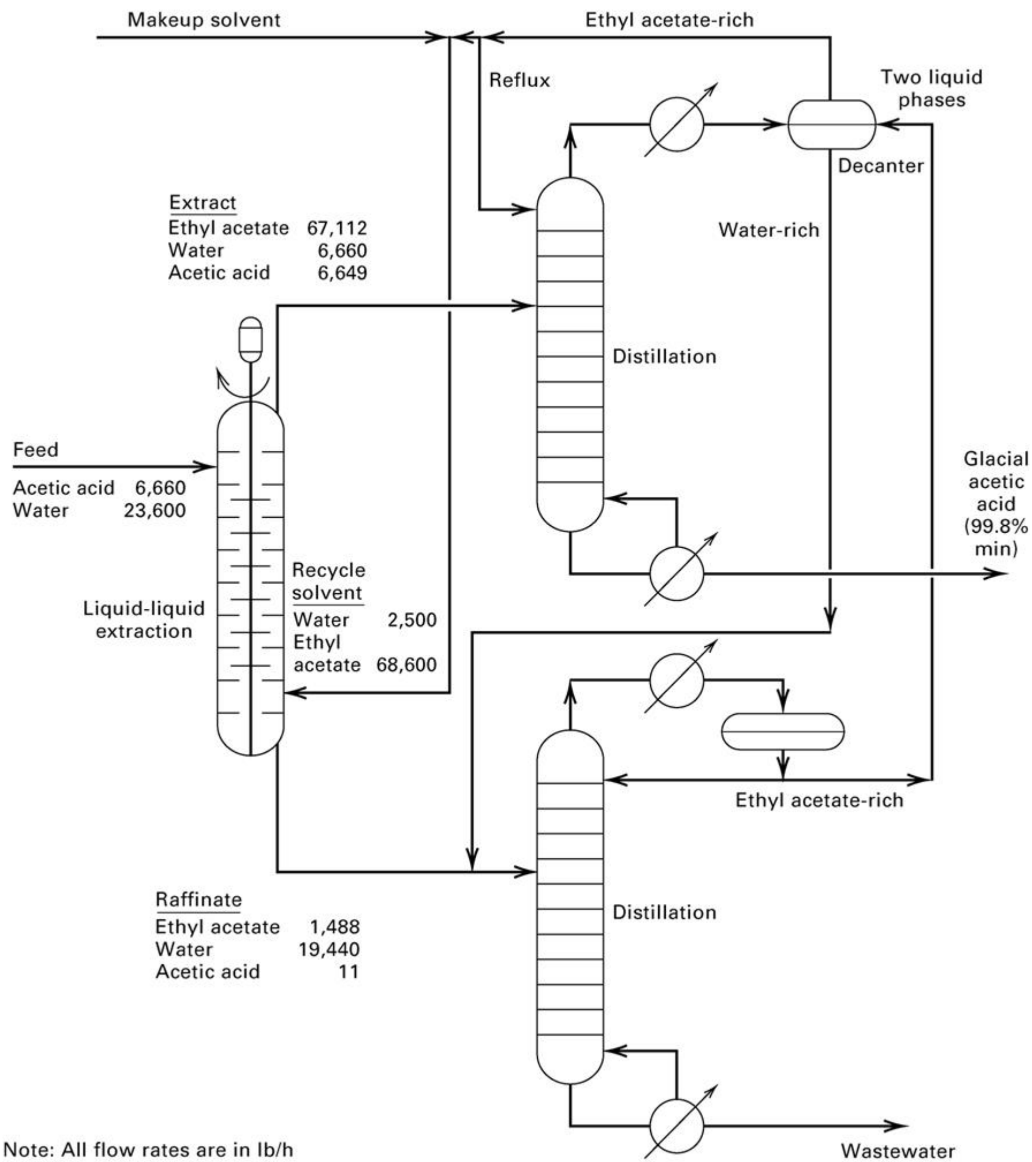
- **Leaching**
  - ✓ Introduction
  - ✓ Leaching equipment, dispersed solid leaching
  - ✓ Cascades leaching, equilibrium analysis
  - ✓ Variable underflow
  - ✓ Ex. 23.1

- **Liquid extraction**
  - ✓ Introduction
  - ✓ Terminology and types

23.1 Introduction to Leaching

- **Definition: method of removing one constituent from a solid or liquid by means of a liquid solvent**

- **Examples**
  - ✓ In chemical process
  - ✓ In daily life



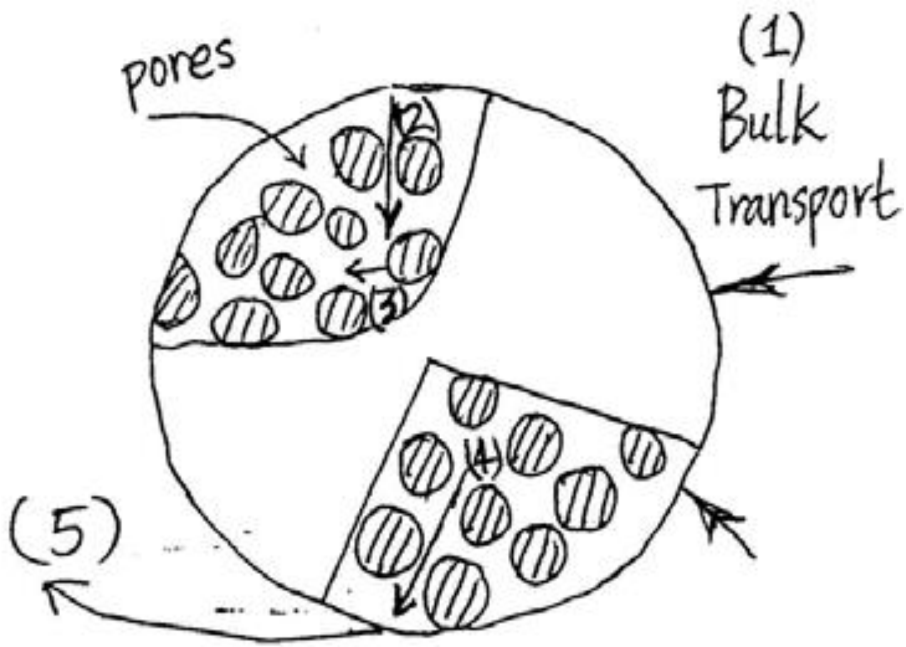
23.1 Mass transport

- **Generally there are five rate steps in the leaching process.**

(1) The solvent is transferred from the bulk solution to the surface of the solid. (*fast*)

(2) The solvent penetrates or diffuses into the solid. (*slow*)

(3) The solute dissolves from the solid into the solvent. (*slow*)



(4) The solute diffuses through the mixture to the surface of the solid.

(5) The solute is transferred to the bulk solution.

23.1 Leaching equipment

- **Generally, two types are used with respect to whether or not the mixture (often solid) is permeable.**
  - ✓ When working with permeable mass, percolation through stationary solid beds may be used.
  - ✓ What will impact percolation?
  - ✓ What will impact leaching?

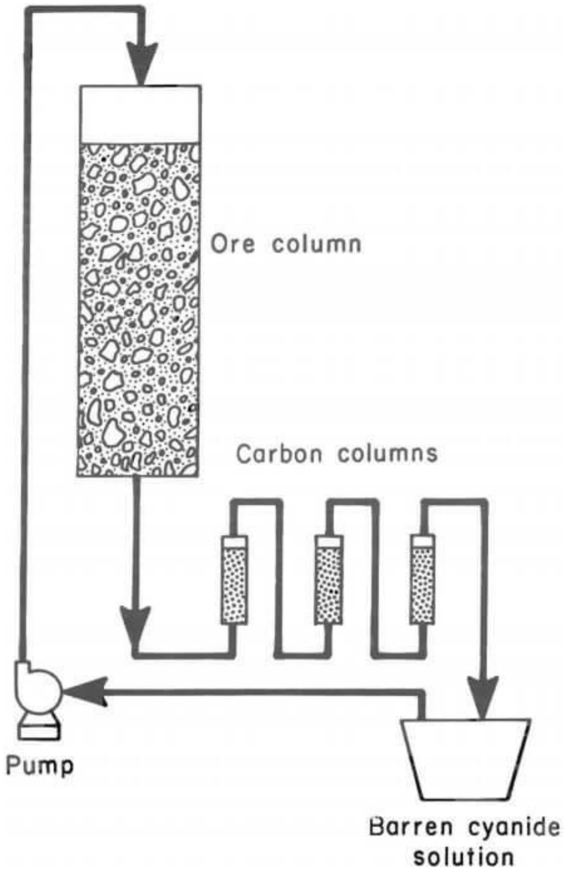


FIGURE 2. - Flow diagram for simulated heap leach experiments.

23.1 Leaching equipment

- **Generally, two types are used with respect to whether or not the mixture (often solid) is permeable.**
  - ✓ When working with impermeable mass, solids are dispersed into the solvent and are later separated from it.
  - ✓ e.g., moving-bed leaching

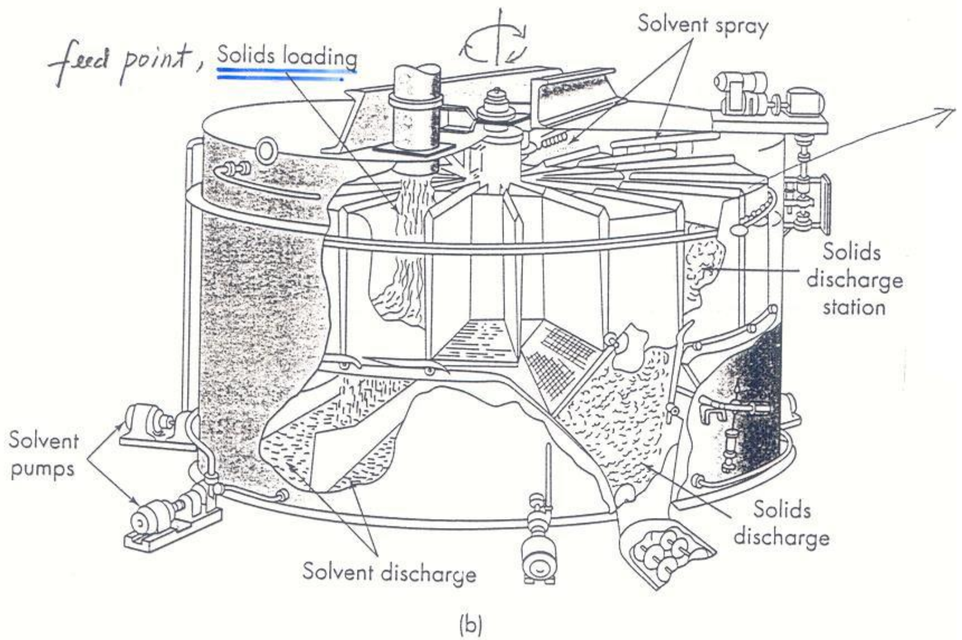
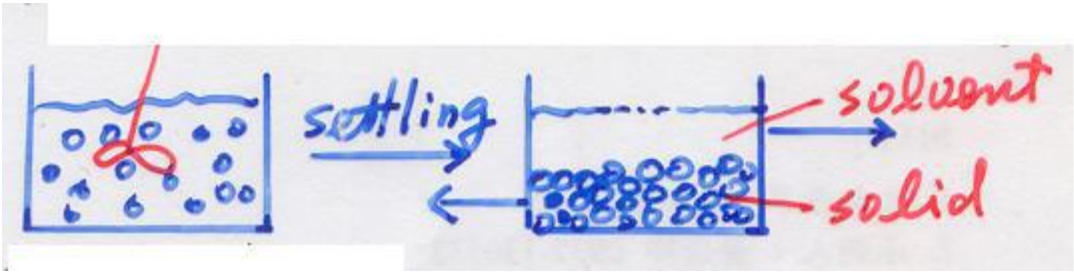


FIGURE 23.1
Moving-bed leaching equipment: (*a*) Bollman extractor; (*b*) Rotocel extractor[11b] (*by permission of McGraw-Hill, Inc.*).

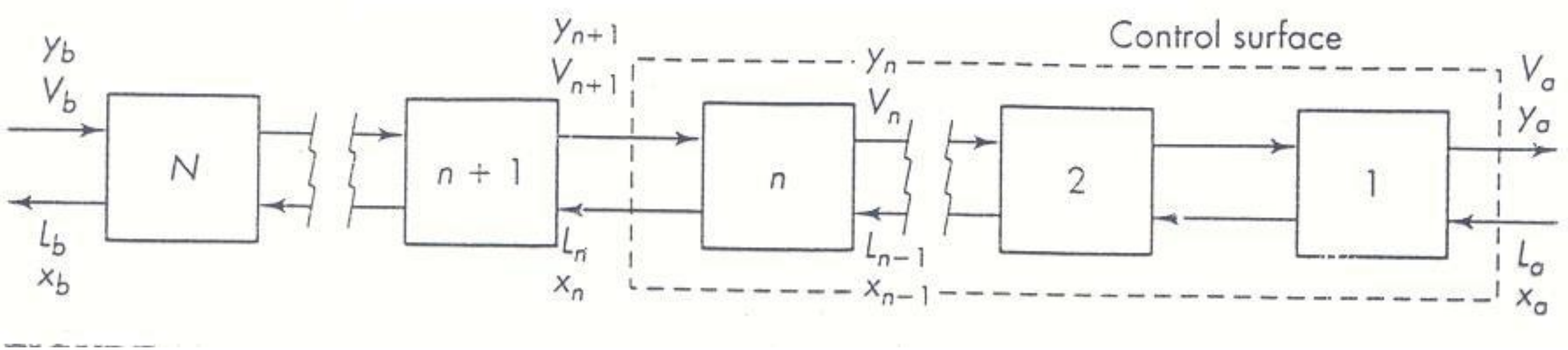
23.1 Dispersed-solid leaching

- **Solid is dispersed in the solvent by mechanical agitation in a tank or flow mixer. The leached residue is then separated by settling or filtration.**



23.1 Cascades leaching

- **It uses continuous, countercurrent flow to leach.**
  - ✓ In ideal stages, the following material balance diagram is true:



  - ✓ The ***V*** phase is the liquid dissolving solute as it moves to stage 1 while the ***L*** phase is the liquid carrying the solid moving to stage *N*.
  - ✓ x_a and x_b represent [solute] in the liquid retained by entering or leaving solid; y_a and y_b [solute] in the leaving vs fresh solvent.
  - ✓ The stages are numbered in the direction of flow of the solid.
  - ✓ Where will *x* and *y* be the highest?

23.1 Equilibrium analysis

- **Assuming (1) sufficient solvent, (2) no adsorption of solute, $x_e = y$.**
  - ✓ This is the equilibrium line for the ideal cascades leaching.
  - ✓ Operating line equation can be derived using material balance for the first *n* stages:

$$L_a + V_{n+1} = L_n + V_a$$

$$L_a x_a + V_{n+1} y_{n+1} = L_n x_n + V_a y_a$$

$$y_{n+1} = \frac{L_n}{V_{n+1}} x_n + \frac{V_a y_a - L_a x_a}{V_{n+1}}$$

  - ✓ The mass of solution retained by the solids is constant (*constant solution underflow*) vs varying.
  - ✓ For constant underflow, you can calculate the number of ideal stages needed using the following eqn.:

$$N = \frac{\ln[(y_b - y_b^*)/(y_a - y_a^*)]}{\ln A} = \frac{\ln[(y_b - y_b^*)/(y_a - y_a^*)]}{\ln[(y_b - y_a)/(y_b^* - y_a^*)]}$$

where y_b^* and y_a^* are ?

23.1 Variable underflow

- **Assuming (1) sufficient solvent, (2) no adsorption of solute, $x_e = y$.**
  - ✓ For variable overflow, you can calculate the number of ideal stages using the McCabe-Thiele method.
  - ✓ The equilibrium line will now be curved. To calculate, use both iterative method and intermediate calculation (shown in **Ex.23.1**).

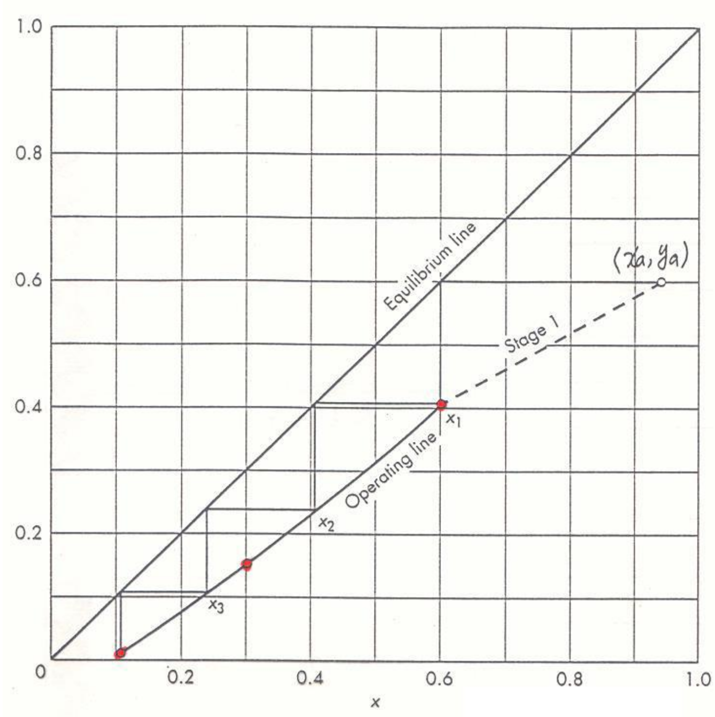


TABLE 23.1
Data for Example 23.1

Concentration, x kg oil/kg solution	Solution retained, kg/kg solid	Concentration, x kg oil/kg solution	Solution retained, kg/kg solid
0.0	0.500	0.4	0.550
0.1	0.505	0.5	0.571
0.2	0.515	0.6	0.595
0.3	0.530	0.7	0.620

23.1 Oil extraction

Ex. 23.1. Oil is to be extracted from meal by means of benzene using a continuous countercurrent extractor. The unit is to treat 1,000 kg of meal (based on completely exhausted solid) per hour. The untreated meal contains 400 kg of oil and is contaminated with 25 kg of benzene. The fresh solvent mixture contains 10 kg of oil and is 655 kg of benzene. The exhausted solids are to contain 60 kg of unextracted oil. (hourly basis)

Find (a) the concentration of the strong solution or extract, y_a; (b) the concentration of solution adhering to the extracted solids, x_b; (c) the mass of solution leaving with the extracted meal, L_b; (d) the mass of extract, V_a; (e) the number of ideal stages required.

23.2 Liquid extraction intro.

- **It is used when separation by distillation is ineffective.**
  - ✓ Close-boiling liquids, substances that cannot tolerate high T
  - ✓ Uses chemical potential differences to separate.

- **Typical industrial uses include the following:**
  - ✓ penicillin extraction from fermentation broth (lower left)
  - ✓ extraction of certain chemicals from petroleum (lower right)

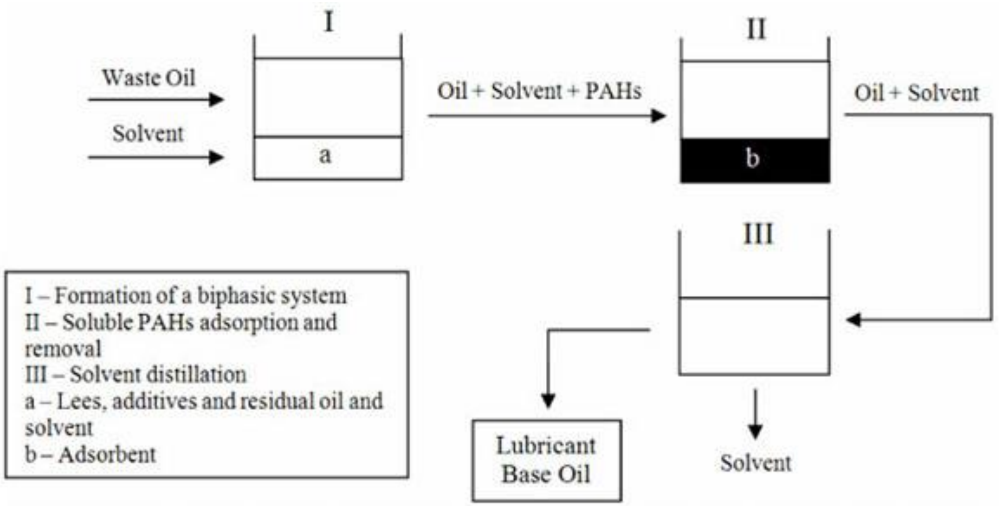


Figure 1: Lubricant base oil recovery process: extraction by solvent, adsorption on solids and solvent evaporation.

23.2 Terminology and types

- **Equipment should enable good contact between the two phases for effective mass transfer.**
  - ✓ The two phases have similar viscosity and density, requiring usually mechanical energy for mixing and separation.
  - ✓ **Extract**: the solvent plus extracted solute
  - ✓ **raffinate**: the liquid phase from which solute has been removed
  - ✓ The following types are used in commercial processes.

TABLE 23.2
Performance of commercial extraction equipment

Type	Liquid capacity of combined streams, $ft^3/ft^2 \cdot h$ [†]	HTU, ft	Plate or stage efficiency, %	Spacing between plates or stages, in.	Typical applications
Mixer-settler			75–100		Duo-Sol lube-oil process
Packed column	20–150	5–20			Phenol recovery
Perforated-plate column	10–200	1–20	6–24	30–70	Furfural lube-oil process
Baffle column	60–105	4–6	5–10	4–6	Acetic acid recovery
Agitated tower	50–100	1–2	80–100	12–24	Pharmaceuticals and organic chemicals

[†] ft^2 is the total cross-sectional area.

23.2 Example processes

https://www.youtube.com/watch?v=Zc_b50JbU14