Separation Processes

Table of Contents

1. Leaching

Leaching separates the solute from a solid feed using a solvent as seen in Figure 1. For example, the coconut oil from copra, the dried white flesh of the coconut using an organic solvent such as hexane.

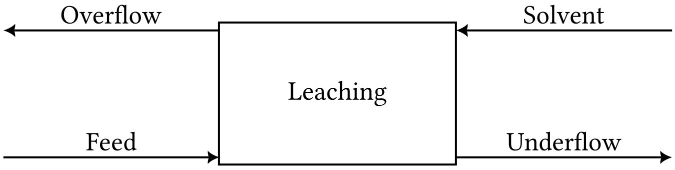

Figure 1: Simple leaching diagram.

It is generally configured in a countercurrent manner wherein the solid feed and the solvent are in opposite directions. Other usage include: instant coffee production, tea, oils from peanuts, pharmaceutical products from leaves, roots, and bark, and leaching metals from ore The solid should first be pretreated. Common methods include, grinding, which increases surface area and thus diffusion rate, drying, for the destruction of cell walls in plant material, and flaking/rolling are generally done for seeds.

1.1. Continuous and Batch Leaching

Leaching can be done either in batches or continuous. The latter is prefferred if longer residence times are required such as for the processing of minerals. One such usage is the leaching of gold from gold ore which uses a chemical reaction as written in Equation 1, the *Elsner reaction*. The gold forms a soluble complex with cyanide in the presence of oxygen gas. The gold ore is first comminuted to ensure efficient reaction.

$$4\mathrm{Au} + 8\mathrm{NaCN} + \mathrm{O_2} + 2\mathrm{H_2O} \rightarrow 4\mathrm{Na[Au(CN)_2]} + 4\mathrm{NaOH} \tag{1}$$

1.2. Leaching Mechanism

The mechanism of leaching can be thought of in 5 steps as visualized in Figure 1:

1. From the liquid bulk, solvent molecules diffuse to the surface of the solid particle.
2. From the surface, the solvent molecules diffuse into solid particle.
3. The solute is solubilized by the solvent.
4. The solvent carries the solute as it diffuses to the surface of the solid particle.
5. From the surface of the solid particle, the solution diffuses out to the liquid bulk.

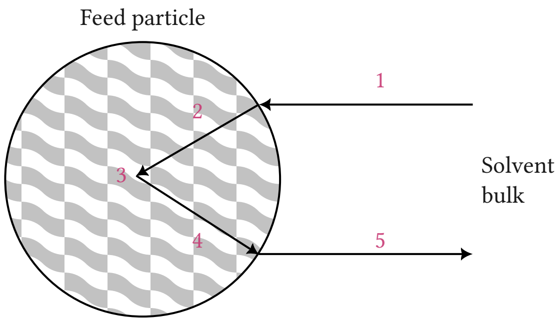

Figure 2: The mechanism of leaching.

It is said the step 4 is the rate limiting step since the solvent diffuses through a resisting solid medium whilst carrying the solute.

1.3. Types of Leaching

The simplest leaching design is of a *fixed bed*. Named accordingly as **fixed bed leaching**. One usage is the extraction of sugar from the sugar beet as shown in Figure 3. This equipment is termed as the *sugar beat diffuser* or *extractor*. The sugar beets are first sliced thinly to produce the so-called *cosettes*. In the vessel, the top part is opened to dump a batch of cosettes inside. Hot water flows through the fixed bed and solubilizes the sugar, leaving at the bottom of the vessel. A countercurrent configuration of multiple sugar beat diffusers is called a *Shanks system*.

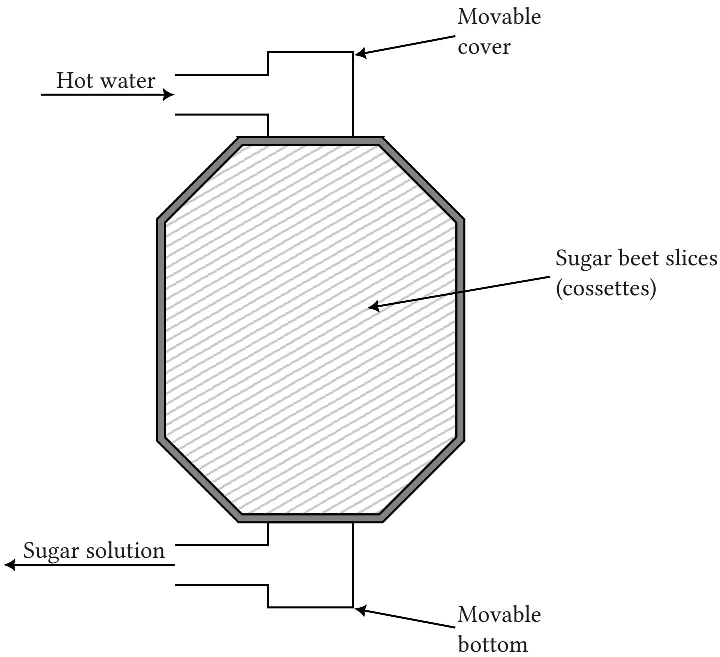

Figure 3: Fixed-bed leaching of sugar beets.

For **moving bed leaching**, the bed of solid feed is (duh) moving. An example is the Bollman bucket-type extractor as shown in Figure 4. The flow of the fesh solvent and the fresh flakes are countercurrent. In the figure above, the solvent is introduced to the left then passes through perforated baskets and extracts some solute from the wet flakes. They exit as the *half miscella* and is recycled again to extract from the fresh flakes and exits as the *full miscella*. The baskets are conveyed in a circular manner akin to a ferris wheel, and the extracted flakes are discarded by flipping the basket over. Another example is the *Hildebrandt extractor* as shown in Figure 5. It is a U-shaped moving bed extractor that consists of screw conveyors. It is configured in a countercurrent manner as the solids are conveyed opposite the direction of the solvent.

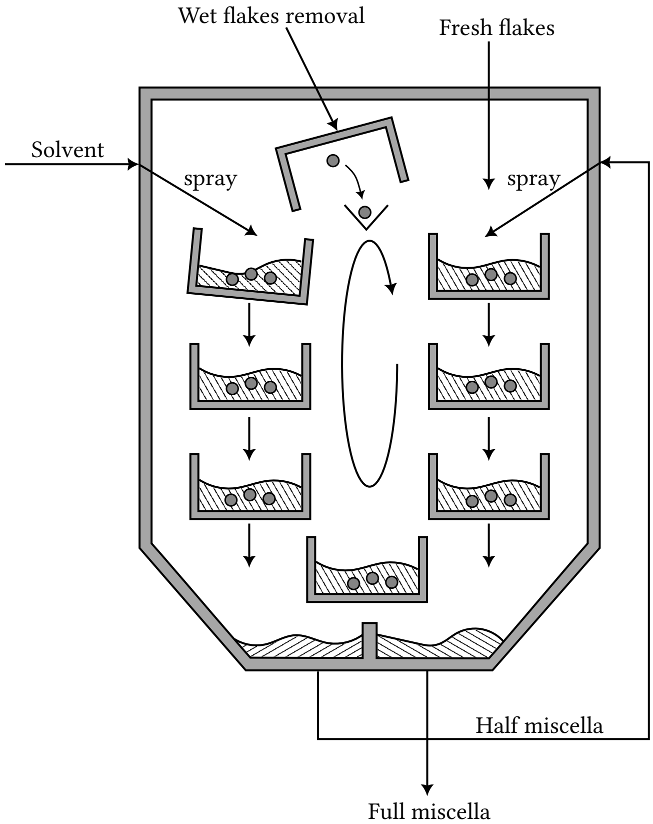

Figure 4: Bollman extractor.

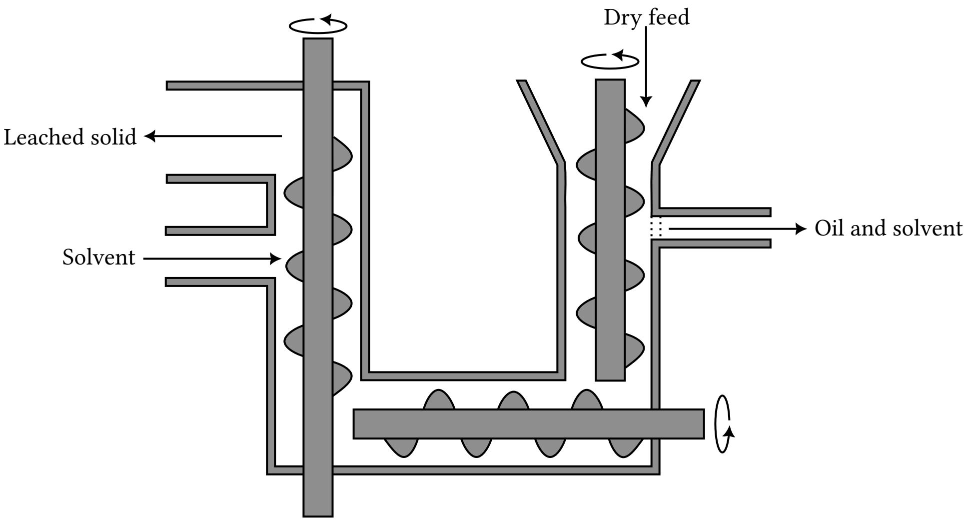

Figure 5: Hildebrandt extractor.

Another type of leaching is the **agitated solid leaching** which is usually done in multiple vessels with common walls such that if there is overflow in one vessel, it will be directed to the other. The slurries exiting the vessels are pumped to the next and the vessels are agitated using slowly rotating *rakes*.

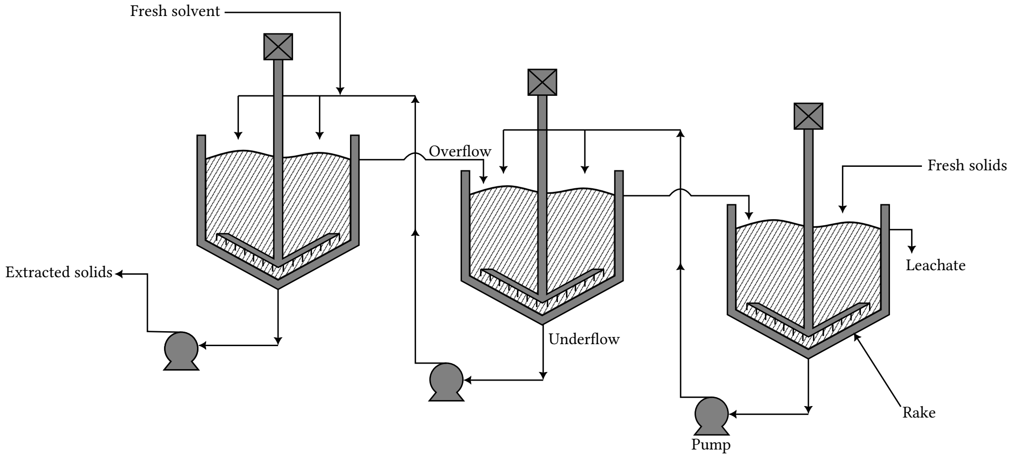

Figure 6: Agitated solid leaching.

1.4. Ideal Leaching

The following assumptions are true for **ideal leaching**:

1. The operating line equations are the material balance equations (neglect leakage)
2. The inert solid is insoluble in the solvent
3. All the solute is dissolved in the first stage.
4. Time is sufficient to dissolve all solute.
5. No solute remains adsorbed onto the inert solid.
6. It is not possible to remove all liquid from the solid.

1.5. Leaching Calculations

1.5.1. Single stage leaching of milled soybean

Find the mass flow rates and composition of the outlet streams of Figure 7

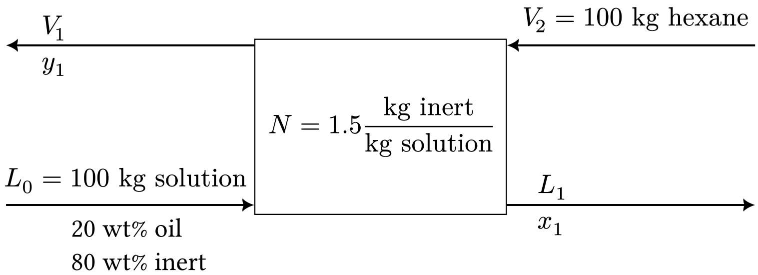

Figure 7: Flowsheet of Section 1.5.1

Solution

1. Calculate L_1 using N.

$$\begin{aligned} L_1 &= 100 \text{ kg} \cdot 0.80 \text{ inert} \cdot \frac{\text{kg solution}}{1.5 \text{ kg inert}} \\ &= 53.33 \text{ kg solution} \end{aligned}$$

2. Do an overall material balance, but exclude the inert solids to find V_1.

$$\begin{aligned} L_0 + V_2 &= V_1 + L_1 \\ 20 \text{ kg} + 100 \text{ kg} &= V_1 + 53.33 \text{ kg} \\ V_1 &= 66.67 \text{ kg solution} \end{aligned}$$

3. Do an oil balance. From Section 1.4, $x = y$.

$$L_0 \cdot 0.2 = V_1(x) + L_1(x)$$
$$100 \cdot 0.2 = 66.67 \cdot x + 53.33 \cdot x$$
$$x = y = 0.167 \frac{\text{kg oil}}{\text{kg solution}}]$$

1.5.2. Single stage leaching of soybean slurry

Find the composition of the outlet streams of Figure 8

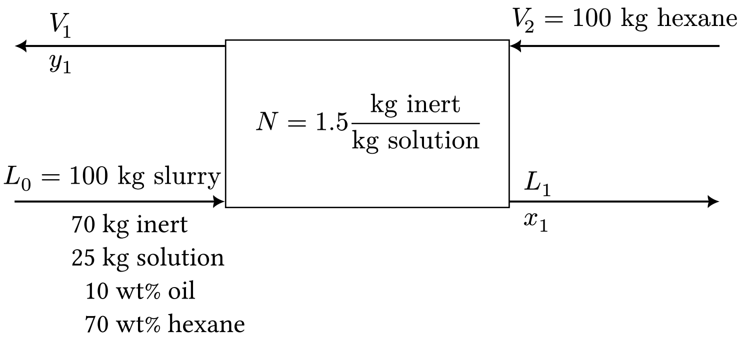

Figure 8: Flowsheet of Section 1.5.2

Solution

1. First, L_1 can be determined using the retention factor N and the inert solids content of the feed.

$$L_1 = 70 \text{ kg inert} \cdot \frac{\text{kg solution}}{1.5 \text{ kg inert}}$$
$$= 46.67 \text{ kg solution}$$

2. Determine V_1 using an overall material balance, excluding the inert solids.

$$L_0 + V_2 = L_1 + V_1$$
$$V_1 = 25 + 100 - 46.67$$
$$= 78.33 \text{ kg solution}$$

3. Determine the product concentrations using $x_1 = y_1$, and a solute balance.

$$x_0 L_0 = x_1 L_1 + y_1 V_1$$
$$x_1 = \frac{x_0 L_0}{L_1 + V_1}$$
$$= \frac{0.1 \cdot 25}{46.67 + 78.33}$$
$$= 0.02 \frac{\text{kg oil}}{\text{kg solution}}$$

Therefore the concentrations of the overflow and the underflow are 0.02.

1.5.3. Leaching of Neem seeds

Find the percent of neem seed oil recovered from.

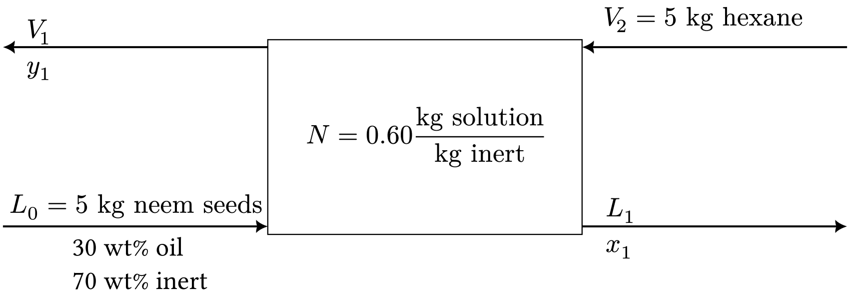

Figure 9: Flowsheet of Section 1.5.3

Solution

$$
\begin{aligned}
L_1 &= 5 \cdot 0.7 \cdot 0.60 \\
&= 2.1 \text{ kg solution}
\end{aligned}
$$

$$
\begin{aligned}
5 \cdot 0.3 + 5 &= 2.1 + V_1 \\
V_1 &= 4.4 \text{ kg solution}
\end{aligned}
$$

$$
\begin{aligned}
5 \cdot 0.3 &= 2.1 \cdot x + 4.4 \cdot x \\
x &= y = 0.2308
\end{aligned}
$$

$$
\begin{aligned}
\% \text{ recovery} &= \frac{4.4 \cdot 0.2308}{5 \cdot 0.3} \\
&= 67.69\%
\end{aligned}
$$