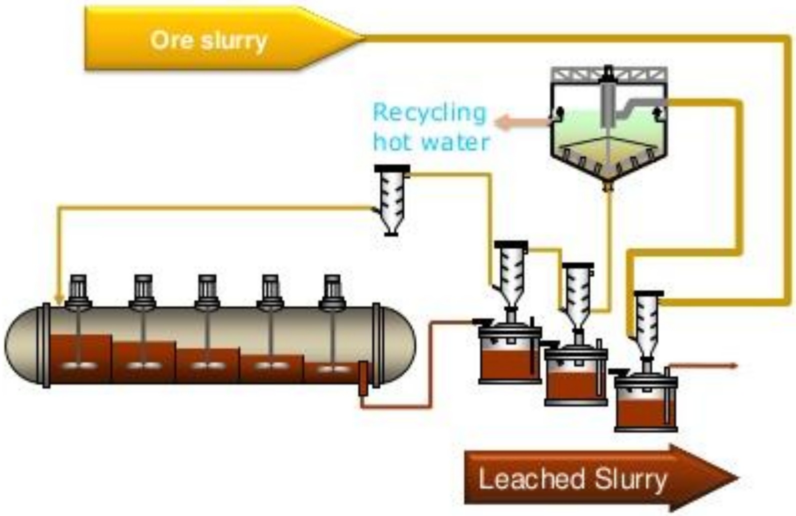
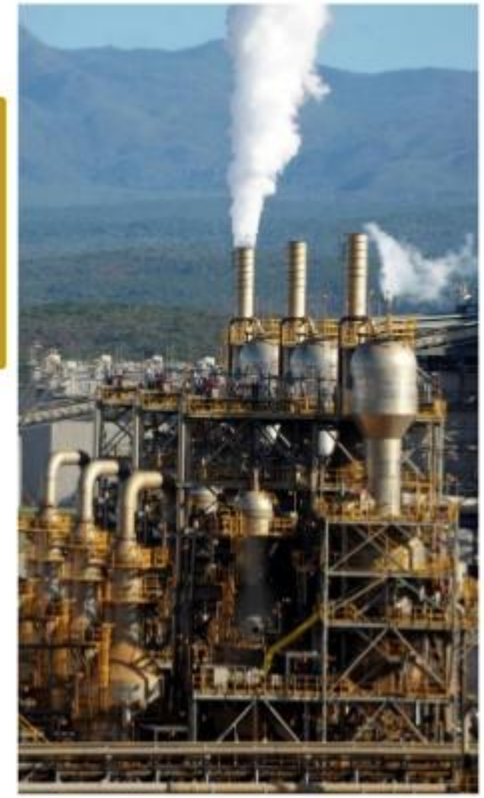
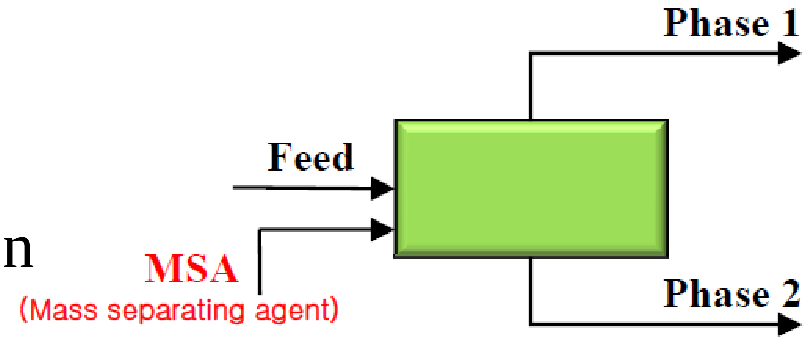
Leaching





Principal reference: Chapter 12 in C.J. Geankoplis book.

Overview and definitions



Based on phase-addition

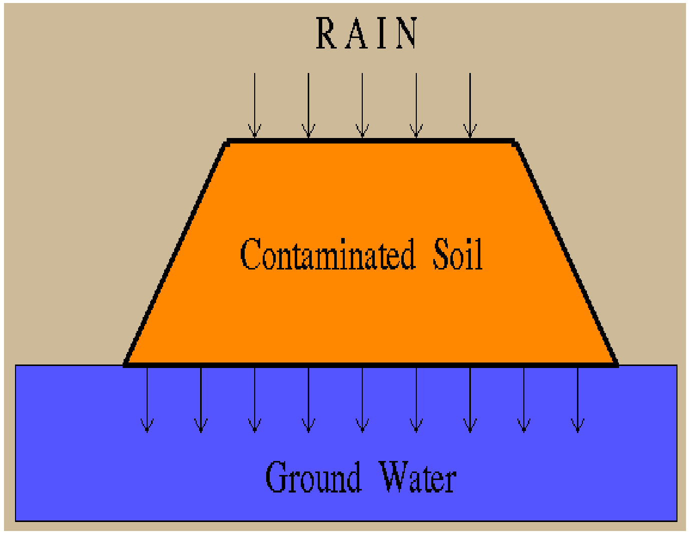
- Leaching is a solid-liquid operation

- Also called **Solid-liquid extraction**

- **Leaching:** removing one constituent from a solid by means of a liquid solvent.

- In leaching when undesirable component is removed from a solid with water, the process is called **washing**.

Making coffee from ground coffee beans and tea from tea leaves is an example of leaching process. **(The complex mixture of chemicals that give coffee and tea their odor, taste, and physiological effects are leached from the solid by hot water)**



Overview and definitions

- In leaching, to separate the desired solute constituent or remove the undesirable solute component from the solid phase, **the solid is contacted with a liquid phase**.

- The two phases are in intimate contact and the solute or solutes can **diffuse from the solid to the liquid phase**, which causes a separation of the components originally in the solid.

- The major difference between Leaching and LLE centers about the **difficulty to transport the solid or the solid slurry from stage to stage.**

Overview and definitions

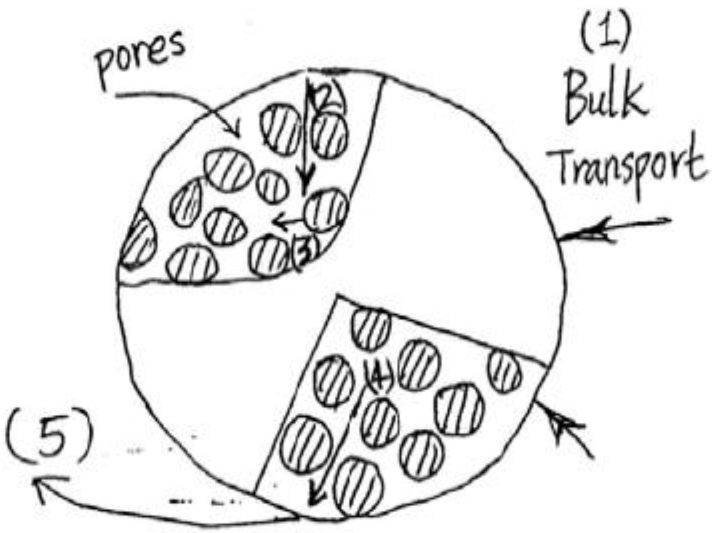
Where leaching is mainly used?

- Leaching widely used under batch, semi–continuous or continuous conditions in ; for example:

1. **Biological and food processing** industries as:
    - Leaching of sugar from sugar beets with hot water.
    - Leaching vegetable oil from peanuts, soybean, sunflower using organic solvents such as hexane, acetone and ether.
    - Many pharmaceutical products are obtained by leaching plant roots, stem, and leaves.

2. **Leaching process for inorganic and organic materials** as:
    - Copper salts are leached from ground ores by sulfuric acid.
    - Gold is leached from its ore using an aqueous sodium cyanide solution.

Principles of leaching



- 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.
2. The solvent penetrates or diffuses into the solid (intraparticle diffusion).
3. The solute dissolves from the solid into the solvent.
4. The solute diffuses through the mixture to the surface of the solid (intraparticle diffusion).
5. The solute is transferred to the bulk solution.

Principles of leaching

- Step 1 and 5 are usually fast. The controlling rate process is generally the **intraparticle diffusion** or the **dissolving step**.
- Intraparticle diffusion is one subject of "Advanced Separation Processes".
- Diffusion through the porous solid can be described by an effective diffusivity.
- **When dissolving step is the controlling process:**

According to Fick's law, the rate of mass transfer of the solute A being dissolved to the solution of volume V is:

$$N_A = k_L A(c_{AS} - c_A)$$

where N_A is kg mol of A dissolving to the solution/s, A is the surface area of particles in m^2, k_L is a mass transfer coefficient in m/s, c_{AS} is the saturation solubility of the solute A in the solution in kg mol/m^3, and c_A is the concentration of A in the solution at time t sec in kg mol/ m^3.

Principles of leaching

- By a material balance, the rate of accumulation of A in the solution is equal to the dissolving flux:

$$\frac{V dc_A}{dt} = N_A = k_L A\left(c_{AS} - c_A\right)$$

Batch System

- Integrating from t = 0 and $c_A = c_{A0}$ to t = t and $c_A = c_A$,

$$\int_{c_{A0}}^{c_A} \frac{dc_A}{\left(c_{AS} - c_A\right)} = \frac{k_L A}{V} \int_{t=0}^{t} dt$$

$$\frac{c_{AS} - c_A}{c_{AS} - c_{A0}} = \exp\left(-\frac{k_L A}{V} t\right)$$

This means that, when **dissolving is the controlling process** the solution approaches a saturated condition **exponentially.**

Preparation of solid for leaching

- **Solid preparation depends on:**
  - The proportion of soluble constituent present.
  - Solute distribution throughout the original solid.
  - The original particles size.

- For example, vegetable and animal materials are cellular in structure and the soluble constituents are generally found inside the cells. The wall cell provide another resistance to diffusion.
  - ✓ The cell walls of soybean are largely ruptured when the material are reduced in size to about 0.1 mm to 0.5 mm.
  - ✓ In leaching of pharmaceutical products from leaves, stems, and roots, drying of the original material rupture the cell walls.

Types of leaching equipments

1. Fixed (stationary) bed leaching

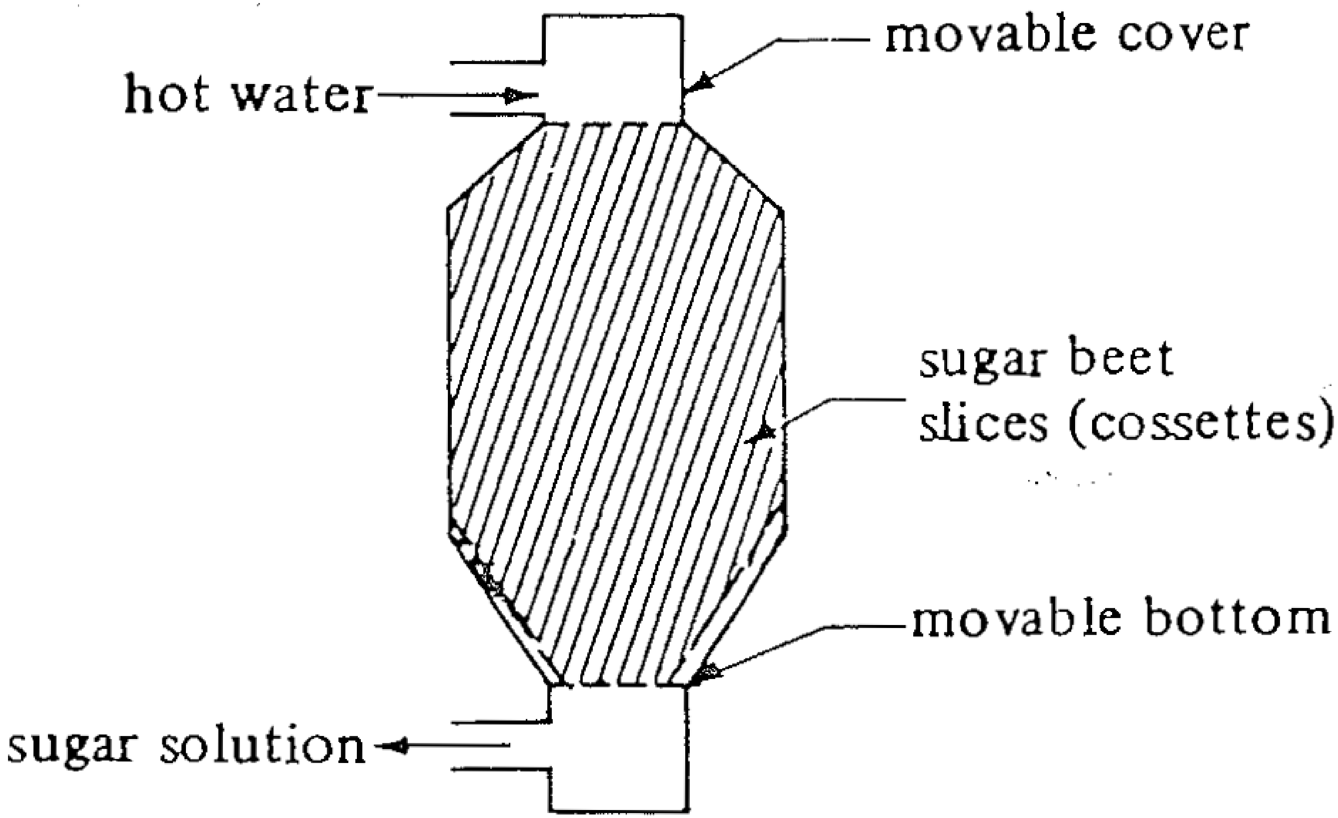


FIGURE 12.8-1. *Typical fixed-bed apparatus for sugar beet leaching.*

Types of leaching equipments

1. Fixed (stationary) bed leaching

▪ It is done in a tank with a perforated false bottom to support the solids and permit drainage of the solvent.

▪ Solids are loaded into the tank, sprayed with solvent until their solute content is reduced to the economical minimum.

▪ In some cases the rate of solution is so rapid that one passage of solvent through the material is sufficient, but **countercurrent flow of the battery of tanks** are more common.

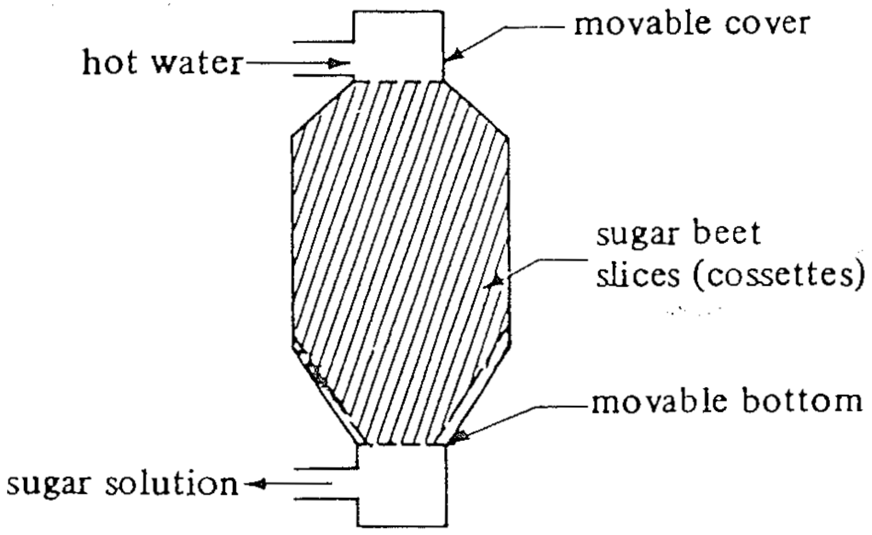
▪ It is used in **beet sugar industry** and is also used for extraction of **tanning extracts from the tanbark**, extraction of **pharmaceuticals from barks** and seeds and other processes.

Types of leaching equipments

1. Fixed (stationary) bed leaching

▪Figure 12.8-1 shows a typical sugar beet diffuser or extractor:

- The cover is removable so that sugar beet slices called ***cossettes*** can be dumped into the bed.
- Heated water at 70-80 °C flows into the bed to leach out the sugar.
- The leached sugar solution flows out the bottom onto the next tank in series (**battery of tanks**) .
- About 95% of the sugar in beets is leached to yield an outlet solution from the system of about 12 wt%.



URE 12.8-1. *Typical fixed-bed apparatus for sugar beet leaching.*

Types of leaching equipments

2. Moving bed leaching

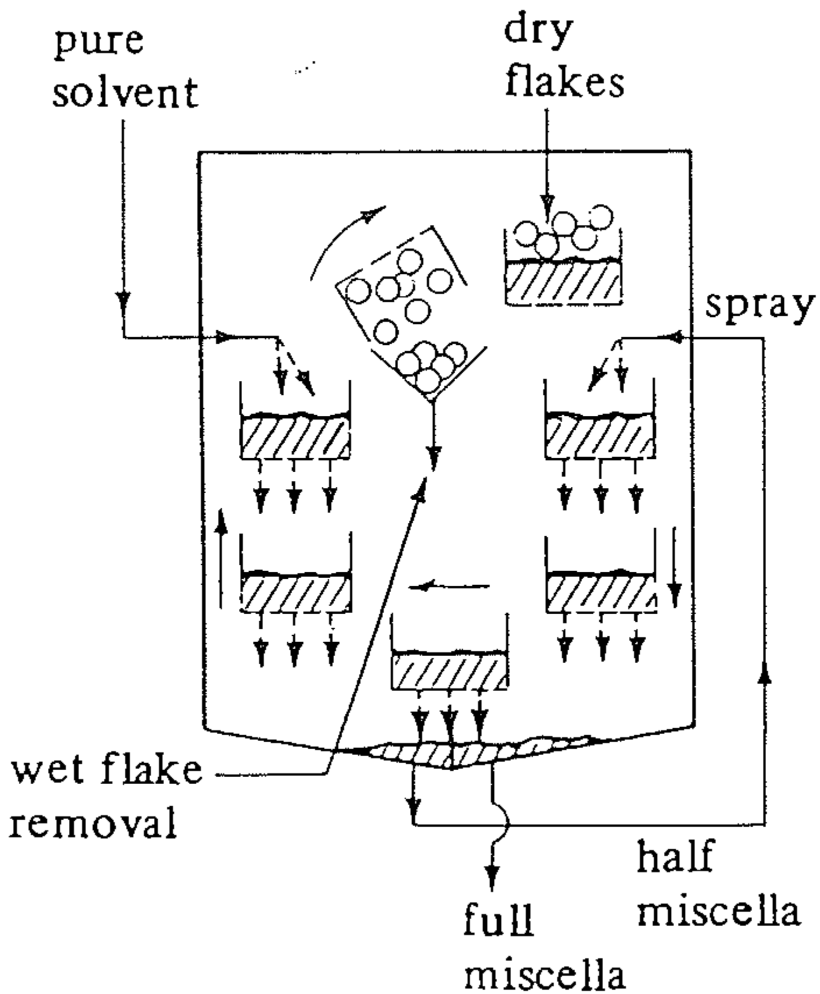
- There are number of devices for stagewise countercurrent leaching where the bed or stages moves.
- Used widely in extracting oil from vegetable seeds such as cottonseeds, peanuts and soybeans.
- The seeds are usually crushed first, sometimes precooked, often partially dried and rolled or flaked.
- The solvents used are particularly hydrocarbons such as hexane and the final solvent – vegetable solution called miscella may contain some finely divided solids.

Types of leaching equipments

2. Moving bed leaching

Bollman extractor:

- It contains a bucket elevator in a closed casing.
- The buckets are loaded with flaky solids such as soybeans.
- The solids are sprayed with appropriate amount of half miscella as they travel downward.
- Half miscella is the intermediate solvent containing some extracted oil and some small solid particles.
- As solids and solvent flow concurrently down the right-hand side of the machine, the solvent extracts more oil from the beans.



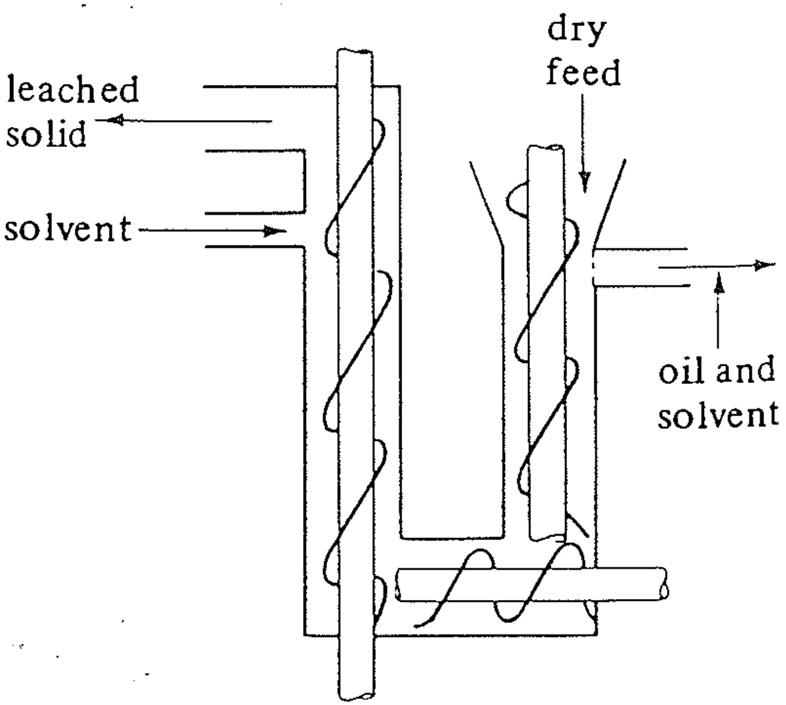
Bollman bucket type extractor

Types of leaching equipments

2. Moving bed leaching

Hildebrandt extractor:

- It consists of three screw conveyors arranged in U shape.
- The solids are charged at the top right, conveyed downward, across the bottom, and then up the other leg.
- The solvent flows counter-currently.



Hildebrandt extractor

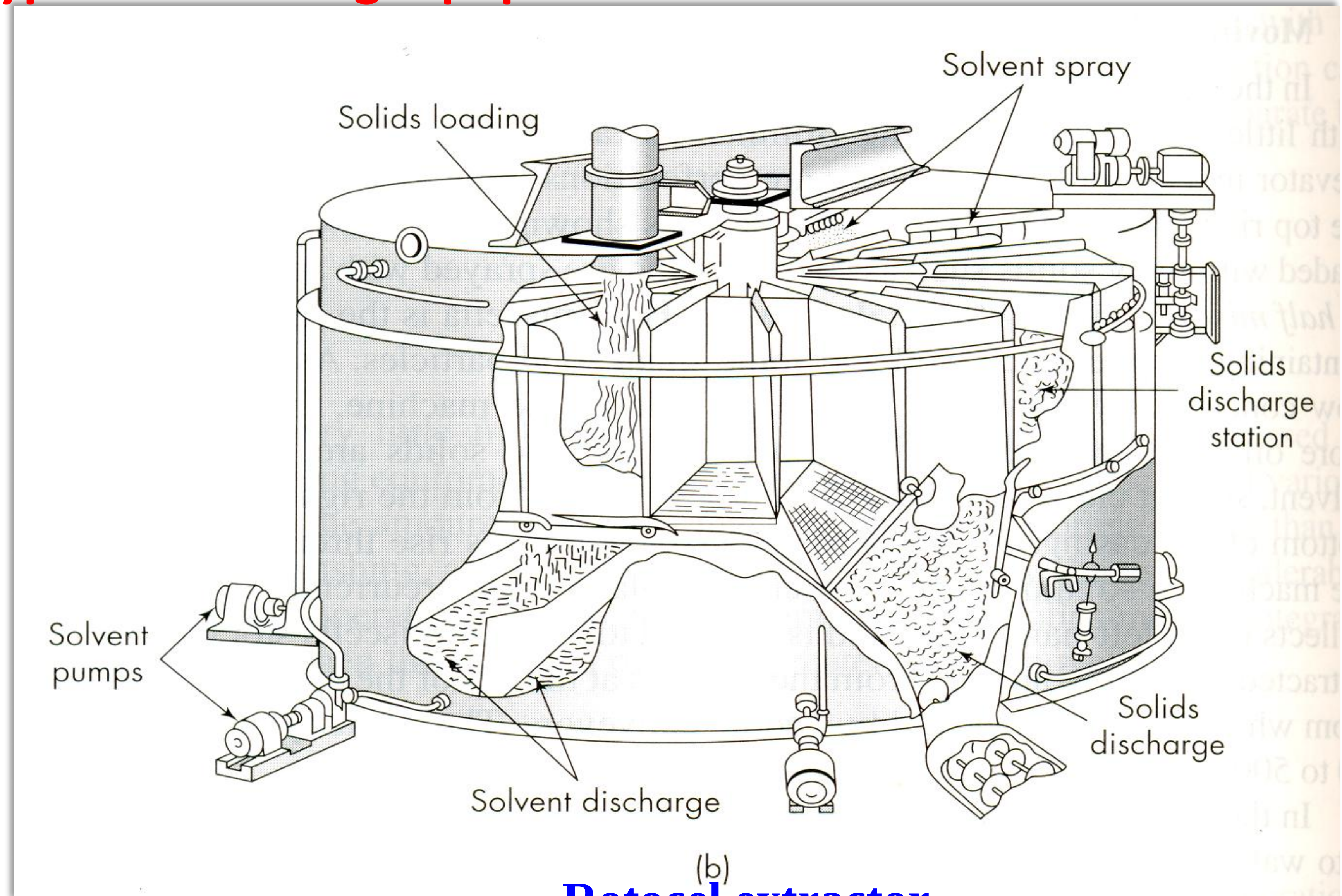
Types of leaching equipments

2. Moving bed leaching

Rotocel extractor:

- Horizontal basket is divided into walled compartments with a floor that is permeable to the liquid.
- The basket rotates slowly about a vertical axis.
- Solid are admitted to each compartment at feed point.
- The compartments then pass a number of solvent sprays, a drainage section and a discharge point.
- To give countercurrent extraction, the fresh solvent is fed only to the last compartment before the discharge point.

Types of leaching equipments



Rotocel extractor

Types of leaching equipments

3. Agitated solid leaching

- When the solid can be ground fine about 200 mesh (0.074 mm), it can kept in suspension by small amounts of agitation.
- Continuous countercurrent leaching can be accomplished by placing the number of agitator in series, with settling tanks or thickeners between each agitator.
- Sometimes thickeners are used as combination contactor – agitators and settlers – shown in Figure 12.8-3.

Types of leaching equipments

3. Agitated solid leaching

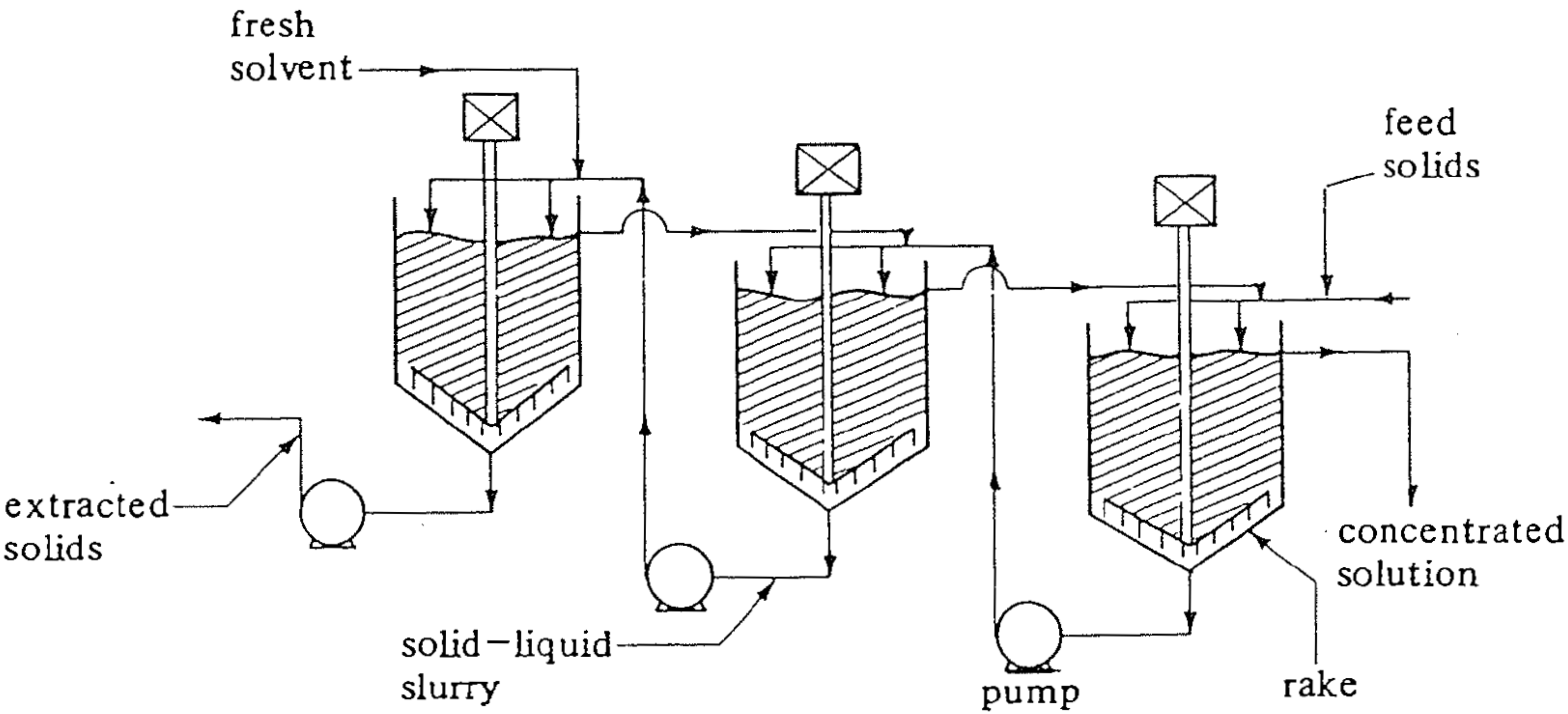
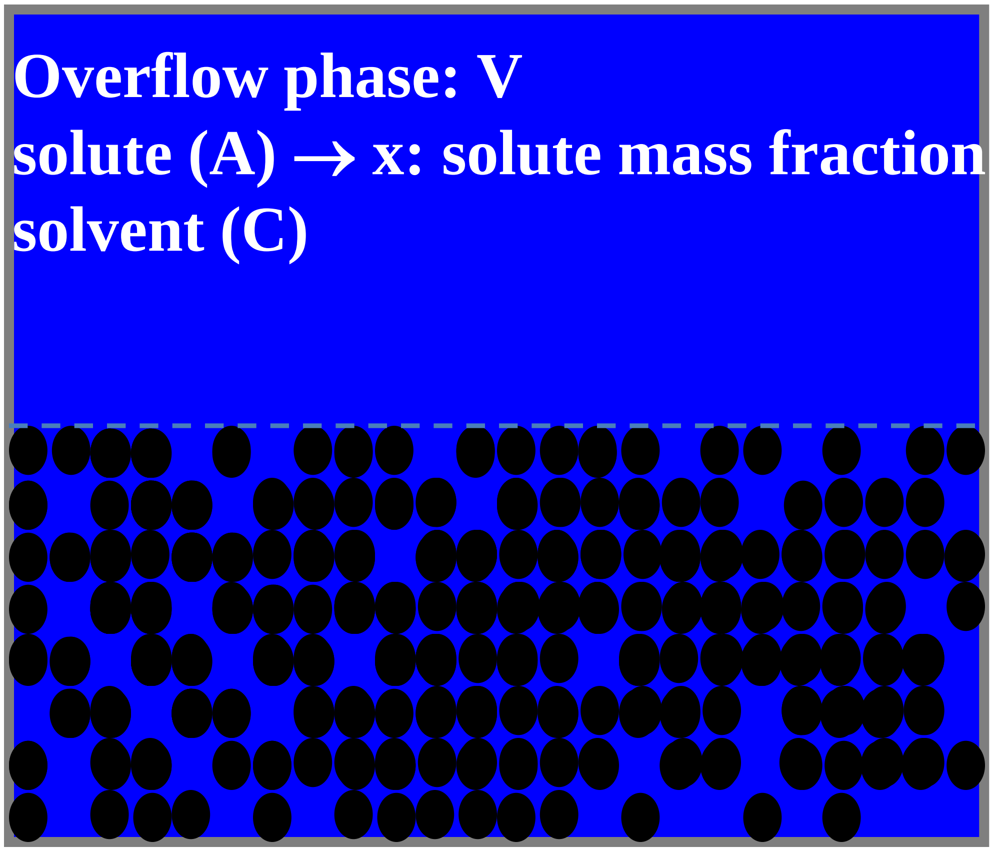


FIGURE 12.8-3. *Countercurrent leaching using thickeners.*

Equilibrium relations in leaching



Underflow or slurry phase: L

solute (A)

y: solute mass fraction

solvent (C)

Inert or leached solid (B)

At certain temperature and pressure

Equilibrium relation in leaching

- **Assumptions made to achieve the equilibrium relations:**
  - Sufficient solvent is present to dissolve solute.
  - No adsorption of the solute by the solid.
  - Sufficient contact time to reach equlibrium.

→Under the above assumptions: the solute concentration in overflow liquid phase is the same as in the settled slurry "underflow" phase. Hence, on an x-y plot, the equilibrium line is on the 45^o line.

Equilibrium phase diagram for leaching

- The concentration of inert or insoluble solid B in the slurry mixture is defined as:

$$N = \frac{\text{kg } B}{\text{kg } A + \text{kg } C} = \frac{\text{kg solid}}{\text{kg solution}} = \frac{\text{lb solid}}{\text{lb solution}}$$

- For the overflow phase (no insoluble solid) $\rightarrow N = 0$
- For the underflow phase, N has dependency upon solute concentration in the liquid. The mass compositions of solute A are defined as :

$$x_A \; or \; x = \frac{\text{kg } A}{\text{kg } A + \text{kg } C} = \frac{\text{kg solute}}{\text{kg solution}} \quad \text{(overflow phase)}$$

$$y_A \; or \; y = \frac{\text{kg } A}{\text{kg } A + \text{kg } C} = \frac{\text{kg solute}}{\text{kg solution}} \quad \text{(slurry or underflow phase)}$$

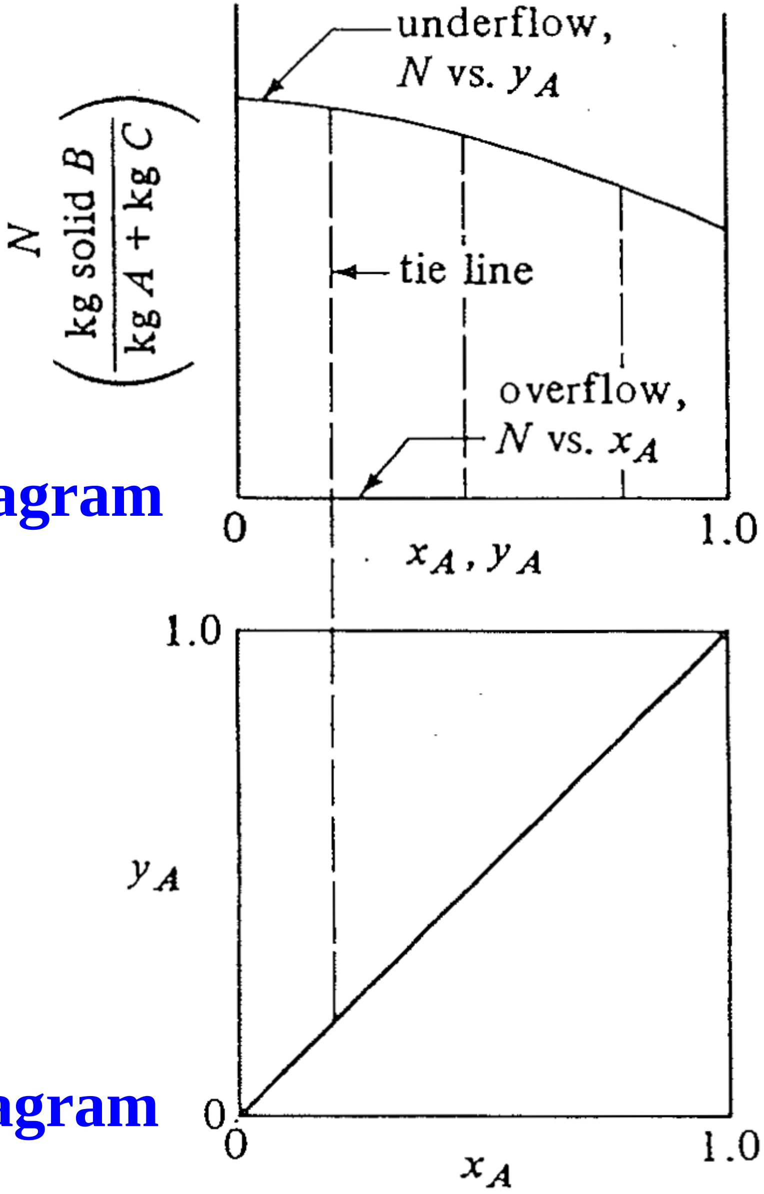
- Remember that at equilibrium: $x_A = y_A$

Equilibrium phase diagram for leaching

- Under the previous assumptions, at equilibrium:
  → y=x, and the equilibrium diagrams will be as shown

N-xy diagram

x-y diagram



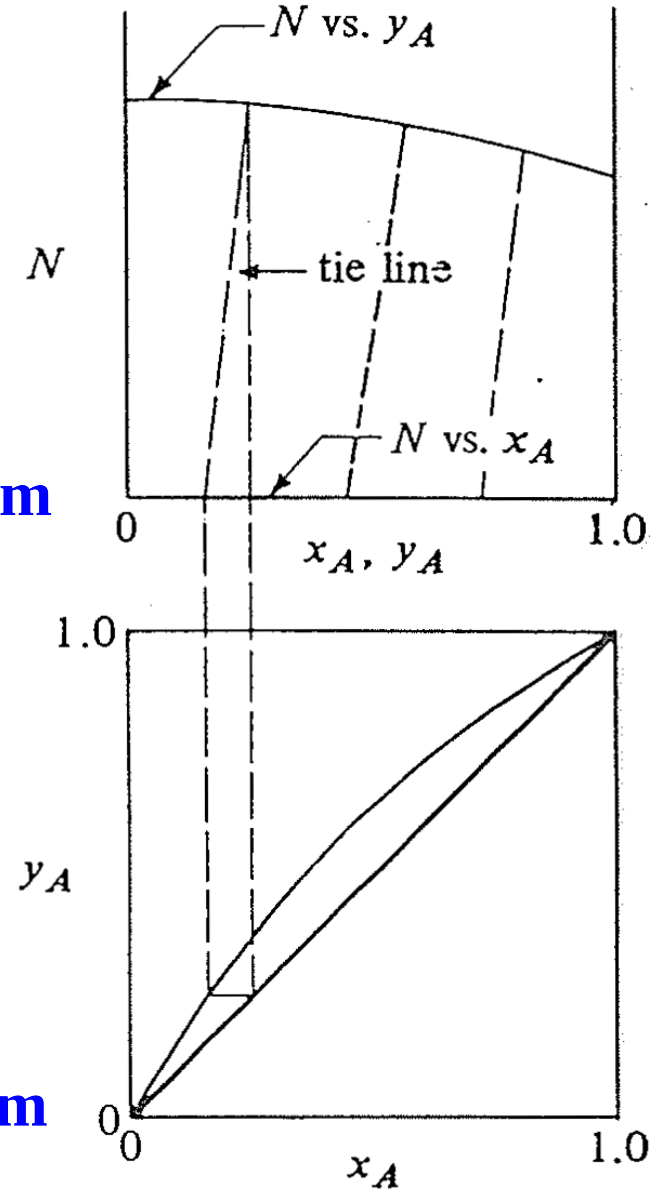
Equilibrium phase diagram for leaching

- If any of previous assumptions did not achieve:

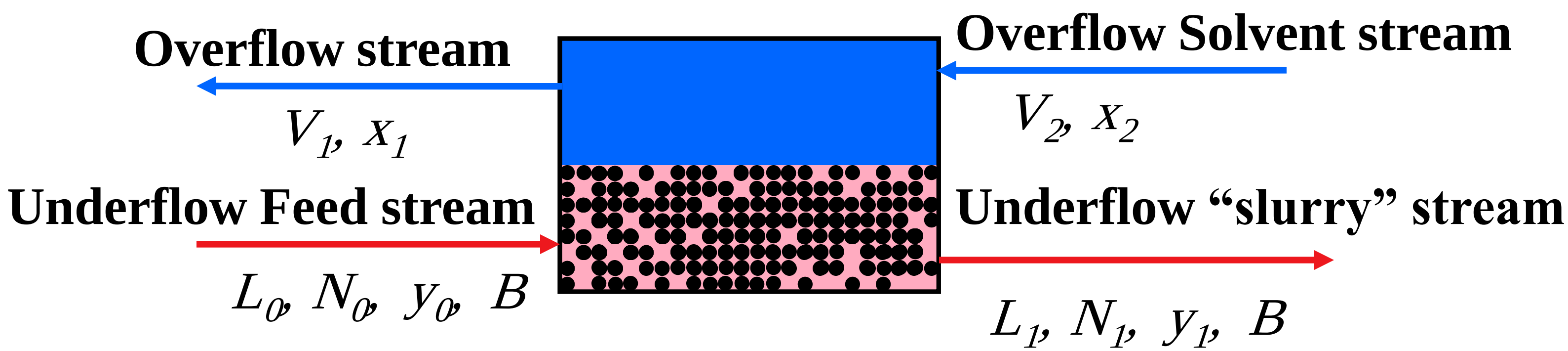
→ y ≠ x (y > x) and the equilibrium diagrams will be as shown

N-xy diagram

x-y diagram



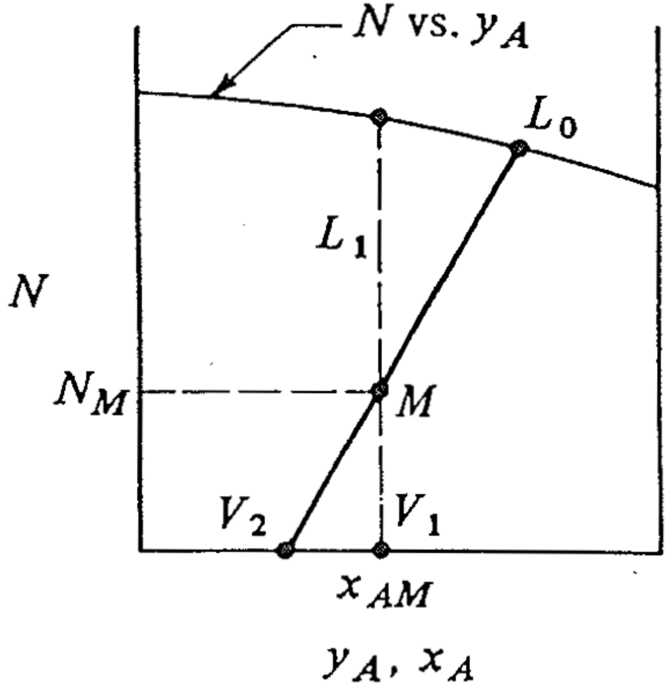
Single stage leaching



V	Mass flow rate of overflow stream (no solid)
L	Mass flow rate of liquid in slurry "underflow" stream
B	Mass flow of dry solid (solute-free solid).
N	=B/L
x	Solute mass fraction in the overflow streams
y	Solute mass fraction in the slurry "underflow" liquid solution

Single stage leaching

- There are three components, thus we can apply three mass balance (MB) equations:



- **Solute and solvent (solution) MB:**

$$L_0 + V_2 = L_1 + V_1 = M$$

- **Solute (A) MB:**

$$y_0 L_0 + x_1 V_2 = y_1 L_1 + x_1 V_1 = x_M M$$

- **Dry solid (B) MB:**

$$B = N_0 L_0 + 0 = N_1 L_1 + 0 = N_M M$$

- **Lever-arm rule can be used as in extraction.**

Single stage leaching

Example. In a single–stage leaching of soybean oil from flaked soybeans with hexane, 100 kg of soybean containing 20 wt% oil is leached with 100 kg of fresh hexane solvent. The mass ratio of insoluble solid to solution for the slurry underflow is essentially constant at 1.5 kg insoluble solid/kg solution. Calculate the amounts and compositions of the overflow and the underflow slurry leaving the stage.

- Feed slurry = 100 kg containing 20 wt% oil
- L_0 = (0.2)100= 20 kg A solute (oil)
- B = (1.0-0.2) 100= 80 kg insoluble solid
- $N_0 = B/L_0$ = 80/20=4.0 kg solid/kg solution (oil)
- Entering pure solvent, V_2 = 100 kg C (solvent), $x_2=0$
- N_1 = 1.5 kg B/kg solution
- L_1 =? ; V_1 =? ; $x_1 = y_1$?

Single stage leaching

Solution using mass balances:

- Total solution balance: $L_0 + V_2 = L_1 + V_1 = M \rightarrow M = 120 \text{ kg}$
- Solute A MB balance: $L_0 y_0 + V_2 x_2 = M x_M$

$$(20)(1.0) + (100)(0) = (120) x_M$$

$$x_M = 0.167 = x_1 = y_1$$

- Solid balance:

$$B = N_1 L_1 = N_M M \rightarrow 80 = (1.5)(L_1) \rightarrow L_1 = 53.3 \text{ kg}$$

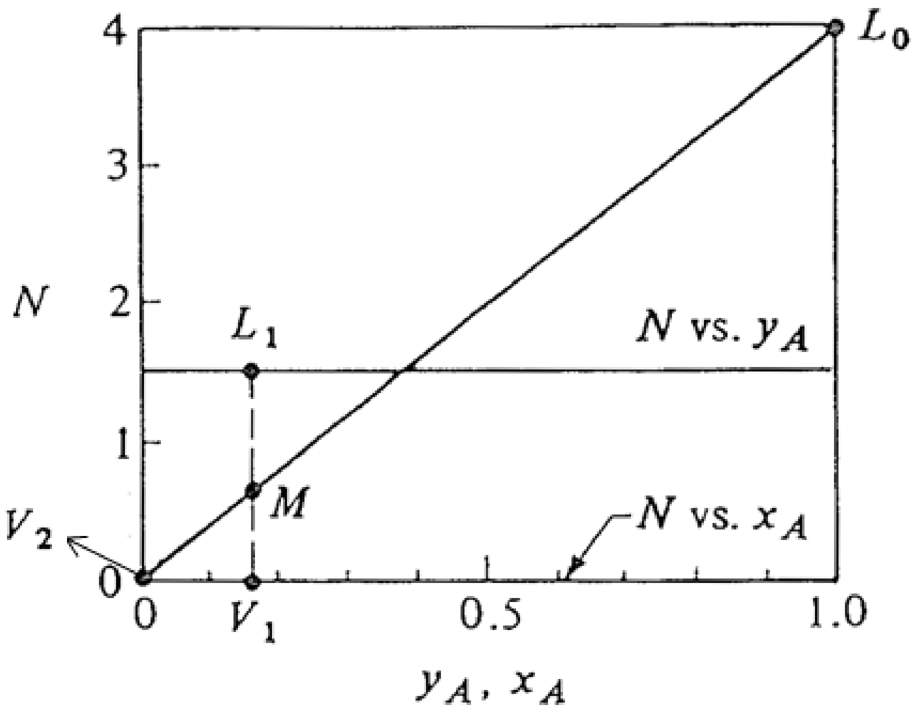
$$V_1 = M - L_1 = 120 - 53.3 = 66.7 \text{ kg}$$

Single stage leaching

Solution using phase diagram and lever rule:

- Draw the N-xy phase diagram
- Locate L_0 and V_2 points on the phase diagram
- $M = L_0 + V_2 = 20 + 100 = 120$ kg solution
- Measure $\overline{L_0 V_2}$
- Lever rule: $\frac{V_2}{M} = \frac{100}{120} = \frac{\overline{ML_0}}{\overline{L_0 V_2}}$
- Draw vertical tie line pass through M
- Lever rule:

$$\frac{V_1}{M} = \frac{V_1}{120} = \frac{\overline{ML_1}}{\overline{L_1 V_1}} = 0.56$$



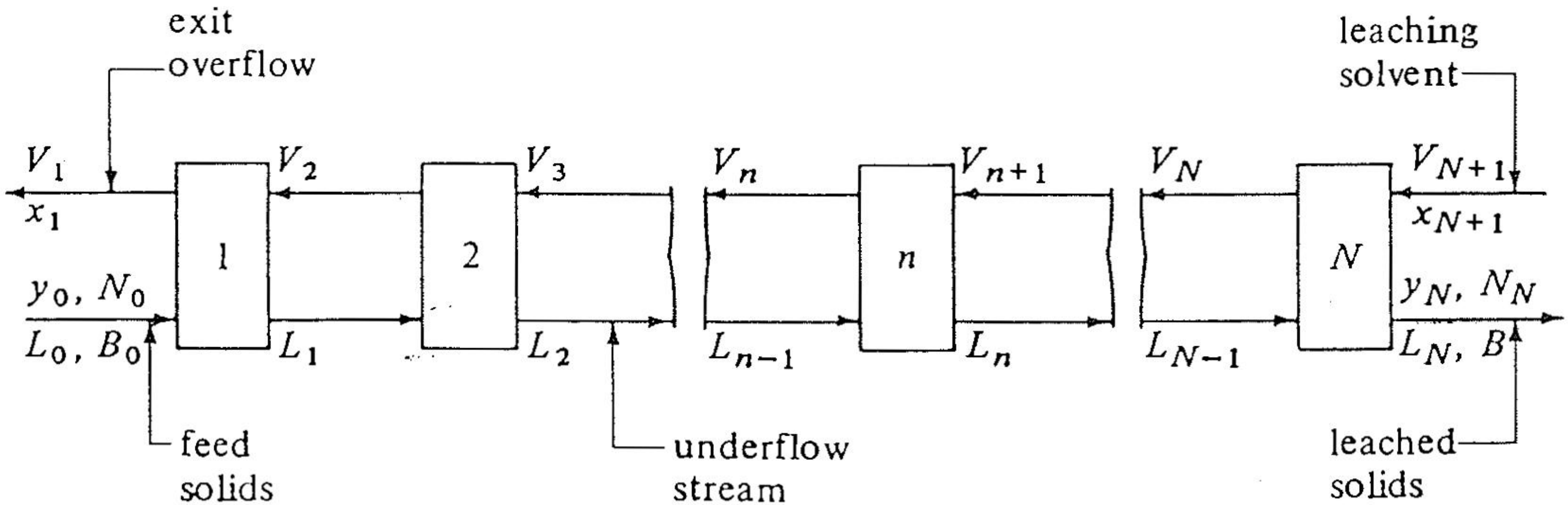
- $V_1 = 67$ kg solution
- Calculate L_1: $L_1 + V_1 = M \rightarrow L_1 = 53$ kg solution
- Read from the equilibrium curve $y_1 = x_1 = 0.16$

Countercurrent multistage leaching

Consider the countercurrent multistage leaching under the conditions:

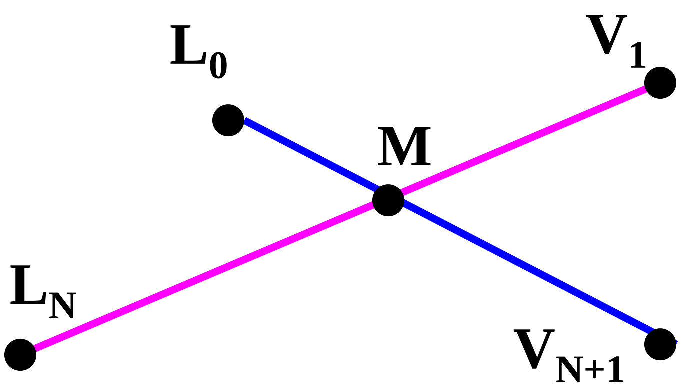
- The ideal stages are numbered in the flow direction of the solids or underflow stream.
- The solvent (C) – solute (A) phase or *V* phase is the liquid phase that overflows continuously from stage to stage counter currently to the solid phase, and it dissolves solute as it moves along.
- The slurry phase L composed of inert solid (B) and liquid phase of A and C is the continuous underflow from each stage.
- Composition of V – denoted by x
- Composition of L – denoted by y
- Assumptions:
  - The solid B is insoluble and is not lost in the liquid V phase.
  - The flow rate of solid is constant throughout the process

Countercurrent multistage leaching



Apply solution mass balance over the overall system:

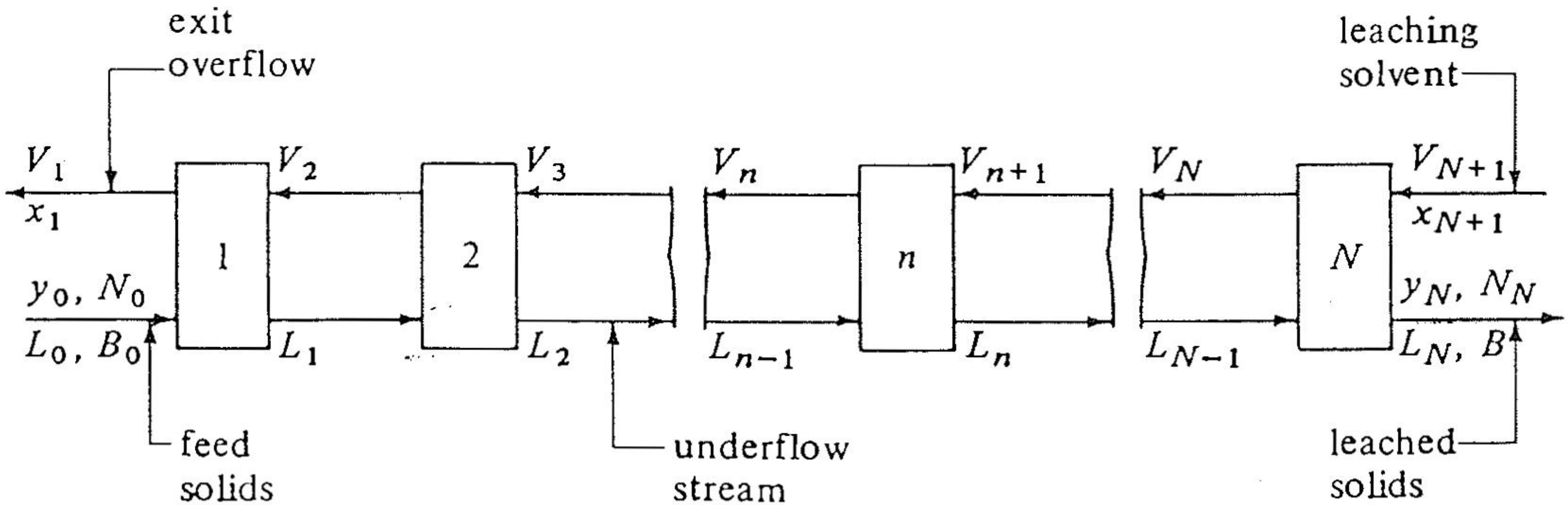
$$L_0 + V_{N+1} = V_1 + L_N = M$$



→Lever-arm rule:

- F, S, and M must located on the same straight line and mixture point M is between F and S.
- E_1, R_N, and M must located on the same straight line and mixture point M is between E_1 and R_N.

Countercurrent multistage leaching

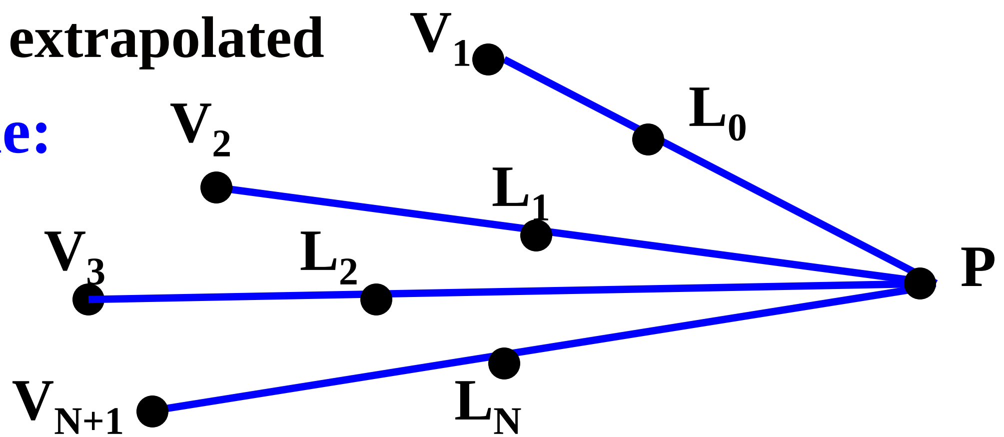


Apply solution mass balance on each stage gives:

$$L_0 - V_1 = L_1 - V_2 = L_2 - V_3 = ... = L_{N-1} - V_N = L_N - V_{N+1} = Constant = P$$

P: operating point is extrapolated

Using Lever-arm rule:



Counter-current graphical solution

General procedure:

1. Connect V_{N+1} and L_0 points with a line.
2. Locate the mixture point M using overall mass balance and lever rule.
3. V_1 is located on the N versus x equlibrium curve (x-axis)
4. L_N is located on the N versus y equlibrium curve.
5. Draw a straight line through M and through V_1 or L_N point. The intersection with the equilibrium curve give the V_1 or L_N point.
6. Locate the operating point P:
   - Connect V_{N+1} through L_N and extrapolate
   - Connect V_1 through L_0 and extrapolate
   - Cross lines at operating point P
6. In general: connect V_n and L_n via equilibrium tie lines.

Counter-current graphical solution

Example. A continuous countercurrent multistage system is to be used to leach oil from vegetable seed meal by benzene solvent (C). The process is to treat 2000 kg/h of inert solid meal (B) containing 800 kg oil (A) and also 50 kg benzene (C). The inlet flow per hour of fresh solvent mixture contains 1310 kg benzene and 20 kg oil. The leached solids are to contain 120 kg oil. Equilibrium data are tabulated below as N kg inert solid B/kg solution and y_A kg oil A/kg solution. Calculate the amounts and concentrations of the stream leaving the process and number of stages

N	y_A	N	y_A
2.00	0	1.82	0.4
1.98	0.1	1.75	0.5
1.94	0.2	1.68	0.6
1.89	0.3	1.61	0.7

Counter-current graphical solution

N=?; L_0=?; y_0 =?, L_N=?; y_N =?;V_1=?; x_1 =? ; V_{N+1}=?; x_{N+1} =?

Solution:

- B = 2000 kg/h of inert solid meal
- L_0=800+50=**850 kg solution/h**
- N_0=B/L_0=2000/850=2.35 kg B/kg solution
- y_0=800/850=**0.941 kg A/kg solution**
- V_{N+1}=1310+20=**1330 kg solution /h**
- x_{N+1}=20/1330 = **0.015 kg A/kg solution**
- The leached solids are to contain 120 kg oil:

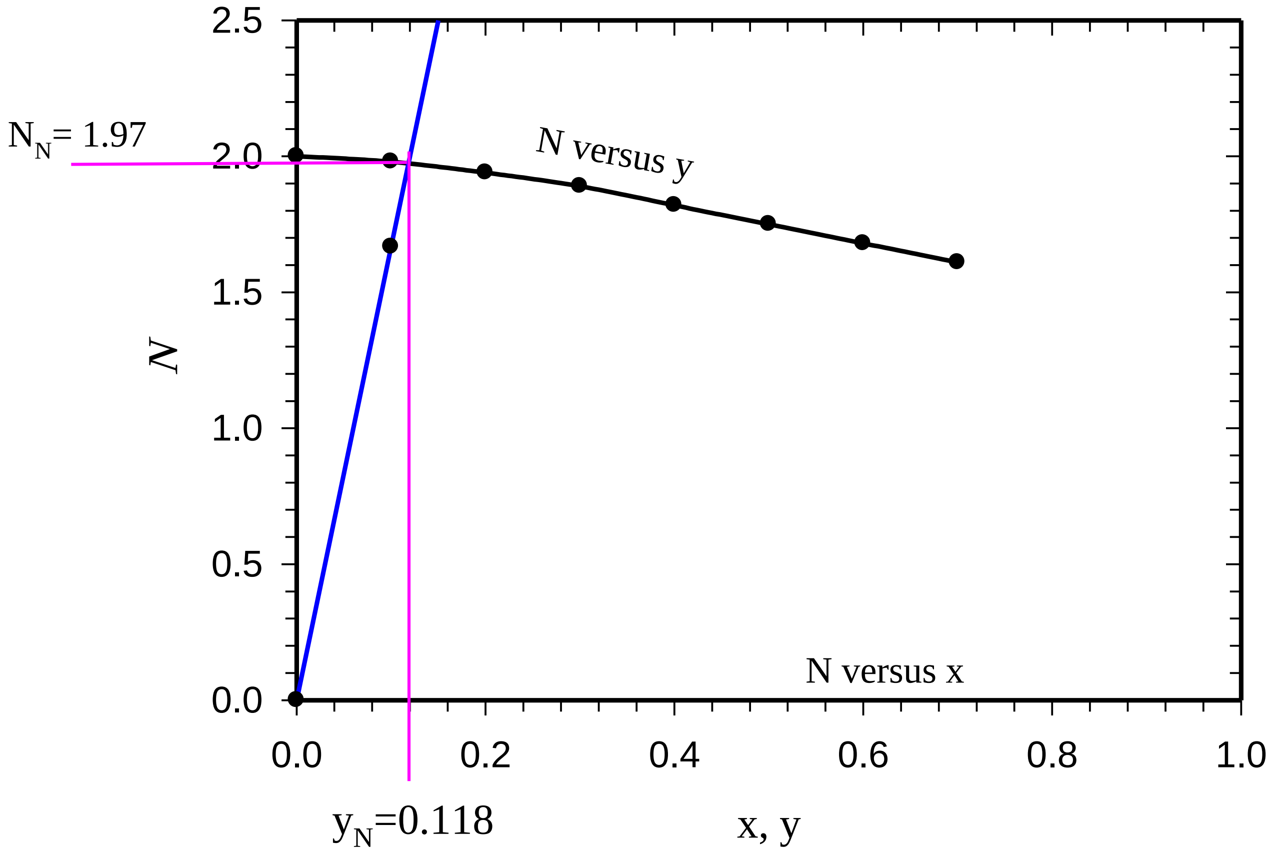
$$N_N = \frac{\text{kg solid}}{\text{kg solution}} = \frac{\text{kg solid/kg solute}}{\text{kg solution/kg solute}} = (\text{kg solid/kg solute})(y_N)$$

$$= (2000/120)\, y_N = 16.67\, y_N$$

- Now draw the equilibrium N versus y curve and line N_N=16.67 y_N. The intersection point locates the point L_N

Counter-current graphical solution

Solution:



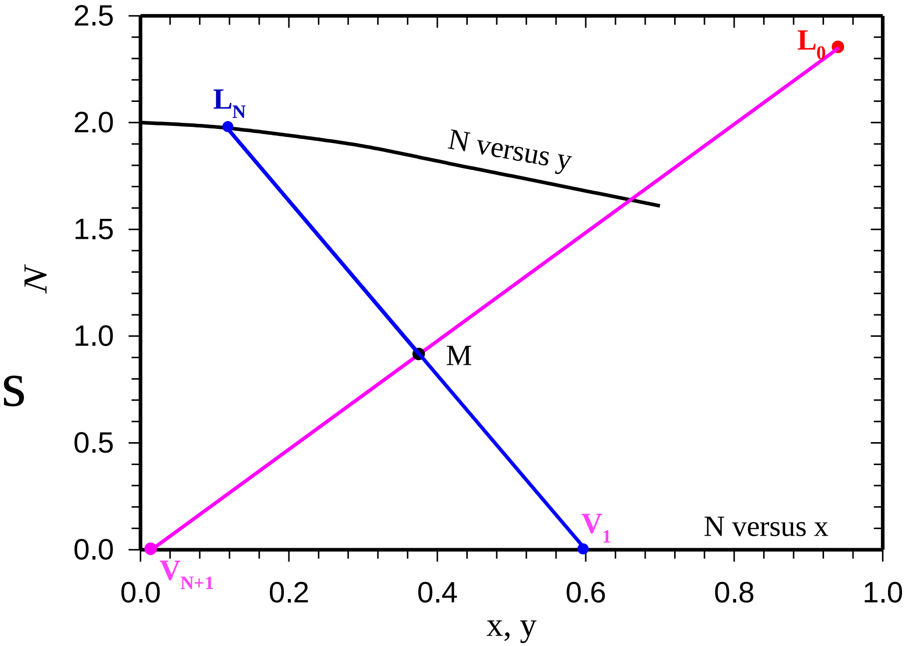
- Thus, the location of L_N is at which, $\mathbf{y_N=0.118}$ and $\mathbf{N_N=1.97}$ kg B/kg solution

Counter-current graphical solution

Solution:

Locate V_1 point using diagram and lever rule:

- L_0=850 kg /h
- V_{N+1}=1330 kg /h
- $M=L_0+V_{N+1}$=2180 kg /h
- Lever rule to locate M point.
- Draw line passes L_N and M
- The intersection with x-axis locate V_1 point: **x_1=0.6**



- **Lever rule:**

L_N =1016 kg/h

$V_1=M- L_N$ =**1164 kg/h**

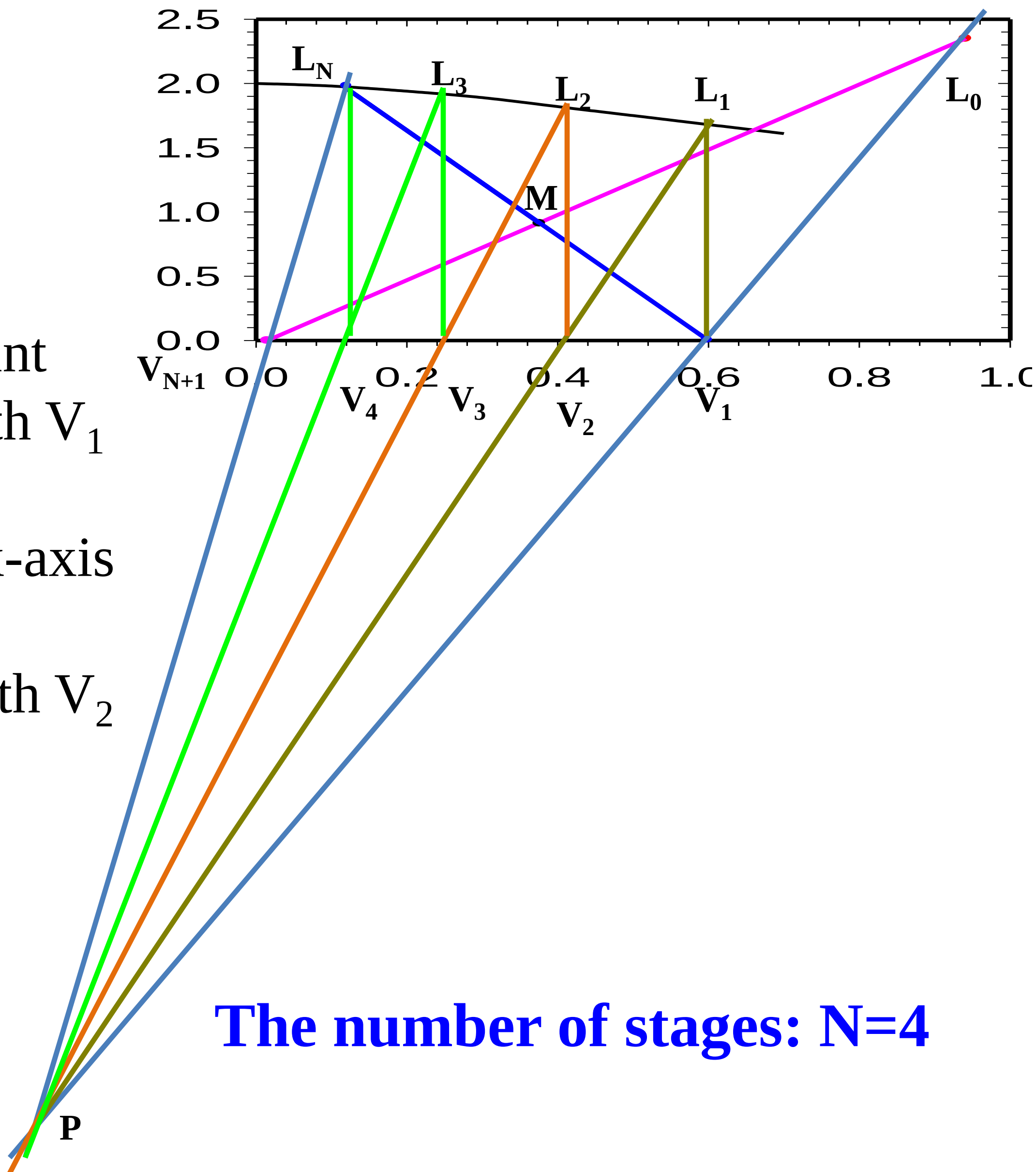
→ **Or locate V_1 point using mass balances over the overall system as done in single stage.**

Counter-current graphical solution

Solution:

To calculate N:

- Draw L_0V_1 line
- Draw L_NV_{N+1} line
- The intersection locate P point
- Locate L_1 in equilibrium with V_1
- Draw PL_1line
- The intersection with x-axis locate V_2
- Locate L_2 in equilibrium with V_2
- Draw PL_2line
- Continue to reach L_n point

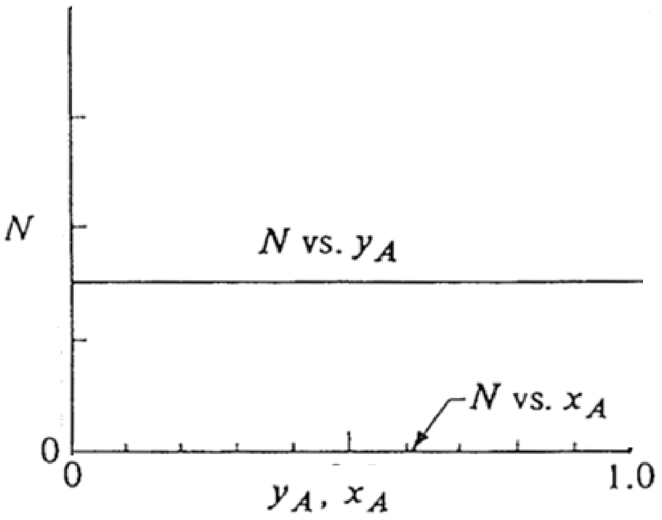


The number of stages: N=4

Counter-current solution using McCabe-Thiele method

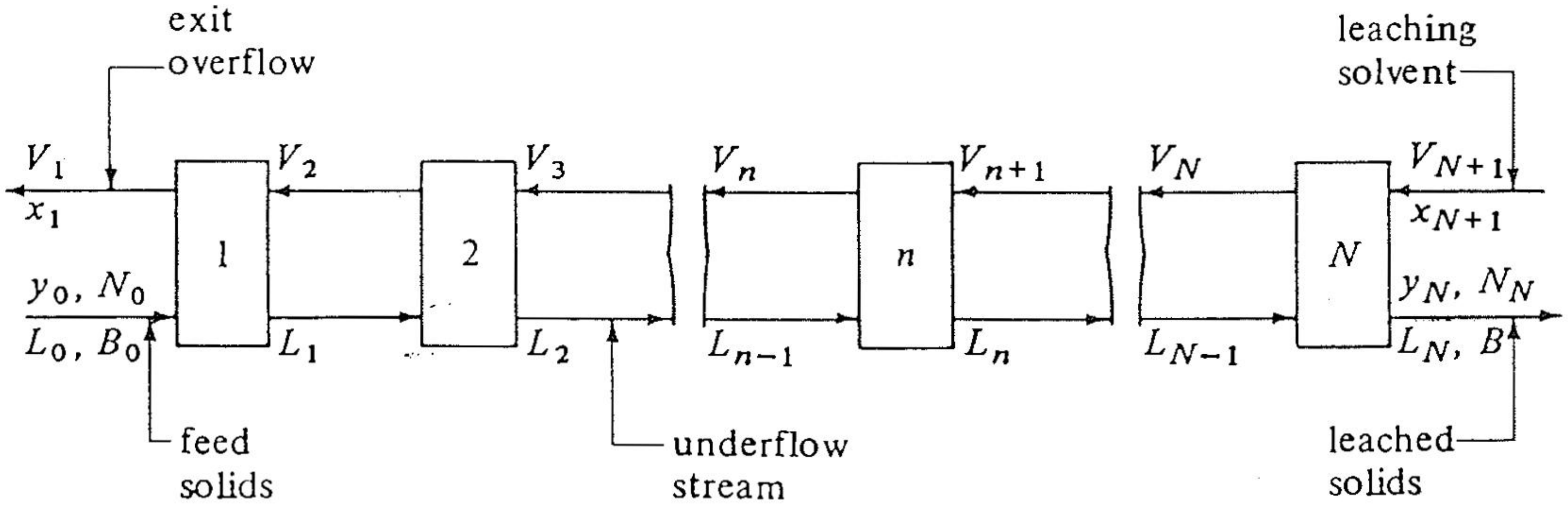
- It is applied in case that L_n and V_n are constant from stage to stage.
- This means that $N_n=B/L_n$ is constant and thus a plot of N versus y_A is a horizontal line.

$$L_0 \neq L_1$$
$$L_1 \approx L_2 \approx .....\approx L_N$$



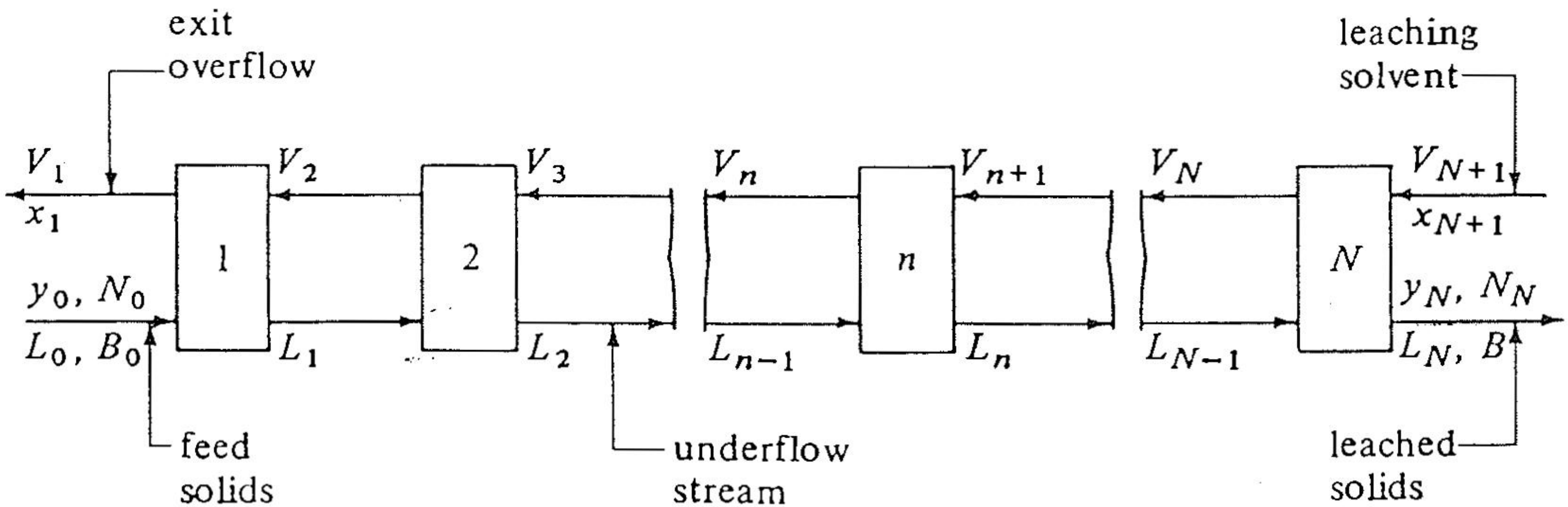
- However, special treatment must be given for the first stage, because L_0 is generally not equal to L_n , since it does NOT contain or contains little solvent. **A separate material balance must be made on stage 1 to obtain L_1 and V_2.**

Counter-current solution using McCabe-Thiele method



- **Solution mass balance over stages 2→n :** $L_1 + V_{n+1} = L_n + V_2$
- **But** $L_0 \neq L_1\ ;\quad L_1 \approx L_2 \approx .... \approx L_N = L = \text{constant}$
- **Thus** $V_2 \approx V_3 \approx .... \approx V_{N+1} = V = \text{constant}$

Counter-current solution using McCabe-Thiele method



- **Applying mass balance for solute A over stages 2→n :**

$$L_1 y_1 + V_{n+1} x_{n+1} = L_n y_n + V_2 x_2 \rightarrow L y_1 + V x_{n+1} = L y_n + V x_2$$

- **Dividing by L and rearranging as:**

$$\boxed{y_n = A x_{n+1} + y_1 - A x_2 \;\; ; n = 2..., N}$$ **Operating line equation**

Slope= $A = V/L$ **Intercept:** $y_1 - A x_2$

Counter-current solution using McCabe-Thiele method

- As in distillation and absorption, the McCabe-Thiele method is used to determine the number of ideal stages by stepping off and counting the number of triangle between the equilibrium line (45^o line) and operating line for stages from (2→N) in the x-y diagram.

- Since operating and equilibrium curves are both straight lines for stages 2→N, **McCabe-Thiele analytical solution** can be used to estimate the number of stages (2→N) from:

$$N-1=\frac{\ln\left[\frac{y_1-x_{N+1}}{y_N-x_{N+1}}\left(1-1/A\right)+1/A\right]}{\ln(A)} \qquad If\ A=V/L\neq 1$$

$$If\ A=V/L=1$$

$$N-1=\frac{y_1-y_N}{y_N-x_{N+1}}$$

Use this method if the difference between L_0 and L_N is large.

Counter-current solution using McCabe-Thiele method

- McCabe-Thiele approximation (from stage 1→N) to estimate the number of stages from:

$$N = \frac{\ln\left[\frac{y_0 - x_{N+1}}{y_N - x_{N+1}}\left(1 - 1/\bar{A}\right) + 1/\bar{A}\right]}{\ln(\bar{A})} \qquad If\ \bar{A} \neq 1$$

$$N = \frac{y_0 - y_N}{y_N - x_{N+1}} \qquad If\ \bar{A} = 1$$

Use this method if the difference between L_0 and L_N is not large.

where

$$\bar{A} = \sqrt{A_1 A_2}$$

(Geometric mean value of A)

and

$$A_1 = V_1 / L_0$$

$$A_2 = V_{N+1} / L_N$$

Counter-current solution using McCabe-Thiele method

Example. Estimate the number of ideal stages in the previous example using

a) McCabe-Thiele analytical approximation (treat first stage separately).
b) McCabe-Thiele analytical approximation (do NOT treat first stage separately).
c) McCabe-Thiele graphical method (treat first stage separately).

The amounts and concentrations of streams entering/leaving the entire process were determined:

- L_0=850 kg /h y_0=0.941
- V_1 = 1164 kg/h y_1=0.6
- V_{N+1} =1330 kg /h x_{N+1}=0.015
- L_N =1016 kg/h y_N=0.118

Counter-current solution using McCabe-Thiele method

a) McCabe-Thiele analytical approximation (treat first stage separately).

- V_1 = 1164 kg/h y_1=0.6
- V_{N+1} =1330 kg /h x_{N+1}=0.015
- L_N =1016 kg/h y_N=0.118

$$A = \frac{V}{L} = \frac{V_{N+1}}{L_N} = 1.309$$

$$N - 1 = \frac{\ln\left[\frac{y_1 - x_{N+1}}{y_N - x_{N+1}}\left(1 - 1/A\right) + 1/A\right]}{\ln A} = 2.8 \rightarrow \boxed{N = 3.8\,\text{stages}}$$

Counter-current solution using McCabe-Thiele method

b) McCabe-Thiele analytical approximation (Do NOT treat first stage separately).

- L_0=850 kg /h y_0=0.941
- V_1 = 1164 kg/h y_1=0.6
- V_{N+1} =1330 kg /h x_{N+1}=0.015
- L_N =1016 kg/h y_N=0.118

$$A_1 = V_1 / L_0 = 1.369$$

$$A_2 = V_{N+1} / L_N = 1.309$$

$$\bar{A} = \sqrt{A_1 A_2} = 1.339$$

$$N = \frac{\ln\left[\frac{y_0 - x_{N+1}}{y_N - x_{N+1}}\left(1 - 1/\bar{A}\right) + 1/\bar{A}\right]}{\ln(\bar{A})} = 3.8\,\text{stages}$$

Same answer since the difference between L_0 and L_N is not too large.

Counter-current solution using McCabe-Thiele method

b) McCabe-Thiele graphical method (treat first stage separately).

- To draw operating line we need (x_2, y_1) and (x_{N+1}, y_N). From previous example:

$y_1 = x_1 = 0.6$

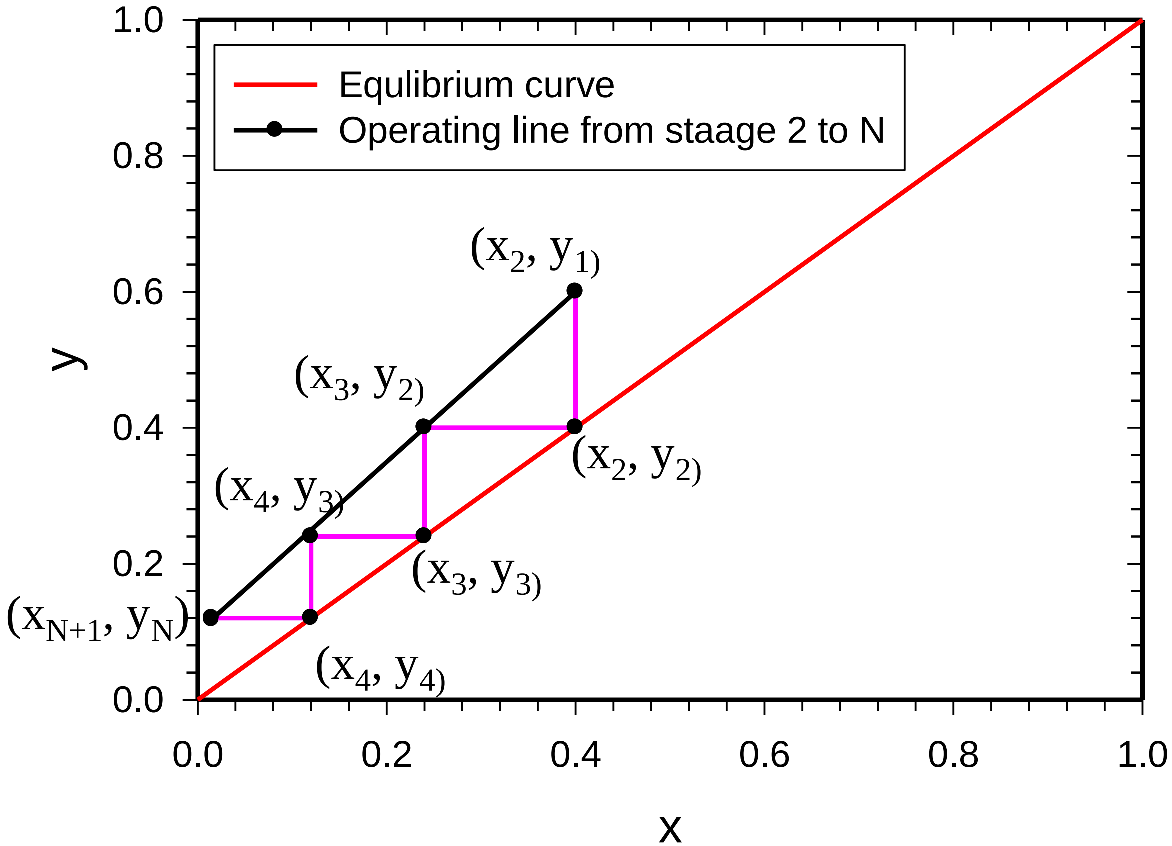
$x_{N+1} = 0.015$

$y_N = 0.118$

- Apply mass balances on first stage to get:

$x_2 = 0.4$

$N = 4 \text{ stages}$



Counter-current solution using McCabe-Thiele method

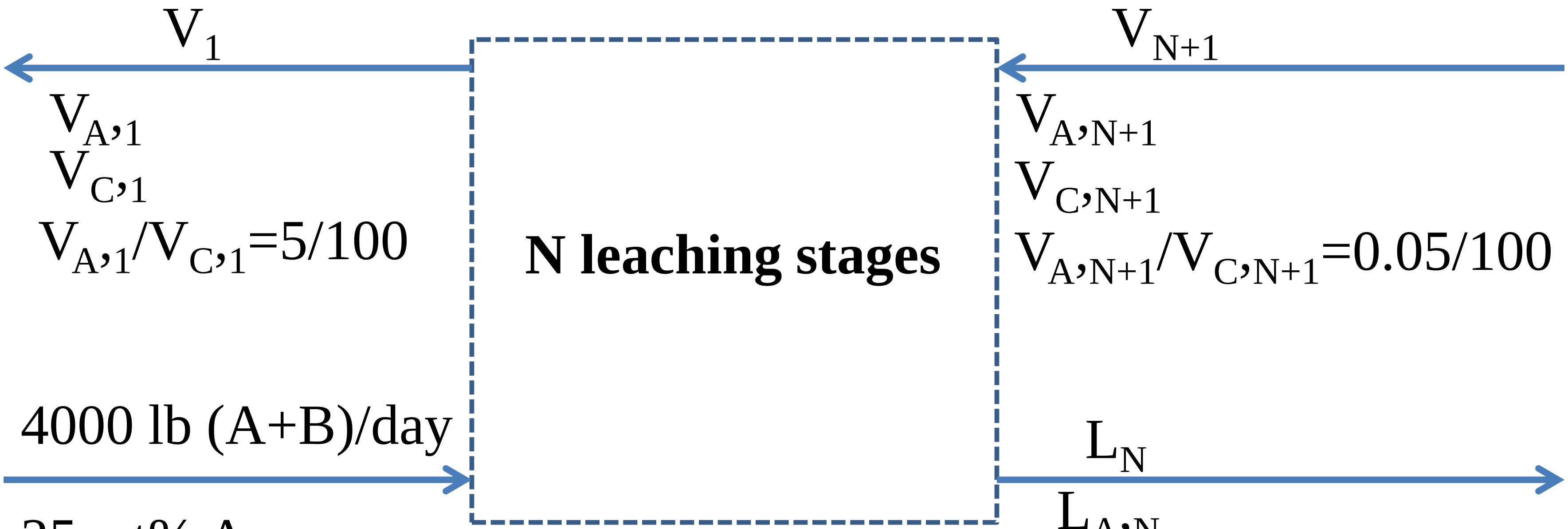
Example. 4000 lb of waxed paper per day is to be dewaxed in a continuous countercurrent multistage leaching. The waxed paper contains, by weight, 25% paraffin wax and 75% paper pulp. The leached pulp is put through a dryer to evaporate the kerosene. The pulp, which retains the unleached wax after evaporation, must not contain over 0.2 lb of wax per 100 lb of wax-free pulp. The kerosene used for leaching contains 0.05 lb of wax per 100 lb of wax-free kerosene. Experiments show that the underflow slurry from each stage will contain 2.0 lb of kerosene per lb of insoluble pulp. The overflow stream from the battery is to contain 5 lb of wax per 100 lb of wax-free kerosene. **How many stages are required?**

Solute A: paraffin wax

Insoluble solid (B): pulp

Solvent C: Kerosene

Counter-current solution using McCabe-Thiele method



25 wt% A

75 wt% B

L_0 = (0.25)(4000)=1000 kg/day

B = (0.75)(4000)=3000 kg/day

$L_{A,N}$ / $L_{B,N}$ = 0.2/100

$L_{C,N}$ / $L_{B,N}$ = 2/1

$L_{A,N}$

$L_{B,N}$

$L_{C,N}$

Counter-current solution using McCabe-Thiele method

V_1 ←

Basis: $V_{C,1}=1$ lb

$V_{A,1}/V_{C,1}=0.05$

$V_{A,1}=0.05$ lb

$x_1=0.05/(0.05+1)=0.0476$

V_{N+1} ←

Basis: $V_{C,N+1}=1$lb

$V_{A,N+1}/V_{C,N+1}=0.05/100$

$V_{A,N+1}=0.0005$ lb

$x_{N+1}=0.0005/(0.0005+1)=0.0005$

→

25 wt% A

75 wt% B

$y_0=1.0$

4000 lb/day

L_N →

Basis: $L_{B,N}=1$ lb

$L_{A,N}/L_{B,N}=0.2/100$

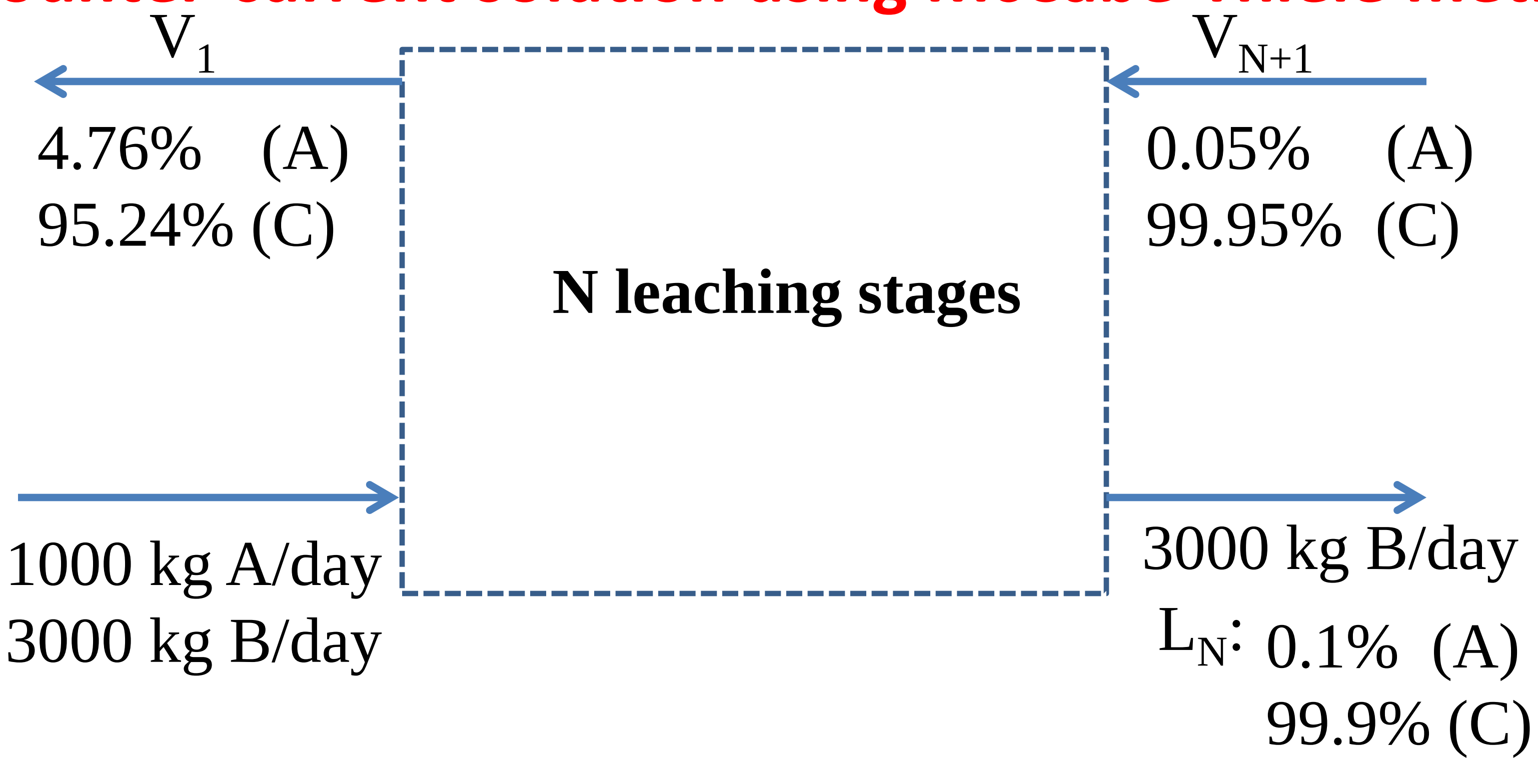
$L_{A,N}=0.002$ lb

$L_{C,N}/L_{B,N}=2/1$

$L_{C,N}=2$ lb

$y_N=0.002/(0.002+2)=0.001$

Counter-current solution using McCabe-Thiele method



- **Other equation:** $0.999\,L_N/3000 = 2 \rightarrow L_N = 6006$ lb/day
- **Solution (A+B) MB:** $1000 + V_{N+1} = V_1 + 6006 \qquad (1)$
- **C MB:** $0.9995V_{N+1} = 0.9524V_1 + (6006)(0.999) \qquad (2)$
- **Solving Eqns. (1) and (2) gives:**

$V_1 = 21147$ kg/day $\qquad V_{N+1} = 26153$ kg/day

Counter-current solution using McCabe-Thiele method

- L_0=1000 kg/day ; y_0= 1.0 ; L_N = 6006 kg/day ; y_N=0.001
- V_{N+1}= 26153 kg/day x_{N+1}=0.0005
- V_1= 21147 kg/day x_1=y_1=0.00476 (in equilibrium)
- N_0=B/L_0= 3 kg B/kg solution
- N_1=…. =N_N=B/L_N= 0.4995 kg B/kg solution

➢ **Since the difference in L_0 and L_N is too large**, first stage must be treated separately:

$$A = V_{N+1} / L_N = 4.354$$

$$N - 1 = \frac{\ln\left[\frac{y_1 - x_{N+1}}{y_N - x_{N+1}}\left(1 - 1/A\right) + 1/A\right]}{\ln A} = 2.8 \rightarrow N \approx 2.3\text{stages}$$