CE407 SEPARATIONS

Lecture 13

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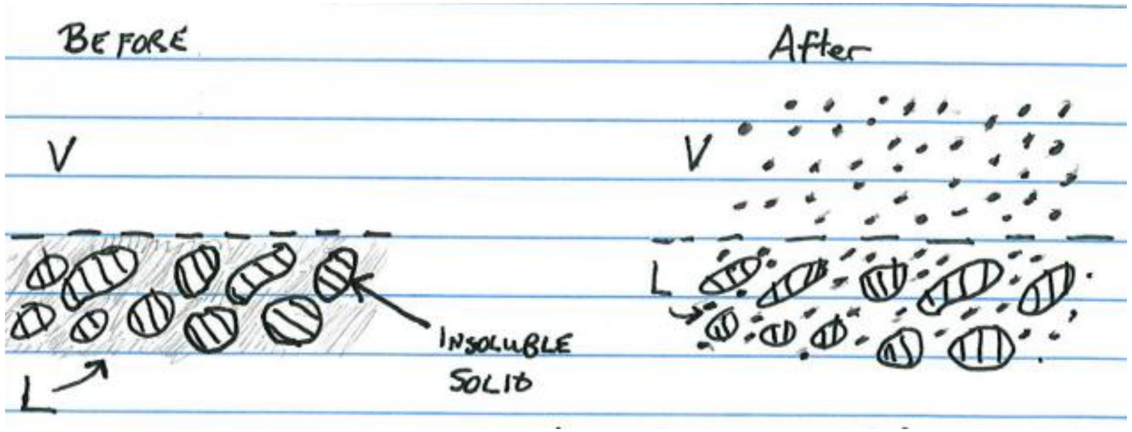
Leaching McSH 764-772

- Using a liquid solvent to dissolve soluble matter from its mixture with an insoluble solid



- **L** and **V** are both liquid phases – no vapor!
  - **L** may be a solid *before* contact with solvent
- **V phase**: Liquid solution that flows out a solid free solution - **"Overflow"**
- **L phase**: Liquid solution that is wetting the surface and/or pores of insoluble solid – **"Underflow"**
  - The insoluble solid is NOT part of **L**
- **L** and **V** are composed of Solvent and Solute

Leaching

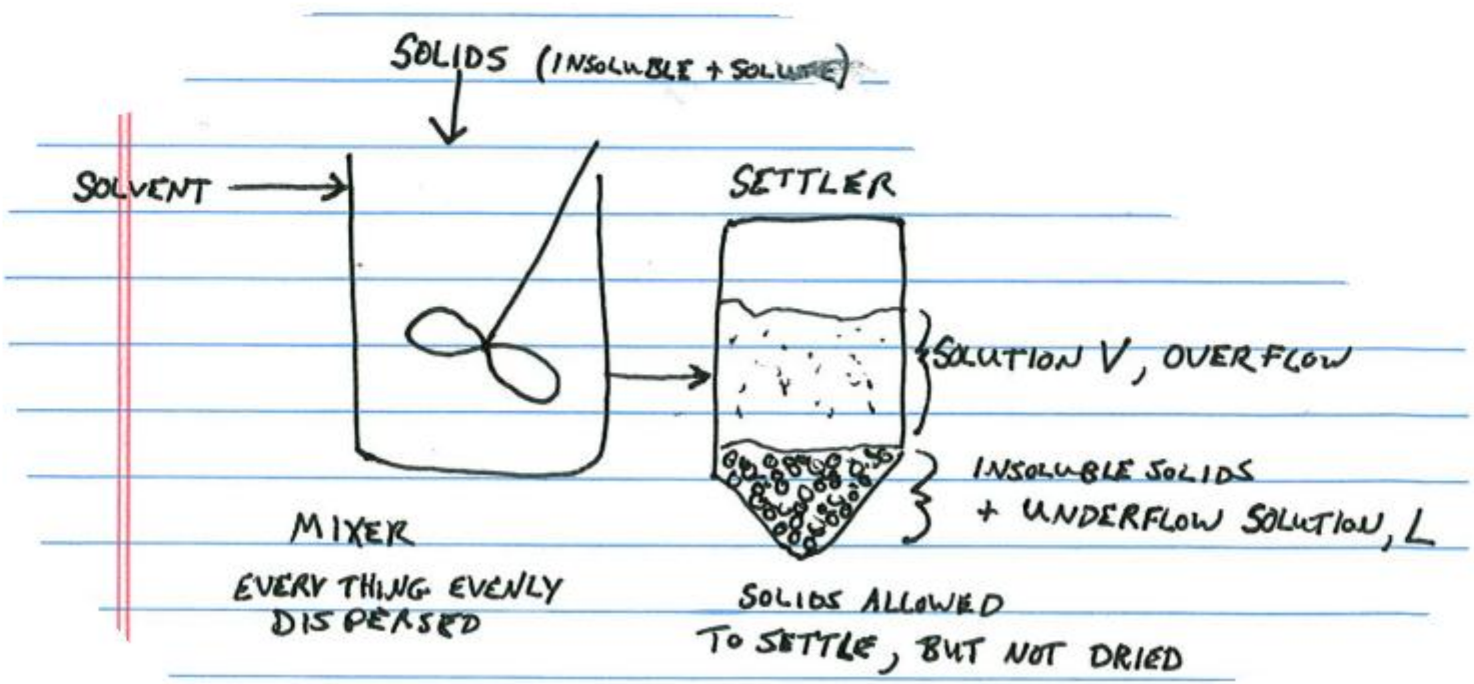
- **Solute**: the material we are trying to remove from the insoluble solid
- **Solvent**: them material we are using to dissolve the solute

Making Tea

- We start with tea leaves:
  - They are composed of insoluble plant fiber (the insoluble solid) and Soluble material that goes into the tea (solute)
- We dip the tea bag into hot water (solvent)
- When we remove the tea bag:
  - Tea in the mug is a solution, **V**, Overflow
  - The tea leaves are wet and have tea solution clinging to them
    - This liquid is the Underflow, **L**
  - The insoluble plant fiber remains in the tea bag and their mass is unchanged – **Insoluble Solid**

Leaching

- Solid and Solvent are introduced into mixer
- **L** phase may 100% solid before introduction of solvent
- During mixing the solid is suspended in the solution and evenly dispersed throughout the vessel
- Suspension is transferred to settling vessel and solids settle out
- Equilibrium Condition
  - Assumes good mixing of vessel contents
  - All one phase (no immiscibility)



- **y** is concentration in **V** phase
- **x** is concentration in **L** phase

$$y = x$$

Units used in Leaching

- In leaching you don't have nice "Clean" chemicals
  - You may have
    - Ore
    - Fish Guts
    - Other odds and ends
- Defining a molecular weight can be a challenge for both the insoluble solids and the solute
  - Solute may be an oil with a distribution of various components
- Therefore Leaching is typically worked out in MASS units (not molar)
- Can define concentration in two different ways:

- In terms of Solution Flow
  - **L** and **V**: Mass flow of SOLUTION
  - **x** and **y**: mass fraction of solute
  - $\frac{mass\ of\ solute}{mass\ of\ solution}$

- In terms of Solvent Flow
  - **L** and **V**: Mass flow of SOLVENT
  - **x** and **y**: mass ratio of solute to solvent
  - $\frac{mass\ of\ solute}{mass\ of\ solvent}$

Units used in Leaching

- In Absorption/Stripping/Distillation we work in molar flow because that is what is applicable to Equilibrium calculations
- In leaching the equilibrium relationship is **x = y**
- We won't be doing equilibrium calculations (and defining MW is a challenge…)

- Mass of solute = **L * x** or **V * y**
  - This is true no matter which convention you choose, but you ***absolutely*** have to use the same convention throughout the calculation!

Leaching

- The insoluble material passes through the equipment unchanged
  - Mass flow of insoluble will be constant throughout the problem
- How much liquid clings to the surface and pores of the solid passing through? (This is the underflow, **L**)
- This would be extremely difficult to predict theoretically
  - It is dependent upon:
    - Surface tension
    - Viscosity
    - Density
    - Surface roughness / pore size of insoluble solid
    - Etc.
- Data is typically determined experimentally

Underflow

- Experimental data may be expressed as:
- $\boldsymbol{mass\ of\ solution/mass\ of\ insoluble\ solid}$

or as

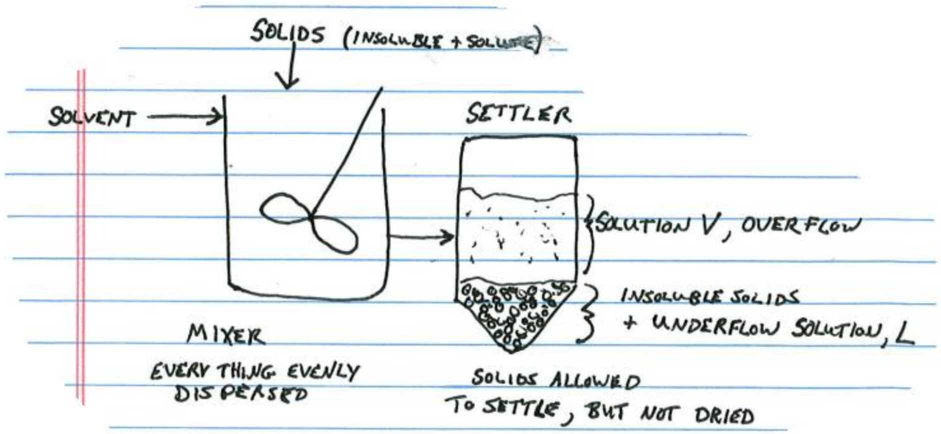
- $\boldsymbol{mass\ of\ solvent/mass\ of\ insoluble\ solid}$
- Example:

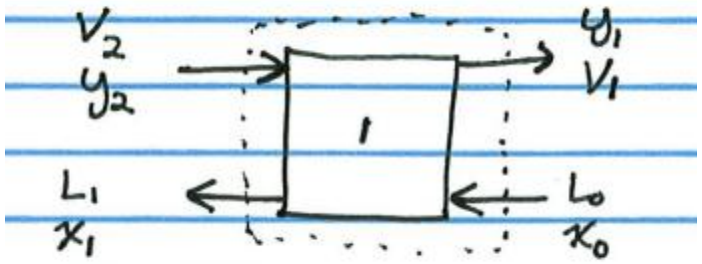
$x = y = {kg\ oil}/{kg\ solution}$	${kg\ solution\ retained}/{kg\ insoluble\ solid}$
0.0	0.0500
0.1	0.0505
0.2	0.0515

- The concentration of the solution affects the viscosity, surface tension, etc and therefore different amounts of solution will cling to the solid
- This data will be very specific to the type of insoluble solid, temperature, etc

Leaching

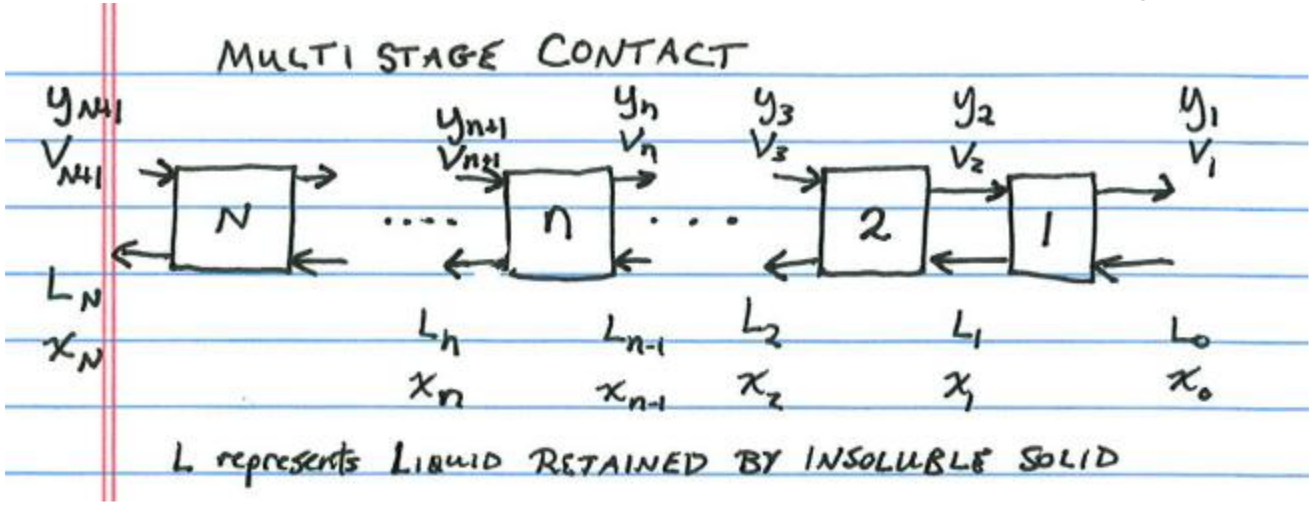
- The equipment shown here
- can be represented like this
- Note: the streams and concentrations are represented with subscripts that indicate what stage they have come ***FROM***
  - This is the same as we are used to from distillation
- Review example 2 from “Leaching More Examples”

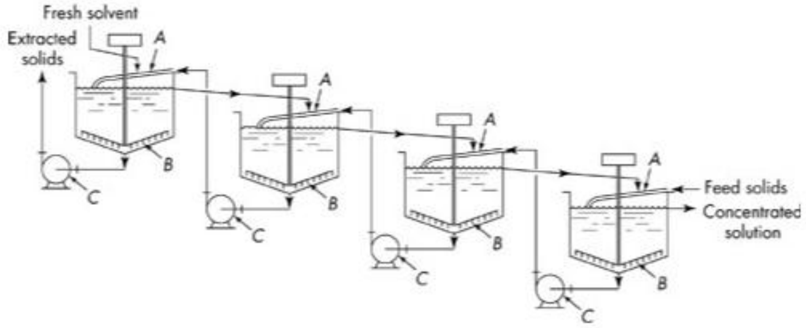




Leaching: Multi-Stage Contact

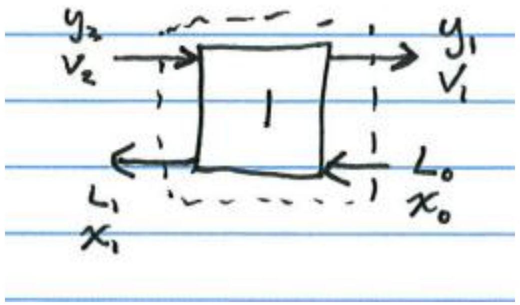
- In order to maximize the amount of solute recovered we use multiple stages
- In this diagram the left hand side is the "clean" side and the RHS is the "dirty" side
- Incoming Solvent stream may be fresh, with $\mathbf{y_{N+1} = 0}$ or it may be recycled
- $\mathbf{V_1}$ often referred to as "Strong Solution"
- Advantage of countercurrent:
  - On LHS where $\mathbf{x_N}$ is relatively small, $\mathbf{y_{N+1}}$ is also at its lowest, providing driving force
  - On RHS where $\mathbf{y_1}$ is at its greatest, $\mathbf{x_0}$ is at its largest, so there is still driving force





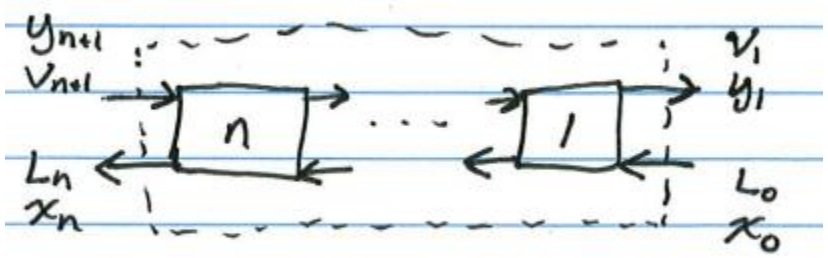
Control Volumes

- There are three control volumes that will prove to be of particular use
- Control volume around stage 1
- Often times raw material coming in has no solvent at all
- If **L** is pure solute, $\mathbf{x_0}$ = 1
- **L** will pick up a very large amount of solvent in this stage
- $\mathbf{L_0}$ and $\mathbf{L_1}$ will be very different

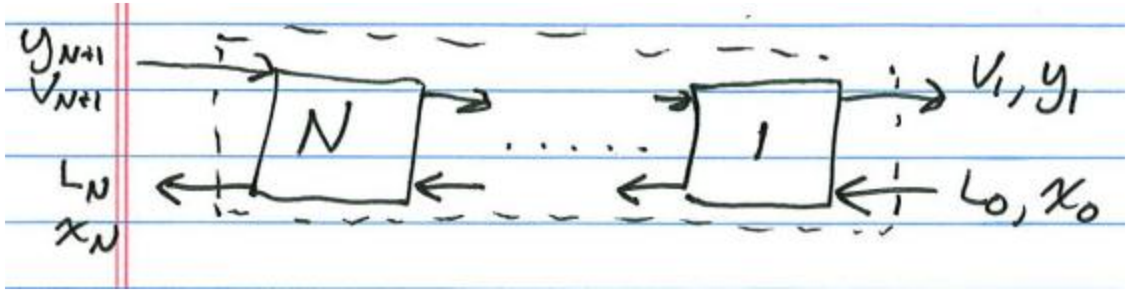


Control Volumes

- Control Volume from beginning of battery up to and including generic stage **n**



- Control Volume around entire battery



How Many Stages Do We Need?

- We can analyze in a similar manner to absorption or distillation
  - Generate an operating line
  - Generate EQ curve
  - Step off stages
- The equilibrium curve is simply $\mathbf{x_n = y_n}$
- However, operating line is very curved and we will need to generate it

Operating Line

- First gather your starting information
  - Feed composition
    - Mass of inert
    - Mass of solute
    - Mass of solvent
  - Fresh Solvent
    - V_{N+1} is usually unknown
    - y_{N+1} will be given
  - Strong Solution (V_1 stream)
    - % recovery of solute
  - Relationship between x_n and amount of solution retained

$x = y = {kg\ oil}/{kg\ solution}$	${kg\ solution\ retained}/{kg\ insoluble\ solid}$
0.0	0.0500
0.1	0.0505
0.2	0.0515

Operating Line – Steps

1. Propagate the information given
   - i.e if it is stated that a 90% recovery of the 0.5 ton of solute
     - 0.45 tons are in the $\mathbf{V_1}$ stream and 0.05 tons are in $\mathbf{L_N}$ stream
   - If given a mass fraction in strong solution then you can calculate the solvent flow and get $\mathbf{V_1}$
2. In general the lack of constant flows prevents one from jumping into the mass balances
   - You need to sort out $\mathbf{L_N}$ by trial and error
   - Guess a value for $\mathbf{x_N}$
   - From step 1 we know how much solute there is
   - $x_N = {mass\ solute_N}/{mass\ solution_N}$
   - Suppose 100 kg of inert and mass balance indicated 1 kg of solute exits stage **N**
     - **Note: this is a different case than the one listed for Step 1!**
   - Guess $\mathbf{x_N}$ = 0.1 Then $\mathbf{L_N}$ = 0.0505 x 100 kg solid = 5.05 kg solution (Value of 0.0505 is read off of table)
   - Now $x_N = \frac{1\ kg\ solute}{5.05\ kg\ solution} = \mathbf{0.198} \neq \mathbf{0.1}$ The guess of $\mathbf{x_N}$ = 0.1 is wrong because it doesn't add up
   - Guess $\mathbf{x_N}$ = 0.19 Then $\mathbf{L_N}$ = 0.0514 x 100 kg = 5.14 kg solution (Value of 0.0514 is interpolated from table)
   - Now $x_N = \frac{1\ kg\ solute}{5.14\ kg\ solution} = \mathbf{0.195}$ The guess of $\mathbf{x_N}$ = 0.195 not too bad
   - The $\mathbf{x_N}$ leads to a value for amount of solution. The known amount of solute and that calculated amount of solution must lead to a concentration that matches the guess…

Operating Line – Steps

3. Perform Solute and Solution Balance across the entire battery

In = Out

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

Solute $$y_{N+1}V_{N+1} + x_0L_0 = y_1V_1 + x_NL_N$$

- We know y_1, y_{N+1}, and x_0L_0 from problem statement
- We calculated V_1 earlier
- We just solved x_N and L_N with the iteration
- That just leaves us able to solve for V_{N+1}

4. Do Solute and Solution balance around stage 1

In = Out

Solution $$V_2 + L_0 = V_1 + L_1$$

Solute $$y_2V_2 + x_0L_0 = y_1V_1 + x_1L_1$$

- Because we know that $y_1 = x_1$ we can obtain y_2 we now have point (x_1, y_2) for our operating line

Operating Line – Steps

5. Because Operating Line is curved we need at least one intermediate point
   - Choose stage n such that $\mathbf{x_n}$ is between $\mathbf{x_1}$ and $\mathbf{x_N}$
   - Make $\mathbf{x_n}$ a value that is on the chart. Do balances from start of battery through stage **n**

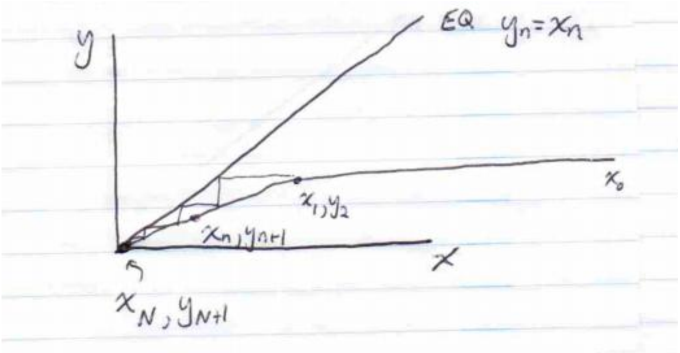
In = Out

Solution $$V_{n+1} + L_0 = V_1 + L_n$$

Solute $$y_{n+1}\,V_{n+1} + x_0\,L_0 = y_1\,V_1 + x_n\,L_n$$

   - Because we know $\mathbf{x_n}$ we can calculate L_n from retention chart value and mass of inert
   - We can now obtain y_{n+1} and therefore (x_n, y_{n+1})

6. Now that we have three points on OP Line we can do McCabe-Thiele



Leaching Example

A source of ore containing NaCl has been located. The mined material contains $\frac{0.2\ tons\ NaCl}{ton\ of\ insoluble\ ore}$. The strong extract exiting stage 1 is to have a concentration $y_1 = 0.20$. We need to recover 85% of the incoming salt using pure water as the solvent

If 5 tons of insoluble are to be processed per hour what is:

a) The required flow rate of water
b) The required number of ideal stages

Solution Retention Data:

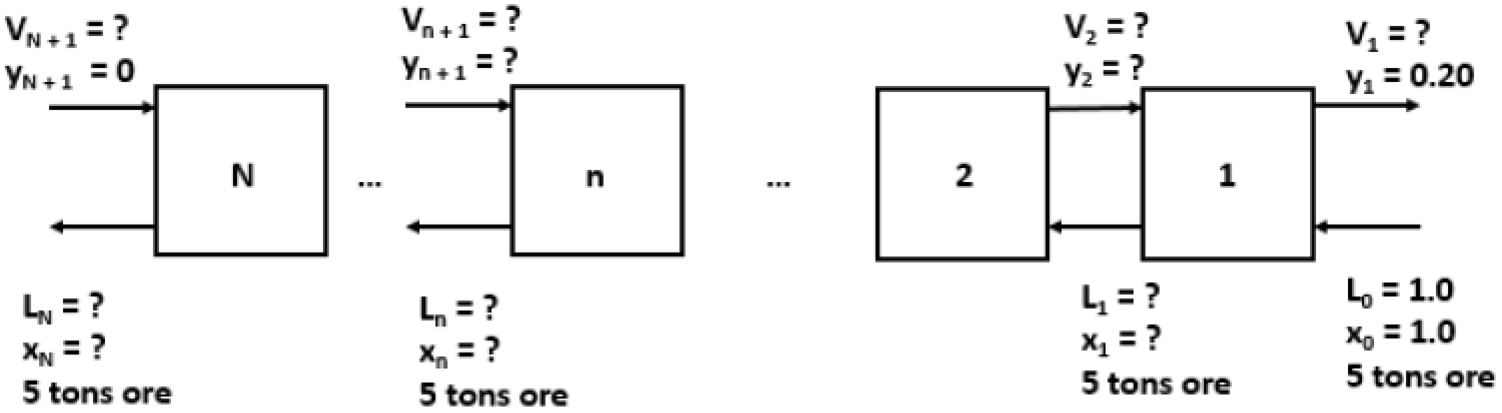
Solution Concentration in Mass % NaCl	Tons of solution retained per ton of exhausted rock
0	0.30
4	0.50
8	0.80
12	1.00
16	1.10
20	1.15

One hour basis:

$$5\ tons\ ore * \frac{0.2\ tons\ salt}{ton\ of\ insoluble\ ore} = 1.0\ tons\ NaCl$$

The battery of leaching vessels has the following information:

Example Leaching Problem



Problem states that we will recover 85% of the NaCl in the extract:

$$y_1 V_1 = 0.85 * (x_0 L_0) = 0.85 * 1.0 = 0.85 \ tons\ NaCl\ in\ V_1$$

$$1.0 - 0.85 = 0.15\ tons\ NaCl\ in\ L_N$$

Problem also states that $y_1 = 0.20$ $\therefore V_1 = {}^{0.85}/_{0.20} = 4.250\ ton\ solution$

Because the flows are very non-constant we need to begin by solving for x_N iteratively.

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Example Leaching Problem

From the retention data on the attached chart and table we can calulate L_N based on a guess of x_N. Then, because we know how much salt in the exiting raffinate, we can calculate what the concentration x_N that would correspond to the value ofcalculated value of L_N. If the value of x_N calculated as a function of L_N does not match the value used when we determined L_N then the guess of x_N was incorrect and we need to iterate.

Guess $x_N = 0.06$

Interpolating the retention data leads to $0.65\ \frac{tons\ solution}{ton\ raw\ ore}$

$\therefore\ L_N = 0.65\ \frac{tons\ solution}{ton\ raw\ ore} * 5\ ton\ ore = \ 3.25\ ton\ solution$

Solution Concentration in Mass % NaCl	Tons of solution retained per ton of exhausted rock
0	0.30
$x_n = 0.04$ 4	0.50
$x_n = 0.08$ 8	0.80
12	1.00
16	1.10
20	1.15

$0.15\ tons\ NaCl\ in\ L_N$ **From mass balance**

Then $x_N = \frac{0.15\ ton\ salt}{3.25\ ton\ solution} = 0.046$ This does not match the value of x_N we used to determine L_N

Guess $x_N = 0.051$

Interpolating the retention data leads to $0.5825\ \frac{tons\ solution}{ton\ raw\ ore}$

$\therefore\ L_N = 0.5825\ \frac{tons\ solution}{ton\ raw\ ore} * 5\ ton\ ore = \ 2.913\ ton\ solution$

Then $x_N = \frac{0.15\ ton\ salt}{2.913\ ton\ solution} = 0.0515$ This does match within our ability to read the graph.

Example Leaching Problem

Solution Balance across the entire battery:

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

$$1.0 + V_{N+1} = 2.913 + 4.25$$

a) $V_{N+1} = 6.16\ tons\ of\ water$

In order to determine the number of stages we need to construct an operating line. We already have two points:

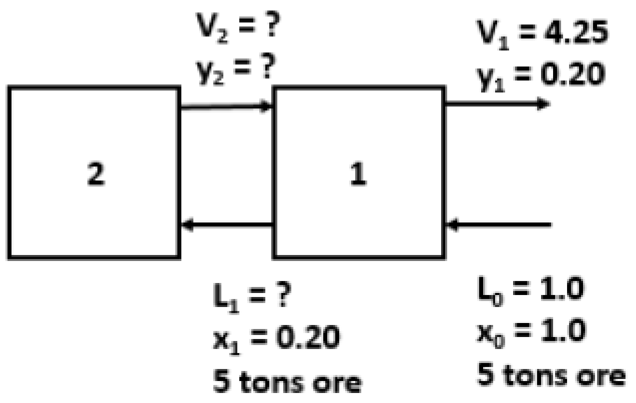
$(x_N, y_{N+1}) = (0.051, 0)$ and $(x_0, y_1) = (1.0, 0.20)$

Example Leaching Problem

The next step is to do balances around stage 1

We know that for ideal stages $x_n = y_n$, therefore $x_1 = y_1 = 0.20$

From data we know that for $x_1 = 0.20$ there are $1.15 \frac{tons\ solution}{ton\ raw\ ore}$ and therefore $L_1 = 1.15 * 5 = 5.75\ ton\ solution$



Solution Retention Data:

Solution Concentration in Mass % NaCl	Tons of solution retained per ton of exhausted rock
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Example Leaching Problem

Solution Balance

$$L_0 + V_2 = L_1 + V_1$$

$$1.0 + V_2 = 5.75 + 4.25$$

$$V_2 = 9.0\ tons$$

NaCl Balance

y2, not y1

$$x_0\ L_0 + y_1\ V_2 = x_1\ L_1 + y_1\ V_1$$

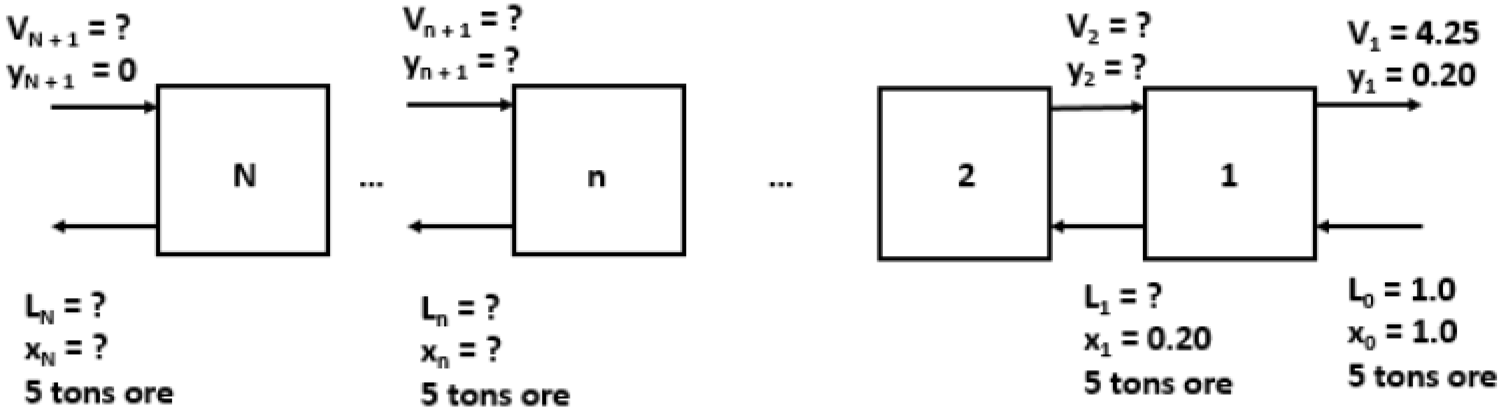
$$1.0 + y_2 * 9.0 = 0.20 * 5.75 + 0.20 * 4.25$$

$$y_2 = 0.111$$

Now we have the point $(x_1, y_2) = (0.20, 0.111)$

Example Leaching Problem

Now we will do balances containing stages 1 to n.



We can choose an arbitrary value for x_n due to the fact that the stage n is an arbitrary location in the battery.

Choose $x_n = 0.12$ this leads to $1.0\ \frac{tons\ solution}{ton\ raw\ ore}$ from the retention data.

Therefore $L_n = 1.0 * 5 = 5\ tons\ solution$

Example Leaching Problem

Solution Balance

$$L_0 + V_{n+1} = L_n + V_1$$

$$1 + V_{n+1} = 5 + 4.25$$

$$V_{n+1} = 8.25 \text{ ton solution}$$

NaCl Balance

$$x_0 L_0 + y_{n+1} V_{n+1} = x_n L_n + y_1 V_1$$

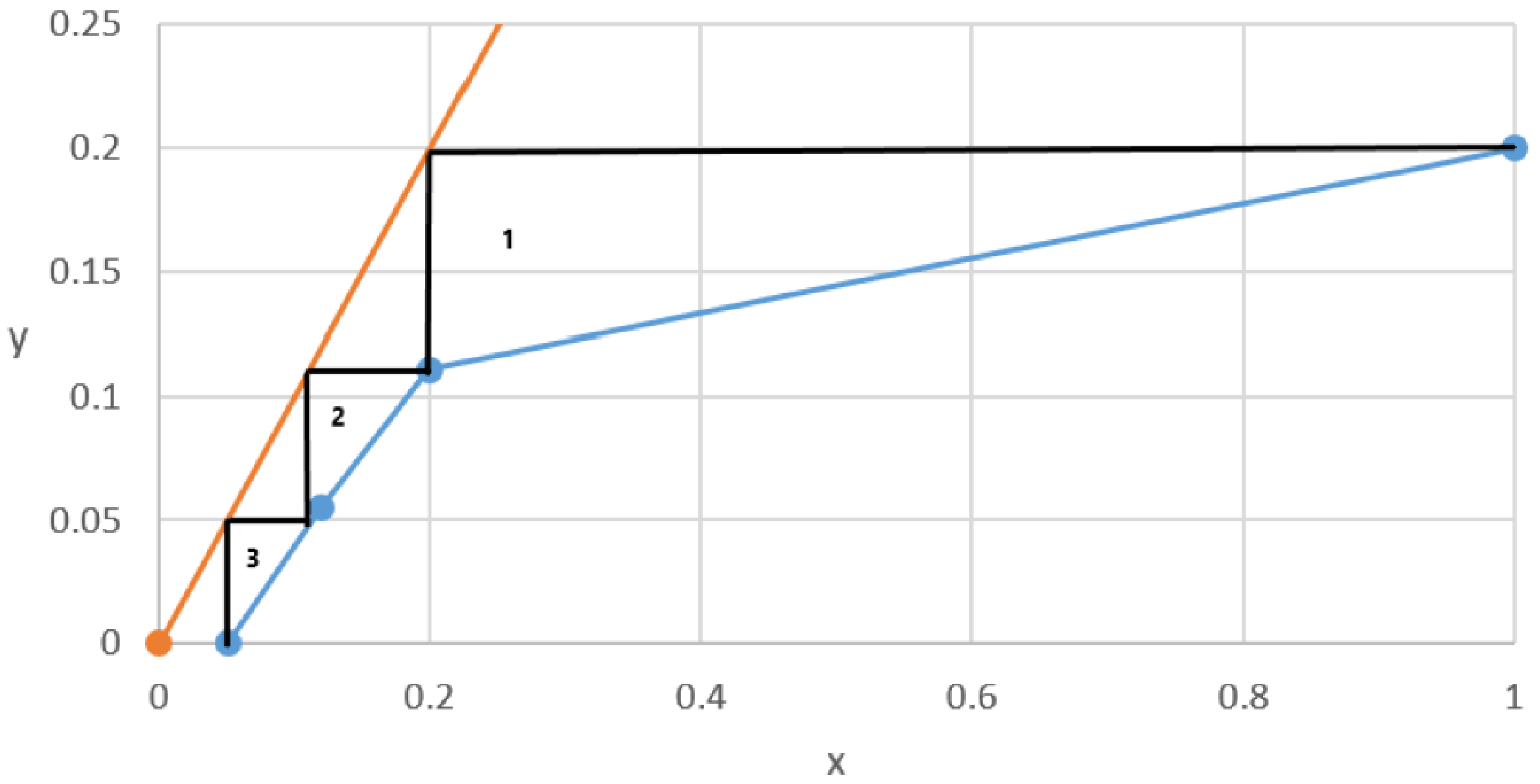
$$1.0 + y_{n+1} * 8.25 = 0.12 * 5.0 + 0.20 * 4.25$$

$$y_{n+1} = 0.055$$

Now we have the point $(x_n, y_{n+1}) = (0.12, 0.055)$

Example Leaching Problem

We can now plot the operating and equilibrium lines. (Remember that equilibrium line is $x_n = y_n$)



b) There are 3 ideal stages required.