Office Hours:

Prof. Miao Yu

3:00 – 4:00 pm on Tuesday

1:00 – 2:00 pm on Thursday

(Please send an email to me (myu9@buffalo.edu) to schedule other meeting times)

CE407 SEPARATIONS

Lecture 13

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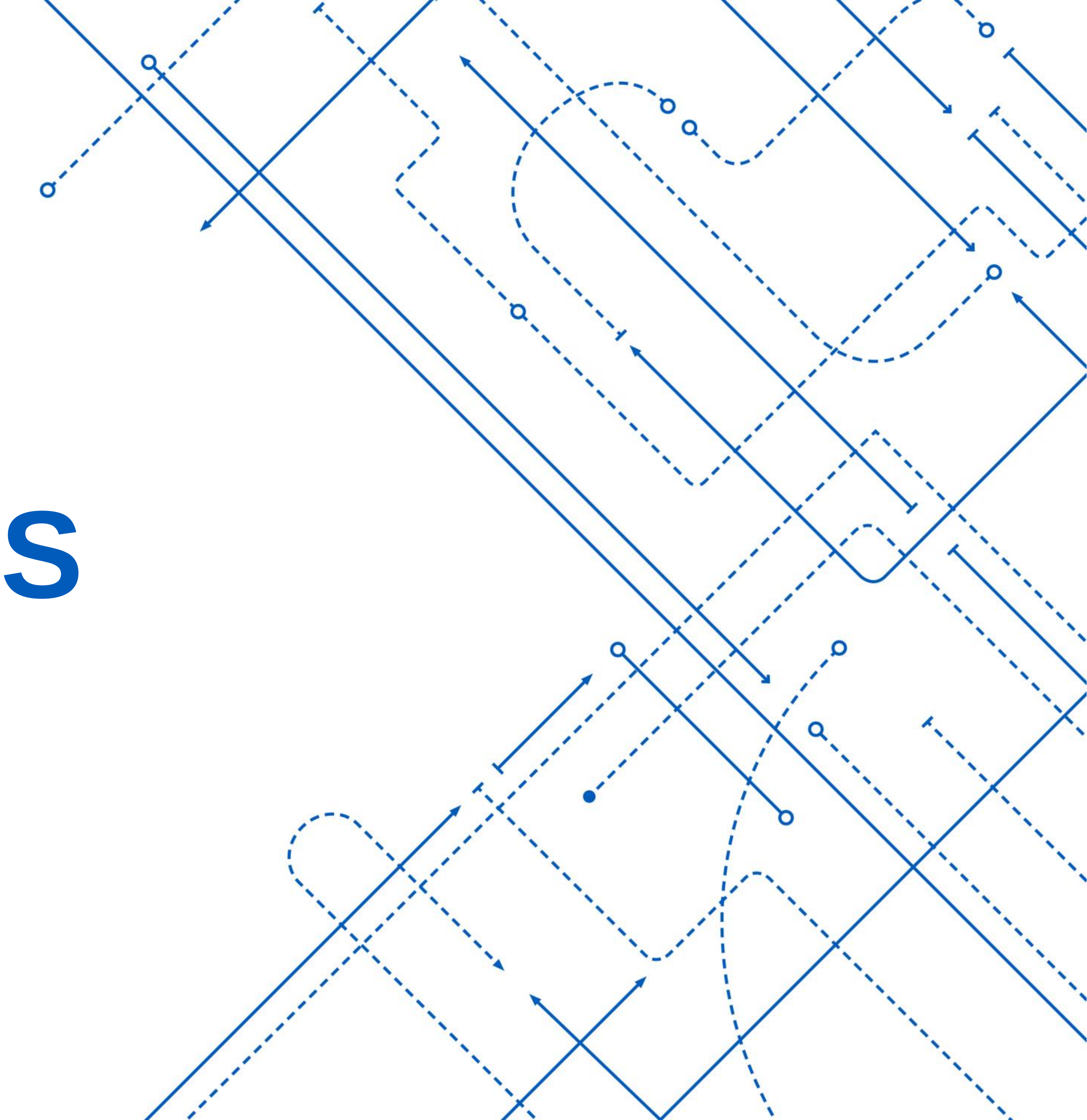
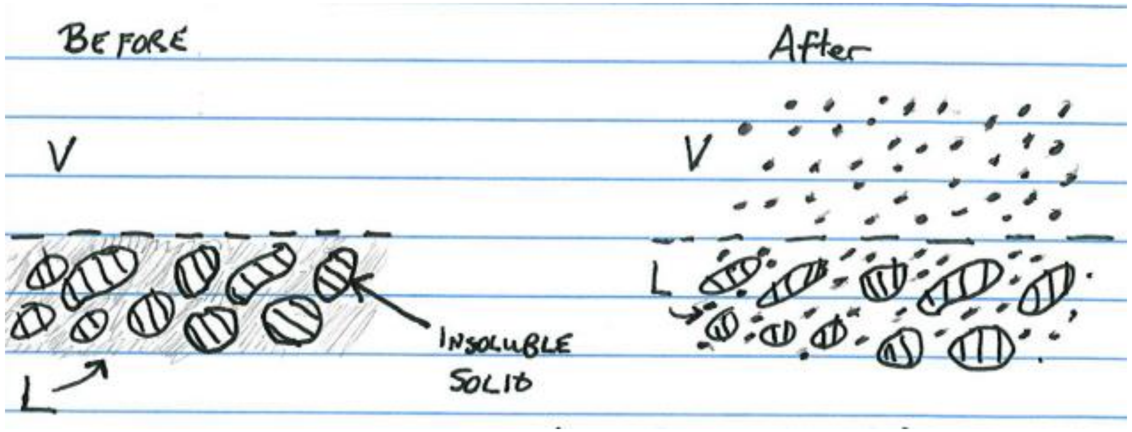


Leaching McSH 764-772

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



- **L** and **V** are both liquid phases – no vapor!
- **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

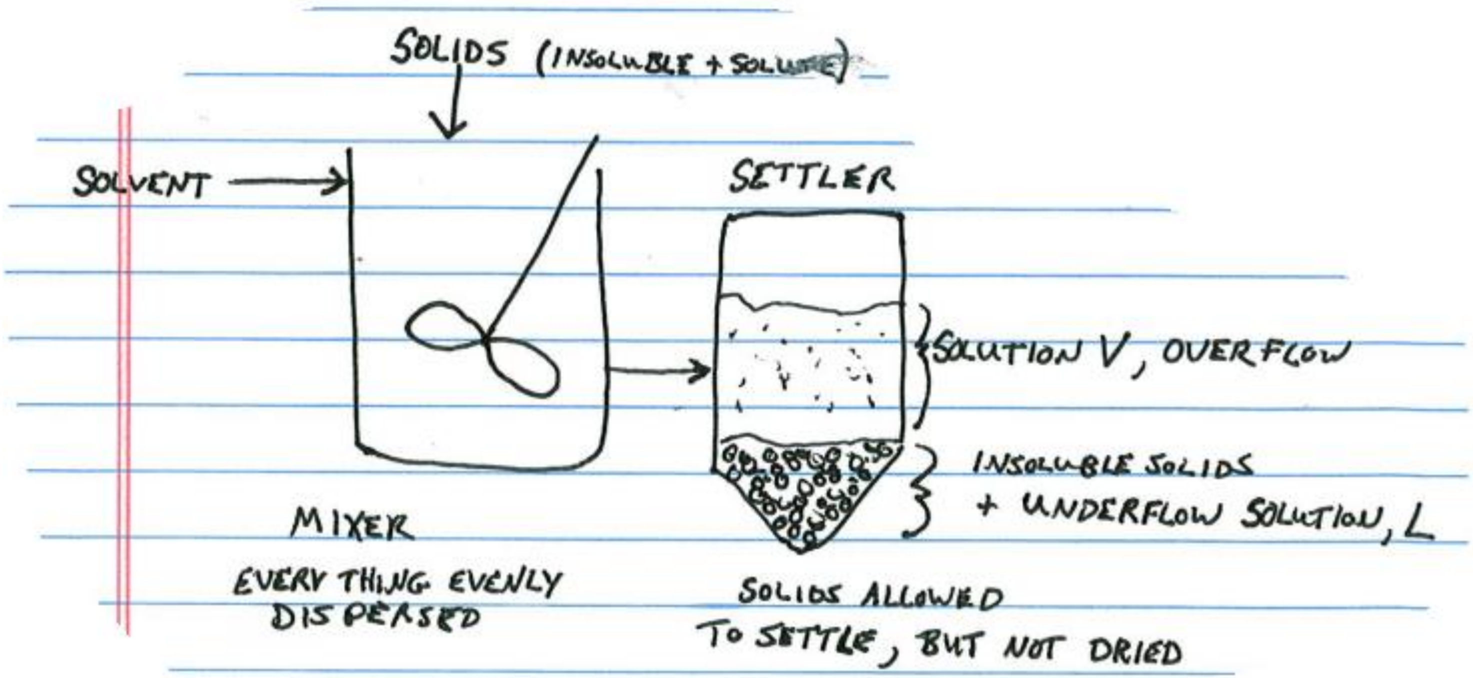
- **Solute**: the material we are trying to remove from the insoluble solid
- **Solvent**: the material we are using to dissolve the solute

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 be 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
- Here is equilibrium 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

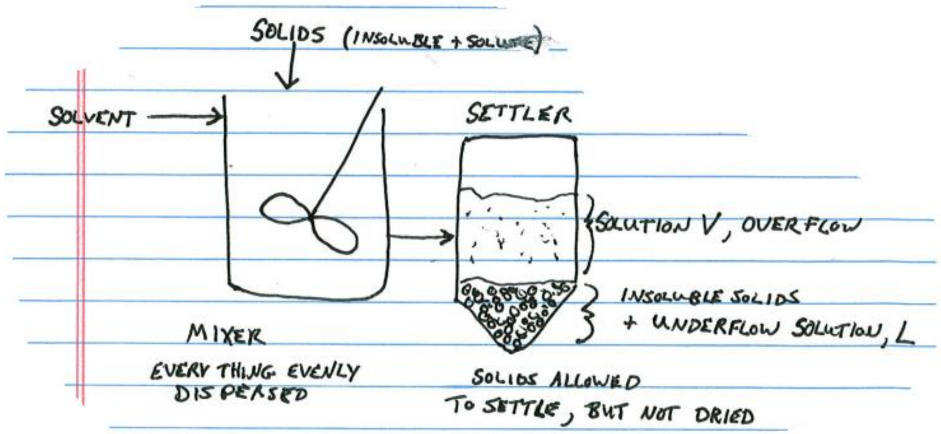
- $\boldsymbol{mass\ of\ solvent/mass\ of\ insoluble\ solid}$
- Example:

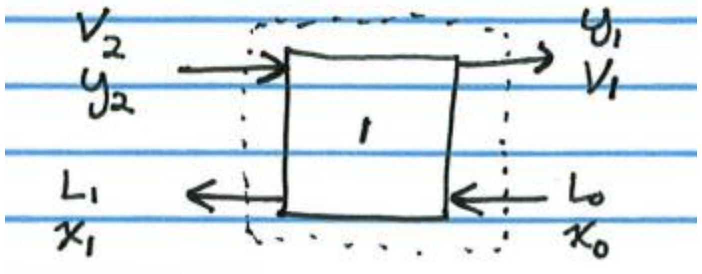
$x = y = {}^{kg\ oil}/_{kg\ solution}$	${}^{kg\ solution\ retained}/_{kg\ insoluble\ solid}$
0.0	0.0500
0.1	0.0505
0.2	0.0515

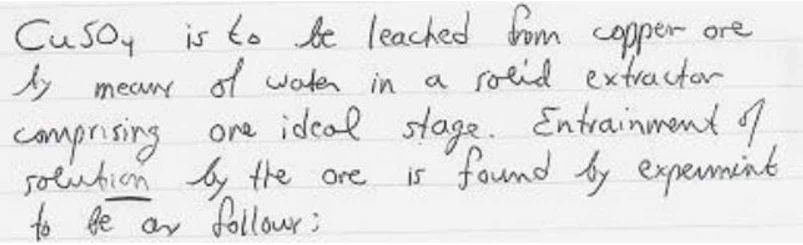
- The concentration of the solution affects the viscosity, surface tension, etc. and therefore different amounts of solution will cling to the solid
- This data will be very specific to the type of insoluble solid, temperature, etc.

Leaching

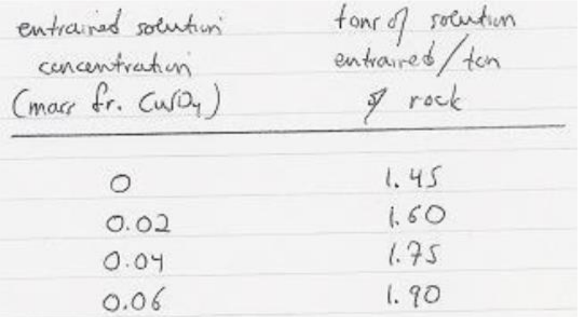
- The equipment shown here
- can be represented like this
- Note: the streams and concentrations are represented with subscripts that indicate what stage they have come ***FROM***
    - This is the same as we are used to from distillation
- Review example 2 from “Leaching More Examples”



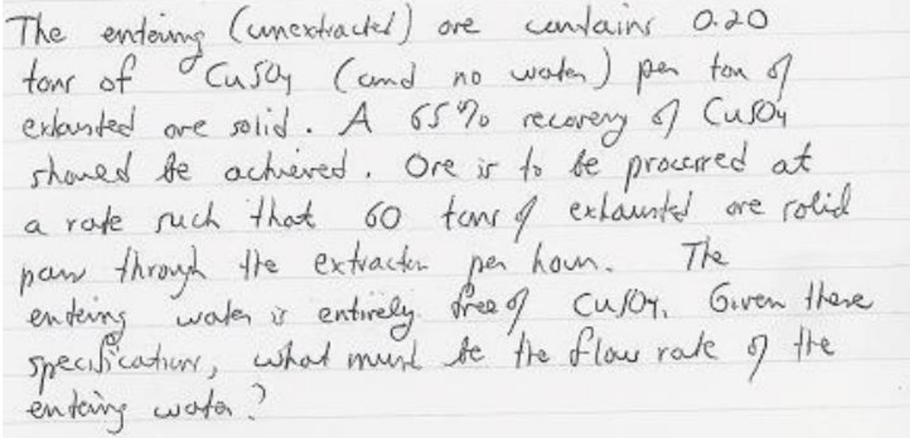




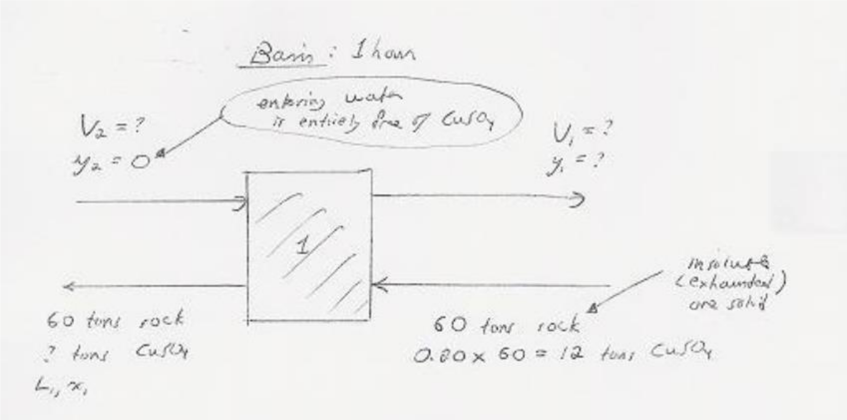
$CuSO_4$ is to be leached from copper ore by means of water in a solid extractor comprising one ideal stage. Entrainment of solution by the ore is found by experiment to be as follows:

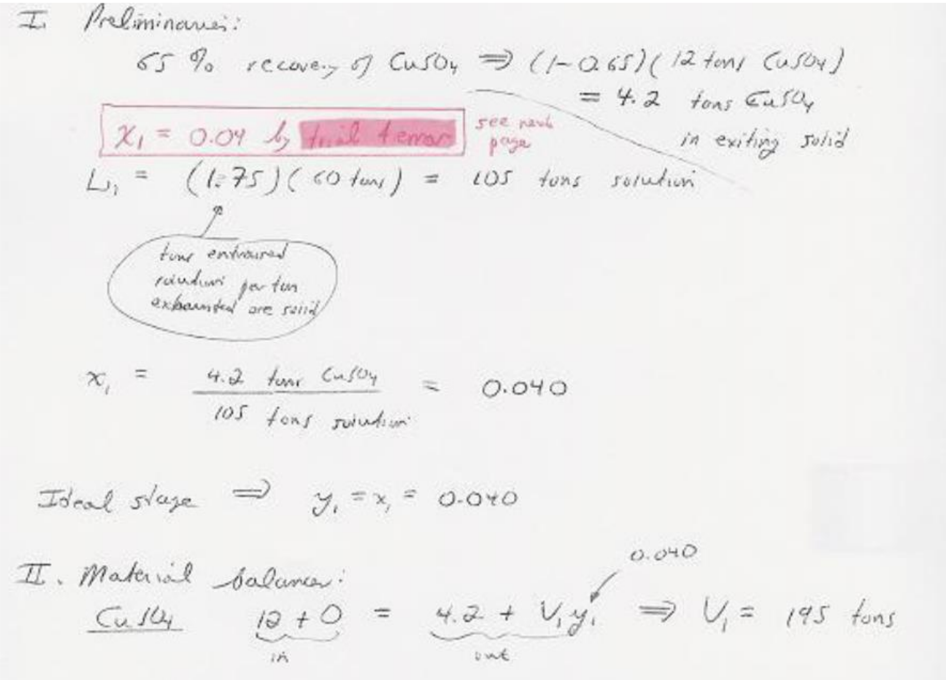


entrained solution concentration (mass fr. $CuSO_4$)	tons of solution entrained / ton of rock
0	1.45
0.02	1.60
0.04	1.75
0.06	1.90



The entering (unextracted) ore contains 0.20 tons of $CuSO_4$ (and no water) per ton of exhausted ore solid. A 65% recovery of $CuSO_4$ should be achieved. Ore is to be processed at a rate such that 60 tons of exhausted ore solid pass through the extractor per hour. The entering water is entirely free of $CuSO_4$. Given these specifications, what must be the flow rate of the entering water?





I. Preliminaries:

65 % recovery of $CuSO_4$ $\Rightarrow$ $(1-0.65)(12 \text{ tons } CuSO_4) = 4.2 \text{ tons } CuSO_4$ in exiting solid

$\boxed{x_1 = 0.04 \text{ by trial \& error}}$ see next page

$L_1 = (1.75)(60 \text{ tons}) = 105 \text{ tons solution}$

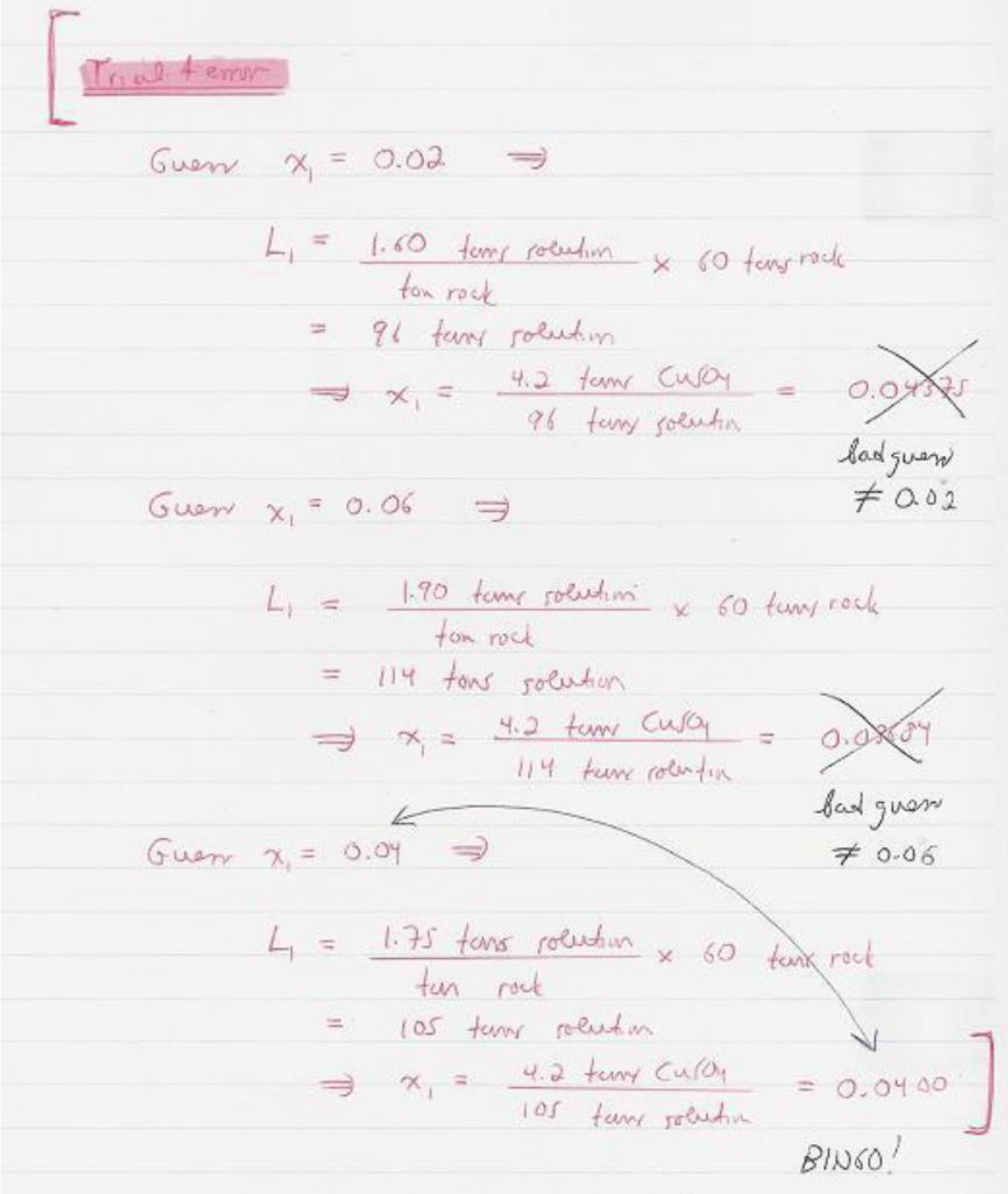
tons entrained solution per ton exhausted ore solid

$$x_1 = \frac{4.2 \text{ tons } CuSO_4}{105 \text{ tons solution}} = 0.040$$

Ideal stage $\Rightarrow$ $y_1 = x_1 = 0.040$

II. Material balance:

$$\underline{CuSO_4} \quad \underbrace{12 + 0}_{in} = \underbrace{4.2 + V_1 \overset{0.040}{y_1}}_{out} \Rightarrow V_1 = 195 \text{ tons}$$



Trial + error

Guess $x_1 = 0.02 \Rightarrow$

$$L_1 = \frac{1.60 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

$$= 96 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{96 \text{ tons solution}} = \cancel{0.04375}$$

bad guess

$\neq 0.02$

Guess $x_1 = 0.06 \Rightarrow$

$$L_1 = \frac{1.90 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

$$= 114 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{114 \text{ tons solution}} = \cancel{0.03684}$$

bad guess

$\neq 0.06$

Guess $x_1 = 0.04 \Rightarrow$

$$L_1 = \frac{1.75 \text{ tons solution}}{\text{ton rock}} \times 60 \text{ tons rock}$$

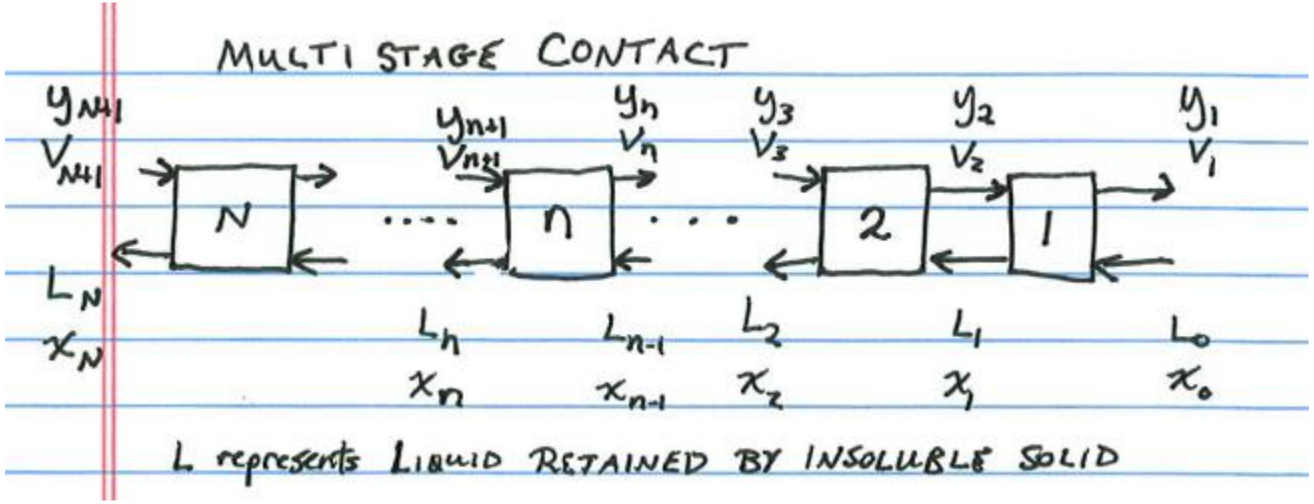
$$= 105 \text{ tons solution}$$

$$\Rightarrow x_1 = \frac{4.2 \text{ tons } CuSO_4}{105 \text{ tons solution}} = 0.0400$$

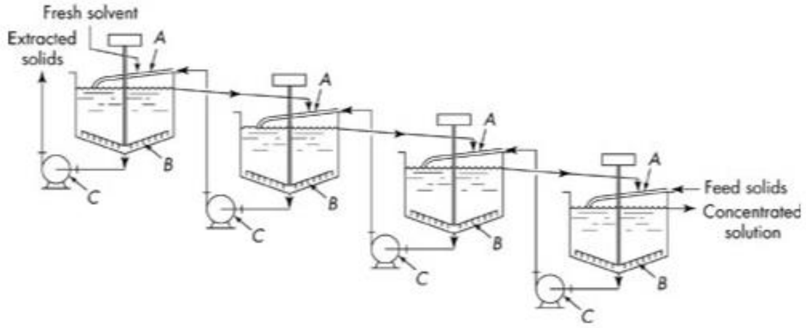
BINGO!

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

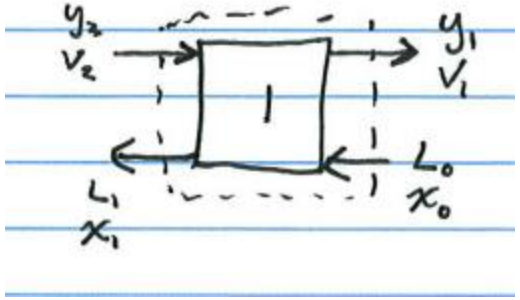


L represents LIQUID RETAINED BY INSOLUBLE SOLID



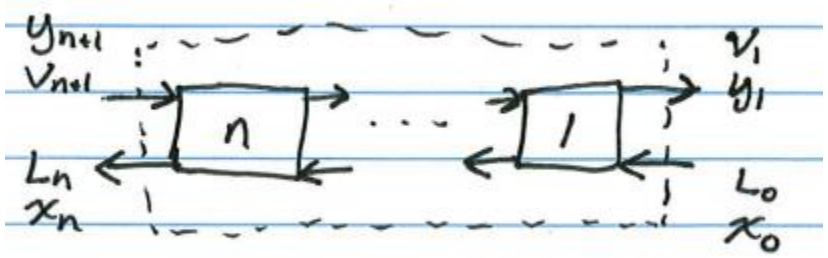
Control Volumes

- 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

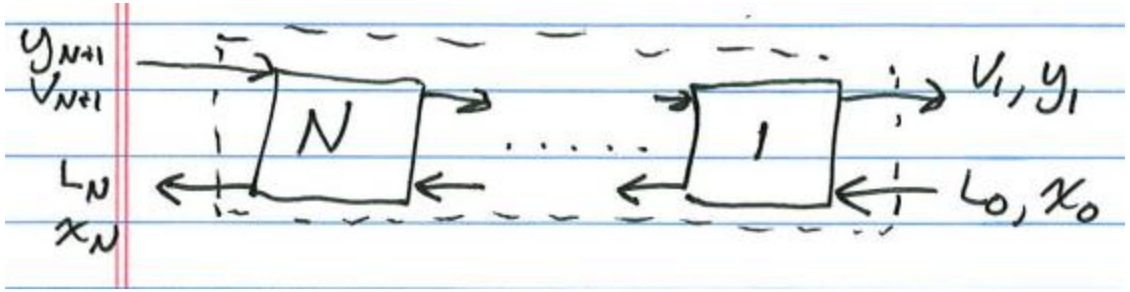


Control Volumes

- 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 $\mathbf{x_n} = \mathbf{y_n}$
- 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
    - $\mathbf{V_{N+1}}$ is usually unknown
    - $\mathbf{y_{N+1}}$ will be given
  - Strong Solution ($\mathbf{V_1}$ stream)
    - % recovery of solute
  - Relationship between $\mathbf{x_n}$ and amount of solution retained

Operating Line – Steps

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

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**
   - 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