CE407 SEPARATIONS

Lecture 15

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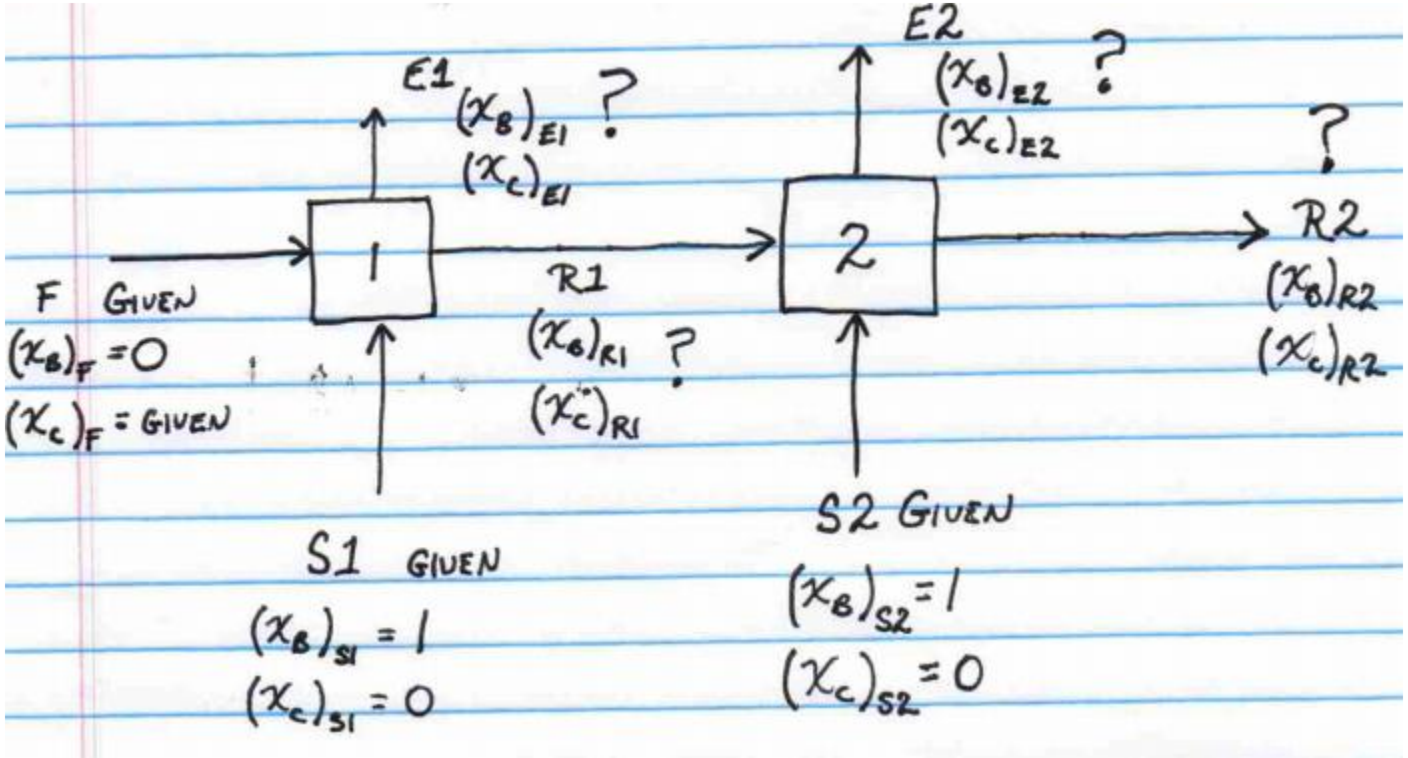
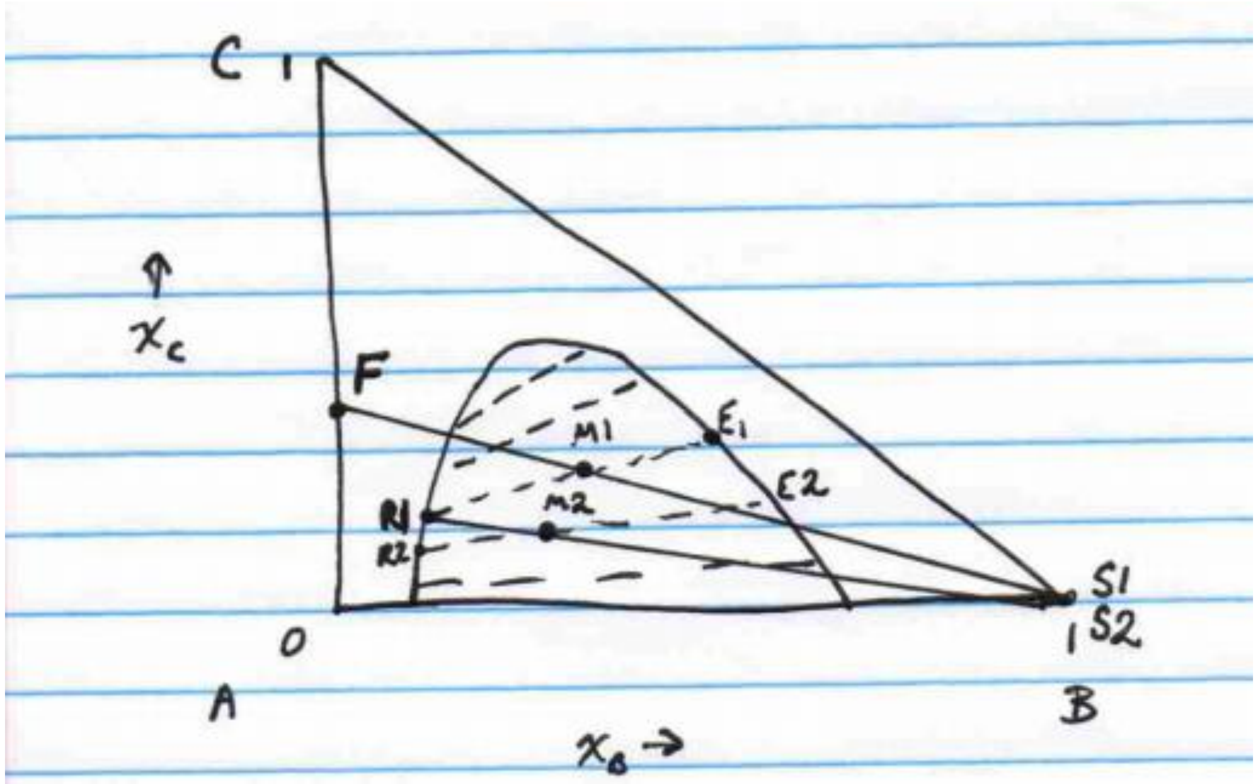
Multi-Stage Cross Current LLE Treybal pp 446-448

- Counter Current is more efficient but cross current is often used in lab work or small scale processes
- Streams exiting a given stage are in equilibrium with each other



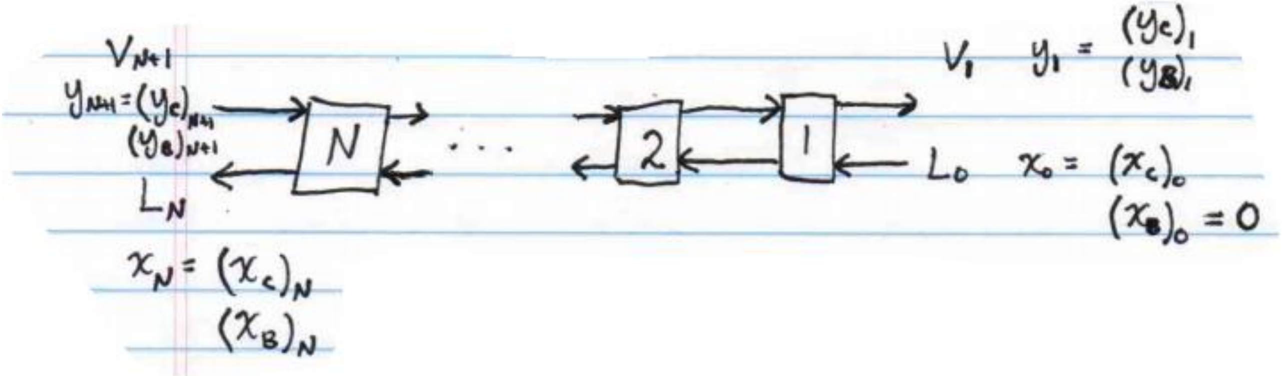
Multi-Stage Cross Current LLE

- The raffinate from the first stage is treated with a second batch of solvent
- A new mixture M_2 is created which then separates into R_2 and E_2
- Note that each successive extraction leads to a lower solute content in the extract



Multi-Stage Countercurrent LLE McSH pp 784-786 Treybal pp 450-451

- Raffinate and extract leaving a given stage are in equilibrium with one another
- Overall Mass Balance – control volume around entire process
- **L** is Raffinate and **V** is Extract -both are liquid
  - X refers to raffinate mass fraction, y to extract mass fraction
  - Letter subscript indicates component, Number refers to the stage that flow comes FROM
  - If there is no letter subscript the mass fraction is a solute mass fraction
- Feed stream $\mathbf{L_0}$ has known flow rate and composition
- Entering Solvent Stream, $\mathbf{V_{N+1}}$
  - Composition will be known
    - Often a pure solvent $(\boldsymbol{y_B})_{\boldsymbol{N+1}} = \mathbf{1}$. Sometimes solvent is recycled, then $(\boldsymbol{y_B})_{\boldsymbol{N+1}} \neq \mathbf{1}$, but close
    - For NOW we will look at cases where we do know the flow rate

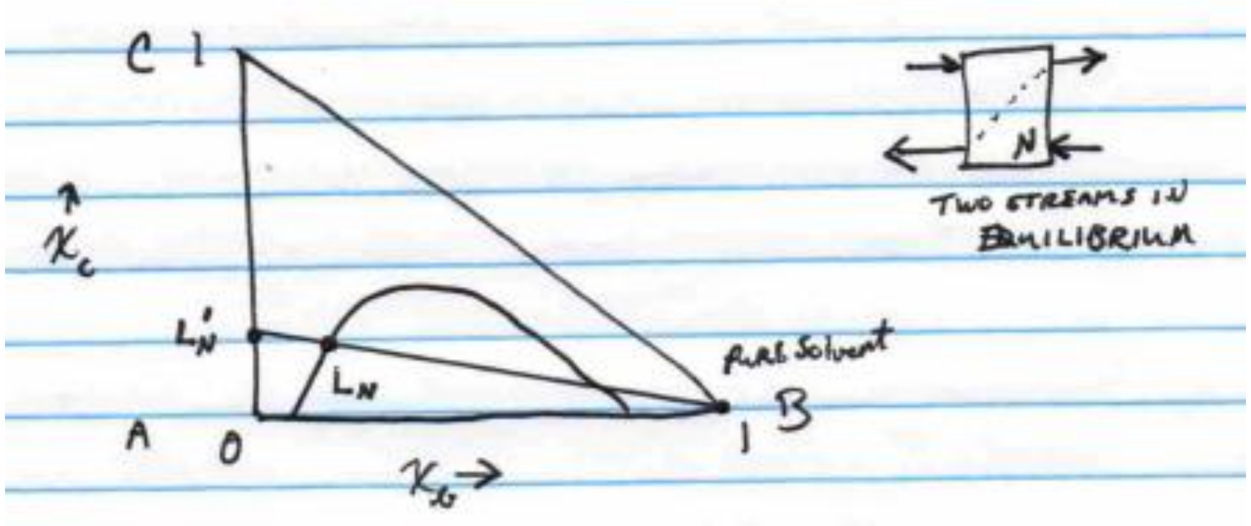


Multi-Stage Countercurrent LLE

- Exiting Raffinate, $\mathbf{L_N}$, is usually specified with at requirement reaches some low number
- The raffinate will usually have some solvent, **B**, in it. **A** and **B** are typically not totally immiscible
- Often the mass fraction of solute in the raffinate is given on a "Solvent Free" basis
  - This is a hypothetical raffinate $\mathbf{L_N}$**'** which has had all solvent removed
  - It is therefore a binary mixture of solute, **C**, and diluent, **A**
- The reason for this is that when it is determined that one needs to design an extraction for cleaning up $\mathbf{L_0}$ you don't necessarily know what solvent will be used and therefore cannot predict how miscible the solvent is likely to be with the diluent
  - But you can set up a specification for how much solute relative to the diluent you are willing to accept in your raffinate

Multi-Stage Countercurrent LLE

- If we have **L_N'**, how do we determine the composition of the actual raffinate, **L_N**?
- The actual raffinate is a mixture of the hypothetical raffinate, **L_N'**, and pure solvent
- It will therefore lie on the line connecting **L_N'** to the pure solvent corner of the diagram
  - Use pure solvent in this step even if the process does not use pure solvent, the hypothetical **L_N'** needs to have only **B** added to it to obtain the actual **L_N**
- As it is in equilibrium with the extract that is leaving stage **N**, it must be on the phase boundary



Multi-Stage Countercurrent LLE

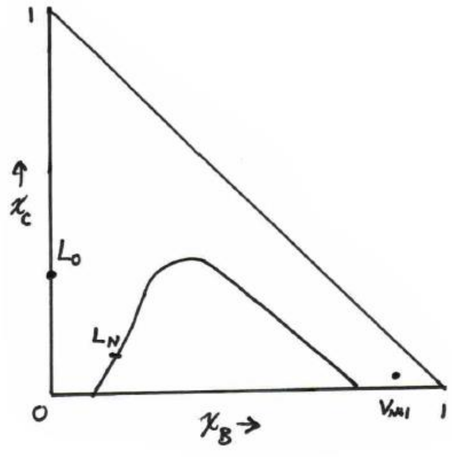
- After locating the actual $\mathbf{L_N}$ composition, create a new phase diagram (to avoid clutter)
  - This graph shows a case with recycled solvent
- Total mass balance

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

- Solute mass balance

$$L_0 x_0 + V_{N+1} y_{N+1} = L_N x_N + V_1 y_1 = M x_M$$

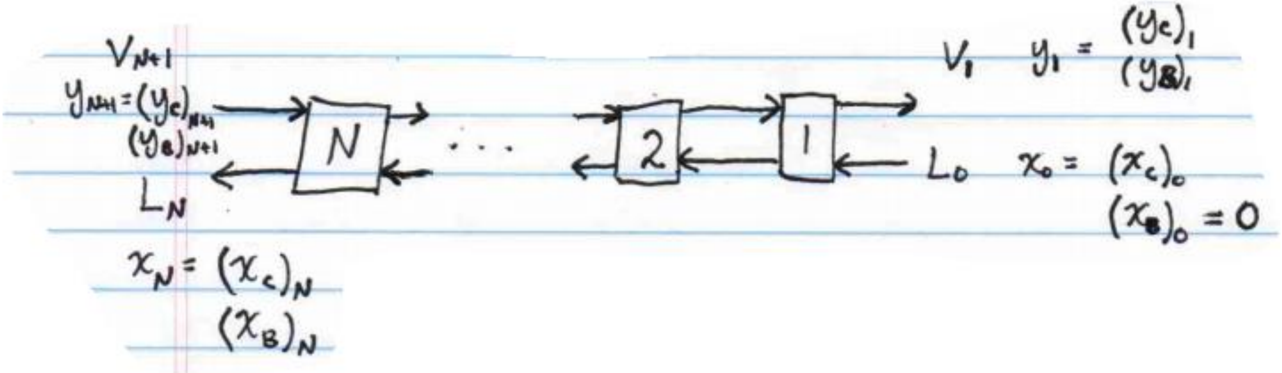
- **M** is the rate at which mass enters (and exits) the process
- **M x$_M$** is the rate at which solute enters (and exits) the process



Let’s talk about M…

$$\boldsymbol{L_0 + V_{N+1} = L_N + V_1 = M}$$
$$\boldsymbol{L_0 x_0 + V_{N+1} y_{N+1} = L_N x_N + V_1 y_1 = M x_M}$$

- M sure looks like a mixture of $\boldsymbol{L_0}$ and $\boldsymbol{V_{N+1}}$
- Except that $\boldsymbol{L_0}$ and $\boldsymbol{V_{N+1}}$ are NEVER in contact, so this mixture does not actually exist
- M has the physical significance of being the sum of the two streams entering the system (also the sum of the two exiting)
- $\boldsymbol{x_M}$ is a hypothetical value that satisfies the solute mass balance
- That said, M (located by its composition $\boldsymbol{x_M}$) WILL lie on the line between $\boldsymbol{L_0}$ and $\boldsymbol{V_{N+1}}$
- M (located by its composition $\boldsymbol{x_M}$) WILL also lie on the line between $\boldsymbol{L_N}$ and $\boldsymbol{V_1}$



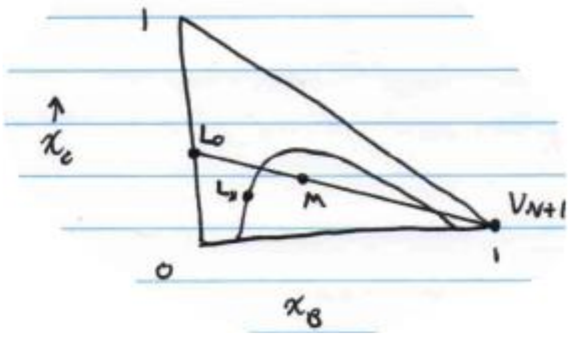
Multi-stage Countercurrent LLE

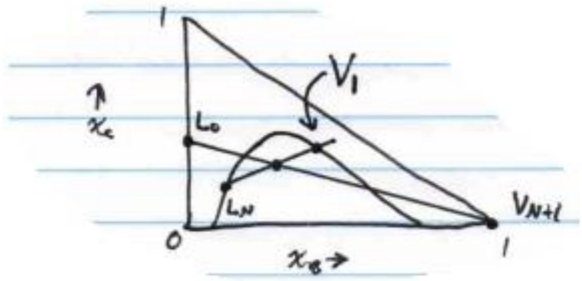
- We know $\boldsymbol{L_0}$, $\boldsymbol{x_0}$, $\boldsymbol{y_{N+1}}$, and $\boldsymbol{V_{N+1}}$so we can calculate $\boldsymbol{M}$ and $\boldsymbol{x_M}$
- We can locate point $\boldsymbol{M}$ on the phase diagram
- We know that $\boldsymbol{L_N}$, $\boldsymbol{M}$, and $\boldsymbol{V_1}$ are all on a straight line…
  - So we can locate $\boldsymbol{V_1}$, it will be where that line intersects the phase boundary
- We now have the composition of all four streams which exit or enter the system
- Flow rates can be determined by a solute mass balance

$$\boldsymbol{L_N x_N + V_1 y_1 = M x_M = (L_N + V_1) x_M}$$

  - Remember $\boldsymbol{L_N + V_1 = M}$

$$\boldsymbol{V_1 (y_1 - x_M) = L_N (x_M - x_N)}$$





Multi-stage Countercurrent LLE

$$V_1(y_1 - x_M) = L_N(x_M - x_N)$$

$$\boxed{\frac{V_1}{L_N} = \frac{x_M - x_N}{y_1 - x_M}}$$

- Note that $L_N + V_1 = L_N\left(1 + {}^{V_1}/_{L_N}\right) = \boxed{M = L_0 + V_{N+1}}$

$$\boxed{L_N = \frac{M}{1 + {}^{V_1}/_{L_N}}}$$

and

$$\boxed{V_1 = M - L_N}$$

Multi-stage Countercurrent LLE

- Notice that we did this procedure and NEVER used tie lines
  - We were looking at overall mass balances and never looked at individual stages
    - Tie lines indicate the equilibrium balance between steams exiting a given stage
  - The $\boldsymbol{L_N}$ and $\boldsymbol{V_1}$ streams ARE in equilibrium with $\boldsymbol{V_N}$ and $\boldsymbol{L_1}$ streams, respectively and that is why they are located on the phase boundary.
  - $\boldsymbol{L_N}$ and $\boldsymbol{V_1}$ are NOT in equilibrium with each other and are therefore NOT connected to one another by a tie line
- It is best to use a phase diagram WITHOUT tie lines for this analysis
  - Removes the temptation to try to use tie lines