

CE407 SEPARATIONS

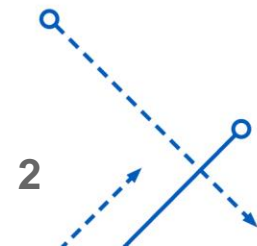
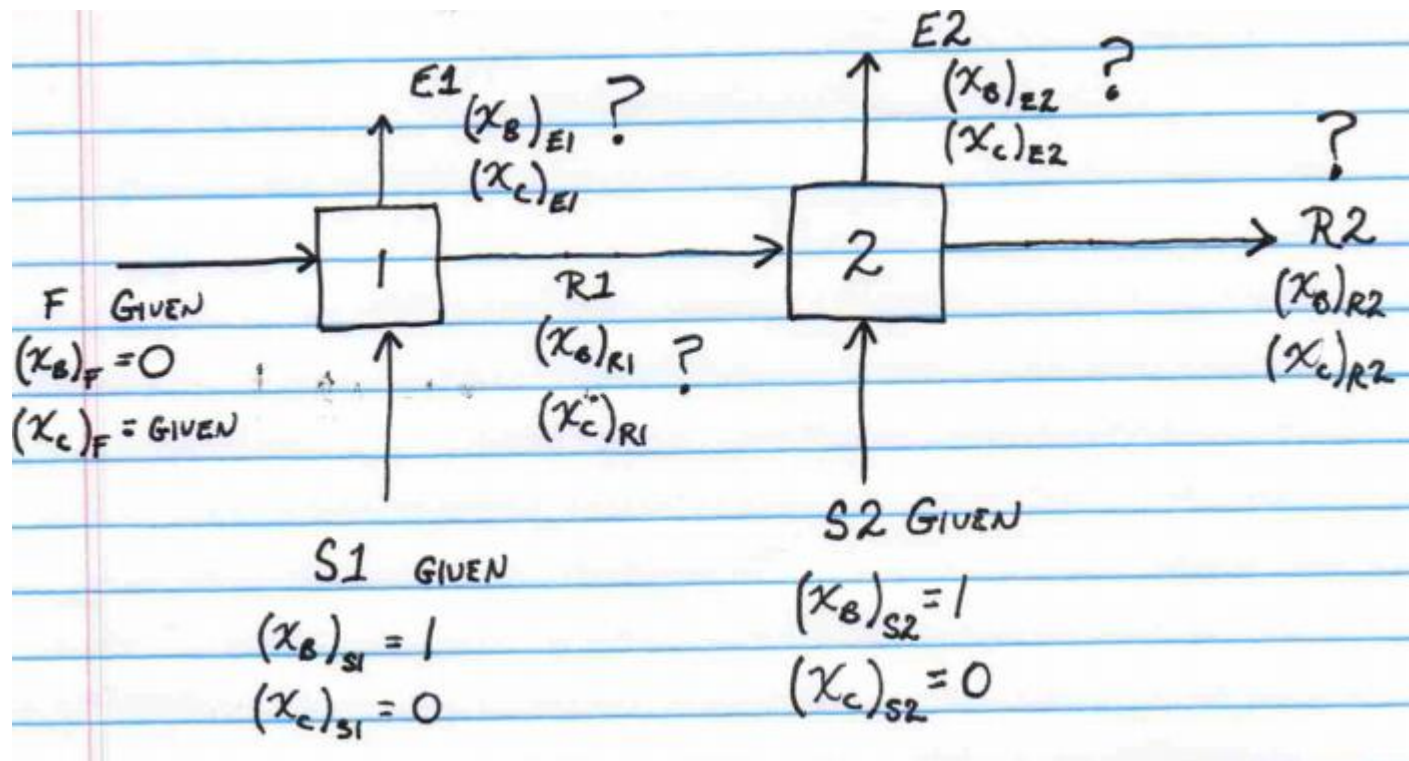
Lecture 15

Instructor: Miao Yu



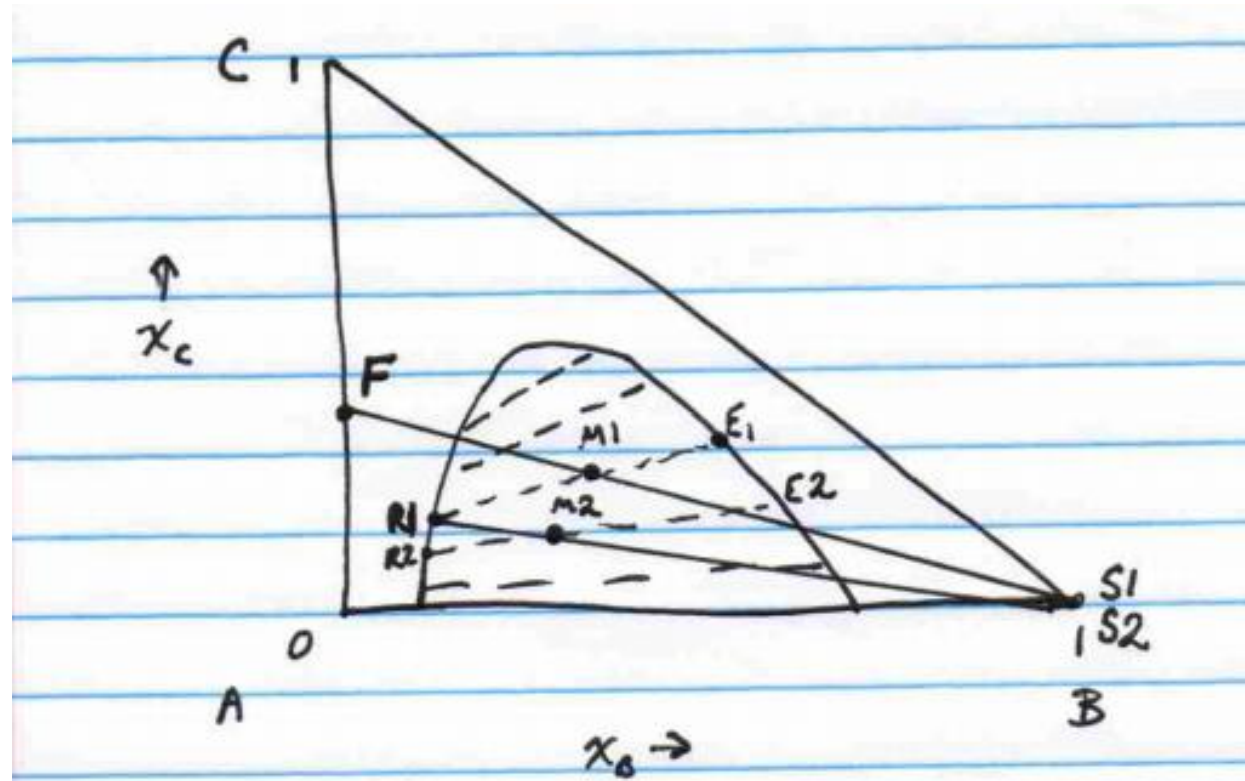
Multi-Stage Cross Current LLE Treybal pp 446-448

- 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



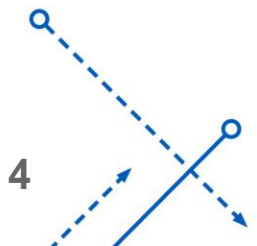
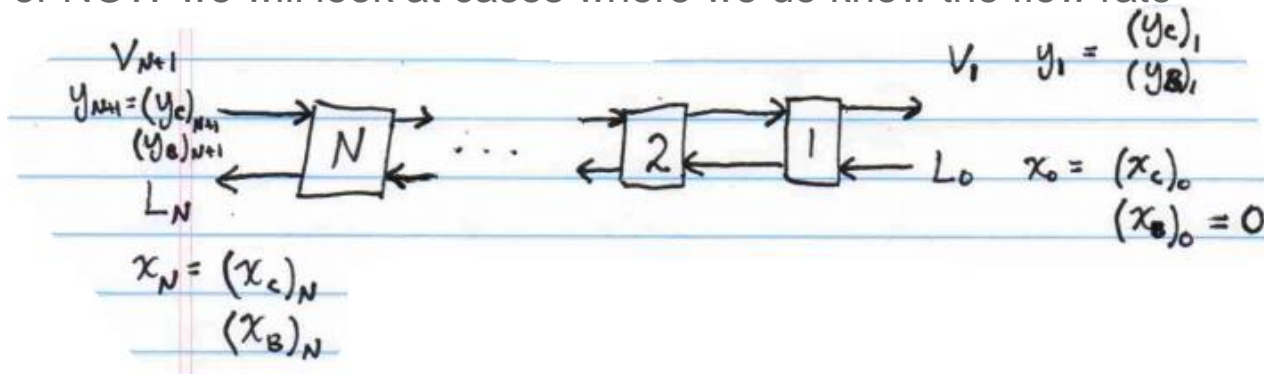
Multi-Stage Cross Current LLE

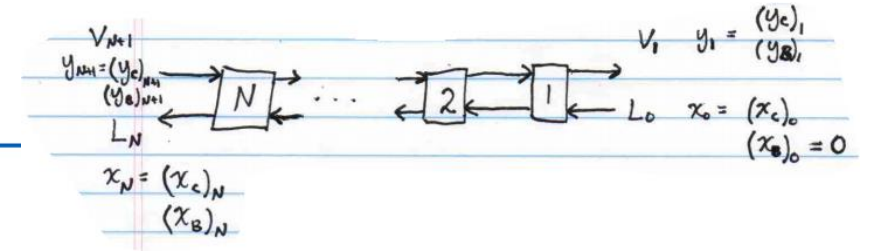
- The raffinate from the first stage is treated with a second batch of solvent
- A new mixture M_2 is created which then separates into R_2 and E_2
- Note that each successive extraction leads to a lower solute content in the extract



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

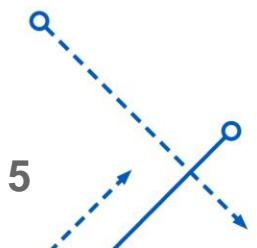
- Raffinate and extract leaving a given stage are in equilibrium with one another
- Overall Mass Balance – control volume around entire process
- **L** is Raffinate and **V** is Extract -both are liquid
 - x refers to raffinate mass fraction, y to extract mass fraction
 - Letter subscript indicates component, 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 L_0 has known flow rate and composition
- Entering Solvent Stream, V_{N+1}
 - Composition will be known
 - Often a pure solvent $(y_B)_{N+1} = 1$. Sometimes solvent is recycled, then $(y_B)_{N+1} \neq 1$, but close
 - For NOW we will look at cases where we do know the flow rate





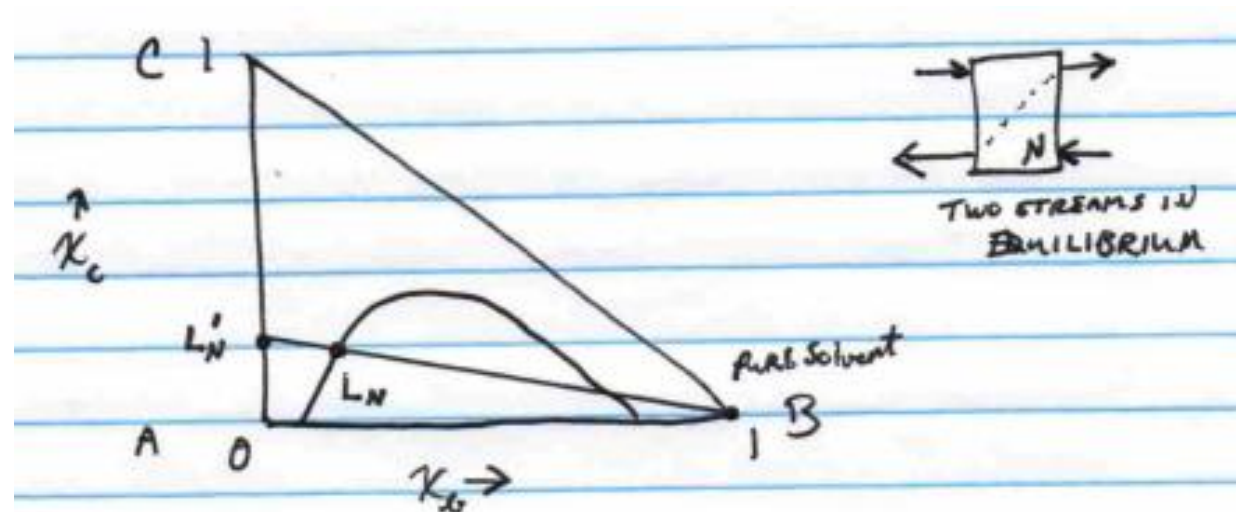
Multi-Stage Countercurrent LLE

- Exiting Raffinate, 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 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 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
 - If you did not specify on a solvent free basis, you could meet the specification by flooding it with a ridiculous amount of solvent. This could be wasteful of solvent and also lead to more unrecovered solute than desired.



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

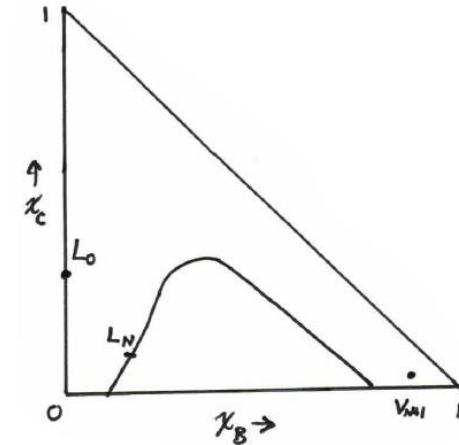
- After locating the actual L_N composition, create a new phase diagram (to avoid clutter)
 - This graph shows a case with recycled solvent
- Total mass balance

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

- 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

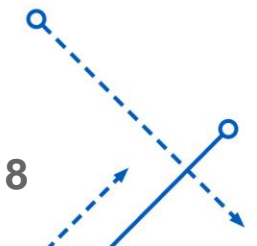
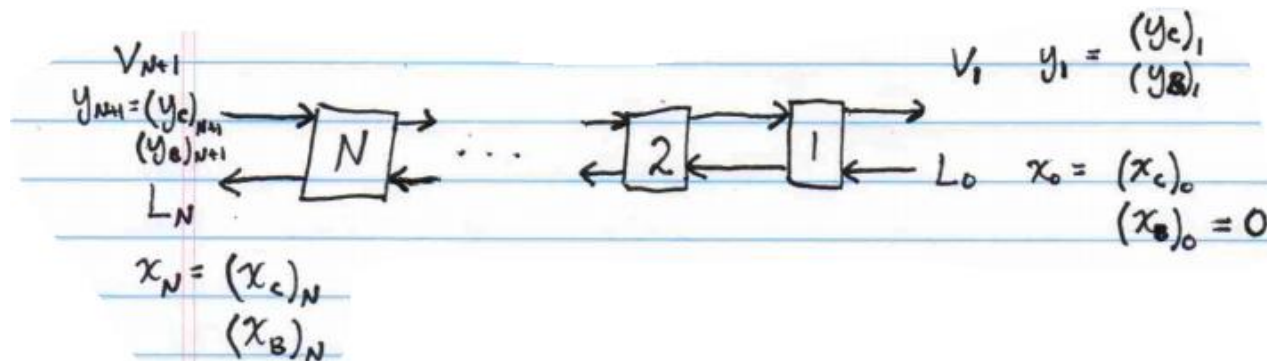


Let's talk about M...

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

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

- M sure looks like a mixture of L_0 and V_{N+1}
- Except that L_0 and 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)
- x_M is a hypothetical value that satisfies the solute mass balance
- That said, M (located by its composition x_M) WILL lie on the line between L_0 and V_{N+1}
- M (located by its composition x_M) WILL also lie on the line between L_N and V_1



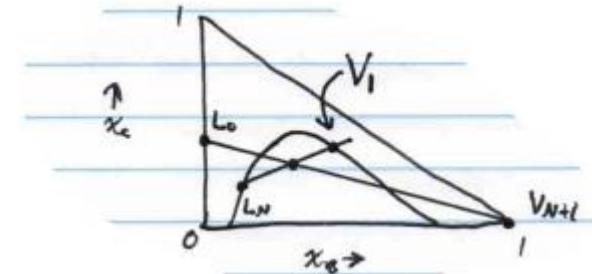
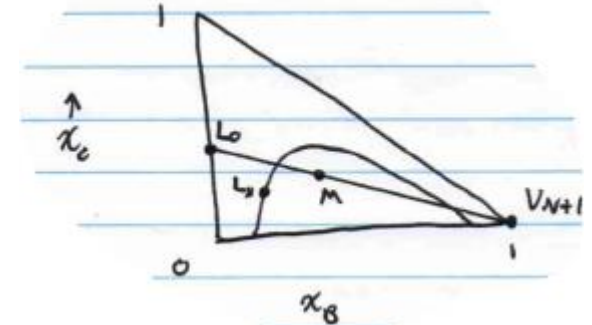
Multi-stage Countercurrent LLE

- We know L_0 , x_0 , y_{N+1} , and V_{N+1} so we can calculate M and x_M
- We can locate point M on the phase diagram
- We know that L_N , M , and V_1 are all on a straight line...
 - So we can locate 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

$$L_N x_N + V_1 y_1 = M x_M = (L_N + V_1) x_M$$

- Remember $L_N + V_1 = M$

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



Multi-stage Countercurrent LLE

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

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

- Note that

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

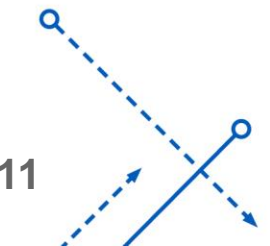
$$L_N = \frac{M}{1 + V_1/L_N}$$

and

$$V_1 = M - L_N$$

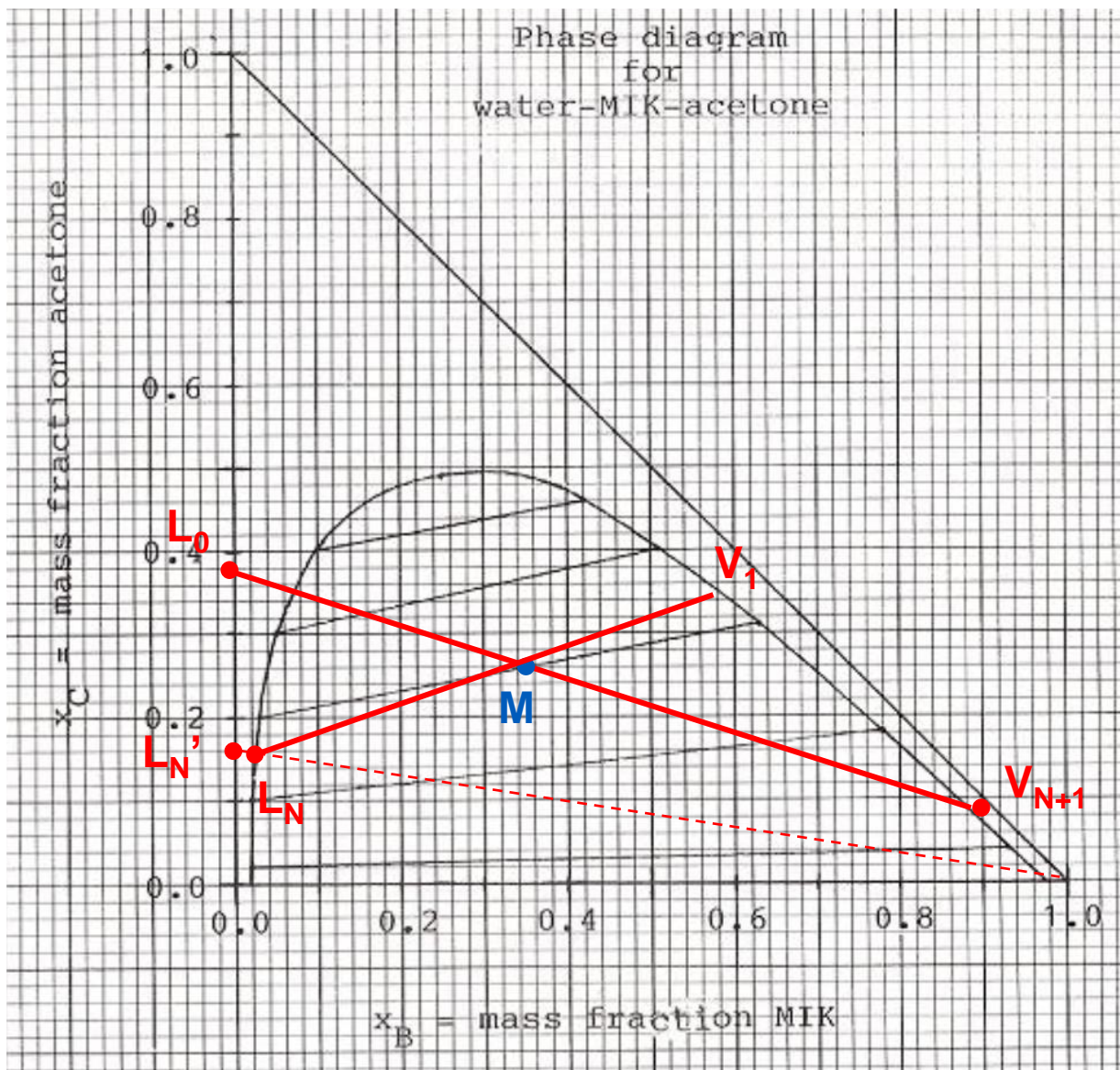
Multi-stage Countercurrent LLE

- 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 streams exiting a given stage
 - The L_N and V_1 streams ARE in equilibrium with V_N and L_1 streams, respectively, and that is why they are located on the phase boundary.
 - L_N and 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



1. A 450 kg/h feed stream with composition 38 mass percent acetone (solute, C), 62 mass percent water (diluent, A) is to be contacted countercurrently with 300 kg/h of an MIK-rich solution of which the precise composition is 90 mass percent MIK (solvent, B), 9 mass percent acetone and the balance water. The exiting raffinate should contain acetone and water in the ratio 16/84 by mass. What will be the ratio mass acetone/mass MIK in the exiting extract? Note that you are NOT being asked to determine the number of stages required. The phase diagram for the system water(A) + MIK(B) + acetone(C) is supplied.

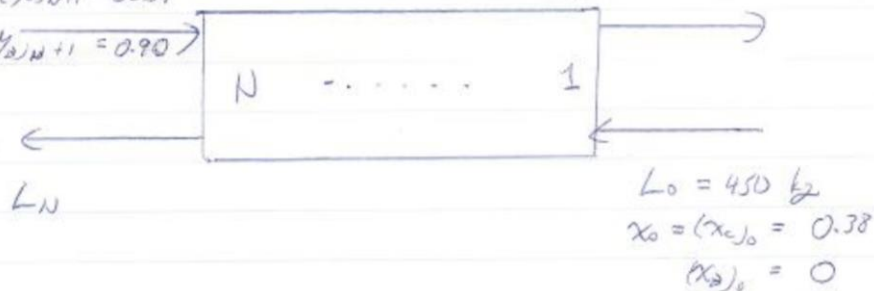




$$V_{N+1} = 300 \text{ kg}$$

$$y_{N+1} = (y_{A,N+1}) = 0.09$$

$$(x_{A,N+1}) = 0.90$$



(i) Fictitious mixture pt:

$$M = \text{rate @ which liquid enter} = L_0 + V_{N+1}$$

$$\begin{aligned}
 (x_C)_M &= \frac{L_0 x_0 + V_{N+1} y_{N+1}}{L_0 + V_{N+1}} = \frac{(450)(0.38) + (300)(0.09)}{450 + 300} \\
 &= 0.264. \text{ Locate on } \overline{L_0 V_{N+1}}.
 \end{aligned}$$

(ii) Locate exiting raffinate by "mixing" 16/84 c/A solution with some pure B (see dashed line).

(ii) $M = \text{rate} \oplus$ which material leaves also
 $= L_N + V_1$

$\therefore M$ lies on $\overline{L_N V_1}$, so extend $\overline{L_N M}$ to
 find V_1 on B-rich side of binodal curve.

Can read off mass fractions

$$(y_B)_1 = 0.59$$

$$y_1 = (y_C)_1 = 0.34$$

$$\frac{\text{mass C}}{\text{mass B}} \text{ in leaving extract} = \frac{0.34}{0.59} = \boxed{0.58}$$

