Triangular phase diagrams: from laboratory studies

[Flickr# 3453475667]
Using a triangular phase diagrams

[http://www.youtube.com/watch?v=gGYHXhcKM5s]
Lever rule

Mix P and Q

1. mixture = K

2. \[
\frac{PK}{KQ} = \frac{\text{amount Q}}{\text{amount P}}
\]

3. The converse applies also: when separating a settled mixture

4. Applies anywhere: even in the miscible region
Q1: Using the lever rule

Which is a more flexible system?
- $S =$ pure solvent used
- $F =$ feed concentration point (more correctly it is $x_F$)

![Diagram showing two different systems](image)

Answer:
Q2: Using the lever rule

Mix a feed stream, $F$, containing $C$ and $A$ (i.e. $x_F$) with a pure solvent stream $S$ (i.e. $y_S = 0$). Composition of the mixture?
Q3: Going to equilibrium

Let that mixture $M$ achieve equilibrium. What is the composition of the raffinate and extract?
Q4: Altering flows

Same system, but now lower solvent flow rate (to try save money!). What happens to (a) extract concentration and (b) solute recovery?
Q5: Composition of the mixture, \( M \)?

Answer: \( M = \)

\[ x_{\text{M,A}} = \]

\[ x_{\text{M,C}} = \]

\[ x_{\text{M,S}} = \]
Q6: Composition of the 2 phases leaving in equilibrium?

\[
\begin{align*}
F &= 250 \text{ kg} \\
S &= 100 \text{ kg} \\
xF_A &= 0.24 \\
x_F, C &= 0.76 \\
x_F, S &= 0.00
\end{align*}
\]

\[
\begin{align*}
S &= 1.0 \\
xF_A &= 0.0 \\
x_S, C &= 0.0 \\
x_S, S &= 1.0
\end{align*}
\]
Link units in *series*

[Richardson and Harker, p 723]
Q7: send raffinate from Q6 to second mixer-settler

Question: how much solvent should we use in the second stage?
Series of co-current units

\( N = 3 \) in this illustration

- **Recovery** = fraction of solute recovered

\[
1 - \frac{(x_{R_N})(R_N)}{(x_F)(F)}
\]

- **Concentration of overall extract** = solute leaving in each extract stream, divided by total extract flow rate

\[
\sum_{n=1}^{N} \frac{(y_{E_n})(E_n)}{\sum_{n=1}^{N} E_n}
\]

[Schweitzer, p 1-263]
Co-current vs counter-current

Co-current ($N = 2$ stages)

- We combine multiple extract streams
- (Only 2 in illustration)
- In general: $y_{E_1} > y_{E_2} > \ldots$
- Fresh solvent added at each stage

Counter-current ($N = 2$ stages)

- “Re-use” the solvent, so
- Far lower solvent flows
- Recovery $= 1 - \frac{(x_{RN})(R_N)}{(x_F)(F)}$
- Concentration $= y_{E_1}$

You will have an assignment question to compare and contrast these two configurations
Some theory: Two *counter-current* units

Just **consider** $N = 2$ **stages** for now. Steady state mass balance:

\[
F + E_2 = E_1 + R_1 \quad \quad \quad \quad E_2 + R_2 = S + R_1
\]

Rearrange:

\[
F - E_1 = R_1 - E_2 \quad \quad \quad \quad R_1 - E_2 = R_2 - S
\]

\[
(F - E_1) = (R_1 - E_2) = (R_2 - S) = P
\]

Note: each difference is equal to $P$ (look on the flow sheet where those *differences* are).
Counter-current graphical solution: 2 units

Rearranging again:

\[ F + P = E_1 \]
\[ R_1 + P = E_2 \]
\[ R_2 + P = S \]

**Interpretation:**  
*P* is a fictitious operating point on the ternary diagram (from lever rule)

- *P* connects *F* and *E*₁
- *P* connects *R*₁ and *E*₂
- *P* connects *R*₂ and *S*
For example, let’s require $\chi_{R_2,A} = 0.05$ (solute concentration in raffinate). What is $y_{E_1,A}$ then (concentration of solute in the extract)?
Counter-current graphical solution: 2 units

Note: the line connecting $E_1$ to $R_2$ is not a tie line. We use the lever rule and an overall mass balance ($F + S = E_1 + R_2$) to solve for all flows and compositions of $F$, $S$, $E_1$, and $R_2$. 

$y_{E_1,A} \approx 0.38$ is found from an overall mass balance, through $M$. 
Counter-current graphical solution: 2 units

Extrapolate through these lines until intersection at point $P$. Minimal achievable $E_1$ concentration? mentally move point $M$ towards $S$. What happens to $P$? Alternative (simpler?) explanation on next slide.