Separation Processes
ChE 4M3
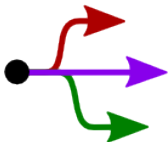
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We appreciate:

- ▶ if you let us know about **any errors** in the slides
- ▶ **any suggestions to improve the notes**

All of the above can be done by writing to

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If reporting errors/updates, please quote the current revision number: 86

Slide 76: Some old and new terminology

Recall from ultrafiltration:

- $R = 1 - \dfrac{C_P}{C_F}$

- This rejection coefficient also applies to reverse osmosis.

- A new term = cut = conversion = recovery = $\theta = \dfrac{Q_P}{Q_F}$ is between 40 and 50% typically

Slide 78: Relaxing the assumption of $C_R = C_{feed}$

1. Usually we specify the desired cut, $\theta = \dfrac{Q_P}{Q_F}$

2. $Q_F C_F = Q_R C_R + Q_P C_P$

3. $Q_F = Q_R + Q_P$

4. $1 = \dfrac{Q_R}{Q_F} + \theta$

5. $C_F = (1 - \theta)C_R + \theta C_P$ from equation (2) and (4)

6. $J_{solv} C_P = A_{solv}(\Delta P - \Delta \pi)C_P = $ salt flux leaving in permeate

7. $J_{salt} = A_{salt}(C_R - C_P) = $ salt flux into membrane
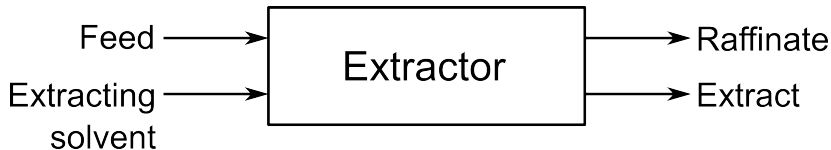
- Specify C_F and θ
- Guess C_P value [how?]
- Calculate C_R from equation 5
- Calculate $J_{solv} C_P$ from equation 6, noting however that $J_{solv} = f(\pi_R, \pi_P)$. So recalculate π_R and π_P
- Note then that equation 6 and 7 must be equal
- Solve eqn 7 for C_P and use that as a revised value to iterate.

Liquid-liquid extraction (LLE)

Definitions

- solute: species we aim to recover (A) from the feed
- feed or "feed solvent": one of the liquids in the system (*"carrier"*)
- solvent: MSA (by convention: the "added" liquid)
- extract: solute mostly present in this layer $= y_A$
- raffinate: residual solute in this layer $= x_A$
- distribution: how the solute partitions itself $= D_A = \dfrac{y_A}{x_A}$

  - measure of affinity of solute
  - $D_A = \dfrac{\mu_R^0 - \mu_E^0}{RT} = \dfrac{\text{chemical potential difference}}{(R)(\text{temperature})}$

Where/why LLE is used

Where?

- ▶ Bioseparations
- ▶ Nuclear (uranium recovery)
- ▶ Mining: nickel/cobalt; copper/iron
- ▶ Perfumes, fragrances and essential oils
- ▶ Fine and specialty chemicals

Why?

- ▶ Temperature sensitive products
- ▶ High purity requirements
- ▶ High-boiling point species in low quantity
- ▶ Need to separate by species type (rather than relative volatility)
- ▶ Close-boiling points, but high solubility difference
- ▶ Azeotrope-forming mixtures

Extractor types
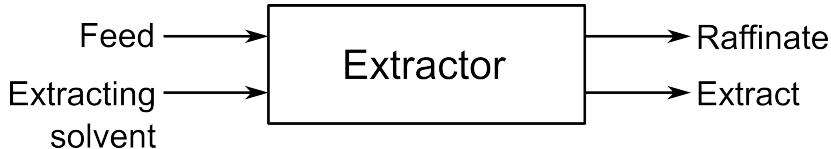
1. Mixing/contacting:
   - turbulent contact between liquid phases
   - small droplet dispersion in a continuous phase
     - which phase is dispersed?
   - mass-transfer between phases
   - limited by solute loading in solvent
2. Phase separation:
   - reverse of mixing step
   - drops coalesce
   - relies on density difference
3. Collection of phases leaving the unit

What are we aiming for?

Assume: solute dissolved in undesirable phase, e.g. solvent

- High recovery of solute in desired phase (phase)
- Concentrated solute in extract (water)

Note: we can have that the solute/solvent is the desirable phase

How to achieve this?

- Counter-current mixer-settlers in series
- High interfacial area during mixing
- Reduce mass-transfer resistance
- Promote mass transfer
  - molecular diffusion
  - eddy diffusion   ← orders of magnitude greater

Equipment for LLE

1. Mixer-settlers
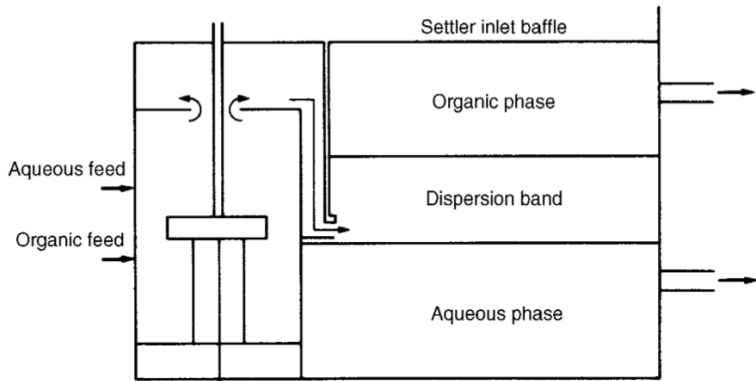   - mix: impellers
   - mix: nozzles
   - mix: feeds meet directly in the pump
   - mix: geared-teeth devices
   - main aim: good contact; avoid droplets smaller than 2 μm
   - settle: baffles, membranes
   - settle: ultrasound
   - settle: chemical treatment
   - settle: centrifuges
2. Columns with:
   - (a) nothing or
   - (b) trays and/or
   - (c) packing and/or
   - (d) pulsating and/or
   - (e) agitation
3. Rotating devices

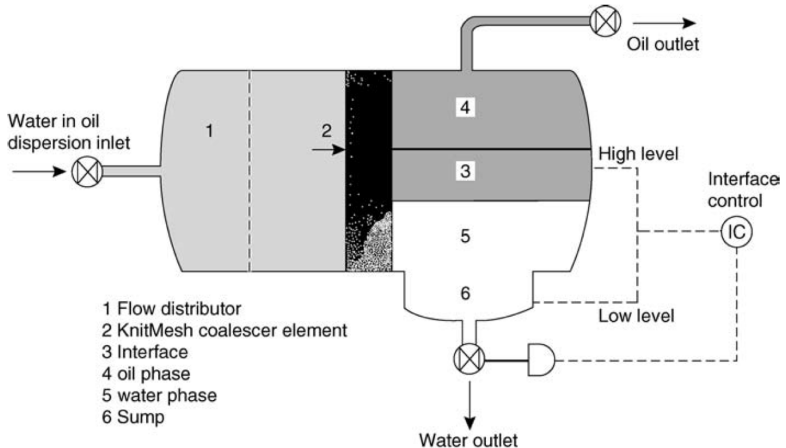# Mixer-settlers

Settler inlet baffle

Organic phase

Dispersion band

Aqueous phase

Aqueous feed

Organic feed

[Richardson and Harker, p 745]

Mixer-settlers

KnitMesh coalescer: consistency of "steel wool"

1 Flow distributor
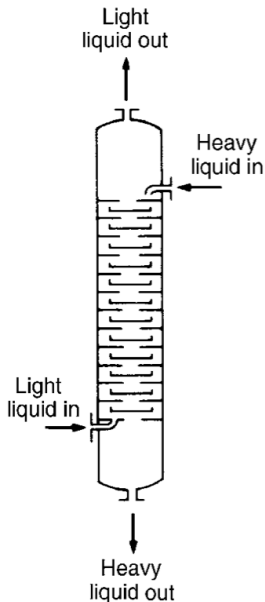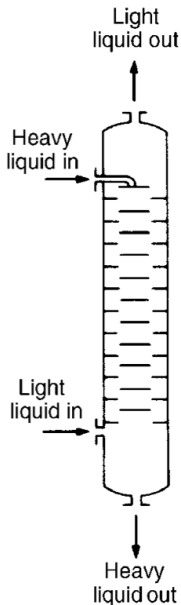2 KnitMesh coalescer element
3 Interface
4 oil phase
5 water phase
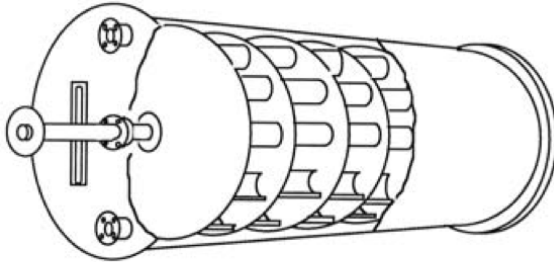6 Sump

[Richardson and Harker, p 747]

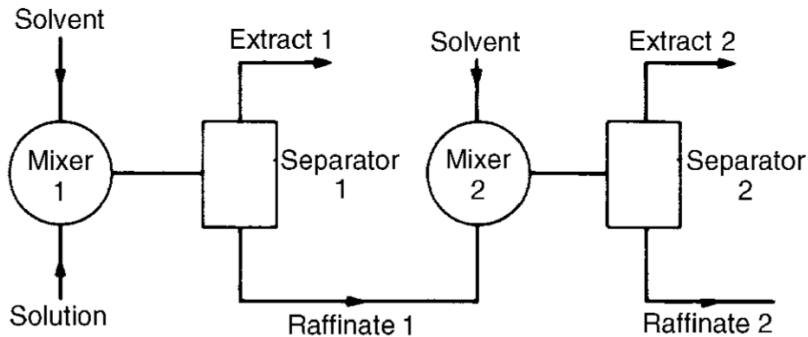# Spray columns: separation principle is gravity
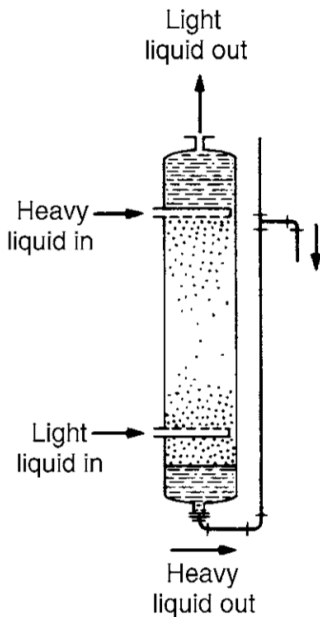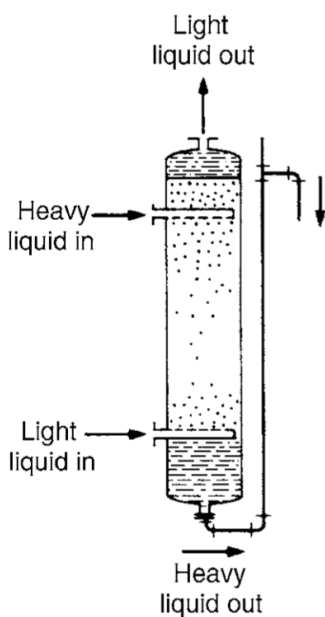
Tray columns

- coalescence on each tray
- tray holes: $\sim$ 3mm
- breaks gradient formation (axial dispersion)

[Richardson and Harker, p 749]

Rotating devices

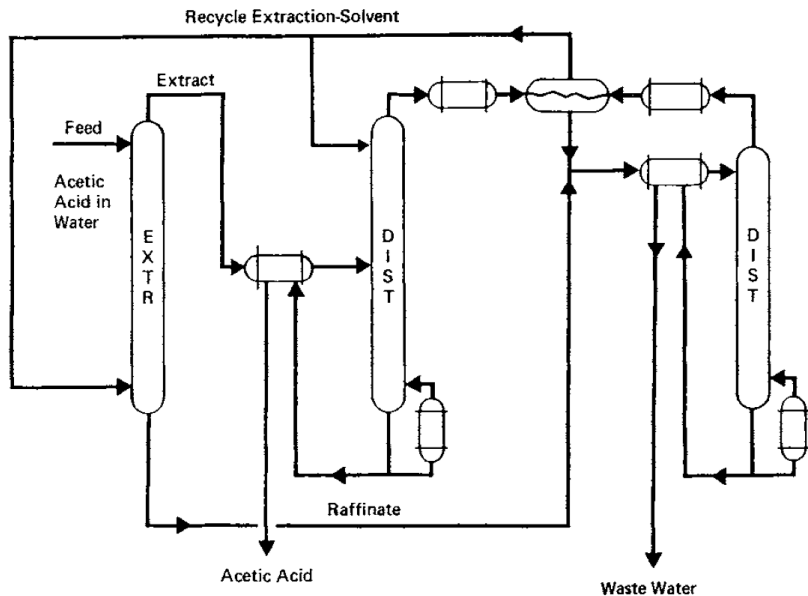# Linking up units (more on this later)

[Richardson and Harker, p 723]

Integration with downstream units

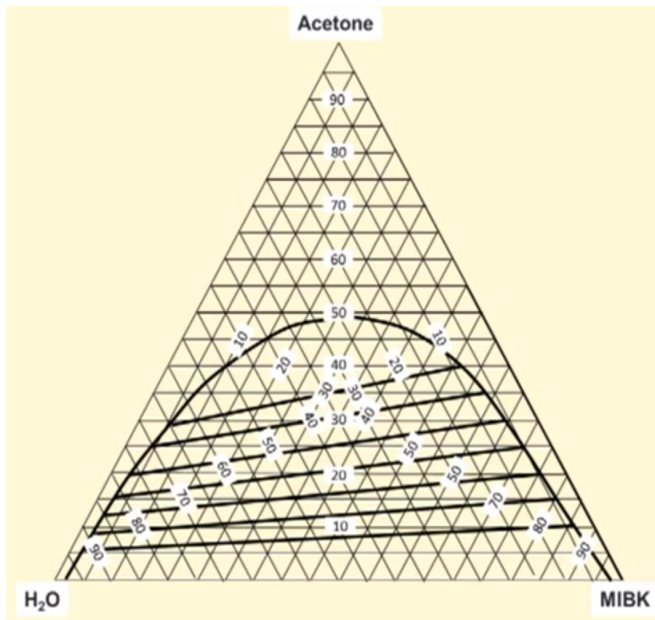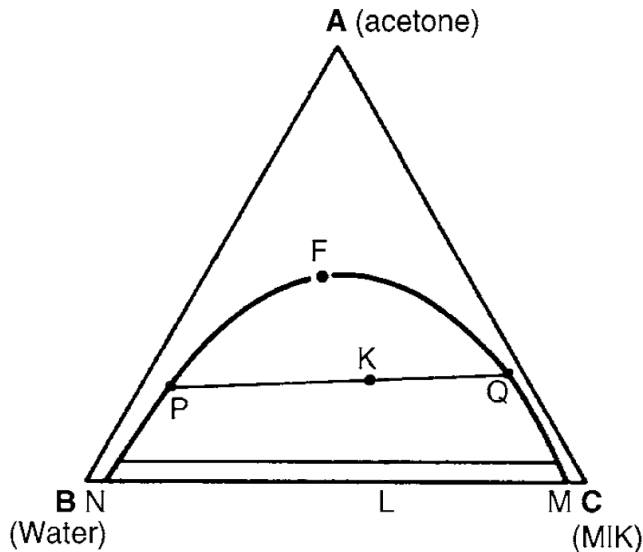# Triangular phase diagrams: from laboratory studies

Using a triangular phase diagrams

Lever rule

Mix P and Q

- mixture = K

- $\dfrac{PK}{KQ} = \dfrac{\text{amount Q}}{\text{amount P}}$

- The converse applies also: when separating a settled mixture

- Applies anywhere: even in the miscible region

Phase rule

Next class

References

- Seader, Henly and Roper, "Separation Process Principles", 3rd edition, chapter 8
- Richardson and Harker, "Chemical Engineering, Volume 2", 5th edition, chapter 13
- Geankoplis, "Transport Processes and Separation Process Principles", 4th edition, chapter 12.5
- Ghosh, "Principles of Bioseparation Engineering", chapter 7
- Uhlmann's Encyclopedia, "Liquid-Liquid Extraction", DOI:10.1002/14356007.b03_06.pub2