Liquid-liquid extraction

Md Khairul Islam (Ph.D)
Applied Chemistry & Chemical Engineering
University of Rajshahi

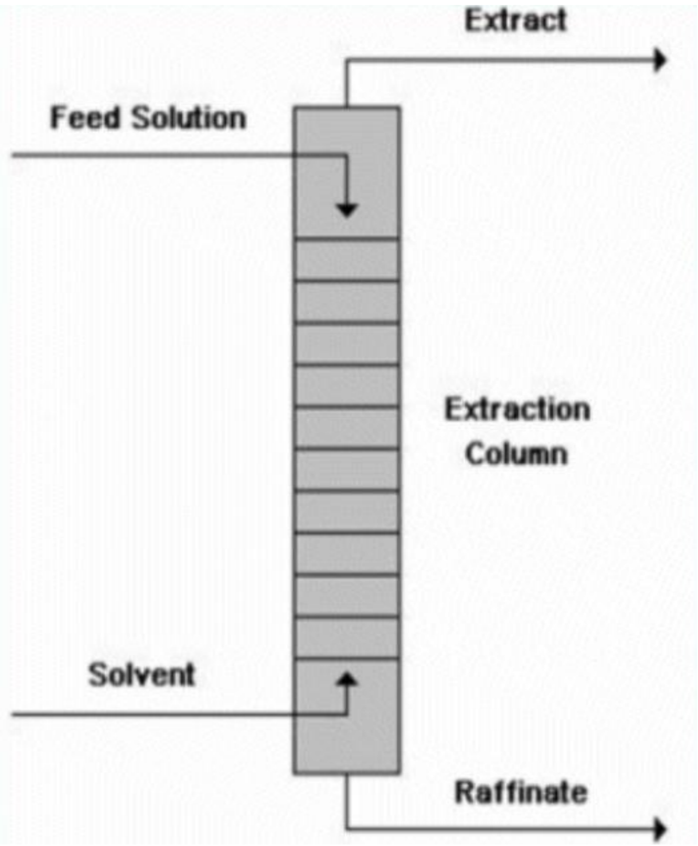
What is liquid-liquid extraction?

- The separation of the components of a liquid mixture by treatment with a solvent in which one or more of the desired components is preferentially soluble is known as liquid-liquid extraction.
- Also known as solvent extraction, which is based on their relative solubilities in two different immiscible liquids.

Basic steps & extractor design

Typical liquid-liquid operations utilizes the differences in the solubilities of the components of a liquid mixtures. The basic steps involved include;

- Contacting the feed with the extraction solvent
- Separation of the resulting phases
- Removal/recovery of solvent from each phase.



Principles of liquid-liquid extraction

The solution which is to be extracted is called feed. Feed phase contains a component, i, which is to be removed. Addition of a second phase (solvent phase) which is immiscible with feed phase but component i is soluble in both phases. Some of component i (solute) is transferred from the feed phase to the solvent phase. After extraction, solvent rich product is called extract(E) and the residual liquid (feed) from which solute has been removed is the raffinate (R). respectively.

Continued.

- Normally one of the two phases is an organic phase while the other is an aqueous phase.
- Under equilibrium conditions the distribution of solute i over the two phases is determined by the distribution law.
- After the extraction the two phases can be separated because of their immiscibility. Component i is then separated from the extract phase by a technique such as distillation and the solvent is regenerated.
- Further extractions may be carried out to remove more component i. Liquid liquid extraction can also be used to remove a component from an organic phase by adding an aqueous phase.

Choice of solvents (Factors to be considered)

- Selectivity
- Distribution coefficient
- Insolubility of solvent
- Recoverability of solute from solvent
- Density difference between liquid phases
- Interfacial tension
- Chemical reactivity
- Cost
- Viscosity & vapor pressure
- Flammability & toxicity

Factors to be considered

Selectivity:

$$\beta = \frac{(\text{mass fraction B in E})/(\text{mass fraction A in E})}{(\text{mass fraction B in R})/(\text{mass fraction A in R})}; \quad \beta > 1$$

Distribution coefficient:

$$K = y/x$$

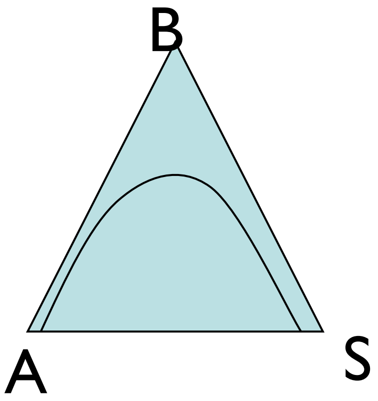
Large values are desirable since less solvent is required for a given degree of extraction

Density

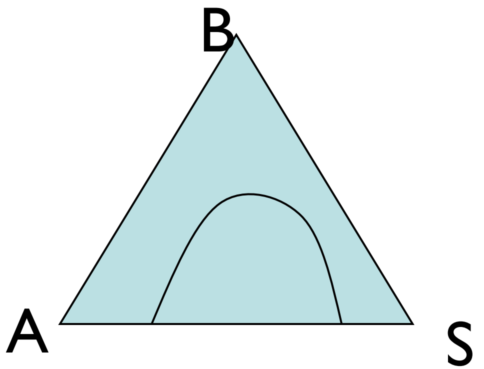
A density difference is required between the two phases.

Factors to be considered

Insolubility of solvent



Preferred solvent –
A and S have limited solubility



S very soluble in A and
A very soluble in S

Recoverability of solvent and solute

- No azeotrope formed between solvent and solute
- Mixtures should have a high relative volatility
- Solvent should have a small latent heat of vaporisation

Factors to be considered

Interfacial tension

The larger the interfacial tension between the two phases the more readily coalescence of emulsions will occur to give two distinct liquid phases but the more difficult will be the dispersion of one liquid in the other to give efficient solute extraction.

Chemical reactivity

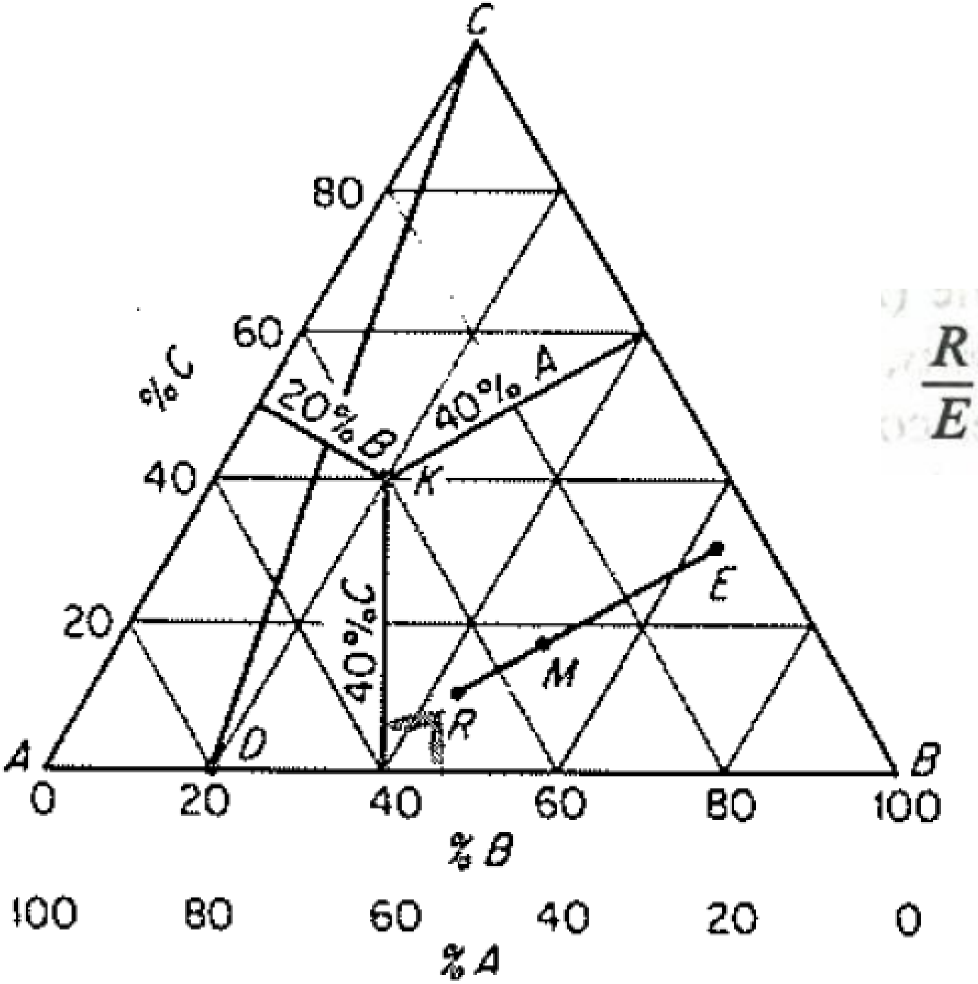
Solvent should be stable and inert.

Physical properties

For material handling:

- Low viscosity
- Low vapor pressure
- Non-flammable (high flash point)
- Non-toxic

Equilateral triangular diagram



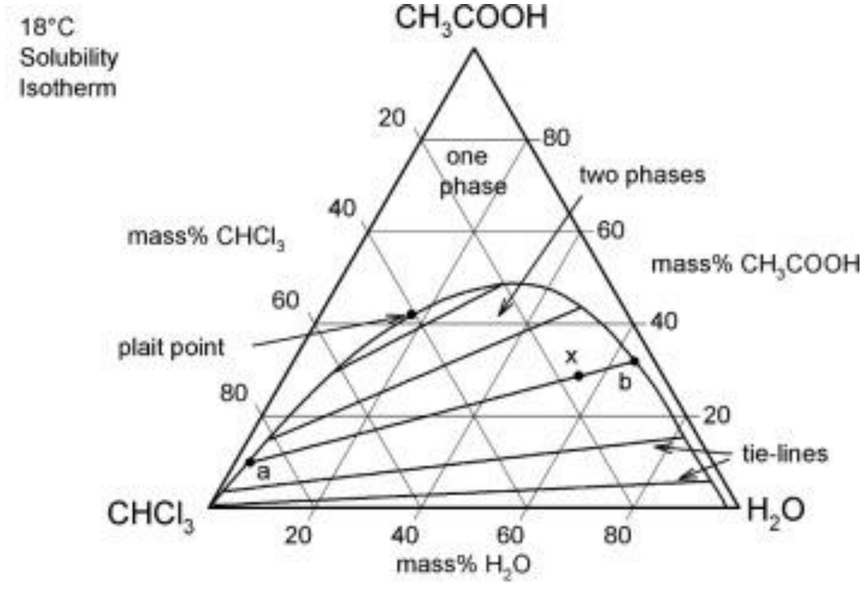
$$\frac{R}{E} = \frac{\text{line } ME}{\text{line } RM} = \frac{x_E - x_M}{x_M - x_R}$$

Three liquids- one pair partially soluble

Solutrope is a ternary mixture with two liquid phases and a third component distributed between the phases, or selectively dissolved in one or the other of the phases.

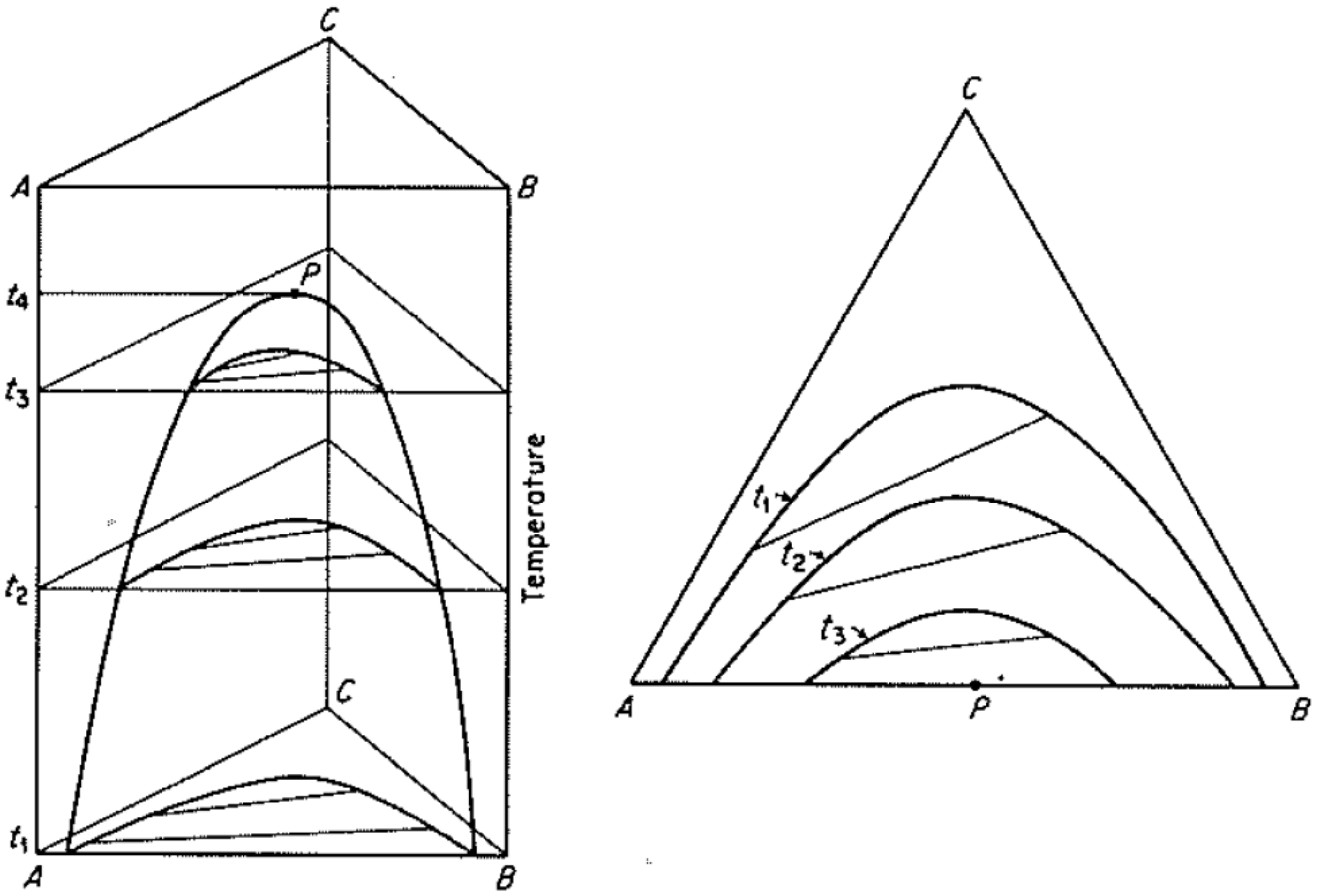
The Plait Point P, is the intersection of the raffinate-phase and extract-phase boundary curves. At this point, the equilibrium phases become coincident and no separation can be made at that point.

Straight lines can be drawn across the immiscible region to connect points on the solubility envelopes. These 2 points represent equilibrium-phase compositions. These lines are called tie lines.



$CHCl_3$-H_2O-CH_3COOH

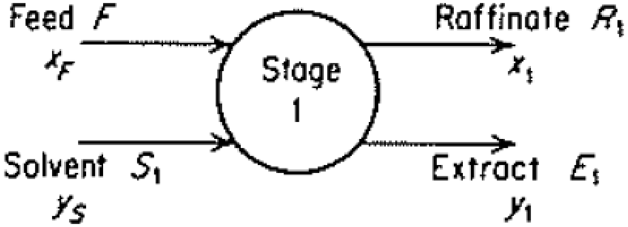
Effect of temperature

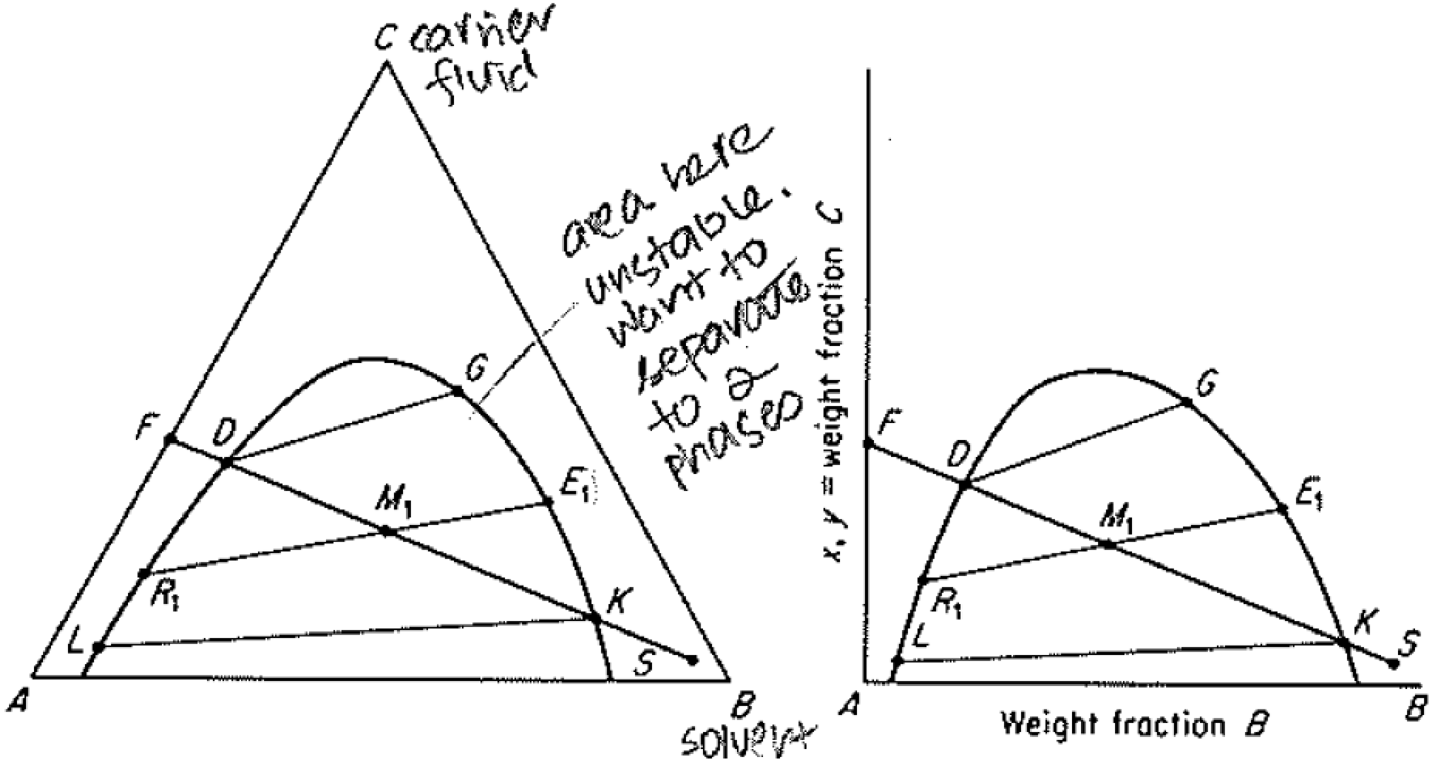


(a) (b)

Effect of pressure?

Single stage extraction





Mass balance of single stage extraction

$$F + S_1 = M_1 = E_1 + R_1$$

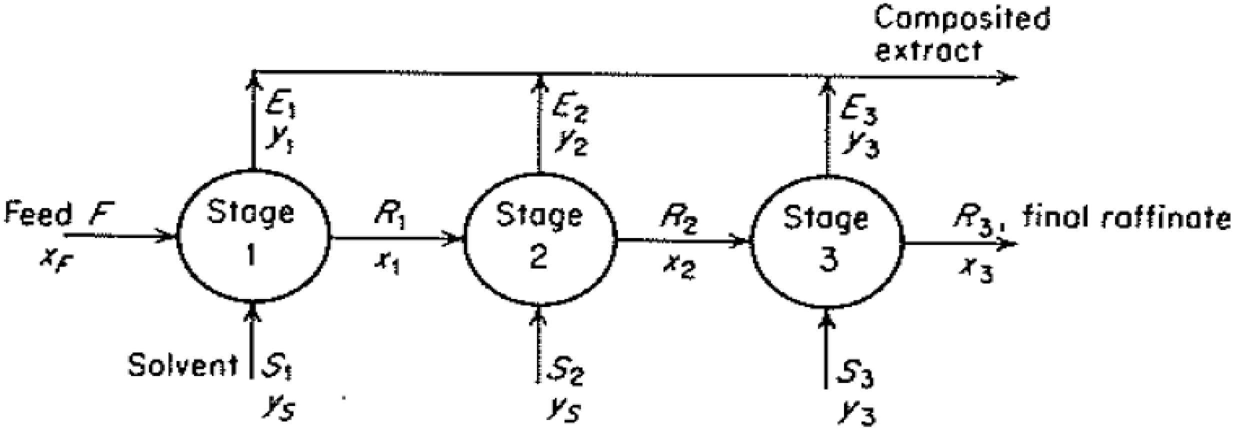
$$Fx_F + S_1 y_S = M_1 x_{M1}$$

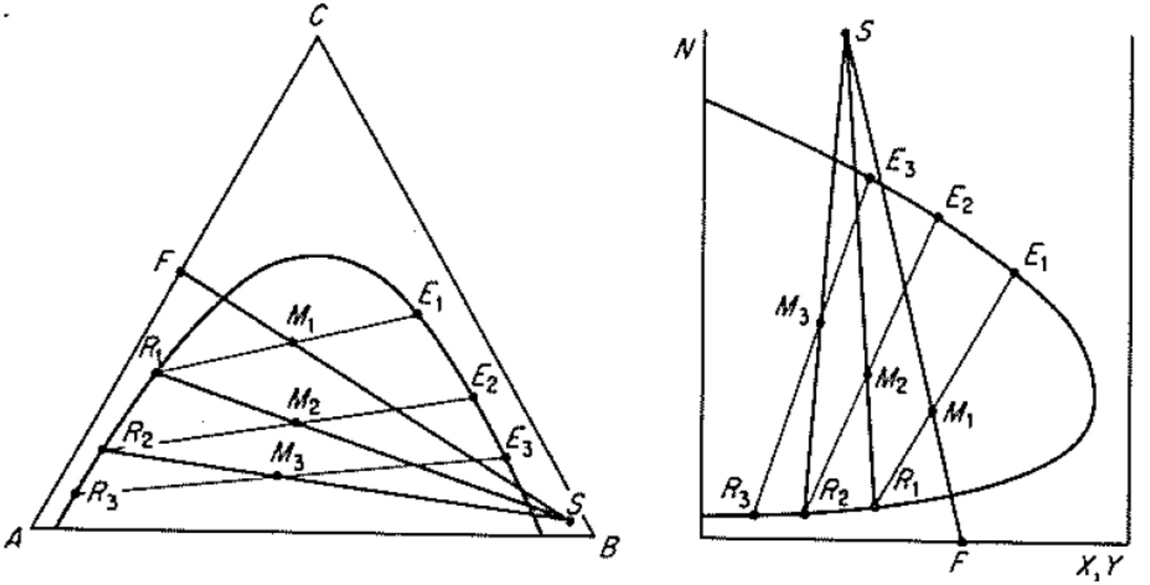
$$\frac{S_1}{F} = \frac{x_F - x_{M1}}{x_{M1} - y_S}$$

$$E_1 y_1 + R_1 x_1 = M_1 x_{M1}$$

$$E_1 = \frac{M_1(x_{M1} - x_1)}{y_1 - x_1}$$

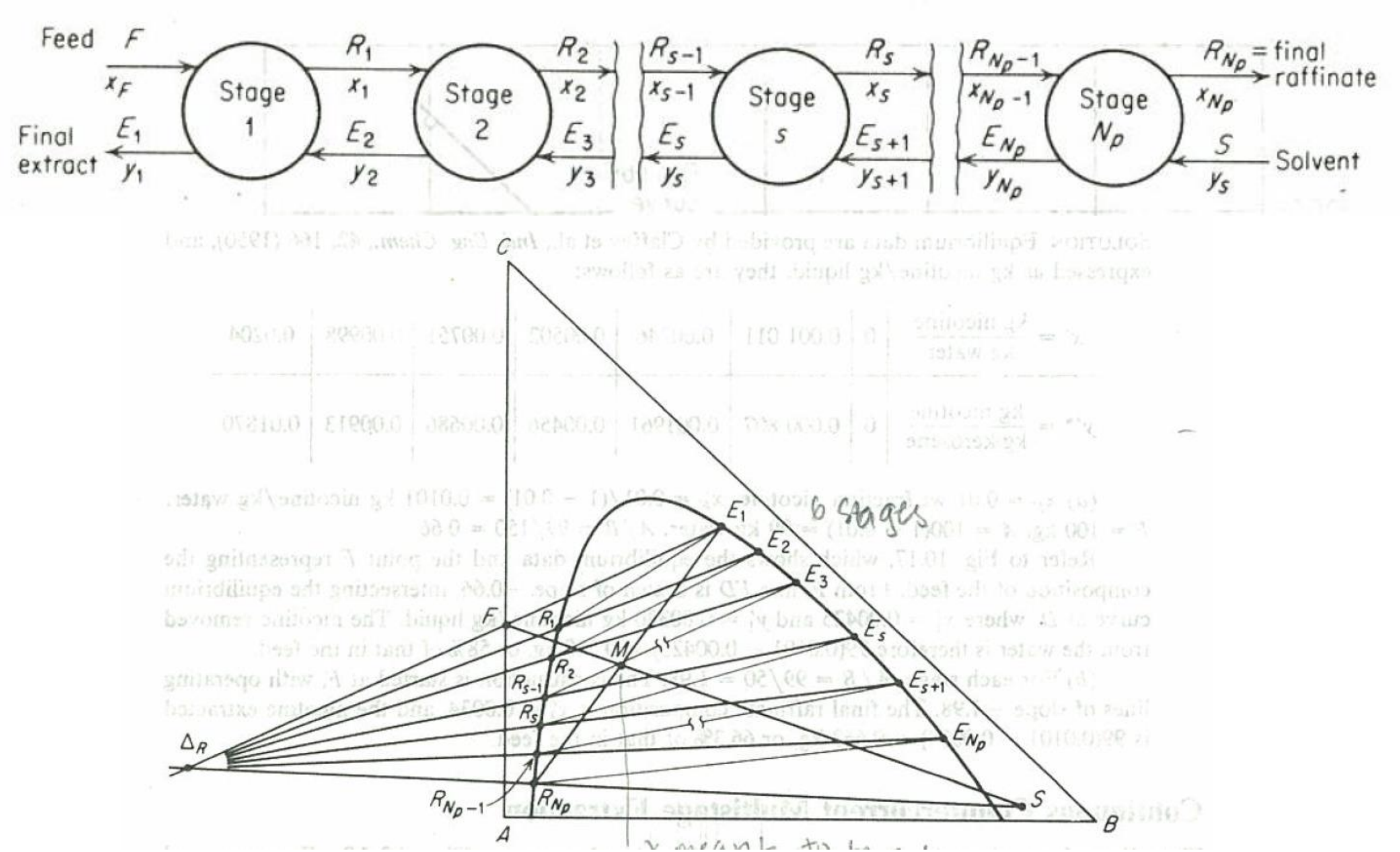
Multi-stage extraction





Cross current extraction

Multi-stage extraction



Counter current extraction

Application of liquid-liquid extraction

- Remove products and pollutants from dilute aqueous streams
- Wash polar compounds or acids/bases from organic streams
- Heat sensitive products
- Non-volatile materials
- Azeotropic and close boiling mixtures
- Alternative to high cost distillations

Disadvantages of liquid liquid extraction

- LLE include use of large solvent volumes,
- Multiple extractions, and
- Long extraction times