Extraction

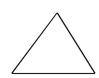
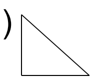
A is transferred between two phases (normally from B-phase to C-phase)
"Use solvent C to extract A from B"

12.5 LLE (liquid-liquid equilibrium) and single stage

12.7 Multistage

1. Special case: Immiscible liquids and dilute (12.7 C):
   - B and C do not mix ("inerts")
   - Can use same methods as for absorption/stripping (McCabe-Thiele)
   - Example. A=nicotine, B=water, C=kerosene (hydrocarbon)
2. General case: B and C mix (12.7 B)
   - Need triangular diagrams
   - Operating lines go through point which could be outside diagram (!)
   - Example, A=acetic acid, B=water, C=isopropyl ether

Liquid-liquid equilibrium

- Triangular diagrams for 3 components
  - Two versions (both are common):
    - Triangular coordinates (Fig. 12.5-1/2) 
    - Rectangular coordinates (Fig. 12.5-3/4) 

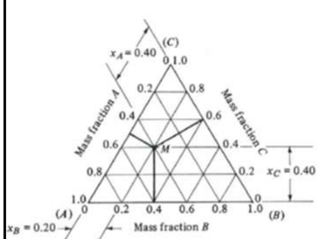


FIGURE 12.5-1. Coordinates for a triangular diagram.

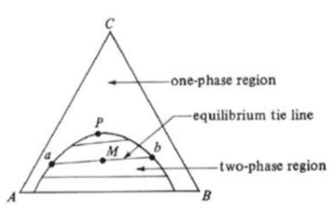


FIGURE 12.5-2. Liquid–liquid phase diagram where components A and B are partially miscible.

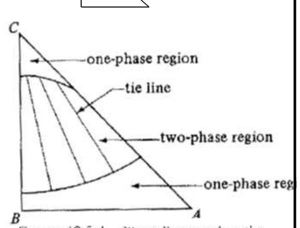
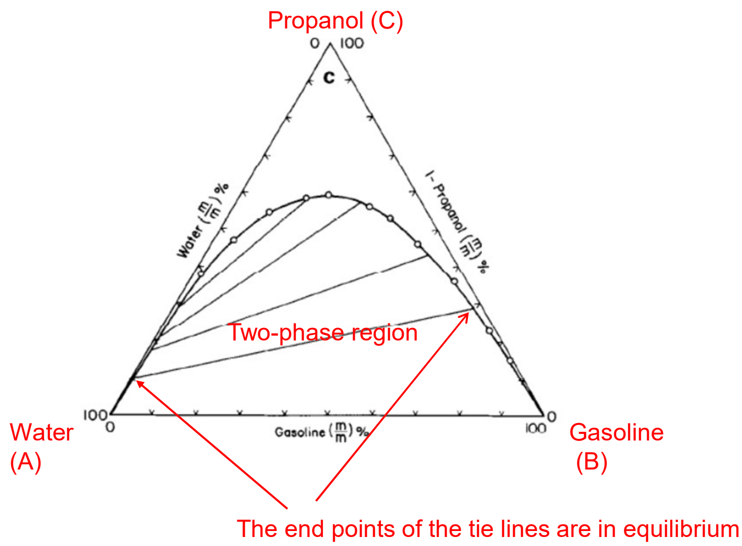


FIGURE 12.5-4. Phase diagram where the solvent pairs B–C and A–C are partially miscible.



Ternary phase diagrams for gasoline–water–alcohol mixtures: T. M. Letcher et al.

curve. The resultant tie-line was checked to see that it did indeed pass through the composition of the overall mixture.

Because the fuel blends used in South Africa contained between 10 and 15 vol or wt% alcohol, detailed water miscibility measurements were obtained at various temperatures for blends in this composition range. In order to ensure uniformity of the blends, a 200 g stock blend of each alcohol-gasoline mixture was made up. The miscibility measurements were carried out taking 20 cm^3 aliquots with different amounts of water using the syringe technique described above.

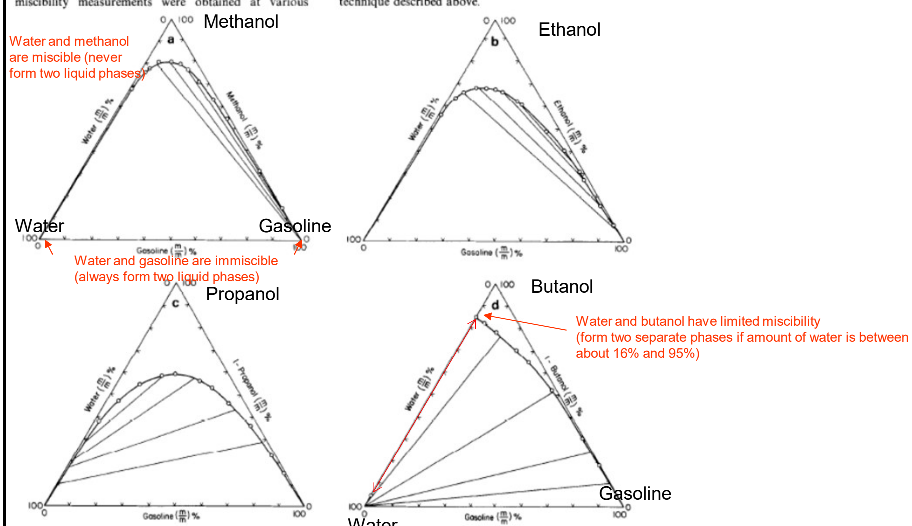


Figure 1 The binodal curves and tie-lines for gasoline–water–alcohol ternary systems: a, methanol; b, ethanol; c, 1-propanol; d, 1-butanol; 25C

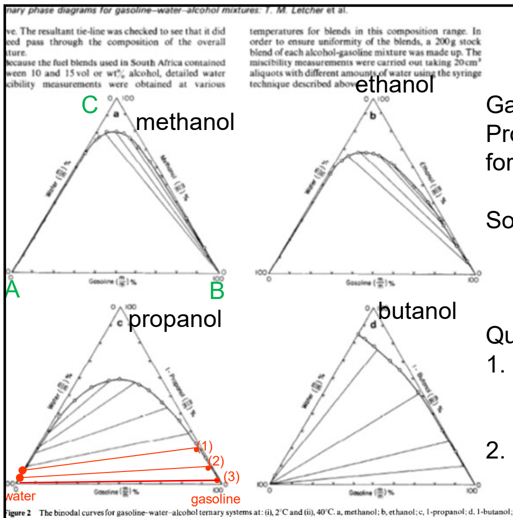


Figure 2 The binodal curves for gasoline-water-alcohol ternary systems at: (i), 2°C and (ii), 40°C. a, methanol; b, ethanol; c, 1-propanol; d, 1-butanol;

Data for gasoline phase at 2C:

(1) 20% propanol,1.6% water, rest gasoline

(2) 10% propanol, 0.5% water, rest gasoline

QUIZ

(Note: Actually opposite of a separation process)

Gasoline (B) tank (50kg) cold day:
Problem: Water (A) condenses and forms separate phase

Solution (?): Add alcohol (C) that "extracts" water into the gasoline phase (so that water phase disappears)

Questions (see data):

1. Which alcohol is the most effective?

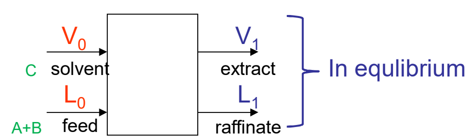
?

2. If we add 100 g (0.2%) of this alcohol, how much water can we "extract" ?

(1) 20% alcohol: Alcohol/water=20/1.6=12.5
(2) 10% alcohol: Alcohol/water=10/0.5 = 20
(3) Tank: 0.2% alcohol: Assume Alcohol/water=25

↓

Single-stage extraction (12.5C)



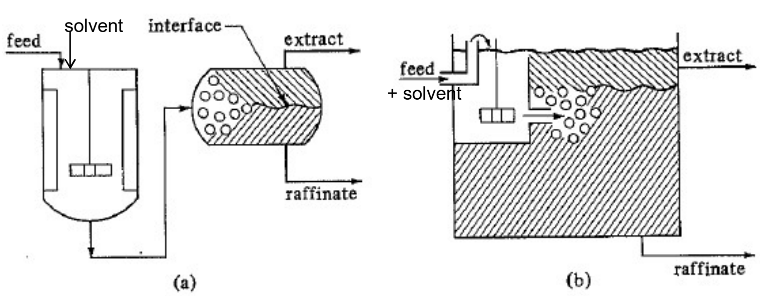


FIGURE 12.6-1. *Typical mixer–settlers for extraction: (a) separate mixer–settler, (b) combined mixer–settler.*

Lever arm rule *(vektstangregelen)*

Useful for graphical methods

From mass balances:

- Mixture (M) is on straight line between feeds (L & V)

1. Amounts follow lever arm rule:

$$\frac{L[\text{kg}]}{V[\text{kg}]} = \frac{l_{VM}}{l_{LM}} = \frac{\overline{VM}}{\overline{LM}}$$

"Mass-ratio is inverse of distance-ratio"

(Mixture is closest to the largest feed!)

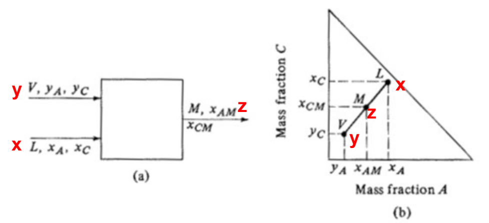


FIGURE 12.5-5. *Graphical addition and lever-arm rule: (a) process flow, (b) graphical addition*

Proof: Mass balances!

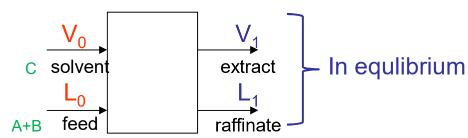
(1) M = L + V

(2) zM = xL + yV

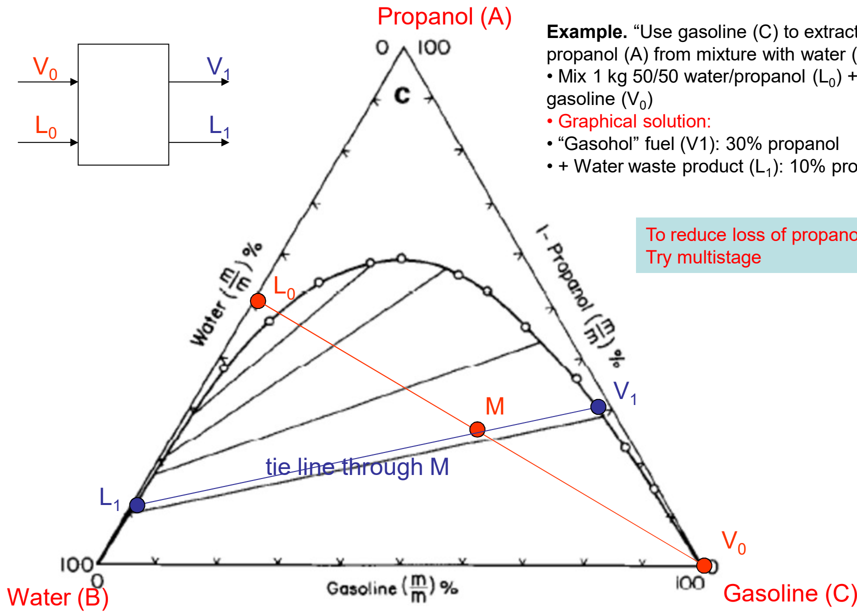
Solve to get:

$$\frac{L}{V} = \frac{y-z}{z-x} = \frac{\overline{VM}}{\overline{LM}}$$

Single-stage extraction (12.5C)



Graphical solution
1. Locate Vo
2.Locate Lo
3. Locate M (mass balance or lever arm rule)
4, Find tie line through M (interpolate)
5. Find V1 and L1 at end of tie lines (compositions)
6. Find amount of V1 and L1 from mass balance



Example. "Use gasoline (C) to extract propanol (A) from mixture with water (B)".

- Mix 1 kg 50/50 water/propanol (L_0) + 1 kg gasoline (V_0)
- Graphical solution:
- "Gasohol" fuel (V1): 30% propanol
- + Water waste product (L_1): 10% propanol

To reduce loss of propanol in L1: Try multistage

Single-stage extraction: Extract propanol (in L_0) into gasoline (V_0)

Seen from side:

Seen from top:

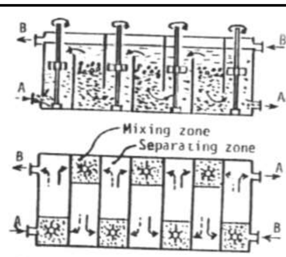


Figure 4.31 Battery of mixer-settlers with heavy phase A and light phase B

Countercurrent multistage

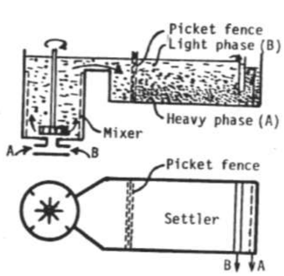


Figure 4.32 General Mills mixer-settler. The mixer is provided with baffles and the settler with a picket fence

Single stage

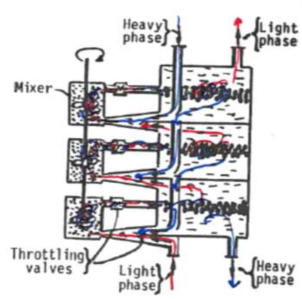


Figure 4.33 Lurgi extractor consisting of stacked mixer–settler units. Capacity for aromatic extraction up to 1600 t/h with column diameter 3 m

Countercurrent multistage

Continuous Multistage countercurrent extraction

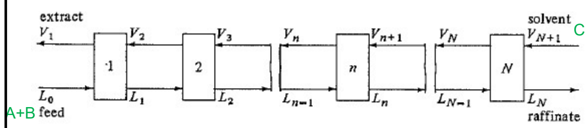


FIGURE 12.7-1. *Countercurrent-multistage-extraction-process flow diagram.*

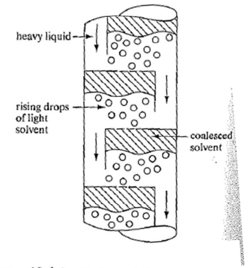


FIGURE 12.6-4. *Perforated-plate or sieve-tray extraction tower.*

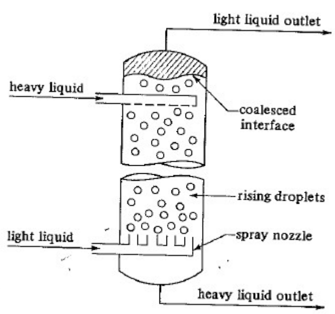


FIGURE 12.6-2. *Spray-type extraction tower.*

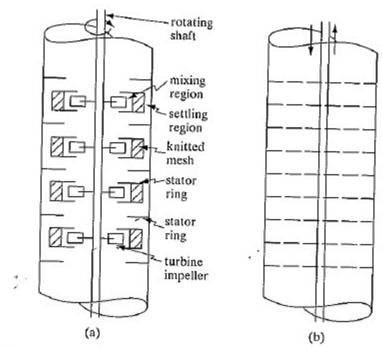


FIGURE 12.6-5. *Mechanically agitated extraction towers: (a) Scheibel rotating-agitator tower, (b) Karr reciprocating-plate tower.*

Simplest case: Immiscible liquids (12.7 C)

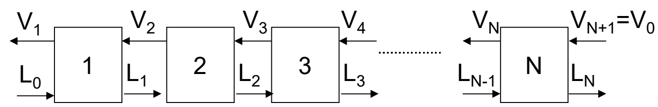
- B and C do not mix
- Dilute mixtures
  - Mole fraction of A less than about 0.15
- Can use methods from absorption/stripping

  x = mole fraction of A in phase B

  y = mole fraction of A in phase C

  Equilibrium (dilute mixtures): y=mx (end of tie lines)

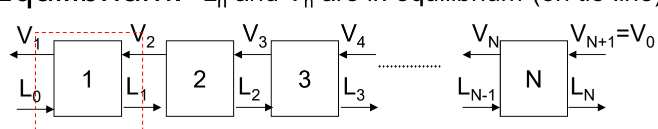
Continuous Multistage <u>countercurrent</u> extraction

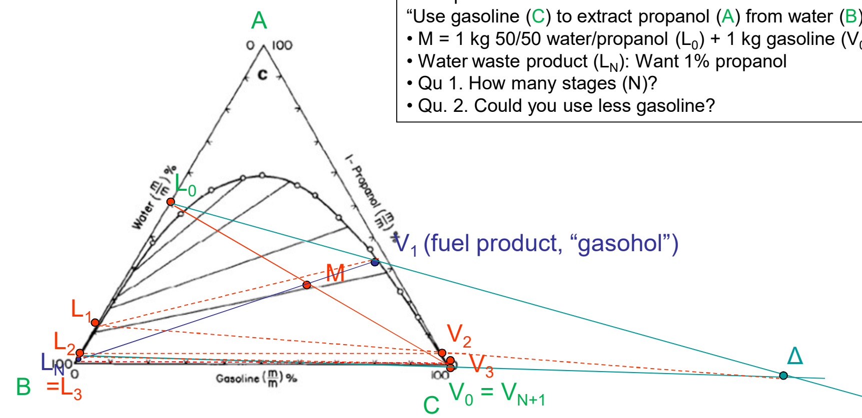


General case: Miscible liquids (12.7 B)

Δ operating point method

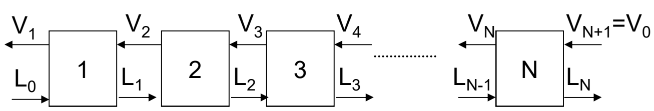
- $\Delta = L_0 - V_1$ = net flow through stages
- Mass balance: $\Delta = L_0 - V_1 = L_1 - V_2 = \cdots L_N - \overbrace{V_{N+1}}^{V_0}$
- Rewrite: $L_0 = V_1 + \Delta$
  - "L_0 is a mixture of V_1 and Δ"
  - "L_0 and V_1 are on a straight line through Δ" } use to locate Δ
  - "L_N and V_{N+1} are on a straight line through Δ" } use to locate Δ
  - "L_1 and V_2 are on a straight line through Δ", etc.
- Equilibrium: "L_n and V_n are in equilibrium (on tie line)"



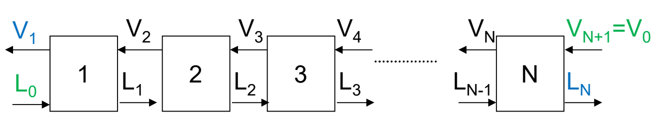


Example.
"Use gasoline (C) to extract propanol (A) from water (B) ".
- M = 1 kg 50/50 water/propanol (L_0) + 1 kg gasoline (V_0)
- Water waste product (L_N): Want 1% propanol
- Qu 1. How many stages (N)?
- Qu. 2. Could you use less gasoline?

$L_N = L_3$: 3 stages



Continuous Multistage countercurrent extraction



Graphical solution to find N (number of stages):

1,2: Locate feeds (V_0 and L_0)

3. Locate total feed M on line through L_0&V_0 (mass balance or lever arm rule)

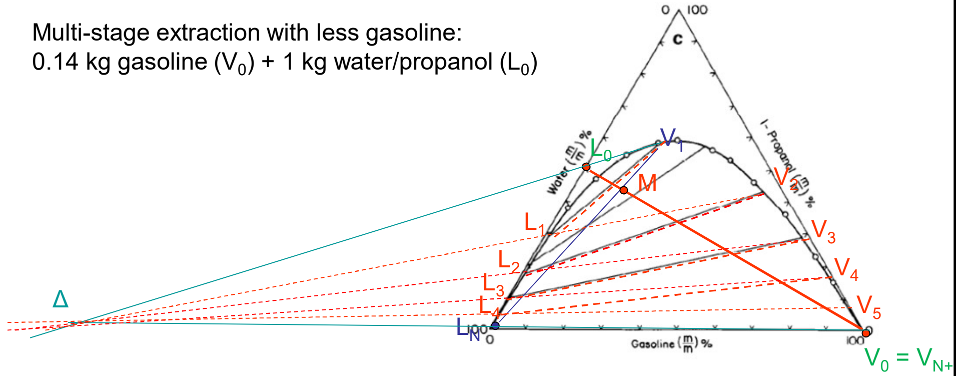
4, 5: Locate products (V_1 and L_N)
- On phase boundary (but on same tie line only for single stage, N=1)
- On line through M

6. Locate Δ-point («net flow between stages»)
- On crossing of lines through L_0&V_1 and L_N&V_0

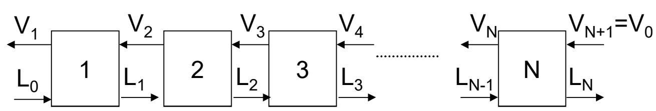
7, 8, ….: Find remaining points by starting in one end., for example V_1
- L_1 in equilibrium with V_1 (other end of tie lie through V_1)
- V_2 on mass balance line through L_1&Δ (and on phase boundary)

- L_2 in equilibrium with V_2
- V_3 on mass balance line through L_2&Δ
- … continue until $L_n = L_N$

Multi-stage extraction with less gasoline:
0.14 kg gasoline (V_0) + 1 kg water/propanol (L_0)

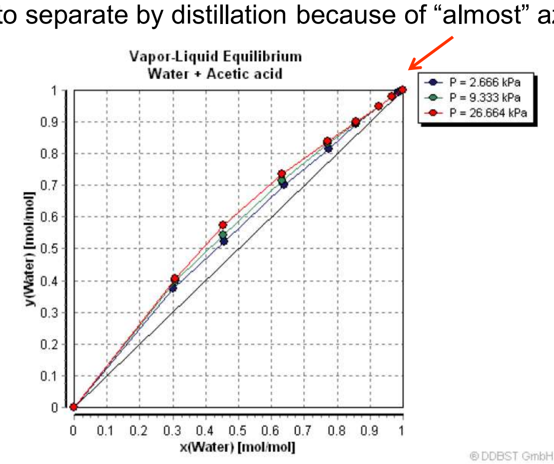


$L_N = L_6$: about 6 stages
BUT: V_1-product contains more than 25% water
(may not be acceptable as fuel)

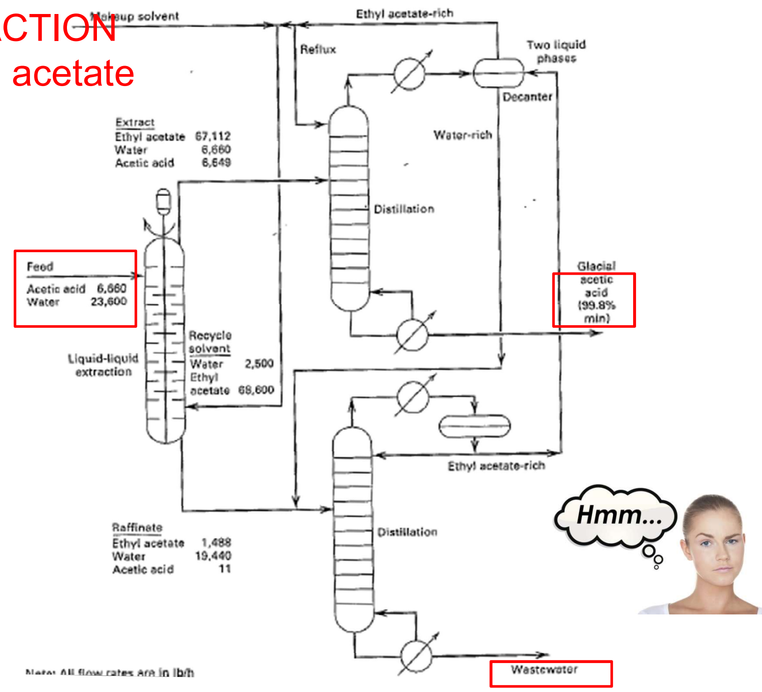


Example: Acetic acid-water separation

- Water, bp = 100C
- Acetic acid, bp=118.5C
- Difficult to separate by distillation because of “almost” azeotrope



1. EXTRACTION using ethyl acetate as solvent



2. Azeotropic distillation using isobutyl acetate (IBA, bp=118C) as entrainer

(Perstorp plant, Singapore until 2014)