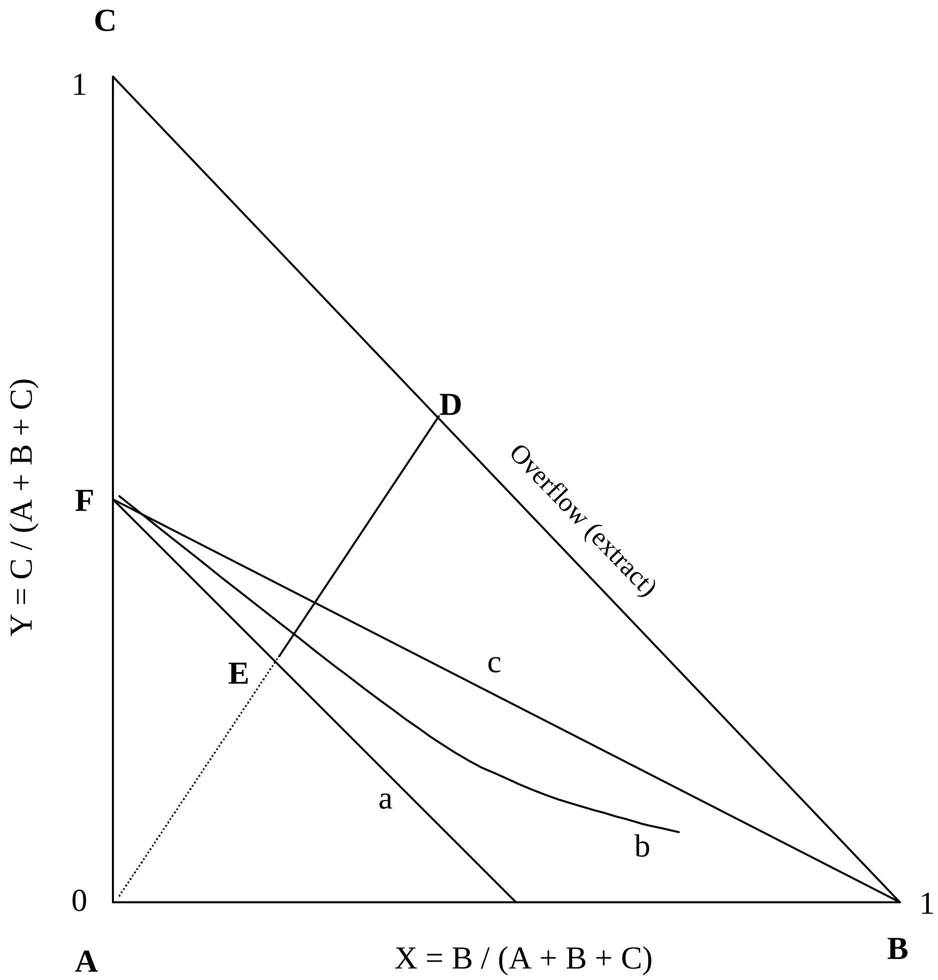
Examples Solid-Liquid Extraction

1. Rectangular Triangle Diagram

A ... inert material

B ... extractable material

C ... solvent



a ... constant underflow

b ... variable underflow

c ... constant ration solvent / inert material

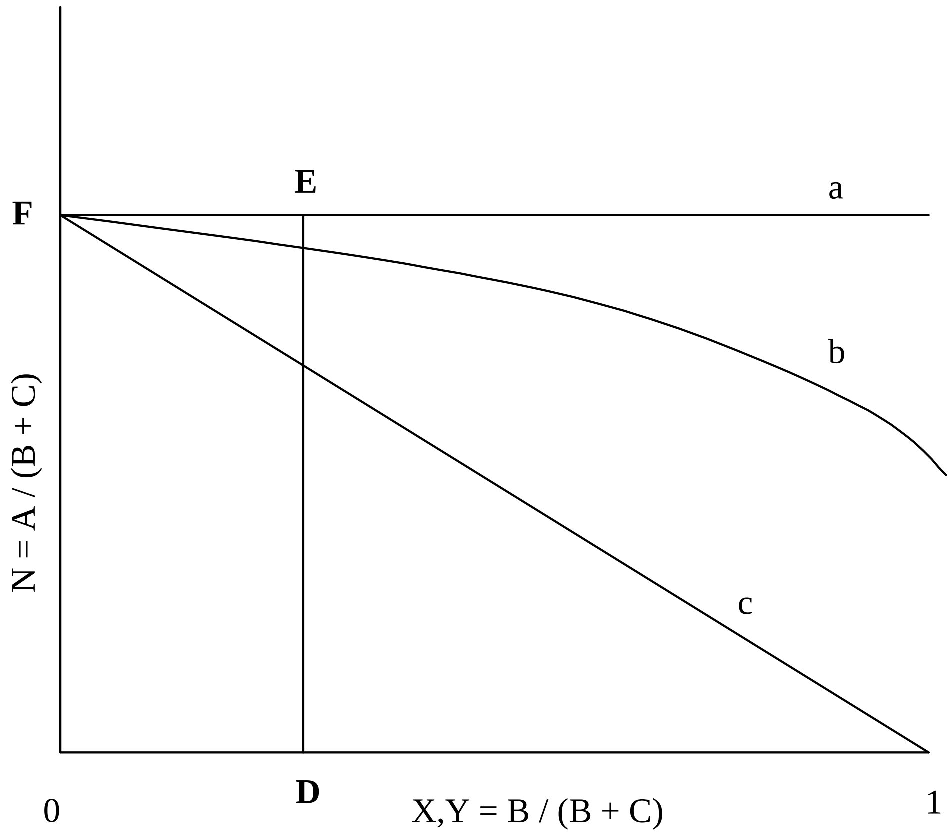
$\overline{DE}$ **... connode**

2. Ponchon - Savarit Diagram

A ... inert material

B ... extractable material

C ... solvent



a ... constant underflow

b ... variable underflow

c ... constant ration solvent / inert material

$\overline{DE}$ **... connode**

$$N = \frac{\text{inert material}}{\text{extractable substance} + \text{solvent}} = \frac{A}{B + C}$$

L = solution = extractable substance + solvent = B + C

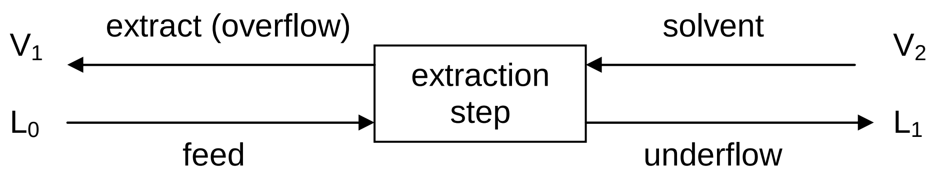
N * L = amount of inert material A

L * X, L * Y = amount of extractable substance B

Example 1: Single Step Extraction

In a single step solid-liquid extraction soybean oil has to be extracted from soybean flakes using hexane as solvent. 100 kg of the flakes with an oil content of 20 wt% are contacted with 100 kg fresh hexane. 1.5 kg of inert material hold back a constant value of 1 kg solution.

Determine in the rectangular triangle diagram and in the Ponchon - Savarit diagram the amount and composition of the flows leaving the extraction plant.



1. Rectangular Triangle Diagram

Total balance:

$$L_0 + V_2 = \underline{\mathbf{M}} = L_1 + V_1 = 100 + 100 = \underline{\mathbf{200\ kg}}$$

Balance for compound A:

$$L_0\, w_{A,L0} + V_2\, w_{A,V2} = M\, w_{A,M}$$

with the feed concentration $w_{A,L0} = 0.8$
and the suggestion, that no solid particles are included in the overflow, so $w_{A,V2} = 0$ follows:

$$100 * 0.8 + 100 * 0 = 200 * w_{A,M}$$

$$\underline{\mathbf{w_{A,M} = 0.4}}$$

Balance for compound B:

$$L_0\, w_{B,L0} + V_2\, w_{B,V2} = M\, w_{B,M}$$

with the feed concentration $w_{B,L0}$ = 0.2 and with the knowledge, that pure hexane is used as solvent, $w_{B,V2}$ = 0, follows

$$100 * 0.2 + 100 * 0 = 200 * w_{B,M}$$

$$\underline{\mathbf{w_{B,M} = 0.1}}$$

The concentration of compound C (solvent) in the mixing point M can be determined either by a mass balance for compound C

$$L_0\, w_{C,L0} + V_2\, w_{C,V2} = M\, w_{C,M}$$

with $w_{C,L0}$ = 0, because no solvent is included in the feed, and with $w_{C,V2}$ = 1, pure hexane, follows

$$100 * 0 + 100 * 1 = 200 * w_{C,M}$$

$$\underline{\mathbf{w_{C,M} = 0.5}}$$

or by the rule, that the sum of the mass percent of each compound in the point M has to be 1.

$$w_{A,M} + w_{B,M} + w_{C.M} = 1$$

$$0.4 + 0.1 + w_{C.M} = 1$$

$$\underline{\mathbf{w_{C.M} = 0.5}}$$

With these concentrations the mixing point M can be drawn in the diagram, which has to be on the connection line of feed point F and solvent C.

It is given, that 1 kg inert material retains 1.5 kg solution (extractable substance + solvent = miscella = overflow). Therefore the concentration of the underflow is

$$w_{A,Underflow} = \frac{\text{inert material}}{\text{inert material} + \text{extractable substance} + \text{solvent}} = \frac{A}{A+B+C}$$

$$w_{A,Underflow} = \mathbf{w_{A,L1}} = \frac{1.5}{1.5+1} = \mathbf{0.6}$$

The amount of the leaving flows L_1 and V_1 can be calculated from the mass balance for compound A

$$M\, w_{A,M} = V_1\, w_{A,V1} + L_1\, w_{A,L1}$$

with $w_{A,V1} = 0$ (no solid material in the overflow) and $w_{A,L1} = 0.6$ (underflow)

$$L_1 = M \frac{w_{A,M}}{w_{A,L1}} = 200\ \frac{0.4}{0.6}$$

L_1 = 133.333 kg

With the total balance

$$M = L_1 + V_1$$

follows

$$V_1 = M - L_1 = 200 - 133.333$$

V_1 = 66.666 kg

The concentrations of B and C in the overflow V_1 are calculated with the suggestion that no inert material A is included in the overflow.

$$w_{B,V1} = \frac{B}{(A) + B + C} = \frac{20}{0 + 20 + 100}$$

$w_{B,V1}$ = 0.1667

$$w_{C,V1} = \frac{C}{(A) + B + C} = \frac{100}{0 + 20 + 100}$$

$w_{C,V1}$ = 0,8333

The composition of the underflow can be calculated by mass balances for compound B and C.

$$L_1\, w_{B,L1} + V_1,\, w_{B,V1} = L_0\, w_{B,L0} + V_2\, w_{B,V2}$$

with $w_{B,V2} = 0$

$$w_{B,L1} = \frac{L_0 * w_{B,Lo} - V_1 * w_{B,V1}}{L_1} = \frac{100 * 0.2 - 66.666 * 0.1667}{133.333}$$

$w_{B,L1}$ = 0.067

$w_{A,L1} + w_{B,L1} + w_{C,L1} = 1$

$w_{C,L1} = 1 - 0.6 - 0.067$

$\underline{\mathbf{w_{C,L1} = 0.333}}$

	total mass [kg]	wt% A	wt% B	wt% C
feed L_0	100	80	20	0
solvent V_2	100	0	0	100
overflow V_1	66.666	0	16.667	83.333
underflow L_1	133.333	60	6.7	33.3

2. Ponchon - Savarit Diagram

Total balance:

$L_0 + V_2 = M = L_1 + V_1$

$\underline{\mathbf{L_0}}$ = B + C **= 20 kg**, no solvent is included in the feed material

V_2 = 100 kg, pure solvent C

M = 20 + 100 **= 120 kg**

Compound balance:

$L_0 X_{L0} + V_2 X_{V2} = M X_M$

X_{L0} = 1 $= \frac{B}{B+C}$, no solvent in the feed material → C = 0

X_{V2} = 0, pure solvent C

$20 * 1 + 100 * 0 = 120 * X_M$

X_M = 0.1667

$N_0 = ?$

N_0 $= \frac{A}{L_0} = \frac{80}{20}$ **= 4**

$N_M = ?$

$N_0 * L_0 = A = N_M * L_M$

L_M = B + C = 20 + 100 **= 120 kg**

N_M $= \frac{A}{L_M} = \frac{80}{120}$ **= 0.667**

The amount of the extract solution V_1 and of the solution, retained by the solid material, L_1 can be determined by law of balance or by calculation.

$M = 120 \text{ kg} = L_1 + V_1$

$N_1 = ?$

It is given, that 1.5 kg of inert material A retains 1 kg solution B+C

→ $\underline{N_1} = \frac{1.5}{1}$ **= 1.5** = underflow, which is constant

$A = N_0 * L_0 = N_1 * L_1 = N_M * M$

$\underline{L_1} = \frac{A}{L_1} = \frac{80}{1.5}$ **= 53.333 kg**

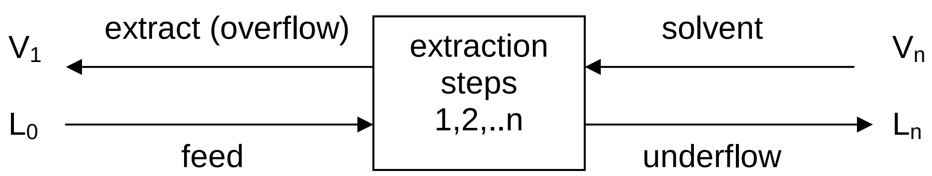
$\underline{V_1}$ **=** $M - L_1 = 120 - 53.333$ **= 66.666 kg**

	L	**N**	**X**
feed L_0	20	4	1
solvent V_n	100	0	0
overflow V_1	66.666	0	0.1667
underflow L_n	53.333	1.5	0.1667

Example 2: Continuous Countercurrent Solid - Liquid Extraction

10.000 kg of wet sugar beet chips with a composition of 28 wt% water, 32 wt% sugar and 40 wt% inert material have to be extracted in a continuous countercurrent extraction plant using hot water as solvent. The produced extract must contain 40 wt% sugar and the total extraction efficiency for sugar has to be 90%.
1 kg inert material retains 3 kg solution and this value is constant.

Determine in the rectangular triangle diagram and in the Ponchon - Savarit diagram the number of ideal steps for this separation problem.



1. Rectangular triangle diagram

90% sugar (B) have to be extracted and the extract solution must contain 40 wt% sugar

$$V_1 * x_{B,V1} = 0.9 * L_0 * x_{B,L0}$$

with $\underline{\mathbf{x_{B,V1} = 0.4,\ L_0 = 10.000\ kg}}$ and $\underline{\mathbf{x_{B,L0} = 0.32}}$

$$\underline{V_1} = \frac{0.9 * 10{,}000 * 0.32}{0.4} \ \underline{\mathbf{= 7.200\ kg}}$$

Balance for inert material A

$$L_n * x_{A,Ln} + V_1 * x_{A,V1} = V_n * x_{A,Vn} + L_0 * x_{A,L0}$$

with

$$\underline{x_{A,Ln}} = x_{A,Underflow} = \frac{A}{A+B+C} = \frac{1}{1+3} \ \underline{\mathbf{= 0.25}}$$

and $\underline{\mathbf{x_{A,V1} = 0}}$ with the suggestion that no solid material is included in the overflow and with $\underline{\mathbf{x_{A,Vn} = 0}}$ because of pure solvent water C follows

$$\underline{\mathbf{L_n}} = L_0 \frac{x_{A,L0}}{x_{A,Ln}} = 10{,}000 \frac{0.4}{0.25} \ \underline{\mathbf{= 16{,}000\ kg}}$$

Balance for sugar B:

$$V_1 * x_{B,V1} + L_n\, x_{B,Ln} = L_0 * x_{B,L0} + V_n * x_{B,Vn}$$

with $\underline{\mathbf{x_{B,Vn} = 0}}$ because the solvent is pure water C follows

$$\underline{\mathbf{x_{B,Ln}}} = \frac{L_0 * x_{B,L0} - V_1 * x_{B,V1}}{L_n} = \frac{10{,}000 * 0.32 - 7{,}200 * 0.4}{16{,}000} \ \underline{\mathbf{= 0.02}}$$

The amount of necessary solvent water C can be calculated by a total mass balance

$$L_0 + V_n = L_n + V_1$$

→ $\underline{\mathbf{V_n}} = L_n + V_1 - L_0 = 16{,}000 + 7{,}200 - 10{,}000$ $\underline{\mathbf{= 13{,}200\ kg}}$

	total mass [kg]	**wt% A**	**wt% B**	**wt% C**
feed L_0	10,000	40	32	28
solvent V_n	13,200	0	0	100
overflow V_1	7.200	0	40	60
underflow L_n	13.200	25	2	73

<u>Determination of the number of ideal steps</u>

First of all the constant underflow with $x_{A,Ln} = 0.25$ and the given points L_0 ($x_{A,L0} = 0.4$, $x_{B,L0} = 0.32$, $x_{C,L0} = 0.28$), V_1 ($x_{A,V1} = 0$, $x_{B,V1} = 0.4$, $x_{C,V1} = 0.6$), V_n ($x_{C,Vn} = 1$) and L_n ($x_{A,Ln} = 0.25$, $x_{B,Ln} = 0.02$, $x_{C,Ln} = 0.73$) are drawn in the diagram.

The one pole line is the connection of V_1 with L_0 and the other one the connection of V_n with L_n. Crossing these pole lines results in the pole point Δ.

Construction of the connode (= connection line with point A) through V_1 gives the underflow L_1 at the underflow line. Connecting L_1 with the pole point Δ give the extract composition V_2, and so on.

Finally the number of ideal steps results with $\mathbf{N_{th} = 10}$

2. Ponchon - Savarit Diagram

Determination of the feed point

$$\underline{\mathbf{N_0 =}} \frac{A}{B+C} = \frac{0.4}{0.32+0.28} \; \underline{\mathbf{= 0.666}}$$

$$\underline{\mathbf{X_{L0} =}} \frac{B}{B+C} = \frac{0.32}{0.32+0.28} \; \underline{\mathbf{= 0.5333}}$$

$\underline{\mathbf{L_0 =}}$ (0.32 + 0.28) * F = (0.32 + 0.28) * 10.000 $\underline{\mathbf{= 6,000\ kg}}$

concentration of the overflow (extract solution)

$$\underline{\mathbf{X_{V1} =}} \frac{B}{B+C} = \frac{0.4}{0.4+0.6} \; \underline{\mathbf{= 0.4}}$$

90% extraction efficiency:

$V_1 * X_{V1} = 0.9 * L_0 * X_{L0}$

→ $$\underline{\mathbf{V_1 =}} \frac{0.9 * L_0 * X_{L0}}{X_{V1}} = \frac{0.9 * 6000 * 0.533}{0.4} \; \underline{\mathbf{= 7.200\ kg}}$$

Balance for solid material:

$N_0 * L_0 = N_n * L_n$

$$\underline{\mathbf{N_n =}} N_{Underflow} = \frac{A}{B+C} = \frac{1}{3} \; \underline{\mathbf{= 0.333}}$$

→ $$\underline{\mathbf{L_n =}} \frac{N_0 * L_0}{N_N} = \frac{0.666 * 6{,}000}{0.333} = \underline{\mathbf{12.000\ kg}}$$

Total balance:

$L_0 + V_n = L_M = L_n + V_1$

→ $\underline{\mathbf{L_M =}}$ 12,000 + 7,200 $\underline{\mathbf{= 19,200\ kg}}$

→ $\underline{\mathbf{V_n =}}$ 19,200 - 6,000 $\underline{\mathbf{= 13,200\ kg}}$

Balance for sugar B:

$$L_0 * X_{L0} + V_n * X_{Vn} = L_M * X_M = V_1 * X_{V1} + L_n * X_{Ln}$$

with $X_{Vn} = 0$ (pure solvent) follows

$$\underline{X_{Ln} =} \frac{L_0 * X_{L0} - V_1 * X_{V1}}{L_n} = \frac{6{,}000 * 0.533 - 7{,}200 * 0.4}{12{,}000} = \underline{\mathbf{0{,}0267}}$$

	L	N	X
feed L_0	6,000	0.666	0.533
solvent V_n	13,200	0	0
overflow V_1	7,200	0	0.4
underflow L_n	12,000	0.333	0.0267

<u>Determination of the ideal number of steps:</u>

Drawing of the points L_0 ($N_{L0} = 0.666$, $X_{L0} = 0.533$), V_1 ($N_{V1} = 0$, $X_{V1} = 0.4$), V_n ($N_{Vn} = 0$, $X_{Vn} = 0$) and L_n ($N_{Ln} = 0.333$, $X_{Vn} = 0.0267$).

The connection of L_0 and V_1 gives the first pole line and connection of L_n and V_n the second one. Crossing these two pole lines gives the pole point Δ.

The first connode is a vertical line through V_1 which gives at the underflow the point L_1. Connecting this point L_1 with the pole point Δ give the next extract composition V_2 and so on.

Finally the number of ideal steps results with $\underline{\mathbf{N_{th} = 10}}$