7. Short introductions to: Mass transfer; Separation processes; Particulate technology & multi-phase flow

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7.1 Mass transfer processes; Diffusion, convection; Mass transfer coefficient

Mass transfer process examples

- Drying of a solid using heat or dry gas
- Adsorption of gas or liquid using a solid
- Distillation using heat to create a vapour phase
- Gas absorption using a liquid absorbent
- Extraction of liquid or solid using a solvent that creates immiscible phases
- Crystallisation using cooling to create a solid phase

Note the ”support phase”: solvent, sorbent, heat, ...

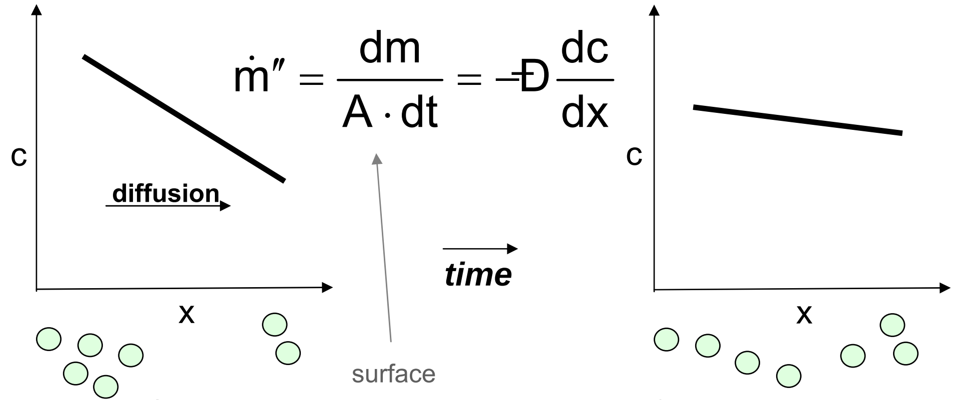
Picture: http://www.petrogas.org/absorption.htm

Mass transfer mechanisms /1

Diffusion: Fick’s Law* (for binary systems)

Spreading of a substance from a region with high concentration to regions with lower concentration; more correct for ”concentration” is ”chemical potential”

Molecular diffusion coefficient Đ; for species A in medium B $Đ = Đ_{AB}$



$$\dot{m}'' = \frac{dm}{A \cdot dt} = -Đ\frac{dc}{dx}$$

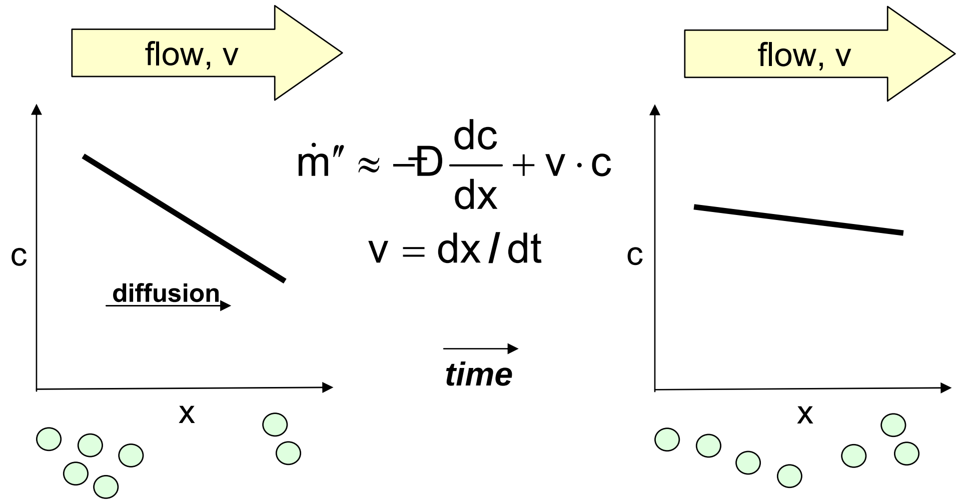
* *Note analogy with Fourier’s Law for heat conduction*

Mass transfer mechanisms /2

Diffusion + (forced or free) convection

Flow as a result of a pressure difference, gravity, ...

If needed, $Đ = Đ_{mol} + Đ_{turb}$ can be used to include turbulent eddy diffusion



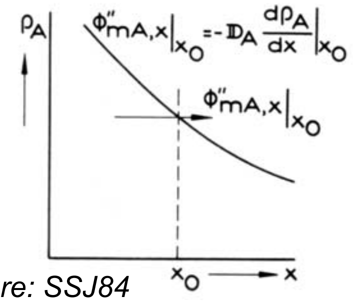
$$\dot{m}'' \approx -Đ\frac{dc}{dx} + v \cdot c$$

$$v = dx / dt$$

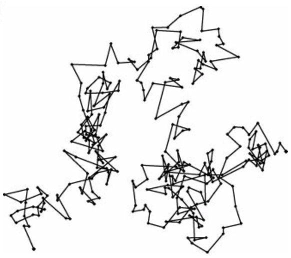
Diffusion

- Transfer of matter as a result of a concentration (or density) difference, more accurately chemical potential difference ("gradient")
- Main cause: **Brownian motion** of molecules

- Mass flux $\Phi''_{mA,x}$ (kg / s per m^2) through a surface (x_0) perpen-dicular to the transport direction (x) as a result of a gradient in mass concentration (ρ_A).
- More conventional for gases: use <u>concentration</u> c_A (mol/m^3)$=\rho_A/M_A=p_A/RT$



Picture: SSJ84



$$\boxed{\Phi''_{molA,x} = -D_A \frac{dc_A}{dx}}$$

Diffusion coefficients (some values)

A	B	$Đ_{AB}$ m^2/s	Temp °C
water	CO_2	1.17×10^{-9}	18
water	N_2	2.01×10^{-9}	22
water	O_2	2.60×10^{-9}	25
air	NH_3	19.6×10^{-6}	0
air	CO_2	13.6×10^{-6}	0
air	H_2O vapour	26×10^{-6}	25

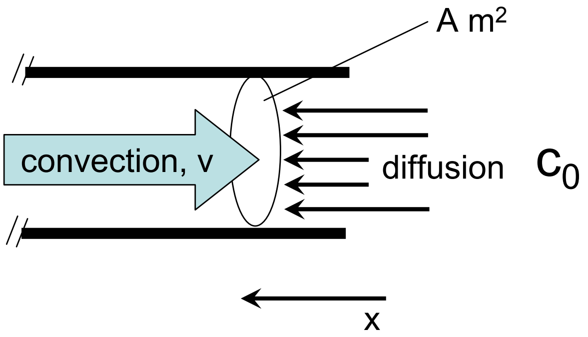
(Ö96 p. 40)

Ambient conditions: Đ ~ 10^{-5} m^2/s in gases
Đ ~ 10^{-8} .. 10^{-9} m^2/s in liquids
Đ ~ 10^{-11} .. 10^{-13} m^2/s in solids

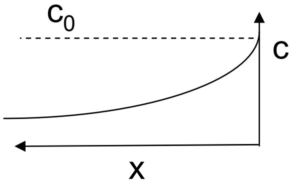
Diffusion and convection

- *An **example**:*

  Flow of a fluid from a tube into a region where c = c_0 for a certain species



- Steady state, mass balance gives



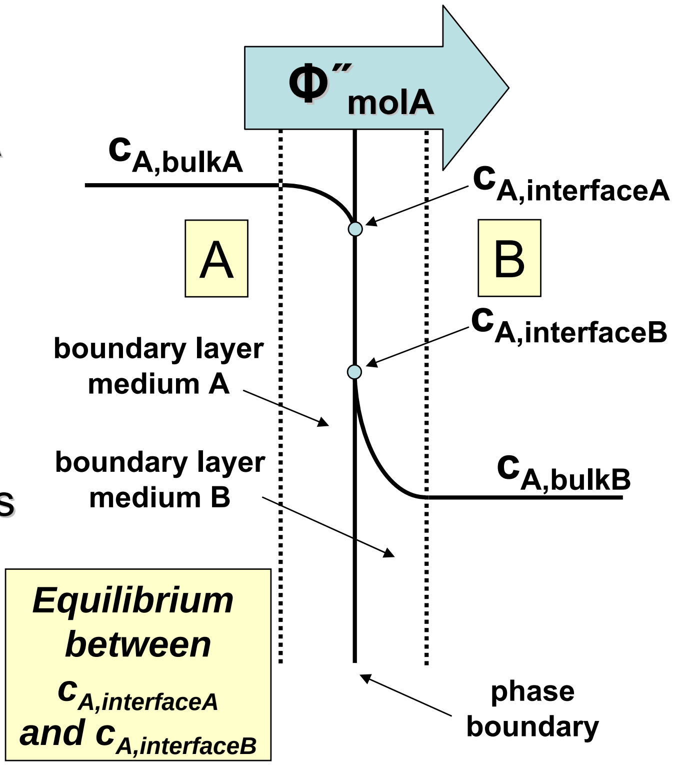
$$0 = -\text{Đ}\cdot A\cdot\frac{dc}{dx} - v\cdot A\cdot c\,; \quad c = c_0 \;@\; x = 0$$

$$\boxed{c = c_0.\mathbf{exp}\left(-\frac{vx}{\text{Đ}}\right)} \qquad with\ \frac{vx}{\text{Đ}} = Pe\ \ (Péclet\ number)$$

$$Pe = \frac{vx}{\text{Đ}} = \frac{\rho vx}{\eta}\cdot\frac{\eta}{\rho \text{Đ}} = Re\cdot Sc\ \ with\ \ Sc = \frac{\eta}{\rho \text{Đ}}\ \ (Schmidt\ \ number)$$

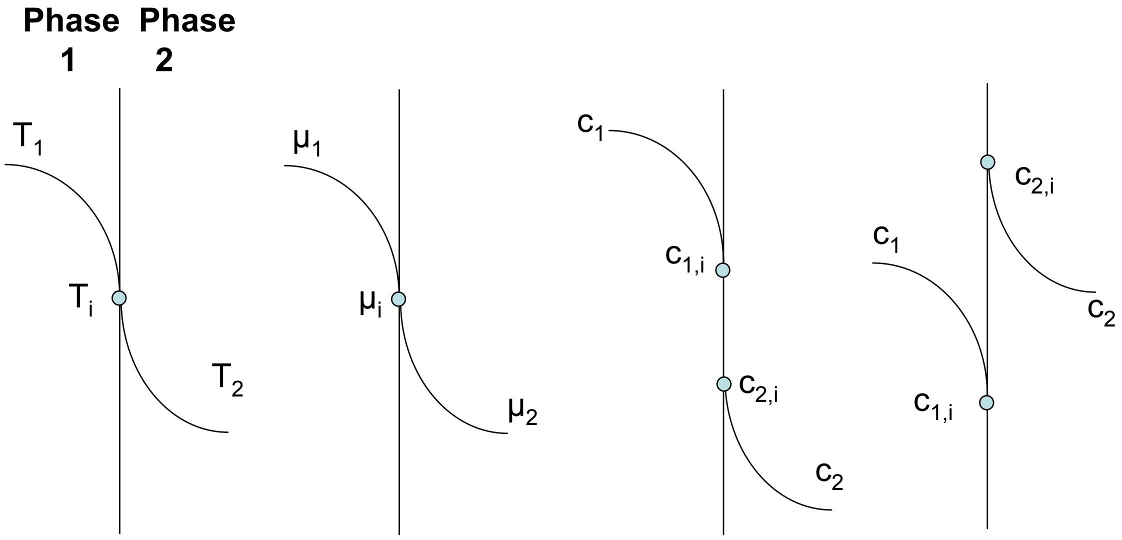
Mass transfer and boundary layers

- For mass transfer between two phases A and B, concentration gradients usually only exist near the physical boundary that separates A and B
- Thus, the driving forces are active only in boundary layers at the separating surface



Equilibrium between $c_{A,interfaceA}$ and $c_{A,interfaceB}$

Mass ↔ heat transfer analogy /1

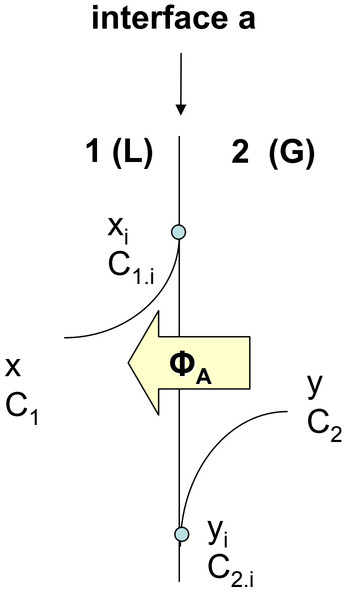


A temperature profile, heat transfer 1→ 2

A chemical potential profile, mass transfer 1→ 2

Concentration profiles, mass transfer 1 → 2

Mass transfer coefficient

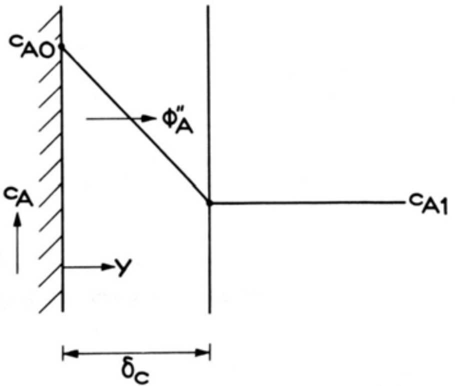


L,G example

- Mass flow species A:
  $\dot{n}_A = \Phi_A$ mol/s
- Mass transfer rate per area:
  $\dot{N}_A = \dot{n}_A/a = \Phi''_A$ mol/(m²·s)
- Mass transfer coefficients, k, (unit: m/s) for both sides of the interface:
  $\dot{N}_A = k_x \cdot(c_{1,i}-c_1) = k_y\cdot(c_2-c_{2,i})$
- Interface concentrations can be eliminated using equilibrium constant $K = c_{1,i}/c_{2,i} = c_1^*/c_2 = c_1/c_2^*$
  $c_1^* = c_1$ at equilibrium with c_2, *etc.*

The film model

- A mass transfer coefficient can be linked to the film model:
  $\Phi''_{A,mol} = k\cdot(c_{A0}-c_{A1}) =$
  $- Đ_A\cdot dc_A/dy = Đ_A\cdot(c_{A0}-c_{A1})/\delta_c$
  which gives $k = Đ_A/\delta_c$
- Thus, the boundary layer thickness can be estimated if k and $Đ_A$ are known.
- The mass transfer limitations are concentrated in a well-defined region.



Picture: SSJ84

See	*heat transfer*	*Nusselt number*	*Nu = hD/λ = D/δ_T*
→	*mass transfer*	*Sherwood number*	*Sh = kD/Đ = D/δ_c*

Mass ↔ heat transfer analogy /2

Heat transfer

- $Nu = f(Re, Pr, L/D, Gr,..)$
- Convection around a sphere:
  $Nu = 2 + 0.6Re^{½}Pr^{⅓}$
- Transfer from a wall and a turbulent flow: $2000 < Re < 10^5$ and $Pr > 0.7$
  $Nu = 0.027Re^{0.8}Pr^{0.33}(\eta/\eta_{wall})^{1/7}$
- General: $Nu = CRe^mPr^n$, where $m = 0.33 .. 0.8$, $n \approx 0.33$

Mass transfer

- $Sh = f(Re, Sc, L/D, Gr,..)$
- Convection around a sphere:
  $Sh = 2 + 0.6Re^{½}Sc^{⅓}$
- Transfer from a wall and a turbulent flow: $2000 < Re < 10^5$ and $Sc > 0.7$
  $Sh = 0.027Re^{0.8}Sc^{0.33}$
- General: $Sh = CRe^mSc^n$, where $m = 0.33 .. 0.8$, $n \approx 0.33$

- **Chilton-Colburn analogies**, heat and mass transfer values j_H, j_D:
  $j_H = NuRe^{-1}Pr^{-⅓}$ $j_D = ShRe^{-1}Sc^{-⅓}$
  $j_H = j_D = CRe^{m-1} = ½f$ f = Fanning friction factor for pipe flow

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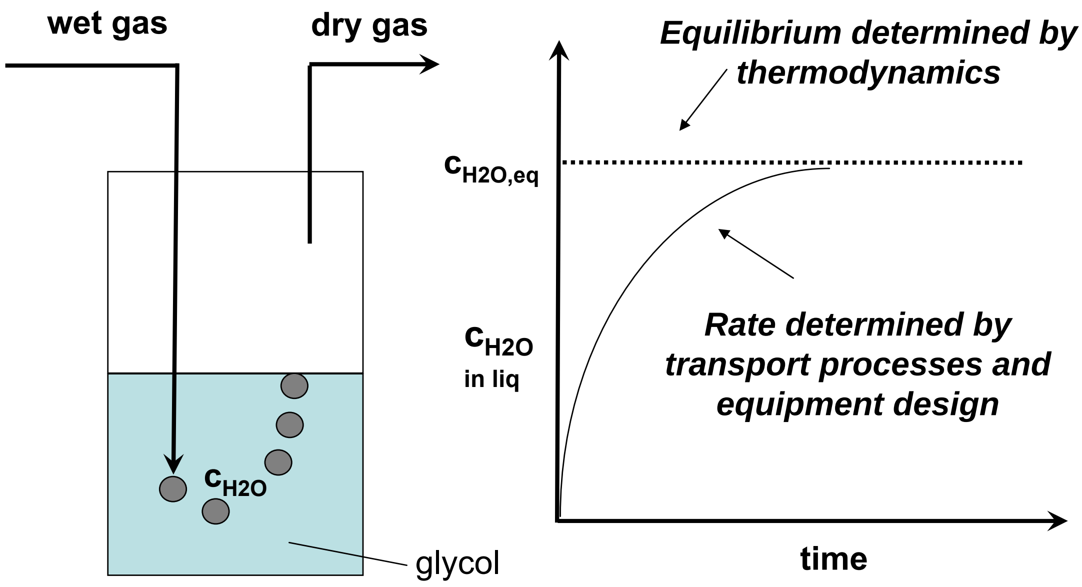
7.2 Phase equilibrium

(gas-gas, gas-liquid, liquid-liquid)
Henry's Law, Raoult's Law

Mass transfer and equilibrium

Drying of wet gas in an glycol absorber


wet gas

dry gas

c_{H2O}

glycol

$c_{H2O,eq}$

c_{H2O} in liq

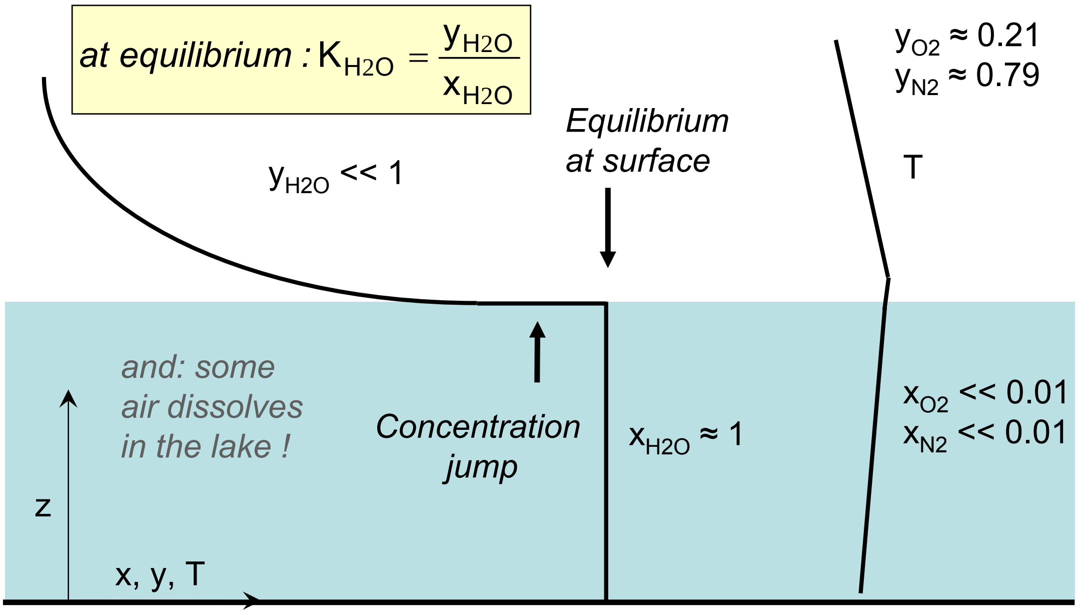
time

Equilibrium determined by thermodynamics

Rate determined by transport processes and equipment design

Air above a lake

at equilibrium : $K_{H2O} = \frac{y_{H2O}}{x_{H2O}}$


$y_{H2O} << 1$

Equilibrium at surface

$y_{O2} \approx 0.21$
$y_{N2} \approx 0.79$

T

and: some air dissolves in the lake !

Concentration jump

$x_{H2O} \approx 1$

$x_{O2} << 0.01$
$x_{N2} << 0.01$

z

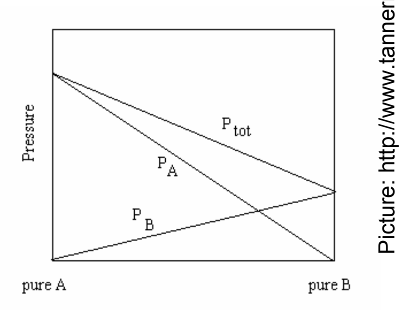
x, y, T

x = fraction in liquid, y = fraction in gas,
z = position coordinate, T = temperature

Gas-liquid phase equilibrium:

Raoult's law

- Assume a liquid mixture of components A, B, C, ... at a temperature T.
- "A" occupies a **large** fraction, say **x_A > 5 %**
- At temperature T, saturation pressure of pure substance A (i.e. A vapour above liquid A) is p_A^0
- For the mixture, the vapour pressure of A equals $\boxed{\mathbf{p_A = y_A.p_{tot} = x_A.p_A^0}}$
- For a two-component mixture of A and B:
- $p_B=x_B.p_B^0 = (1-x_A).p_B^0$, using $x_A+x_B = 1$

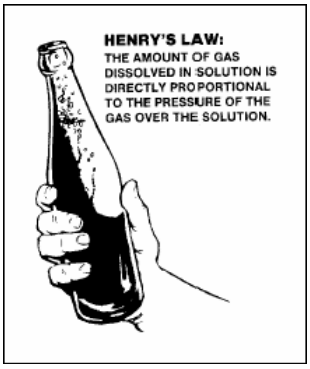


Picture: http://www.tannerm.com/raoult.htm

Gas-liquid phase equilibrium:

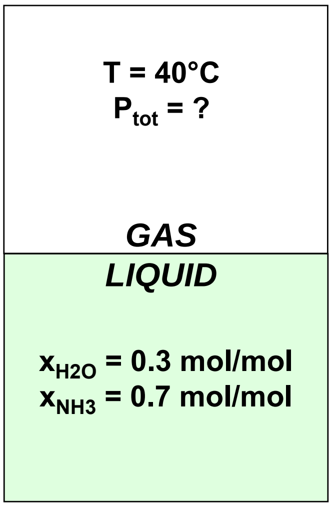
Henry's law

- Assume a liquid mixture of components A, B, C, ... at a temperature T.
- "A" occupies a **small** fraction, say **x_A < 5 %**
- For the mixture, the vapour pressure of A equals **$p_A = y_A.p_{tot} = H_{cA}.x_A$** with **Henry constant** H_c (unit: Pa, bar, ...)
- $\boxed{\mathbf{y_A / x_A = H_{cA}/p_{tot} = \beta,}}$ **$y_A = \beta.x_A$** distribution coefficient β (mol/mol)
- H_c is a function of temperature, but independent of pressure at p_{tot} < 5 bar.



Picture: http://www.pilotfriend.com/aeromed/medical/images/34.gif

Example: Water-ammonia vapour /1



- A mixture of ammonia and water
- 40°C, total pressure unknown
- Liquid composition:
  70 %-mol NH_3 + 30 %-mol H_2O
- What is the composition of the gas, y_{NH3}, y_{H2O} ?
- At equilibrium, no driving forces or temperature gradients,
  $x_{NH3} + x_{H2O} = 1$, $y_{NH3} + y_{H2O} = 1$
  but $x_{NH3} \neq y_{NH3}$, $x_{H2O} \neq y_{H2O}$!!!

Relative volatility of NH_3 with respect to water:

$$\alpha = (y_{NH3} / x_{NH3}) / (y_{H2O} / x_{H2O}) = K_{NH3} / K_{H2O} \text{ at equilibrium}$$

Example: Water-ammonia vapour /2

- Gas above an NH_3/H_2O liquid mixture with
  x_{NH3} = 0.7 and x_{H2O} = 0.3, T = 40°C.
- *Questions: pressure & equilibrium composition of gas ?*
- From tabelised data for saturation pressures, at 40°C :
  $p°_{H2O}$ = 7.348 kPa; $p°_{NH3}$ = 1554.33 kPa
- x-values for liquid >> 5 % : use ***Raoult's Law*** :
  $p_{H2O} = x_{H2O} \cdot p°_{H2O} = 0.3 \cdot 7.348$ kPa = 2.22 kPa
  $p_{NH3} = x_{NH3} \cdot p°_{NH3} = 0.7 \cdot 1554.33$ kPa = 1088.3 kPa
- $P_{total} = p_{H2O} + p_{NH3}$ = 1090.25 kPa = 10.9025 bar
- y_{H2O} = 2.22 kPa / 1090.25 kPa = 0.002 = 0.2 %-v
  y_{NH3} = 1088.3 kPa / 1090.25 kPa = 0.998 = 99.8 %-v

Source: ÇB98

Example: Water in air above a lake

- Assume a lake with T=17°C, p_{tot} = 92 kPa at water surface level.
- At the surface, the water will be saturated with water, which means $p_{H2O} = p°_{H2O}$ = 1920 Pa.
- Fraction of water in the air at the water surface at equilbrium with the air above is then

  $y_{H2O} = p_{H2O}/p_{tot}$ = 1.92 kPa / 92 kPa = 2.09 %

  note: % = %-v (volume %)

Source: ÇB98

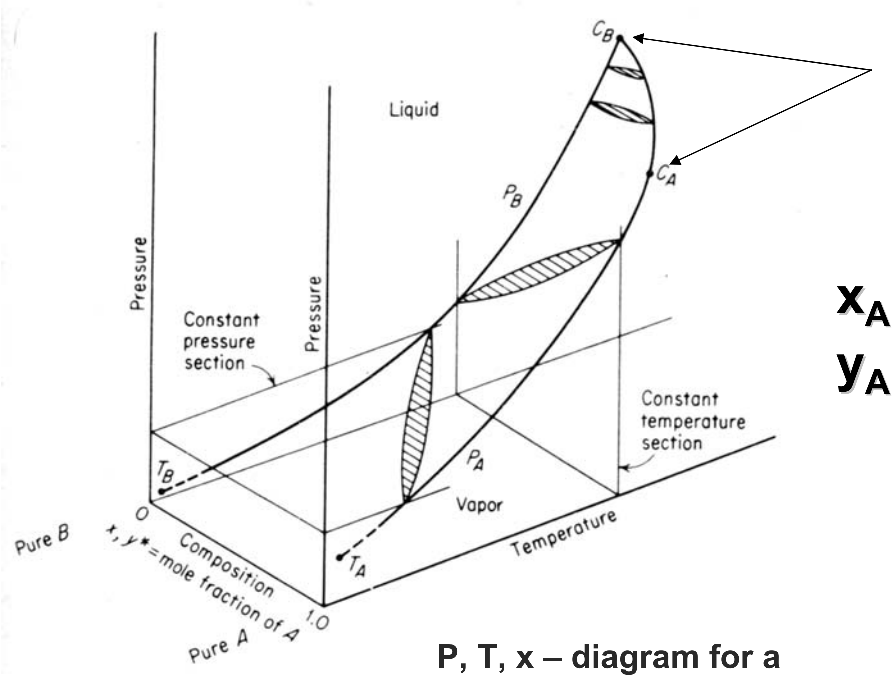
Example: Air dissolved in lake water

- Assume the same lake, T=17°C, p_{tot} = 92 kPa at water surface level. At the surface $p_{H2O} = p°_{H2O}$ = 1920 Pa.
- A small amount (<< 5 %-vol) of air will be dissolved in the water: use ***Henry's Law*** to calculate the equilibrium:
- At T = 290 K, $H_{c\ AIR,water}$ = 6200 MPa
- $p_{AIR} = p_{tot} - p_{H2O}$ = 90.008 kPa
- $x_{AIR,\ water\ side} = p_{AIR,air\ side} / H_{c\ AIR,\ water}$

  = 0.090008 MPa / 6200 MPa = 1.45×10^{-5} = 0.00145 %-v
- This means 1.45 moles air (molar mass ~29 kg/kmol) in 100000 moles water (molar mass 18 kg/kmol), which means 23.4 mg air / kg water

Source: ÇB98

Two-component phase diagram (G/L)



critical points
pure A, B

$x_A = 1 - x_B$

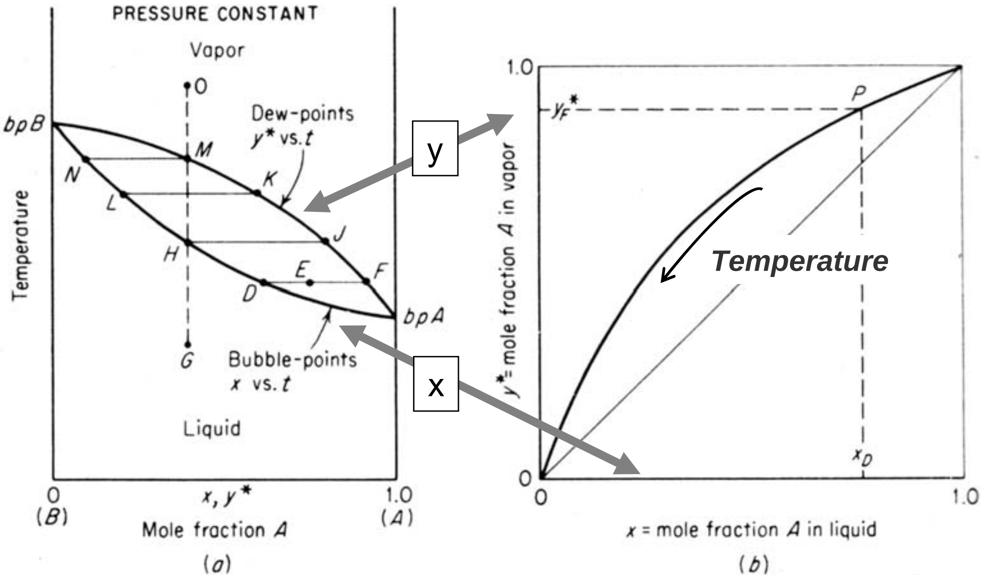
$y_A = 1 - y_B$

P, T, x – diagram for a binary gas-liquid system

Picture: T68

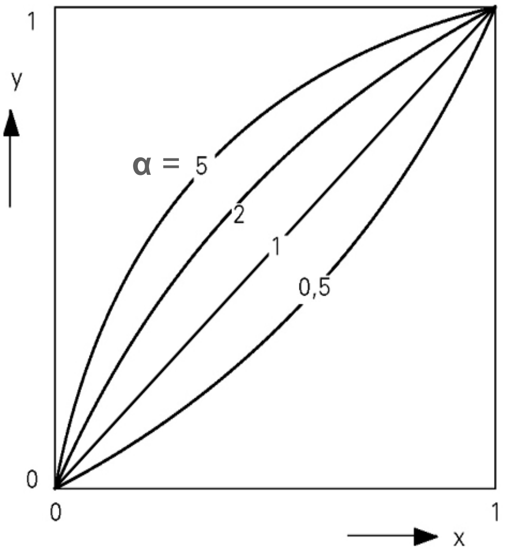
Binary vapour-liquid equilibrium

Constant pressure; the **x-y diagram**



Picture: T68

Relative volatility, α



Picture: WK92

- Raoult (for not-small x_i):
  $y_A = x_A p_A°$, $y_B = x_B p_B°$
- $x_B = 1 - x_A$, $y_B = 1 - y_A$
- $y_B/y_A = \alpha \cdot x_B/x_A$
  α = relative volatility
  $\alpha = p_B°/p_A° = \alpha\ (T)$
- result:
  $(1-y_A)/y_A = \alpha \cdot (1-x_A)/x_A$

$$\mathbf{y_A = \alpha \cdot x_A / (1 + (\alpha - 1) \cdot x_A)}$$

7.3 Separation processes
(gas-gas, gas-liquid, liquid-liquid):
equilibrium stages

Separation of mixtures: 1 stage

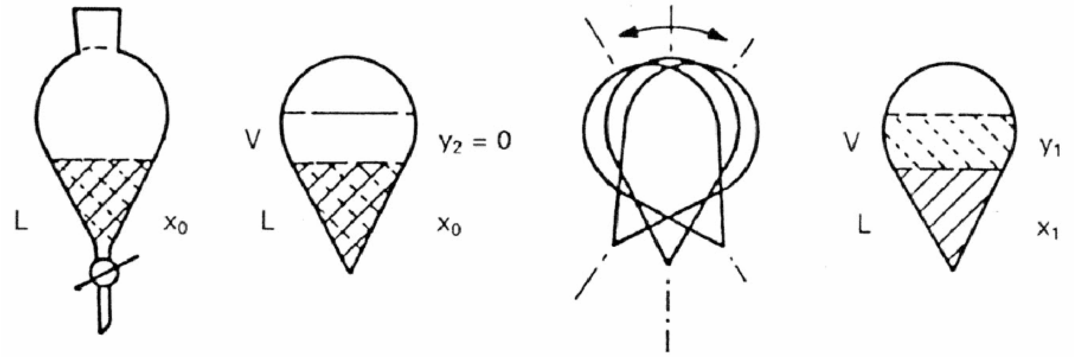
For example: separating phenol from water (L) by adding benzene (V) in a separation funnel.

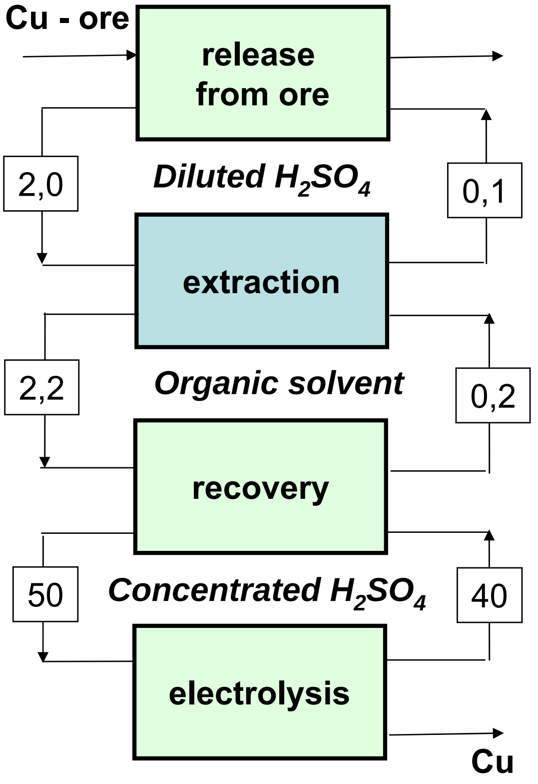
x = phenol conc. in L, y = phenol conc. in V

Equilibrium constant: K = y1 / x1

Separation factor: S = K·V/L

Fraction of phenol separated = S / (S+1) for 1 stage





Cu - ore

release from ore

2,0

Diluted H_2SO_4

0,1

extraction

2,2

Organic solvent

0,2

recovery

50

Concentrated H_2SO_4

40

electrolysis

Cu

Numbers are concentrations kg Cu/m^3

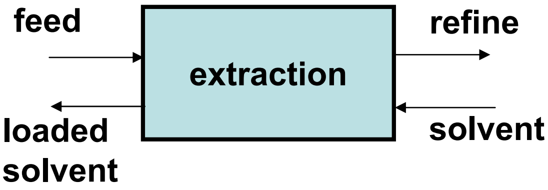
Separation and equilibrium stages

Example

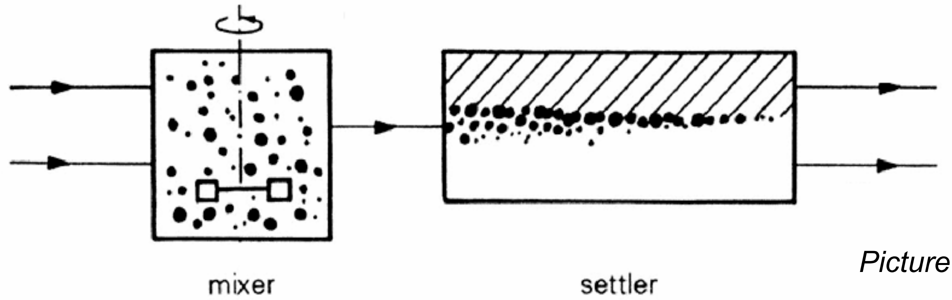
Four-stage processing for Cu recovery from Cu-containing ore (liquid / liquid)

Source: WK92

Phase equilibrium stages /1

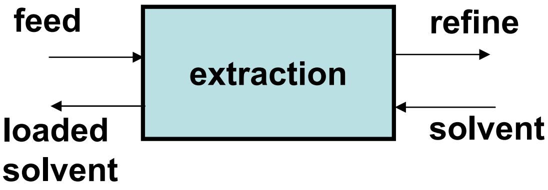


The extraction and the recovery process are combinations of mixing tanks and settling tanks

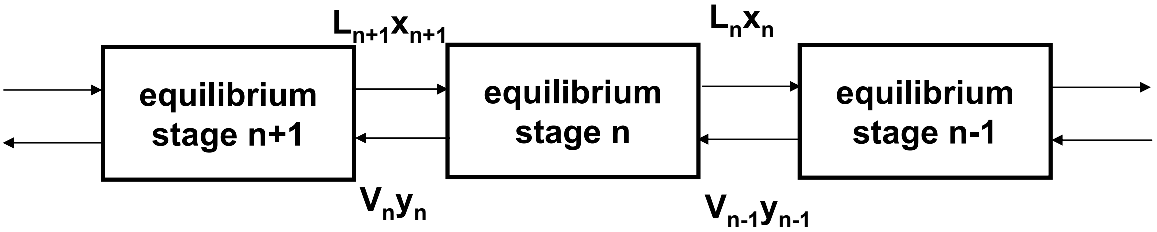


Picture: WK92

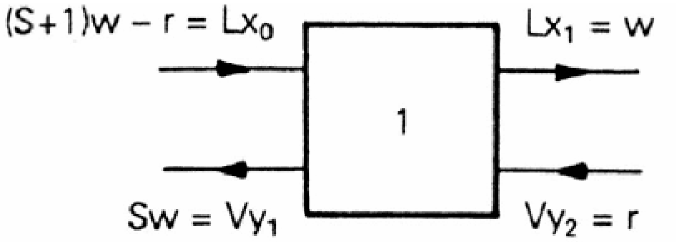
Phase equilibrium stages /2



- Cu is transferred from feed stream L to solvent ("support phase") V; the extraction unit can be described as a series of equilibrium stages.
- Equilibrium constant for Cu in feed stream andsolvent stream is $K = y_{Cu}/x_{Cu}$
- Thus, for an equilibrium stage n: $y_n = Kx_n$
- Streams L and V are often roughly constant
  $L_1 \approx L_2 \approx .. \approx L_n = L$; $V_1 \approx V_2 \approx ... \approx V_n = V$ → separation factor $S = K \cdot V/L$



Example: phase equilibrium stage



Picture: WK92

- For example: phase equilibrium constant K=5; L = 1000 kg/s, V = 800 kg/s → S = KV/L= 4.

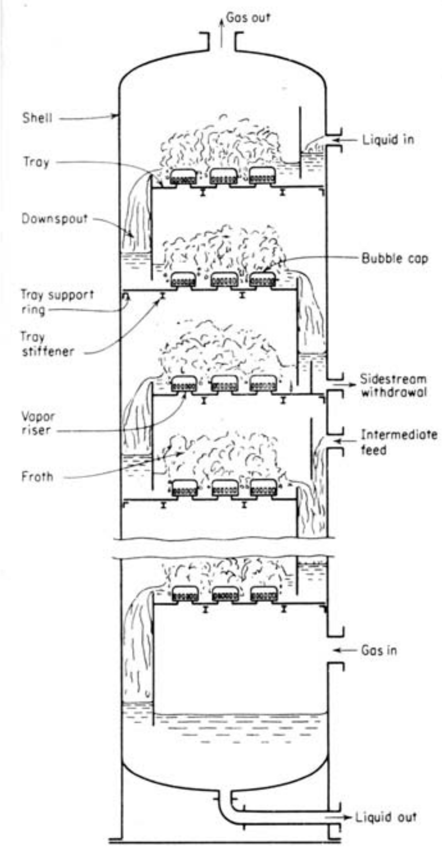
  Cu in feed x_0 = 0.2 %-wt = 0.002 kg/kg
- For clean solvent, y_2=0, then $Vy_1 / Lx_1 = S$
- → Mass balance gives $Lx_0 = (S+1)w-r$

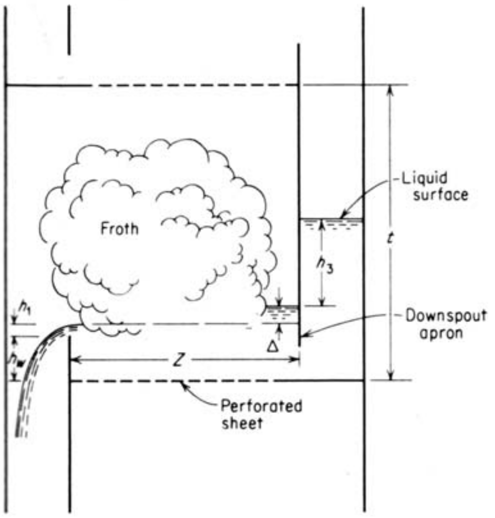
  $Lx_0+Vy_2 = Lx_0 = Lx_1+Vy_1 = Lx_1(1+KV/L) = Lx_1(1+S)$

  → Lx_0 = 2 kg Cu/s w → $Lx_1 = Lx_0 / (1+S)$ = 0.4 kg Cu/s

7.4 Separation processes
(gas-gas, gas-liquid, liquid-liquid):
continuous distillation;
packed tower columns

Continuous distillation

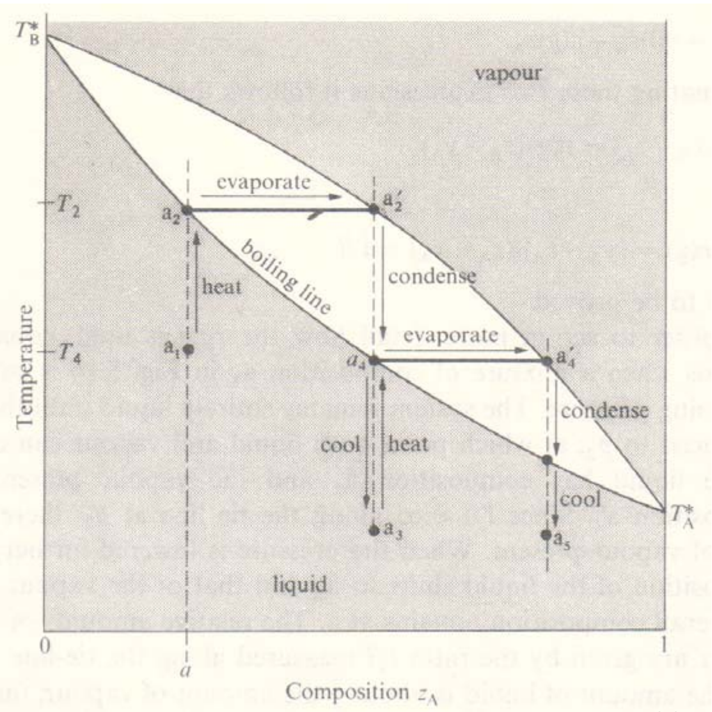




Pictures: T68

Distillation, principle

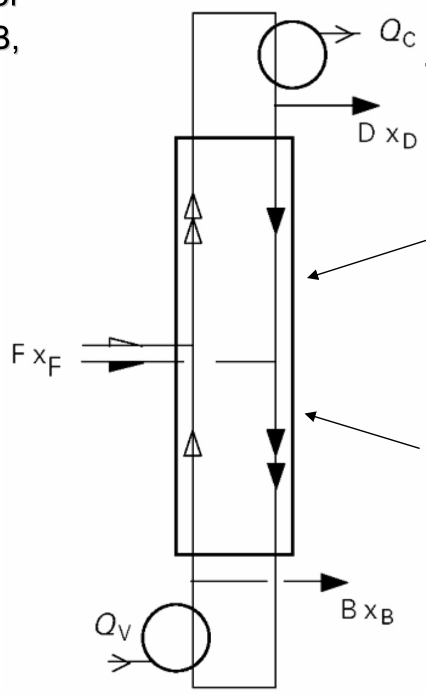
- Liquid with composition a_1 boils at temperature T_2, giving vapour with composition a'_2 which is enriched in component A
- Taking out and cooling vapour a'_2 gives liquid a_4 at temperature T_4
- In equilibrium with liquid a_4 is vapour a'_4, again further enriched in component A



Picture: A83

Continuous distillation (binary)

- Separating a mixture of 2 components A and B, with A more volatile
- Liquid for absorption section produced by condensing some top product
- Gas for stripping section produced by boiling some bottom product
- Roughly equimolar exchange: 1 mol A liquid → gas ~ 1mol B gas → liquid



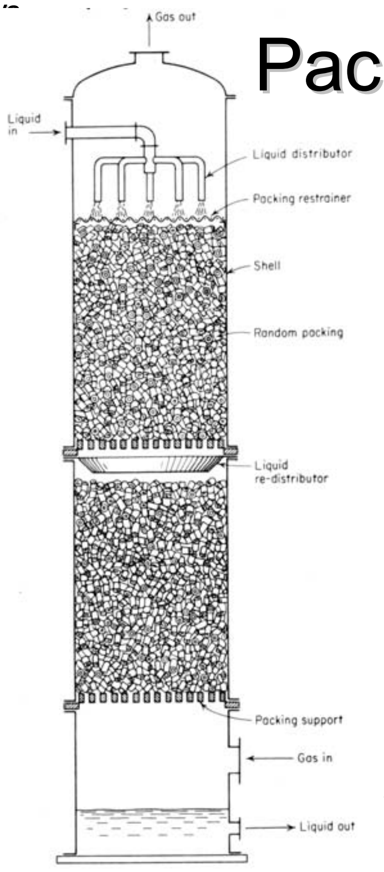
Top product:* *<u>more volatile</u>* *component

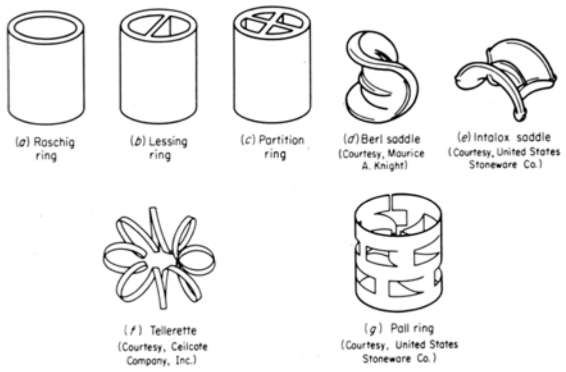
Top section: rectifying section
absorbing the less volatile component

Bottom section: stripping section
desorbing the more volatile component

Bottom product:* *<u>less volatile</u>* *component

Packed tower columns /1



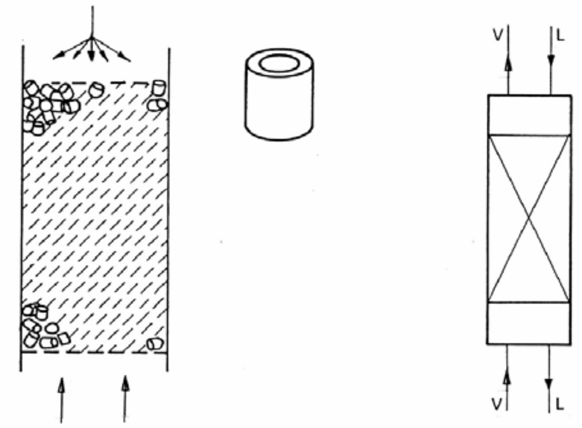


Pictures: T68


”Mellapak”
http://www.sulzerchemtech.com

Packed tower columns /2

- Mass transfer from gas to liquid or *vice versa* where the liquid forms a (thin) film on the surface of packing material elements, creating a large contact surface ”a” (m^2 / m^3 apparatus)
- For relatively small amounts of material transferred (say, < 2% of the streams) the process may be considered isotherm (vaporisation and condensation have a heat effect!) and streams V and L may be considered constant.



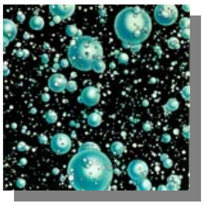
Picture: W92

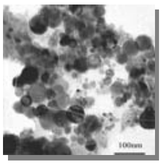
7.5 Particle technology; Multi-phase flows

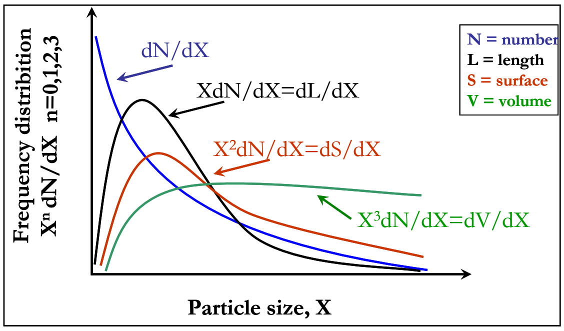
Prof. Brian Scarlett
1938-2004

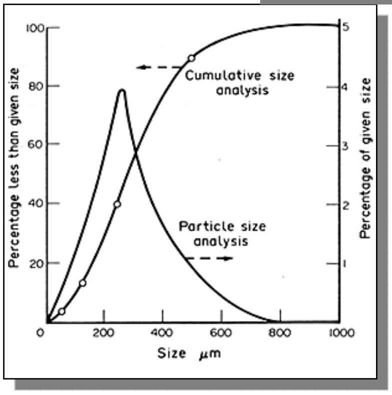
”Consider a particle”

Particle (or droplet) size distribution



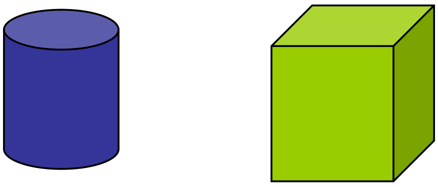






- Different distributions for number, length, surface and volume !
- Different particle size analysers give different distributions: some measure length, others measure surface, *etc*.

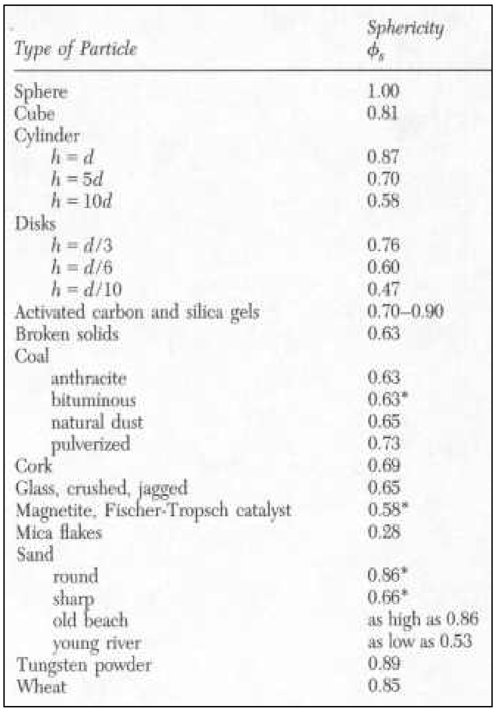
Particle shape



Shape factor, "sphericity" ϕ

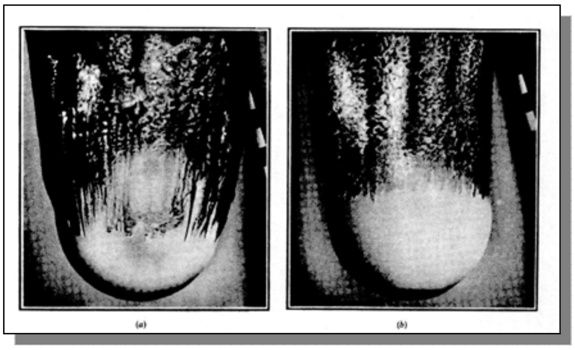
$$\phi = \frac{4.836 \times (\text{volume})^{2/3}}{\text{surface}}$$

$$= \frac{\text{surface of sphere with same volume}}{\text{surface of particle}}$$



Type of Particle	*Sphericity* ϕ_s
Sphere	1.00
Cube	0.81
Cylinder	
$h = d$	0.87
$h = 5d$	0.70
$h = 10d$	0.58
Disks	
$h = d/3$	0.76
$h = d/6$	0.60
$h = d/10$	0.47
Activated carbon and silica gels	0.70–0.90
Broken solids	0.63
Coal	
anthracite	0.63
bituminous	0.63*
natural dust	0.65
pulverized	0.73
Cork	0.69
Glass, crushed, jagged	0.65
Magnetite, Fischer-Tropsch catalyst	0.58*
Mica flakes	0.28
Sand	
round	0.86*
sharp	0.66*
old beach	as high as 0.86
young river	as low as 0.53
Tungsten powder	0.89
Wheat	0.85

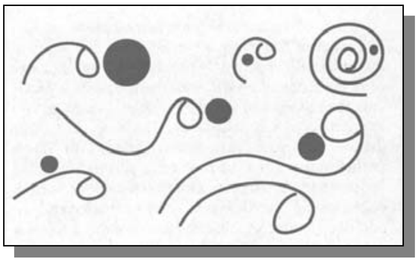
Particles in fluid flows



A smooth (a) and roughened (b) ball entering water at 25 °C

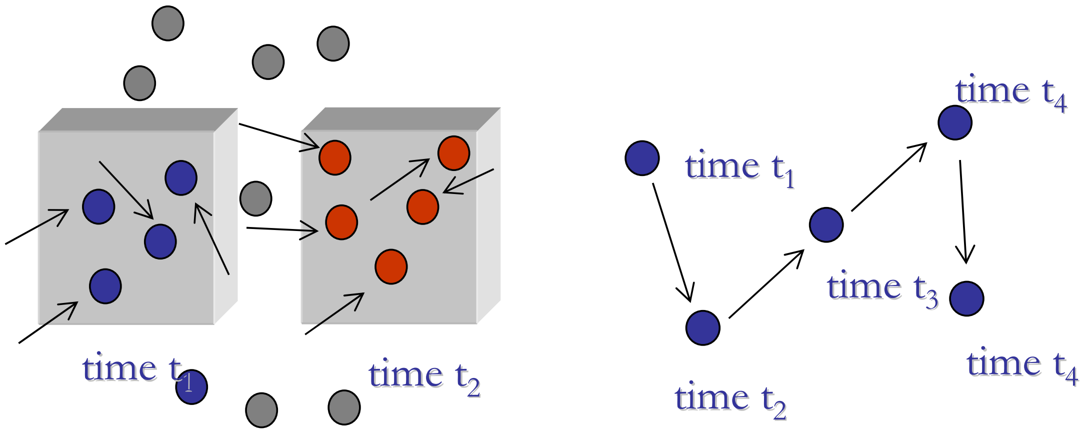
Picture: CR93

Turbulence as seen by Da Vinci



Particles and turbulent eddies

Eulerian *vs.* Lagrangian particle representation



Focussing on a control volume (Euler), *left*,
or focussing on particle trajectories (Lagrange), *right*

Euler-Euler (for fluid and particulate phase) and
Euler-Lagrange methods are both widely used

Source: ZH00

Aerosols

- **Aerosol:** A suspension of solid or liquid particles in a gas. Aerosols are stable for at least a few seconds and in some cases may last a year or more. The term ”aerosol” includes both the particles and the gas, which is usually air. Particle size ranges from 0.001 to over 100 µm.

  For example smoke is a dispersion of solid particles or droplets in air.
- **Sol:** particles dispersed in a liquid, for example ink

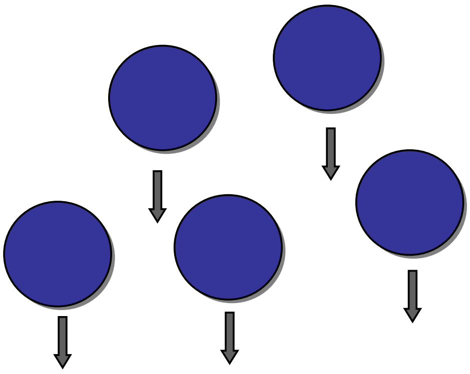
Picture: http://www.aerosol-soc.org.uk/images/Stack_plume.jpg

Picture:http://kapstadt.org/en/photos_of_cape_town/people_of_south_africa/

Source: ZH00

Flow of particle swarms

Drag coefficient for sphere in swarm, C_D^*, corrected for effect of neighbour particles



Small particles, low Re: $f(\varepsilon) = \varepsilon^{-4.7}$

$$C_D^* = C_D \cdot f(\varepsilon) = C_D \cdot \varepsilon^{-n}$$

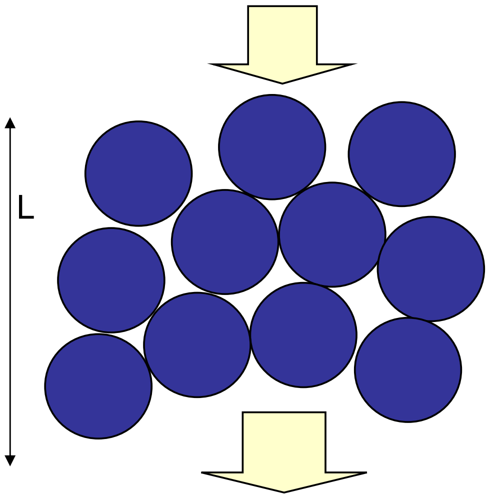
ε = voidage, porosity

Richardson - Zaki hindrance factor:

Re	n
< 0.2	4.65
0.2 ~ 1	$4.35 \times Re^{-0.03}$
1 ~ 500	$4.45 \times Re^{-0.01}$
> 500	2.39

Source: ZH00

Flow in packed beds



Source: ZH00

Darcy's Law:

$$u = K\frac{-\Delta p}{\eta_{\text{fluid}} L}$$

with permeability K

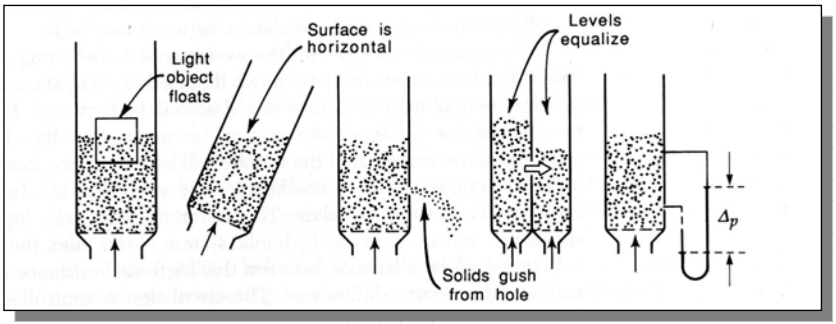
Kozeny - Carman equation:

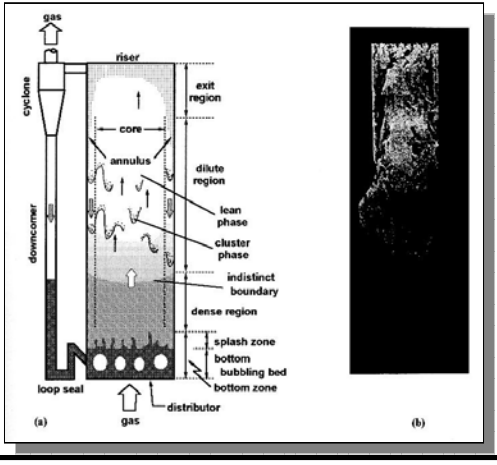
$$u = \frac{\varepsilon^3(-\Delta p)}{5(1-\varepsilon)S_v^2\eta_{\text{fluid}}L}$$

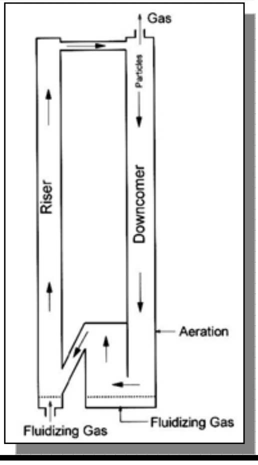
S_v = specific surface = surface/volume

$S_v = 6/d_p$ for a sphere with diameter d_p

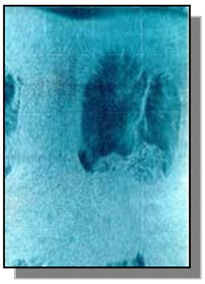
Fluidised beds







Source: ZH00

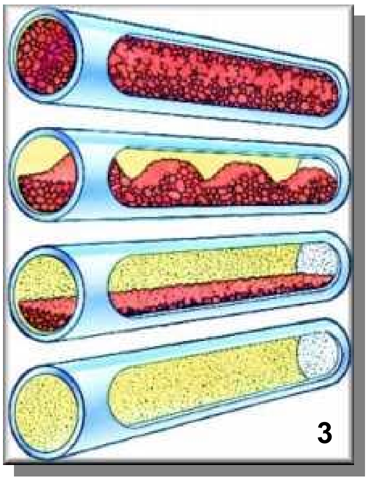


gas bubble in a gas/solid fluidised bed

Conveying systems:
mechanic, pneumatic, hydraulic

Pneumatic conveyor / drier

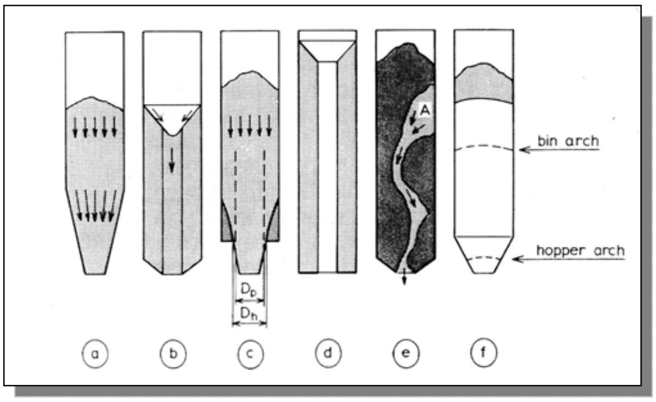
Conveyor belt



4 pneumatic conveying regimes :
- Solid Dense Phase
- Discontinuous Dense Phase
- Continuous Dense Phase
- Dilute Phase

Picture 1: http://www.bateman.co.za/pro-eng-pne.htm
Picture 2: http://www.protectowire.com/images/applications/conveyor/coal-baltimore-lg.jpg
Picture 3:http://www.mactenn.com/pnu_overview.html

Flow of powders in/from silos



a. Mass flow
b. Funnel flow
c. Expanded flow
d. “Pipe”
e. Rathole
f. Arching

Source: ZH00

A gas cyclone

Advantages

Simple, cheap and compact

Large capacity

Disadvantages

Large pressure drop

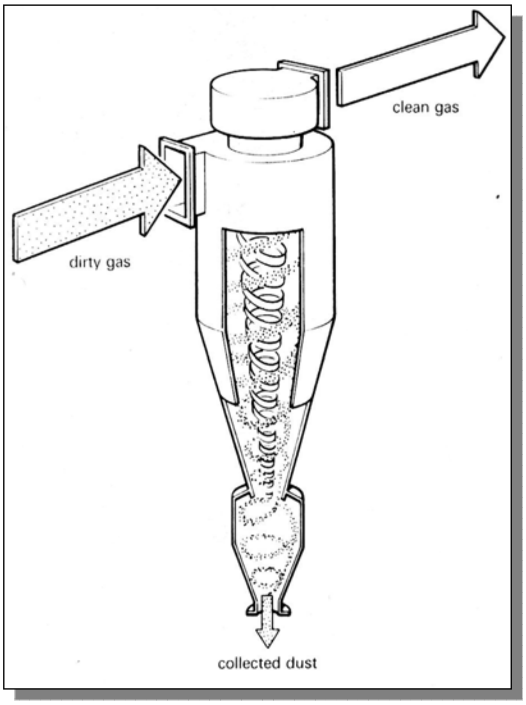
Low efficiency

"Catch" removal problems

No removal below ~5 µm

Problems above ~ 400 °C

See also hydro-cyclones and other cyclones for liquid-solid, liquid-liquid and liquid-gas separations



Source: ZH00

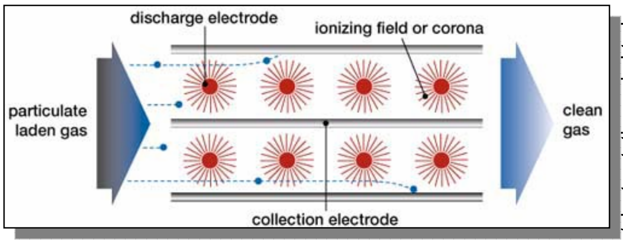
Electrostatic precipitators (ESPs)

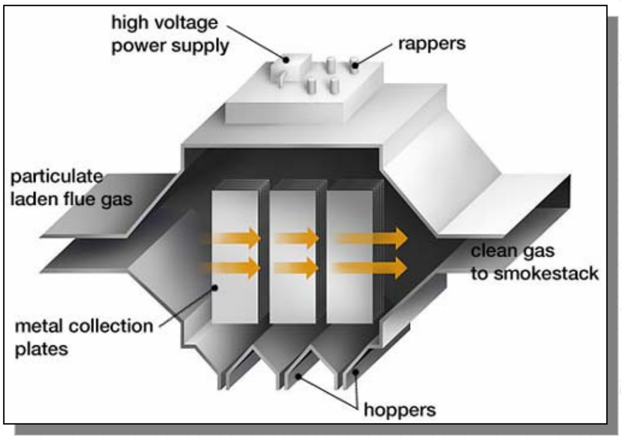
4 process steps:

1. Particle charging
2. Particle movement relative to the gas flow
3. Particle collection at deposition surface
4. Particle removal from deposition surface (often discontinuous)

Note: the electric properties of the particles to be removed should be suitable, otherwise use a filter system

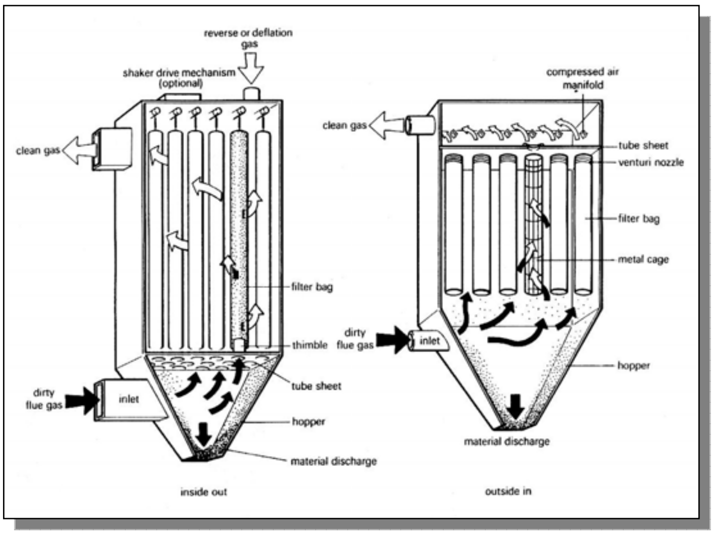
Typically quite large, mainly used at power plants for fly-ash removal from flue gas





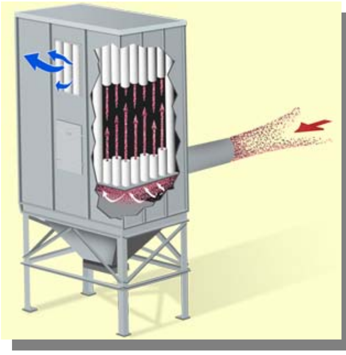
Pictures: http://www.eas.asu.edu/~holbert/wise/electrostaticprecip.html

Baghouse filters



Inside out / outside in operation

Source: ZH00



Picture: http://www.industrysearch.com.au/products/images/cbag.gif
Picture: http://www.agetmfg.com/AgetSite.data/lineartforfilterkop.jpg

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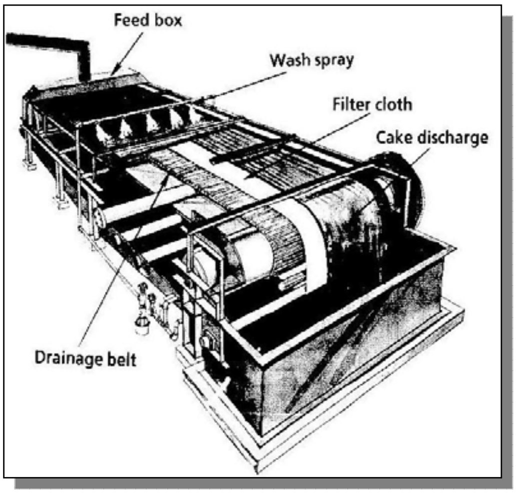
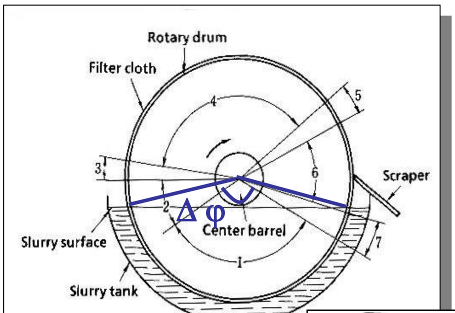
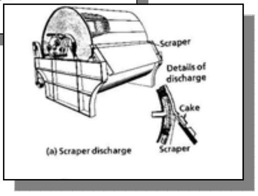
Liquid filtration



Horizontal belt filter

Source: IGH91, ZH00

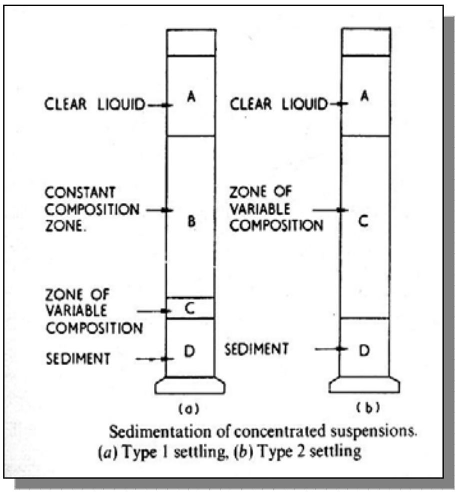




Rotary drum filter

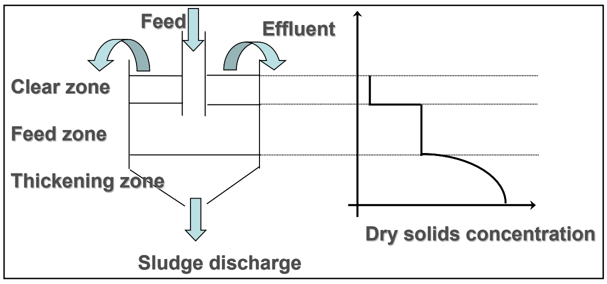
- **~ Constant pressure filtration**
- **N rotation /min (rpm), drum radius R (m),length L (m),**
- **submerged angle $\Delta\varphi = (0 \ldots \pi)$**
- **volume element $\Delta A = R\,L\,\Delta\varphi$ is submerged for a time $\Delta t = \Delta\varphi / (2\pi N)$ (min)**

Sedimentation of suspensions

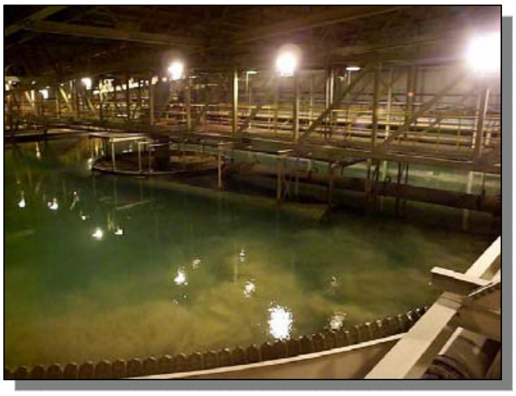


Sedimentation of concentrated suspensions. (*a*) Type 1 settling, (*b*) Type 2 settling

Batch sedimentation test



Continuous thickener



Picture: http://www.geocities.com/fitzgerrell/work_img/thickener.jpg

Source: IGH91, ZH00

Solid-solid separations

- Used for separating unwanted materials or size fractions
- Equipment examples:
  - Sieves, screens
  - Cyclones, centrifuges
  - Hydraulic separators
  - Sink-float, froth flotation separators
  - Magnetic, electrostatic separators

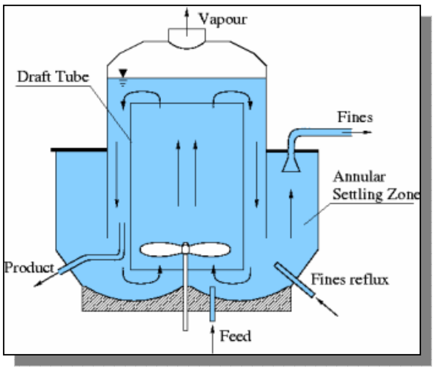
Screens

Froth flotation

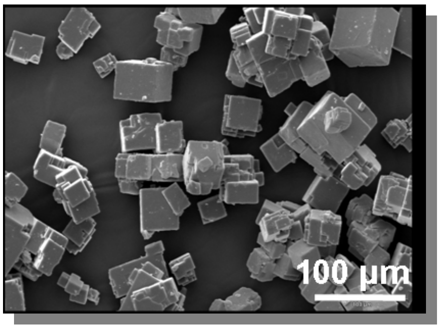
Picture http://www.key.net/p_product.cfm?productid=30
Picture: http://www.carmanahdesign.com/ewgLab.php

Crystallisers

- Solid product crystals can be produced from gases, liquid melts or solutions
- Advantages are: high product purity (crystallisation can be seen as a separation process!), and (except for liquid melts) low energy demand and low temperatures
- Import issues are crystal product morphology, crystal growth kinetics, inclusion of impurities (and crystal water), and process control (temperature ↔ product size distribution and quality)



A continuous crystalliser



Picture http://www.mpi-magdeburg.mpg.de/research/projects/1032/1035/1035_1043

Picture:http://www.tvt.cbi.uni-erlangen.de/deu/forschung/kristalisation/crystallisation.htm

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