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Lecture 12: Froth flotation

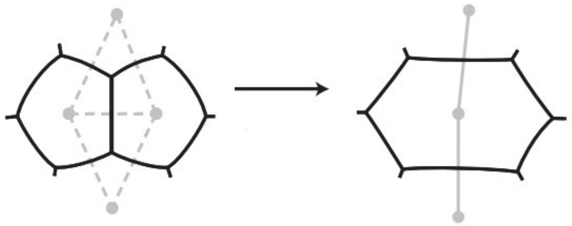
Structure

- Review lecture 11
- Mineral flotation
- Surfactants in Flotation
- Particle attachment
- Froth zone
- Cell design
- Related applications

Foam stability

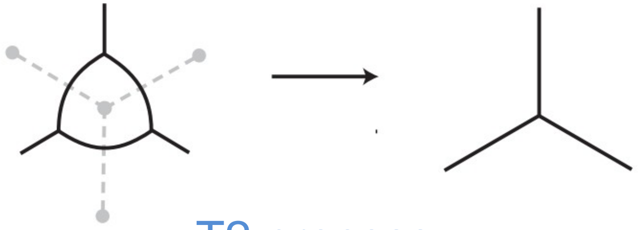
- Two modes of foam destruction:
- A: Coalescence / Film rupture

  → Increased bubble size / reduced foam volume



- B: Coarsening

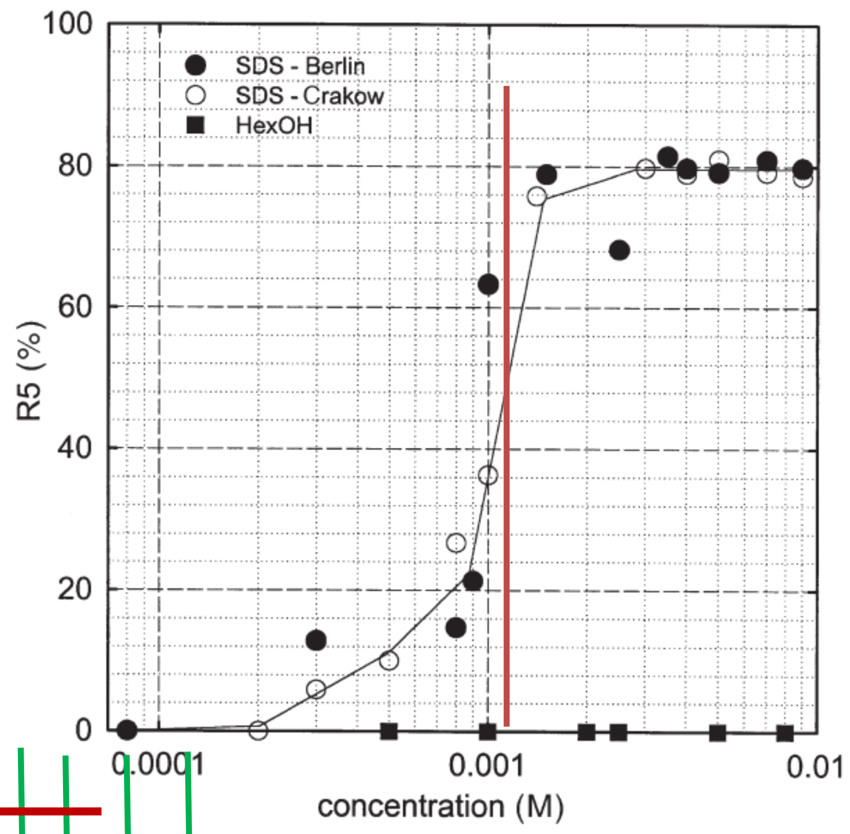
  → increased bubble size

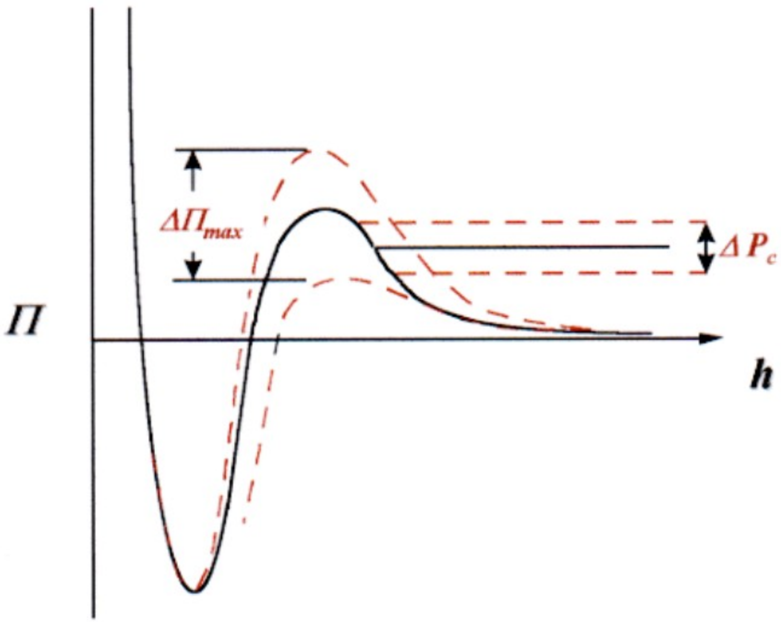


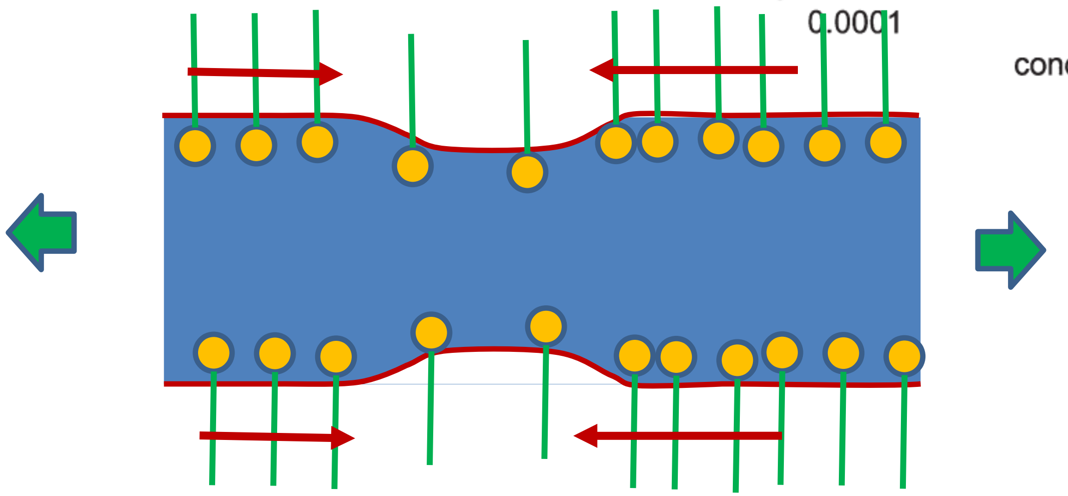
T2 process

Film stability

- Film stretching → locally lower surface coverage
- Marangoni effect cures weak spots

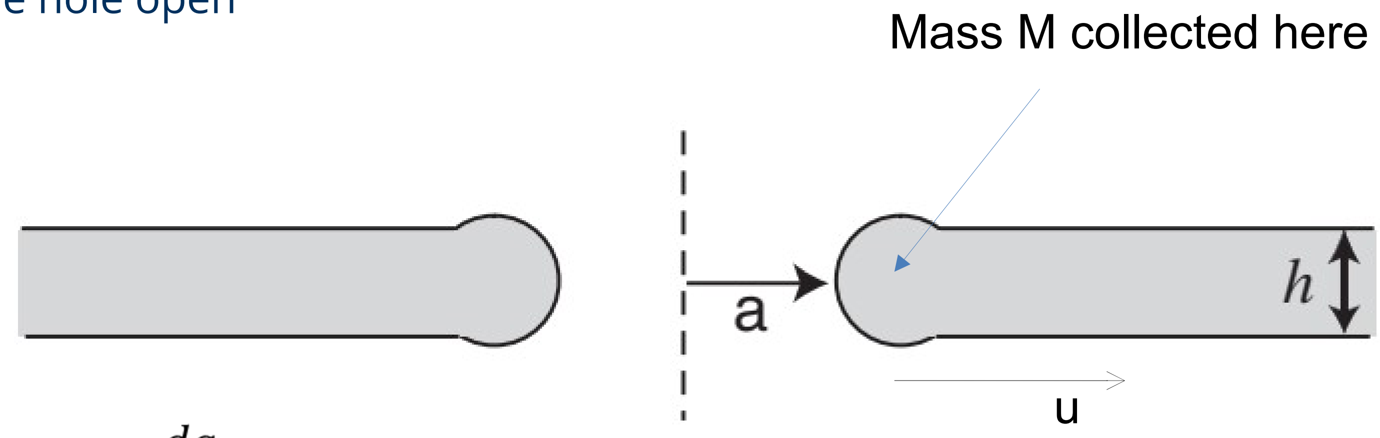






Film rupture velocity

- Surface tension pulls the hole open



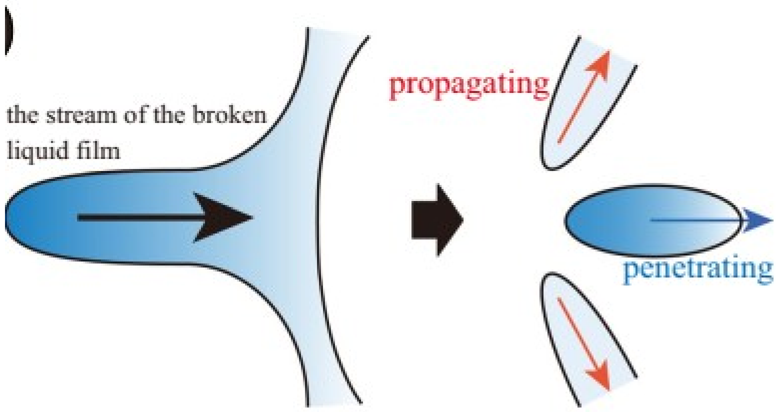
$$\frac{d(M\,u)}{dt} = F = 2\,\gamma\;\;2\pi a\quad, u = \frac{da}{dt}$$

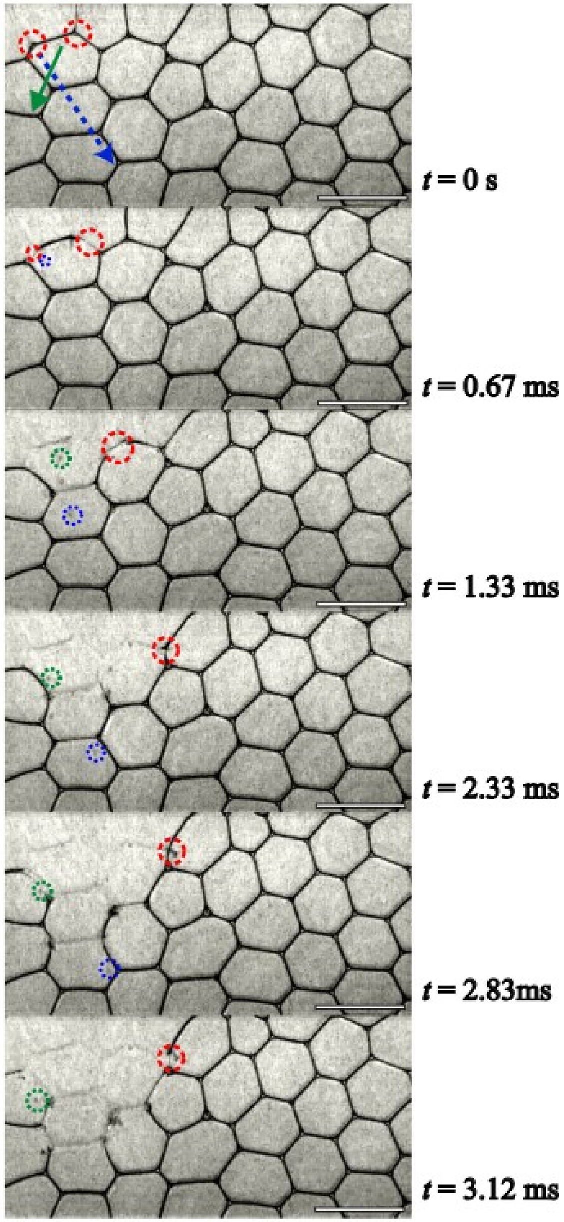
$$M = \rho_l\;\;\pi a^2 h$$

$$u = \sqrt{\frac{2\gamma}{\rho_l h}} \xrightarrow{h \approx 50\,nm} u{\sim}40\,m/s \xrightarrow{R_e \approx 1\,mm} t{\sim}25\,ms$$

Rupture avalanche

- Film rupture might release droplets
- Impact of droplets causes next film rupture



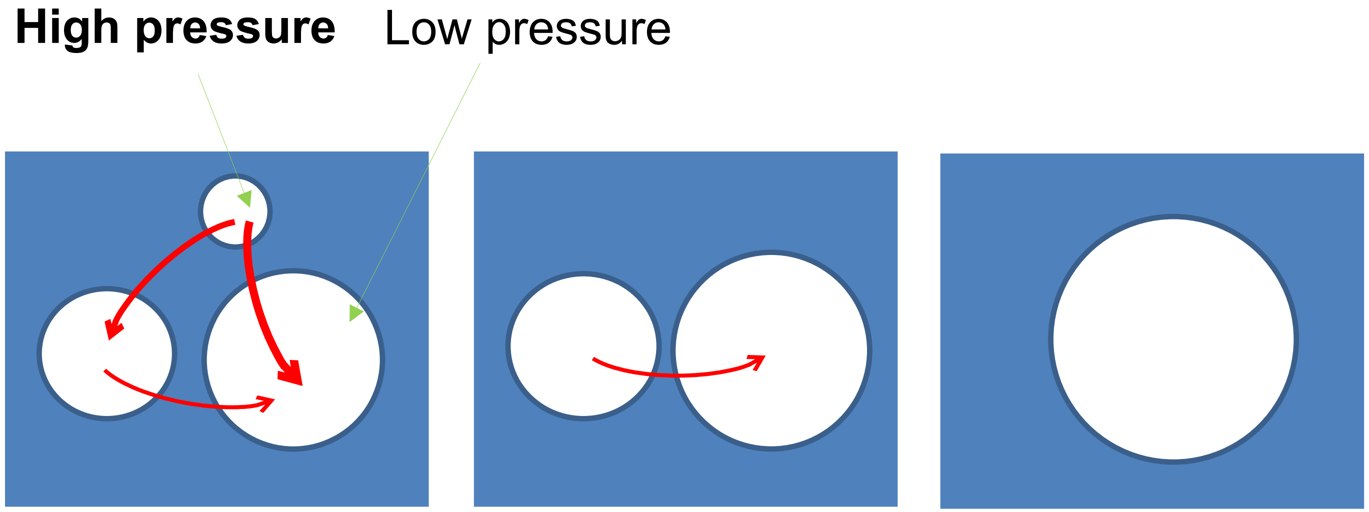


[Yanagisawa & Kurita, 2019]

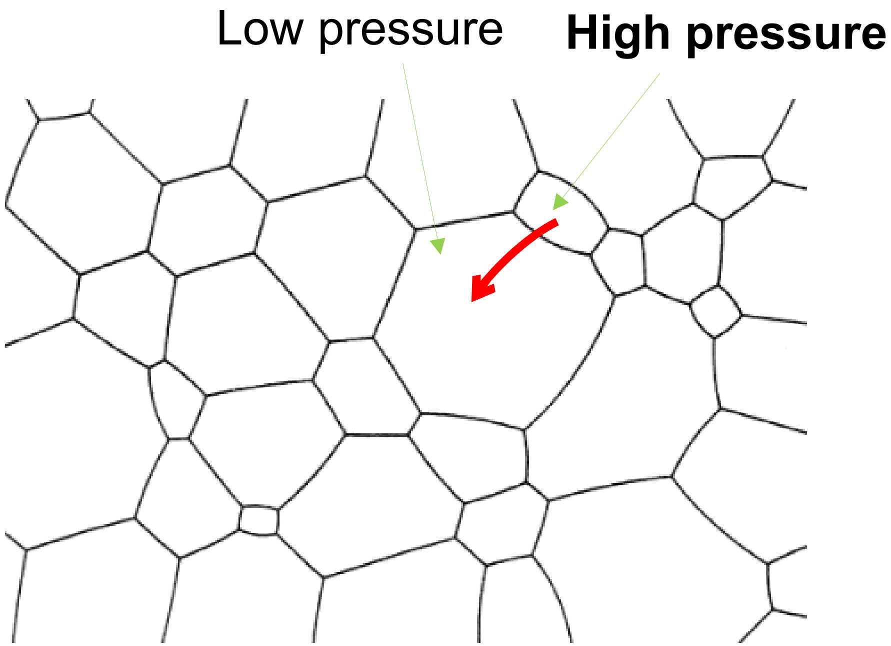
Ostwald ripening vs. von Neumann-Mullins coarsening

- Ostwald ripening for bubbly liquid
- Von Neumann-Mullins coarsening for dry foam

$$\Delta p = \frac{2\gamma}{R_1} - \frac{2\gamma}{R_2}$$

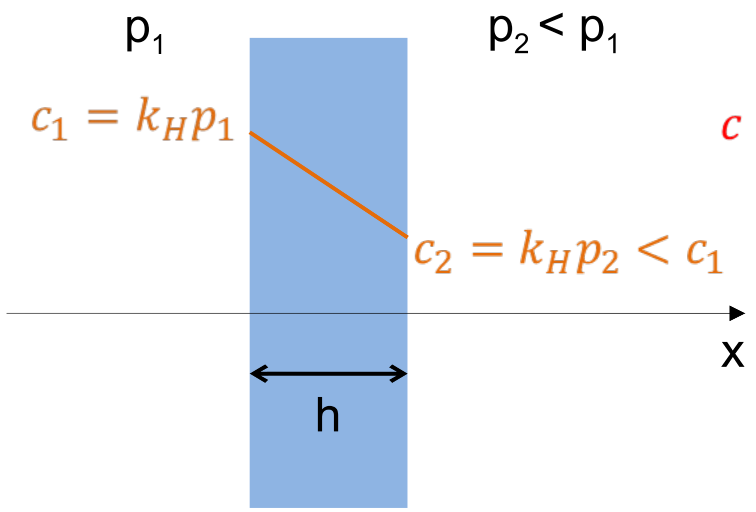


$$\Delta p = 2\gamma \, H_{i,j}$$



Gas diffusion

- Equilibrium over liquid lamella (steady state)
- Neglecting transport to/from the interface (pure gas)



$$c = k_H\, p$$

$$\frac{\Delta c}{h} = \frac{\partial c}{\partial x} = -k_H \frac{p_1 - p_2}{h}$$

Molecular flux through Area A (Fick's law):

$$\frac{\Delta n}{\Delta t} = -D_f\, A\, \frac{\partial c}{\partial x}$$

$$p_0\, V = n\, R\, T$$

$$\Delta V = \Delta n \frac{RT}{p_0}$$

Volumetric flux through Area A:

$$\frac{\Delta V}{\Delta t} = \frac{\Delta n}{\Delta t}\frac{RT}{p_0} = -D_f\, A\, \frac{\partial c}{\partial x}\frac{RT}{p_0}$$

Gradient over lamella:

$$\frac{\Delta V}{A\, \Delta t} = D_f\, k_H \frac{p_1 - p_2}{h}\frac{RT}{p_0}$$

Effective diffusion coefficient D_{eff}

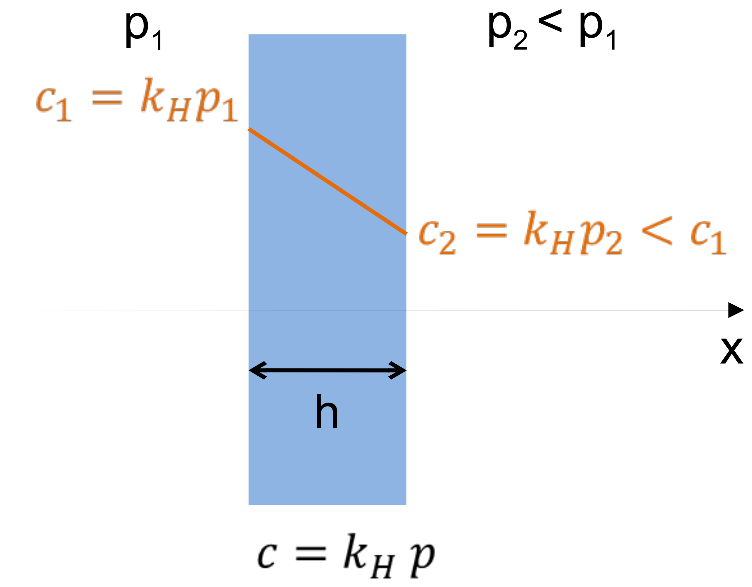
$$\Delta p = 2\gamma\, H_{i,j}$$

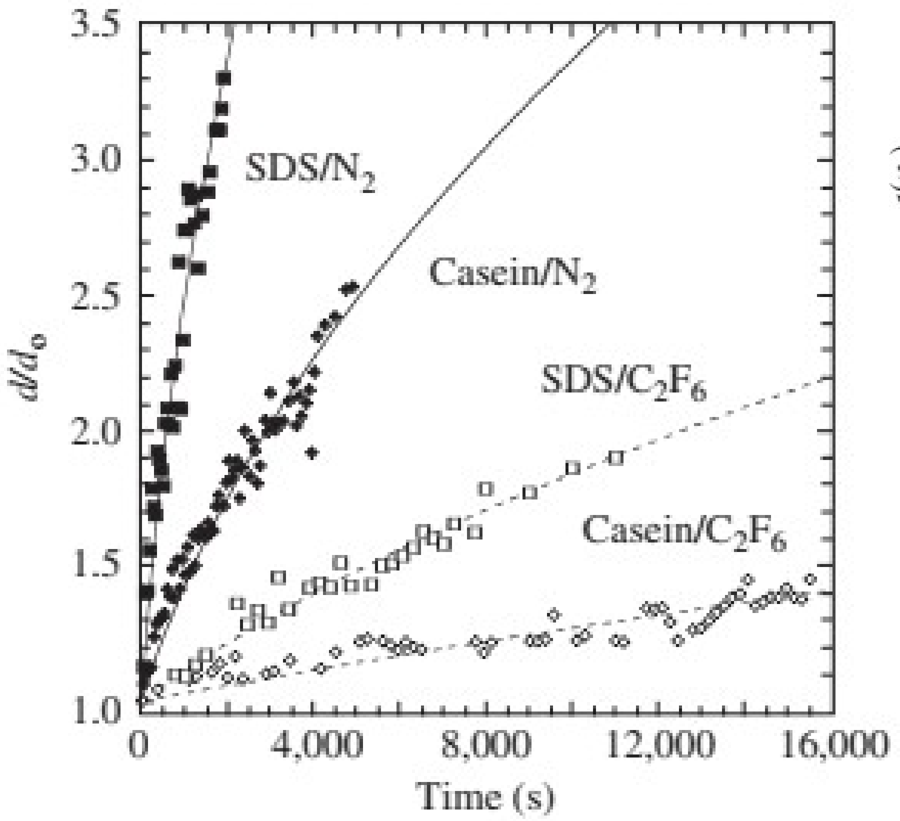
$$\frac{\Delta V}{A\, \Delta t} = D_f\, k_H \frac{p_1 - p_2}{h}\frac{RT}{p_0} = D_{eff} H_{1,2} \rightarrow \boxed{D_{eff} = D_f\, k_H \frac{2\gamma}{h}\frac{RT}{p_0}}$$

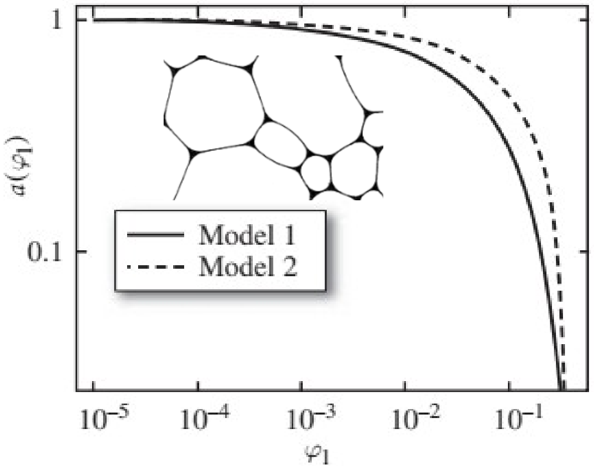
$$[D_{eff}] = m^2/s$$

Gas diffusion

- $C2F6$ → very stable foam
- N2, CO2 → fast coarsening



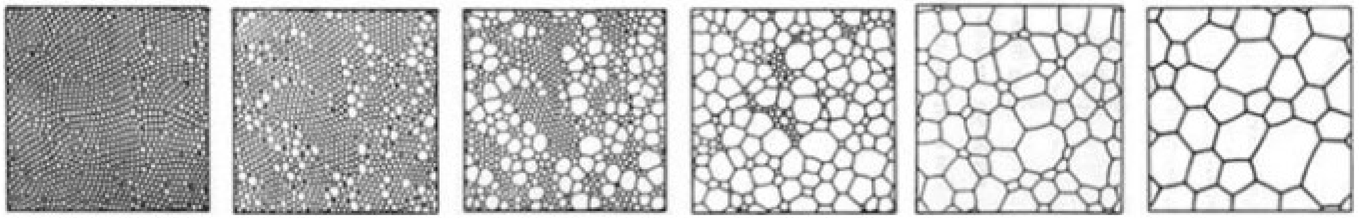


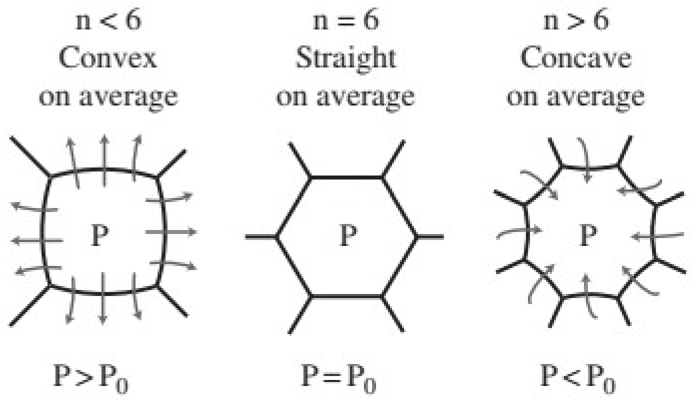


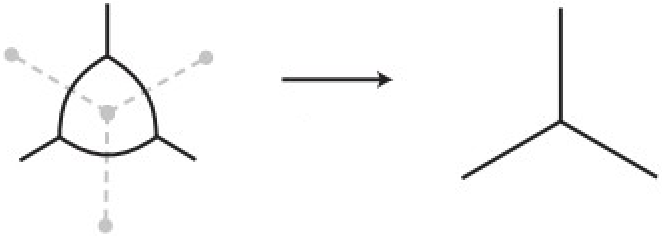
$$D_{eff} = D_f\, k_H \frac{2\gamma}{h} \frac{RT}{p_0} a(\varphi_l)$$

Growth of bubble size

- Small bubbles → small number of neighbours → convex, high mean curvature $H_{i,j}$
- Small bubble vanish, larger bubbles grow







- Average bubble size evolution:

$$R = R_0 \sqrt{1 + \frac{t}{t_c}}$$

$$t_c \approx \frac{\langle V(t=0)\rangle^{2/3}}{b\, D_{eff}}, b \approx 1$$

Exercise: time scale for Coarsening

- Time for a foam to double its average bubble radius by coarsening?
- SDS foam, 50 nm film thickness
- A) 0.1 mm bubble radius, CO_2, 10 % liquid fraction

$$k_H = 3.4 \times 10^{-6} \frac{mol}{m^3\,Pa} \qquad D_f = 1.9 \times 10^{-9} \frac{m^2}{s}$$

$$t_c \approx \frac{\langle V(t=0)\rangle^{2/3}}{b\,D_{eff}} = 290\,s \qquad \frac{R}{R_0} = 2 = \sqrt{1 + \frac{t}{t_c}} \rightarrow t = 3\,t_c = 870\,s = 14\,min$$

- B) 5 mm bubble radius, C_2F_6, 0.1 % liquid fraction

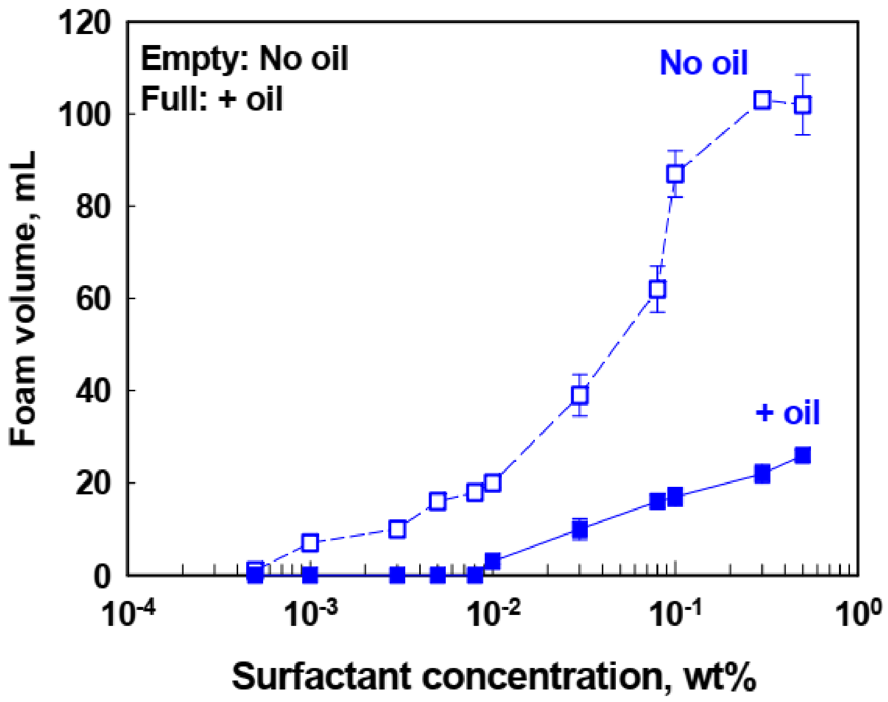
$$k_H = 5.8 \times 10^{-7} \frac{mol}{m^3\,Pa} \qquad D_f \approx 1.2 \times 10^{-9} \frac{m^2}{s}$$

$$t_c \approx \frac{\langle V(t=0)\rangle^{2/3}}{b\,D_{eff}} = 3.4 \times 10^6 s \qquad \frac{R}{R_0} = 2 = \sqrt{1 + \frac{t}{t_c}} \rightarrow t = 3\,t_c = 10^7 s = 100\,days$$

Air: 12 days

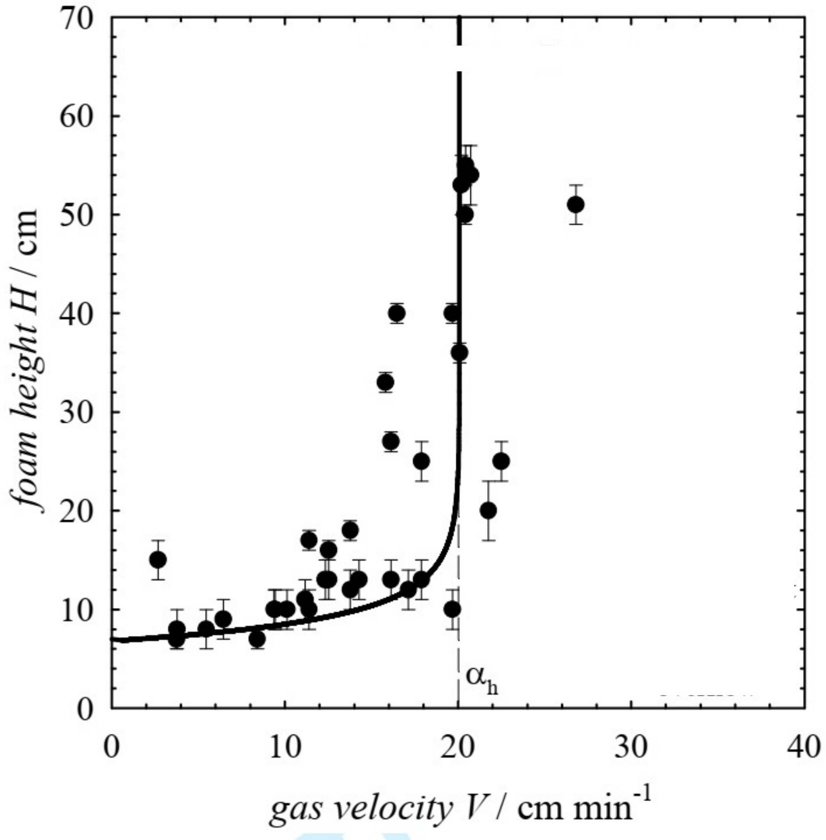
Bartsch test

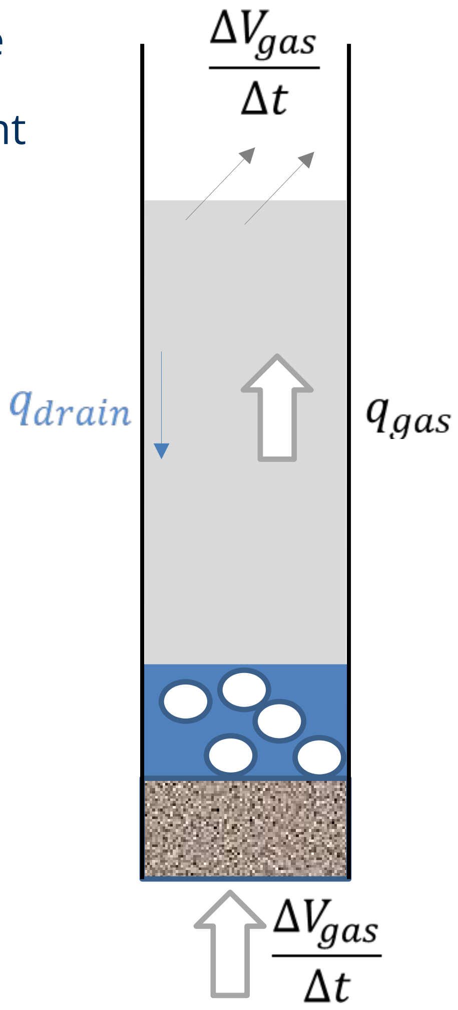
- Shaking with defined frequency, time
- Measurement of resulting foam volume



Bikerman standardized test

- Constant gas flow rate through a porous plate
- Measurement of (steady) resulting foam height





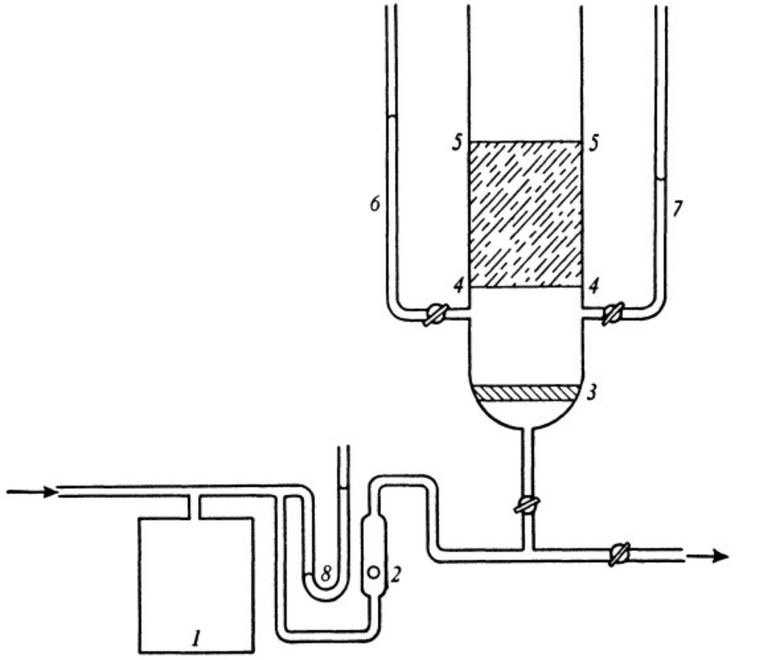


Fig. 3.6. Determination of the liquid volume in foam during bubbling. *1* is the nitrogen reservoir; *2* is the flow meter; *3* is the porous plate; *4*, *4* and *5*, *5* are the boundaries of the foam column; *6* is a buret; and *7* and *8* are manometers (after reference 49).

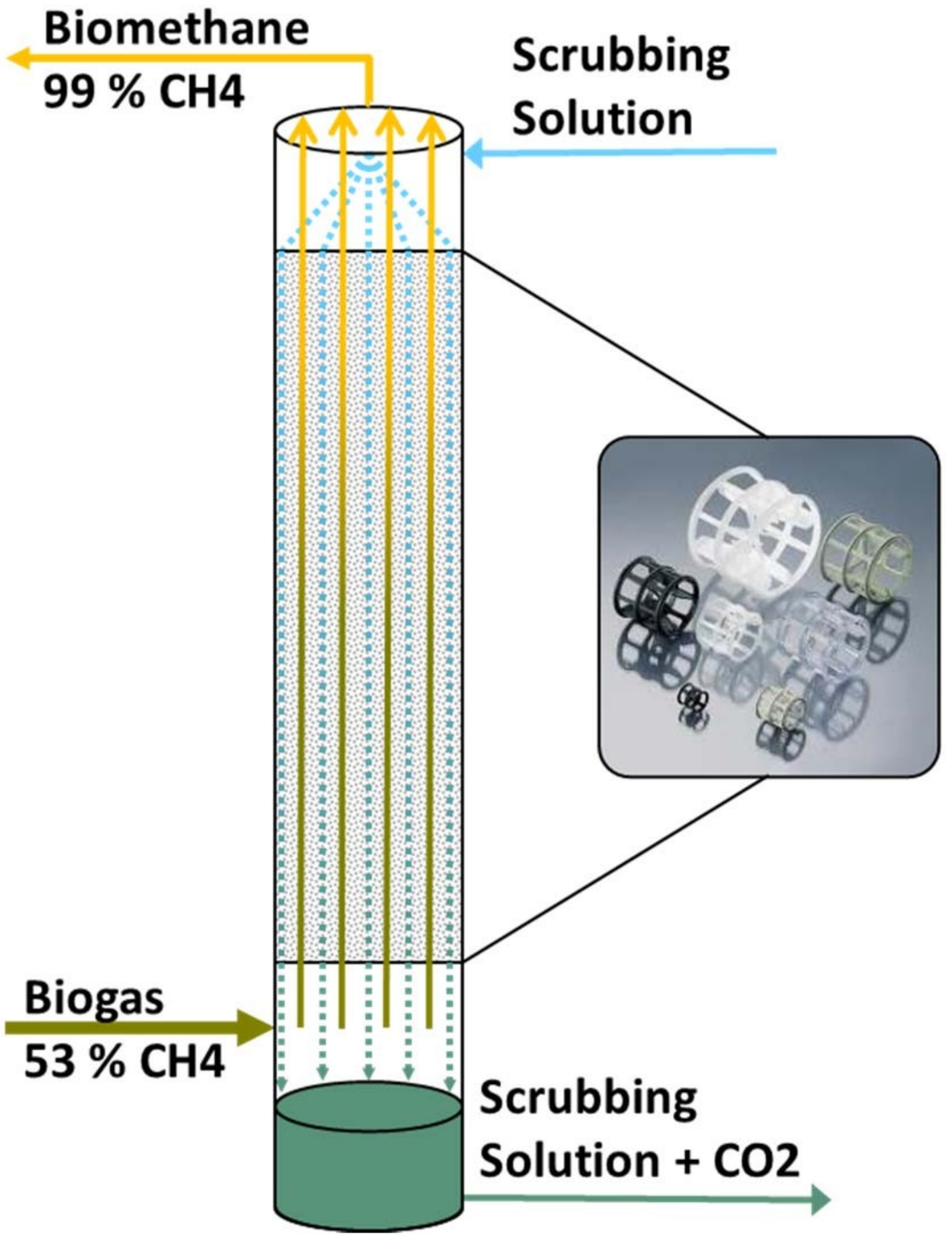
[Bikerman, Foams, 1973]

Structure

- Review lecture 10
- Film rupture
- Coarsening
- Stability testing
- Defoaming

Typical applications

- Removal of CO_2 from biogas
- Packed bed of wrinkled bodies → foam generation
- Foam blocks device, reduces efficiency
- Scrubbing solution contains defoaming agent
- → film rupture



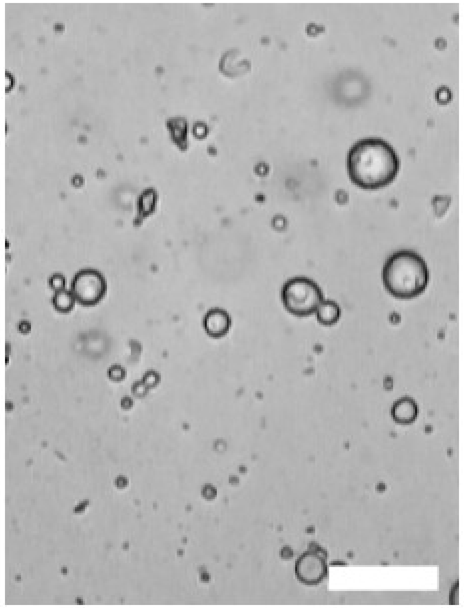
Types of Antifoams

- Additives to the solution that prevent foam formation and/or destroy foam
- Solid antifoams
  - silica, wax, polymer
- Liquid antifoams
  - triglycerides
  - silicon oils, mineral oils
- Solid+liquid antifoams
  - oil + particles

Silica particles

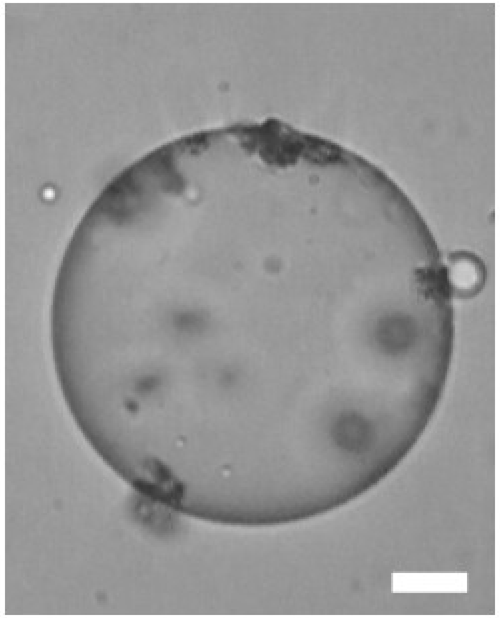
100 nm

Oil emulsion



30 μm

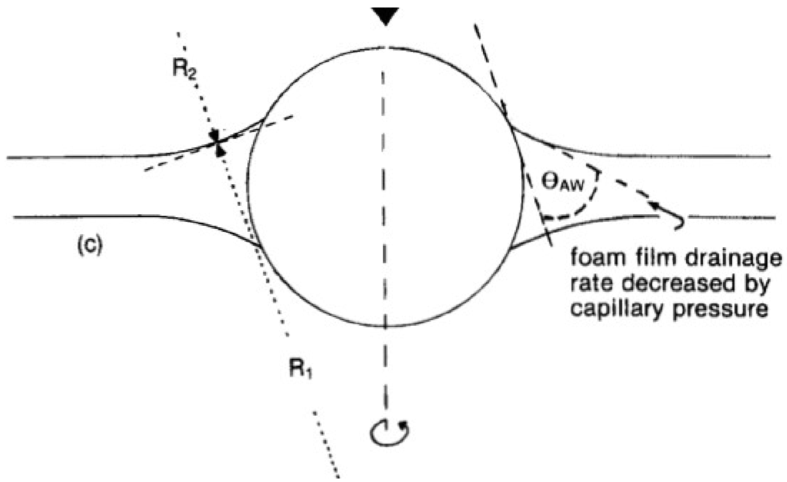
Oil+particles

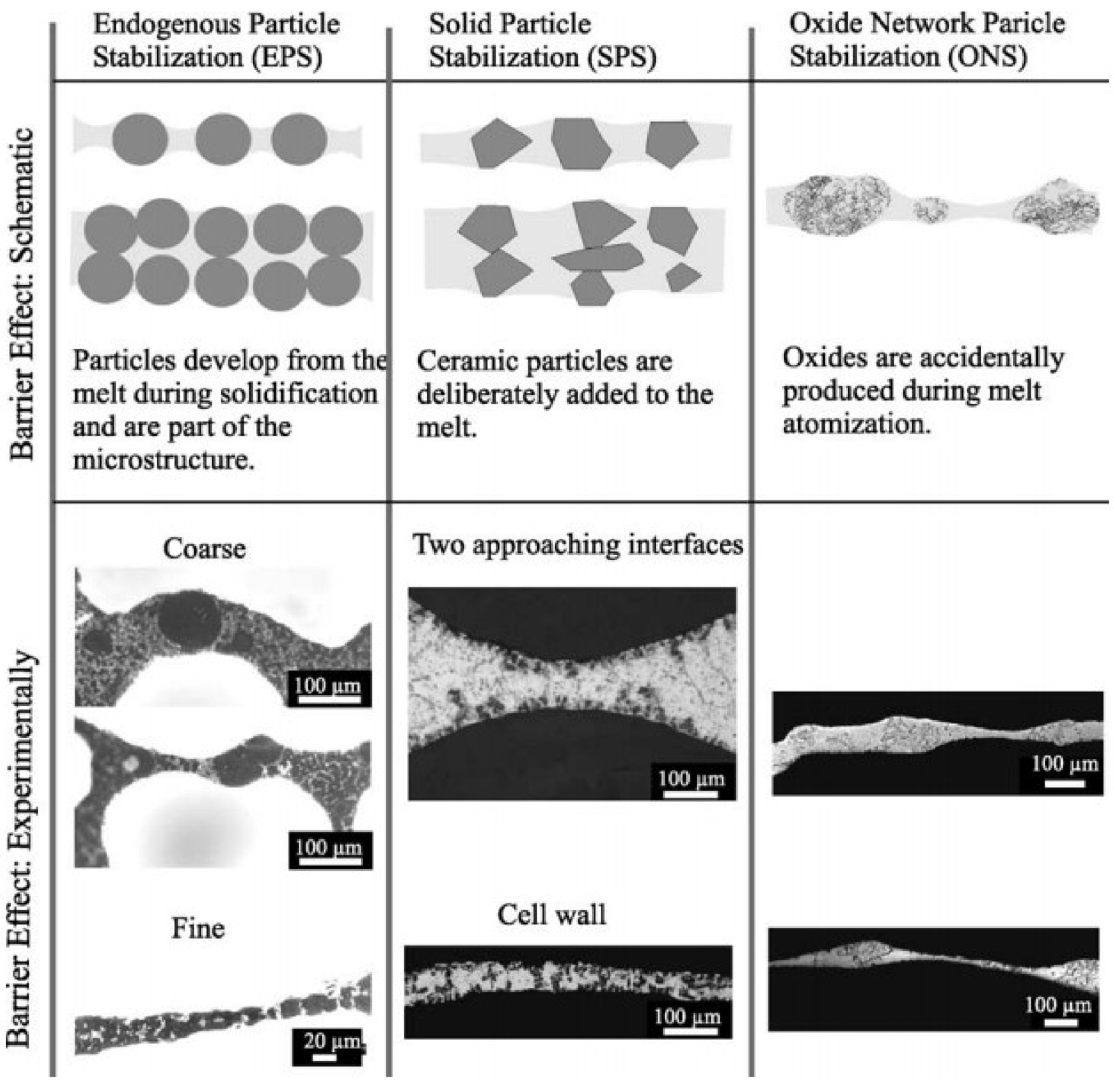


1 μm

Film stabilisation by particles

- Depending on contact angle
- Hydrophilic particles ($\theta < 90°$) reach to stable position

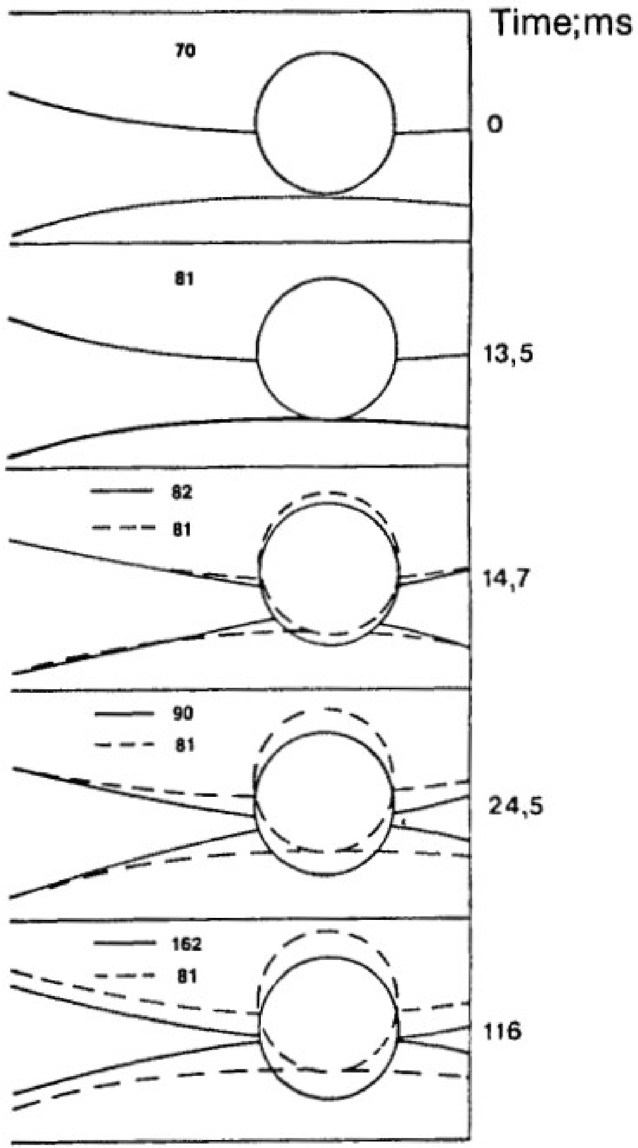




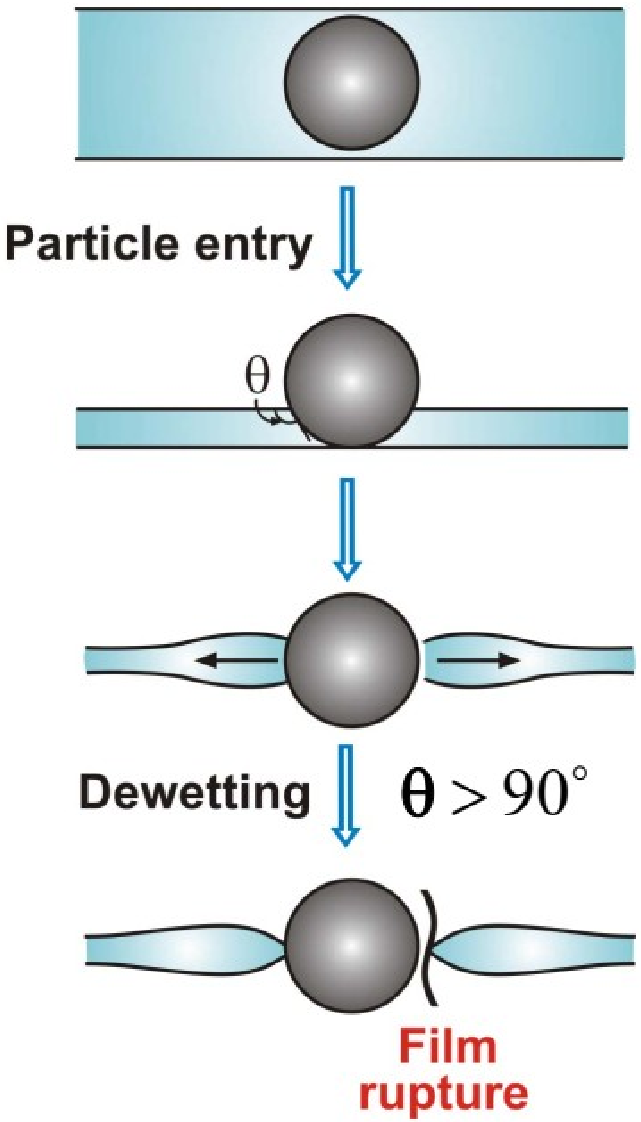
[Körner et al., 2005]

Film rupture by particles

- Depending on contact angle
- Hydrophobic particles ($\theta > 90°$)
- Cause de-wetting and film rupture

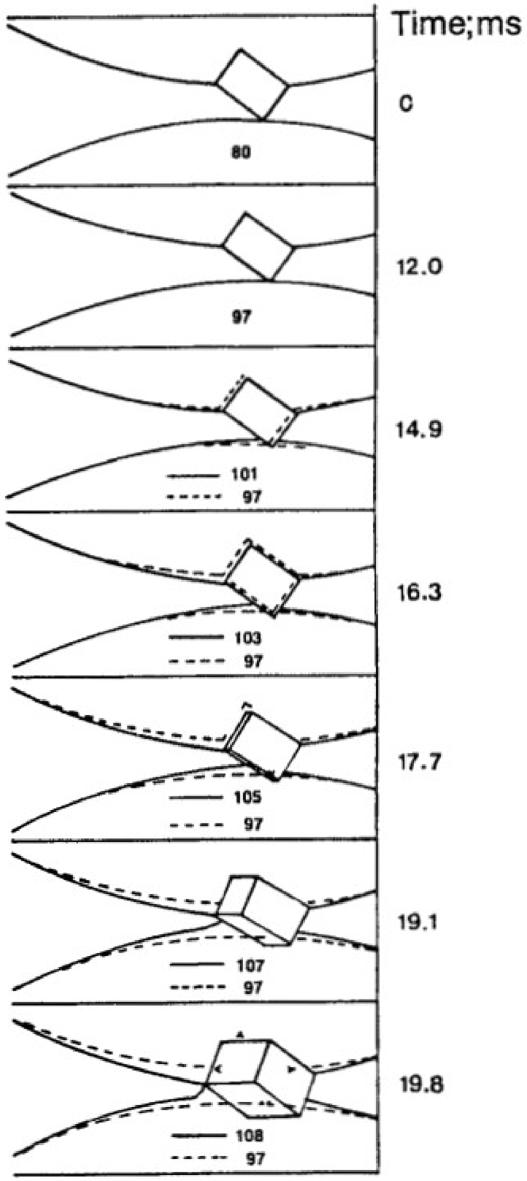


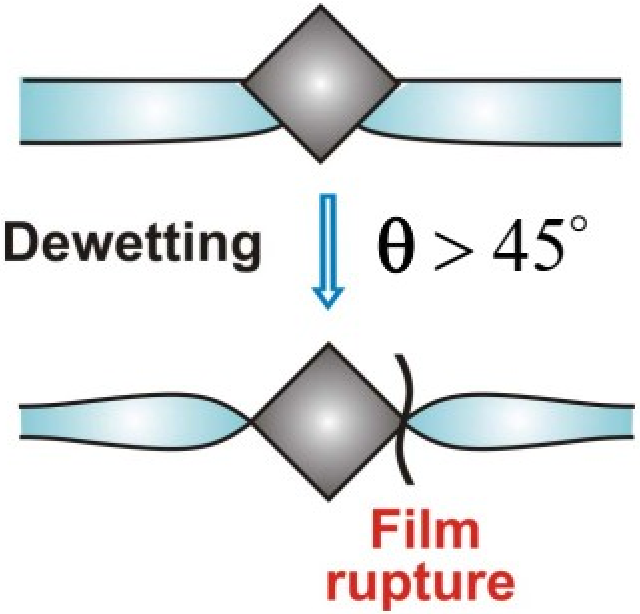
[Garret, Defoaming, 1992]



Film rupture by particles

- Shape of particles can support film rupture
- Sharp edges prevent stable situations
- Relevant e.g. for mineral particles

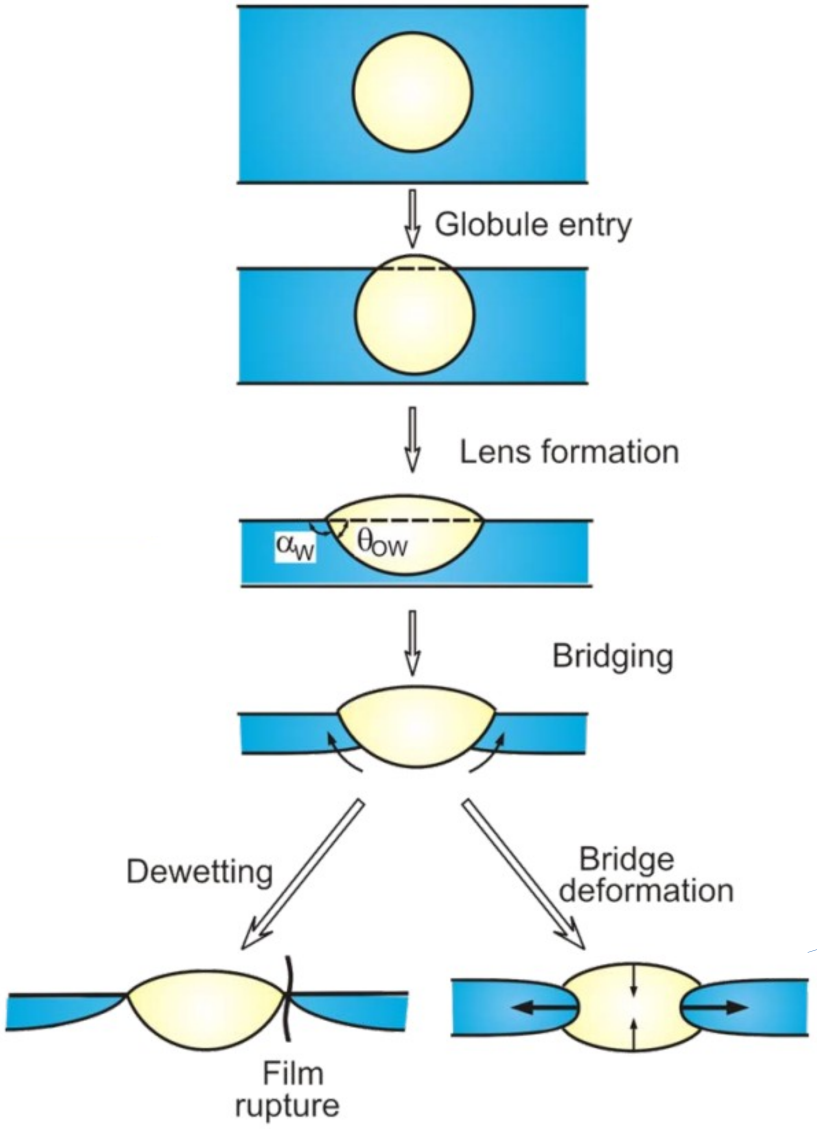


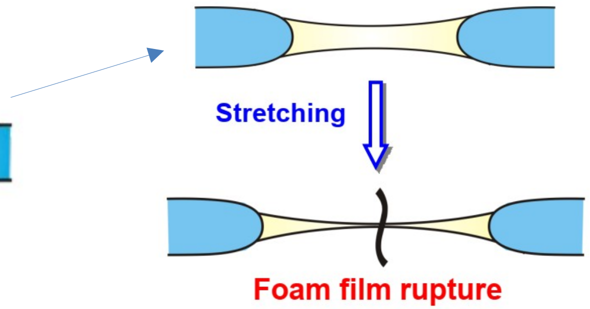


[Garret, Defoaming, 1992]

Film rupture by liquids

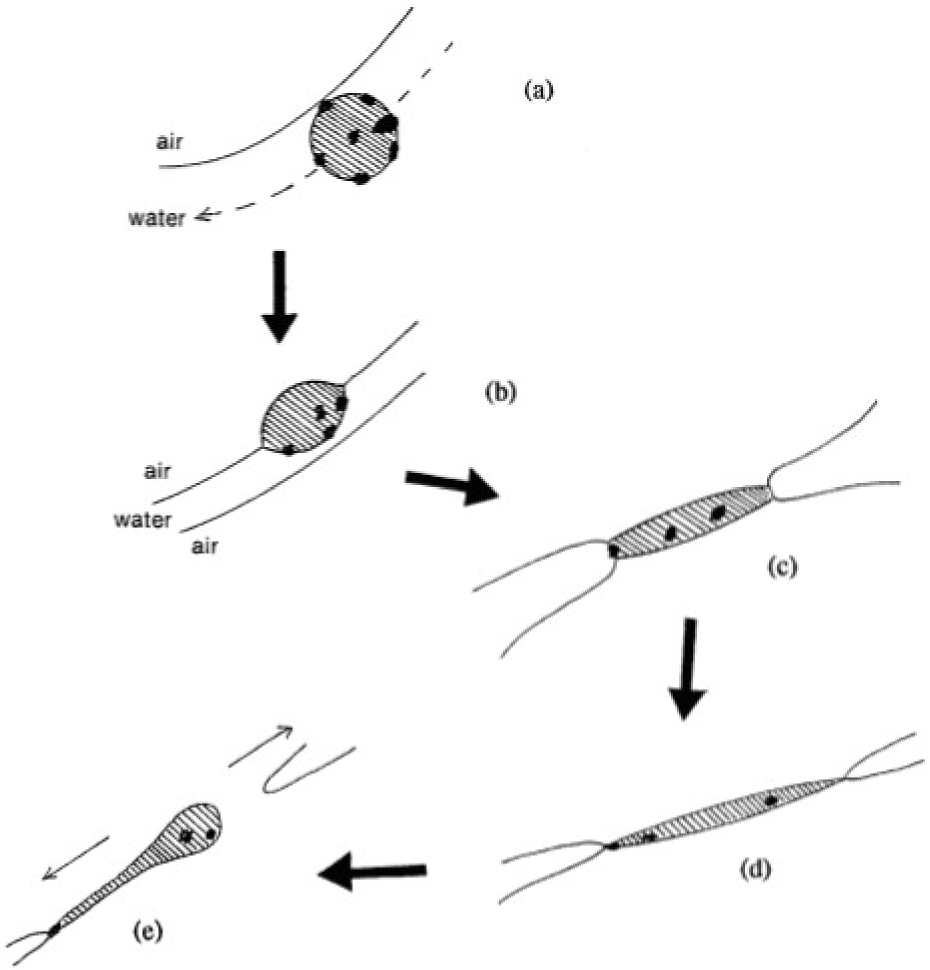
- Droplets adsorbs at water-air interfac
- Droplet bridges film
- Either dewetting or bridge-stretching
- Depending on contact angles
- Depending on drop rheology





Film rupture by compounds

- Particles support rupture of air-water-oil filr
- Oil ruptures film by de-wetting

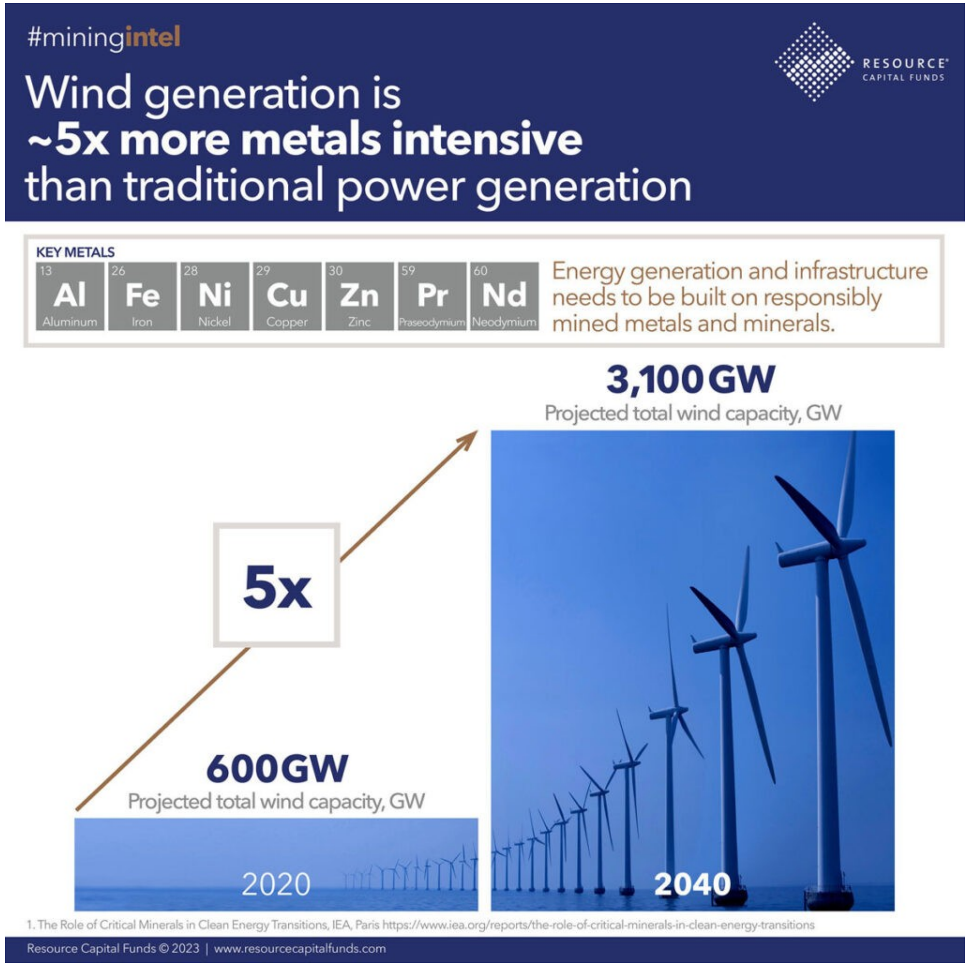


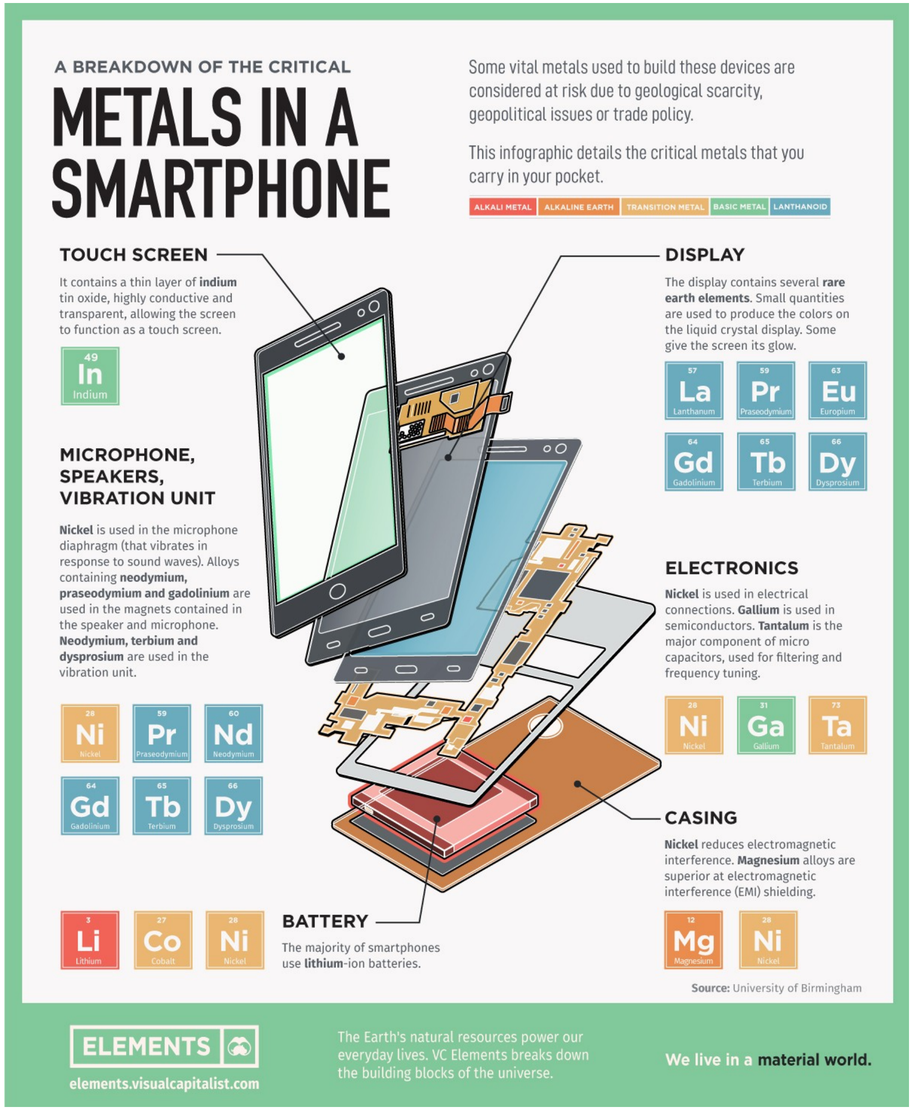
[Garret, Defoaming, 1992]

Structure

- Review lecture 11
- Mineral flotation
- Surfactants in Flotation
- Particle attachment
- Froth zone
- Cell design
- Related applications

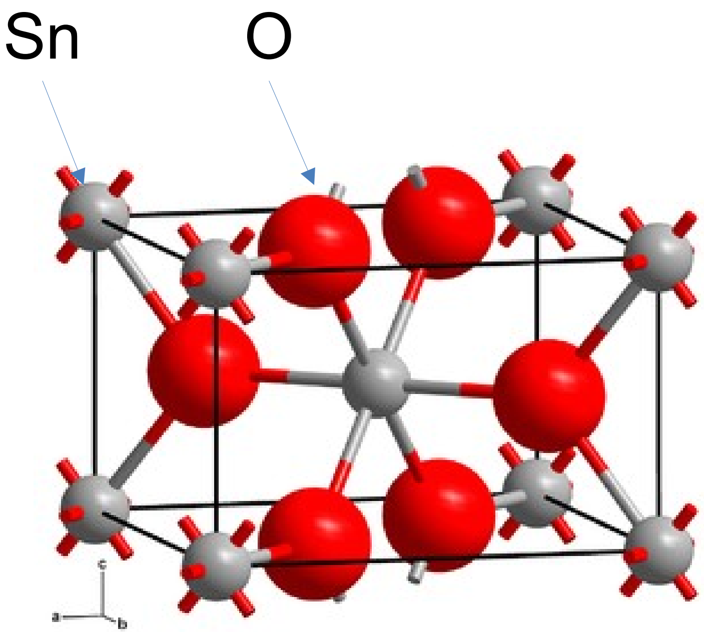
Metal usage

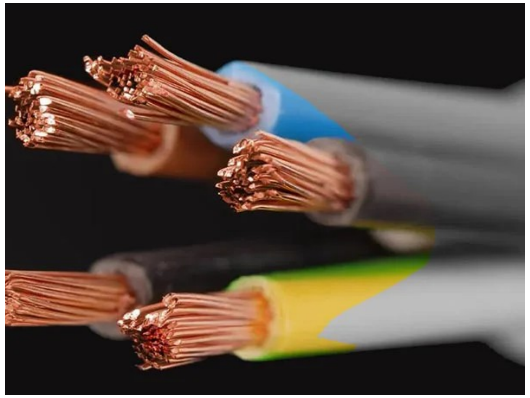

#miningintel
RESOURCE CAPITAL FUNDS
Wind generation is
~5x more metals intensive
than traditional power generation
KEY METALS
13 Al Aluminum
26 Fe Iron
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
59 Pr Praseodymium
60 Nd Neodymium
Energy generation and infrastructure needs to be built on responsibly mined metals and minerals.
3,100GW
Projected total wind capacity, GW
5x
600GW
Projected total wind capacity, GW
2020
2040
1. The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
Resource Capital Funds © 2023 | www.resourcecapitalfunds.com


A BREAKDOWN OF THE CRITICAL
METALS IN A SMARTPHONE
Some vital metals used to build these devices are considered at risk due to geological scarcity, geopolitical issues or trade policy.
This infographic details the critical metals that you carry in your pocket.
ALKALI METAL
ALKALINE EARTH
TRANSITION METAL
BASIC METAL
LANTHANOID
TOUCH SCREEN
It contains a thin layer of indium tin oxide, highly conductive and transparent, allowing the screen to function as a touch screen.
49 In Indium
DISPLAY
The display contains several rare earth elements. Small quantities are used to produce the colors on the liquid crystal display. Some give the screen its glow.
57 La Lanthanum
59 Pr Praseodymium
63 Eu Europium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
MICROPHONE, SPEAKERS, VIBRATION UNIT
Nickel is used in the microphone diaphragm (that vibrates in response to sound waves). Alloys containing neodymium, praseodymium and gadolinium are used in the magnets contained in the speaker and microphone. Neodymium, terbium and dysprosium are used in the vibration unit.
28 Ni Nickel
59 Pr Praseodymium
60 Nd Neodymium
64 Gd Gadolinium
65 Tb Terbium
66 Dy Dysprosium
ELECTRONICS
Nickel is used in electrical connections. Gallium is used in semiconductors. Tantalum is the major component of micro capacitors, used for filtering and frequency tuning.
28 Ni Nickel
31 Ga Gallium
73 Ta Tantalum
CASING
Nickel reduces electromagnetic interference. Magnesium alloys are superior at electromagnetic interference (EMI) shielding.
12 Mg Magnesium
28 Ni Nickel
BATTERY
The majority of smartphones use lithium-ion batteries.
3 Li Lithium
27 Co Cobalt
28 Ni Nickel
Source: University of Birmingham
ELEMENTS
elements.visualcapitalist.com
The Earth's natural resources power our everyday lives. VC Elements breaks down the building blocks of the universe.
We live in a material world.

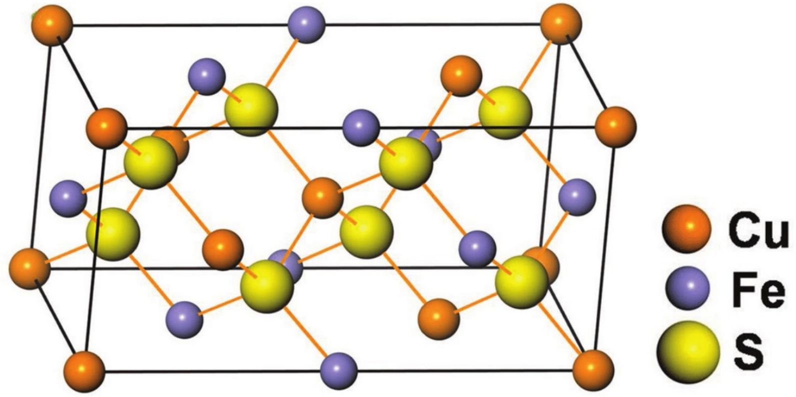
Metals and minerals

Kassiterit = SnO_2

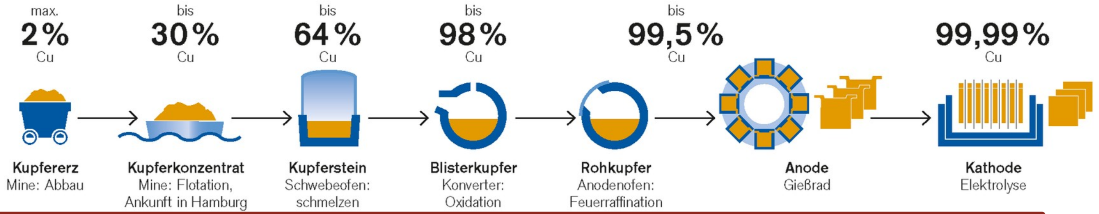




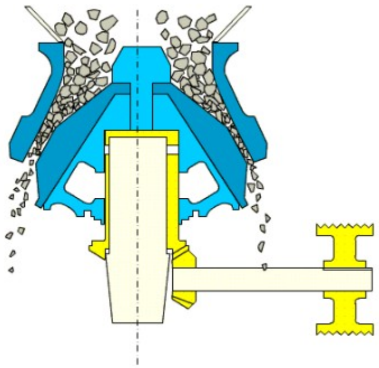
Chalkopyrit = $CuFeS_2$

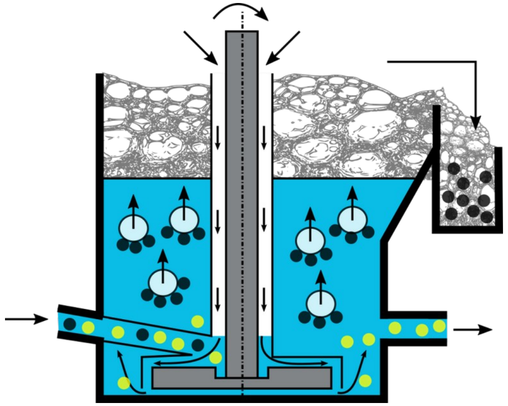


From ore to copper

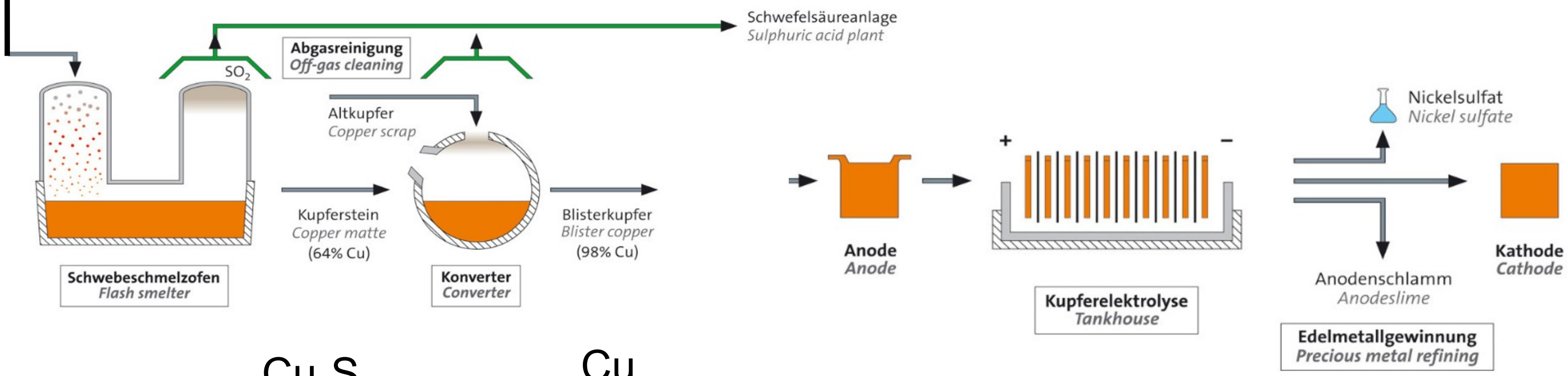


$CuFeS_2$





$CuFeS_2$



Cu_2S

Cu

Sorting in early industrialization

- 18th century: Bal Maidens in Cornwall
- Typically women of age between 8 and 24
- Sorting ore for crushing




Mineral separating techniques

- How to separate valuable mineral particles from valueless gangue particles?

Grinded material

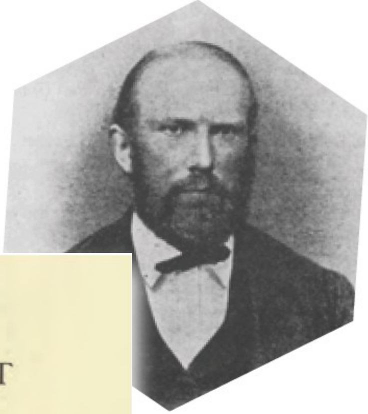
Separation techniques in mineral processing and recyling

Density sorting	Magnetic separation	Electric separation	Physical-chemical separation
> ca. 2-5 mm	> ca. 500 µm		ca. (40…200) µm

> ca. 100 µm (high field gradient mag. sep.)

Flotation patent

- First historically acknowledged patent on flotation in 1877
- Graphite flotation
- Bessel Brothers, Dresden, Germany



Adolph Bessel,
der Erfinder der Flotation

KAISERLICHES PATENTAMT.

PATENTSCHRIFT

№ 42.

GEBRÜDER BESSEL

IN DRESDEN.

VERFAHREN ZUR REINIGUNG VON GRAPHIT.

Klasse 22

FARBSTOFFE, FIRNISSE, LACKE.

BERLIN

GEDRUCKT IN DER KÖNIGL. PREUSS. STAATSDRUCKEREI.

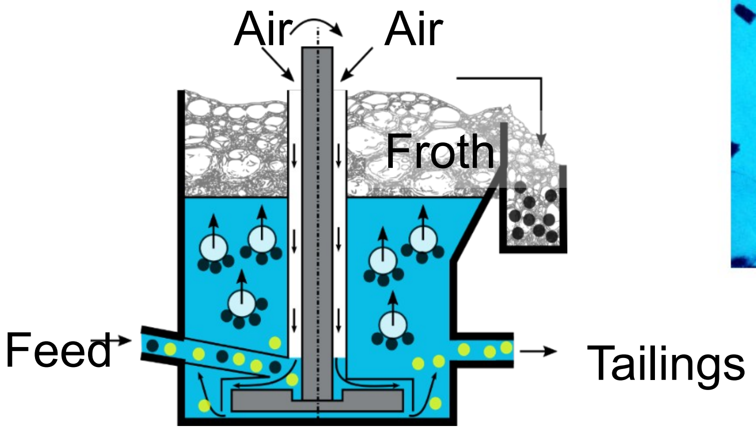
Froth flotation

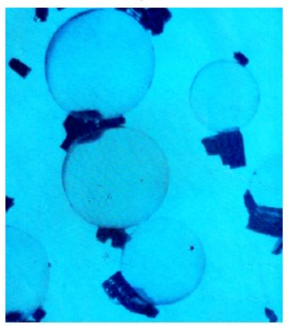
- Most important separation technique in mining
- Extraction of valuable mineral particles from valueless gangue particles
- Billion tons of ore are processed every year
- 2% of world’s primary energy goes into mineral processing

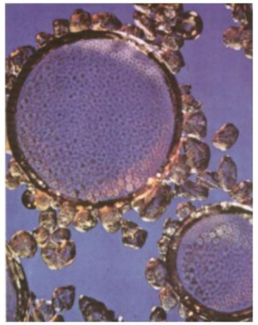
- Also employed for paper recycling, waste water treatment
- Research regarding electronic waste and lithium-ion battery recycling

Froth flotation

- Grinded particles added to surfactant solution
- Collectors (surfactants) render mineral particles hydrophobic, suppressors render gangue hydrophilic
- Bubbles are introduced, pick up particles, transport to top
- Frothers (surfactants) cause generation of meta-stable froth zone
- Overflowing froth extracts particles







Structure

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- Surfactants in Flotation
- Particle attachment
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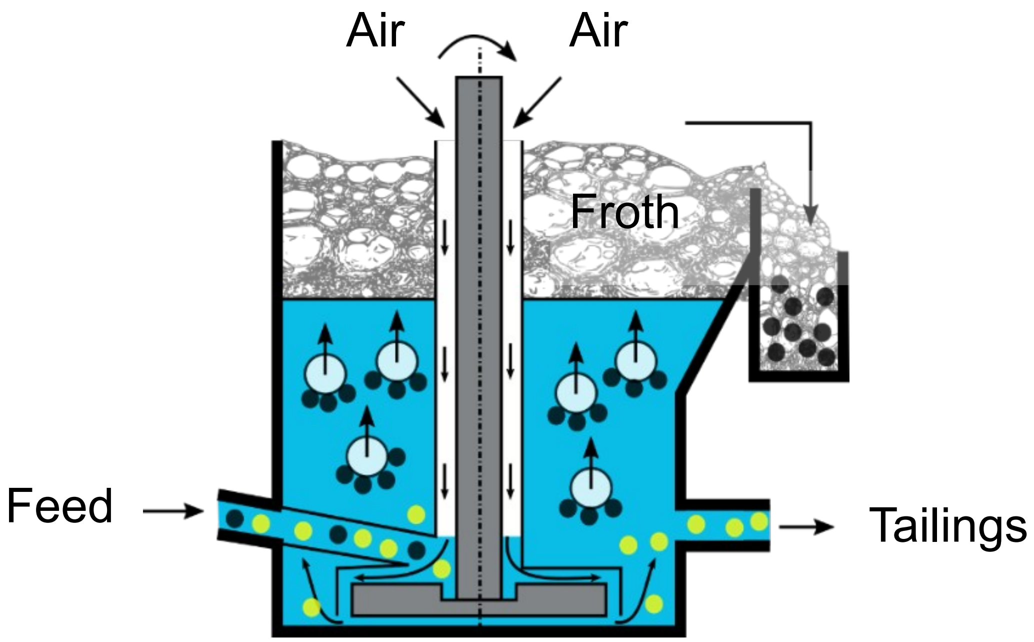
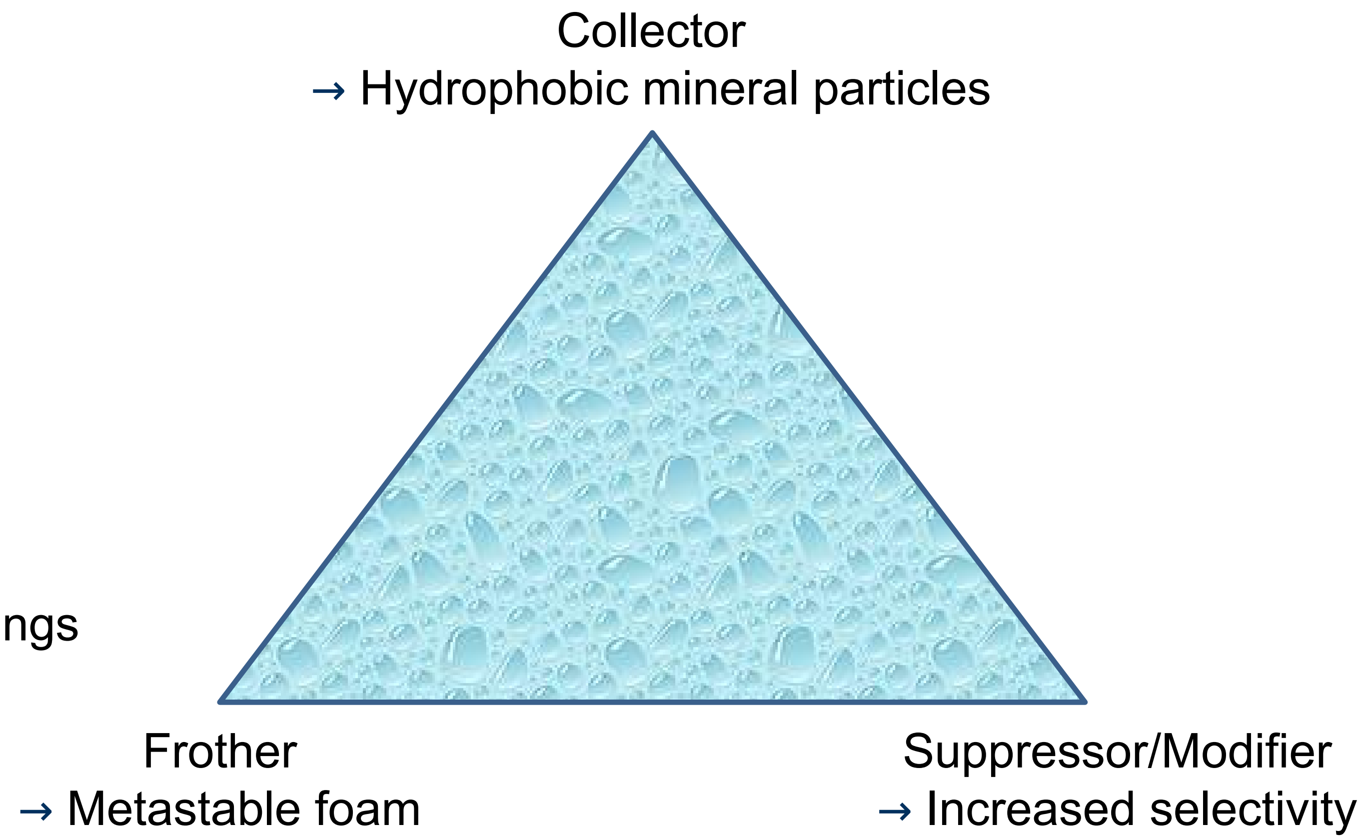
- Related applications

Types of surfactants

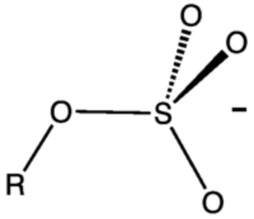
- Important branch of chemical industry
- Purposely designed molecules for different classes of ores/minerals



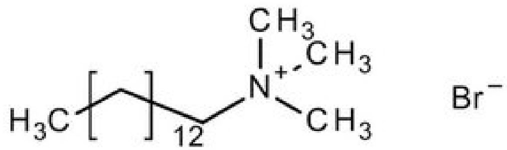


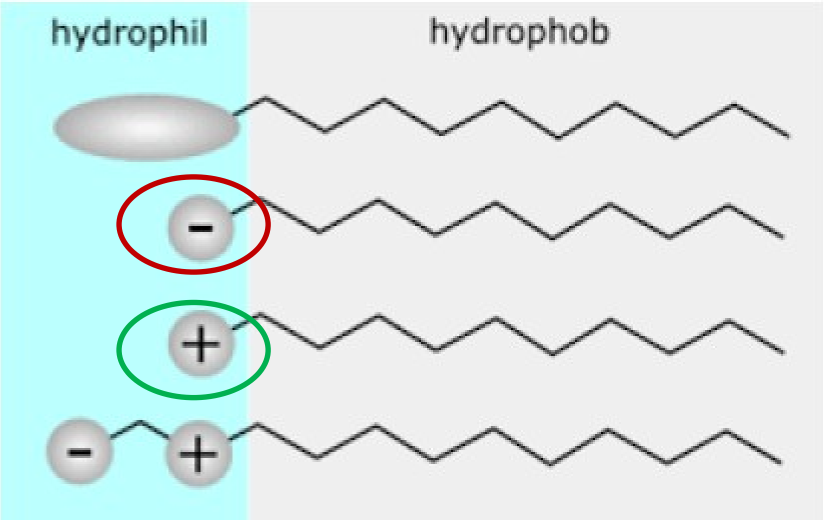
Collector

- Ionic surfactants
- Typical anionic surfactants: organosulfates (e.g. SDS)



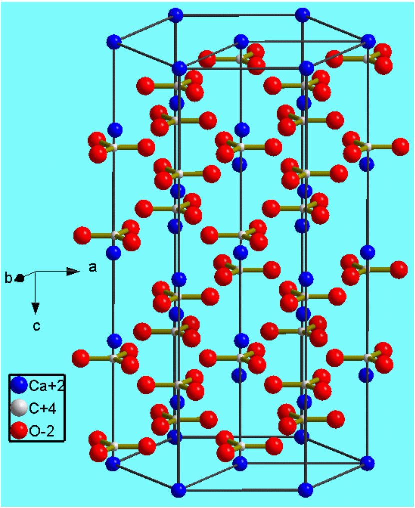
- Typical cationic surfactants: quaternary ammonium cations (e.g. TTAB)

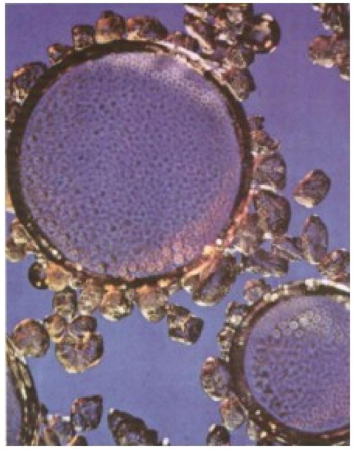




- Optimum at $C_{12}...C_{14}$
- Compromise between solubility (few C-atoms)
  and surface activity (many C-atoms)

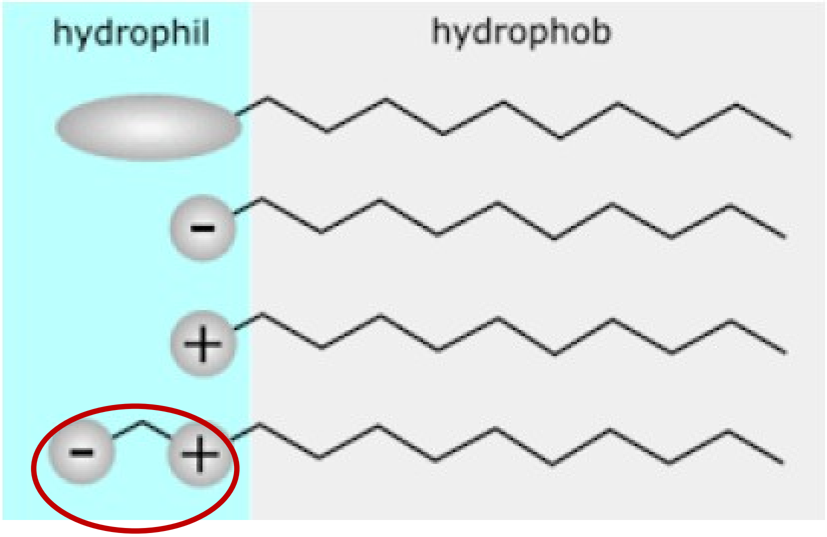
- Particles are conditioned before
  entering the flotation cell

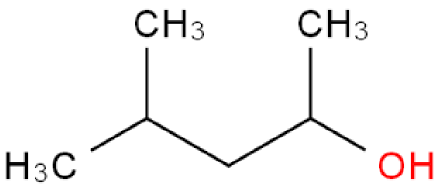


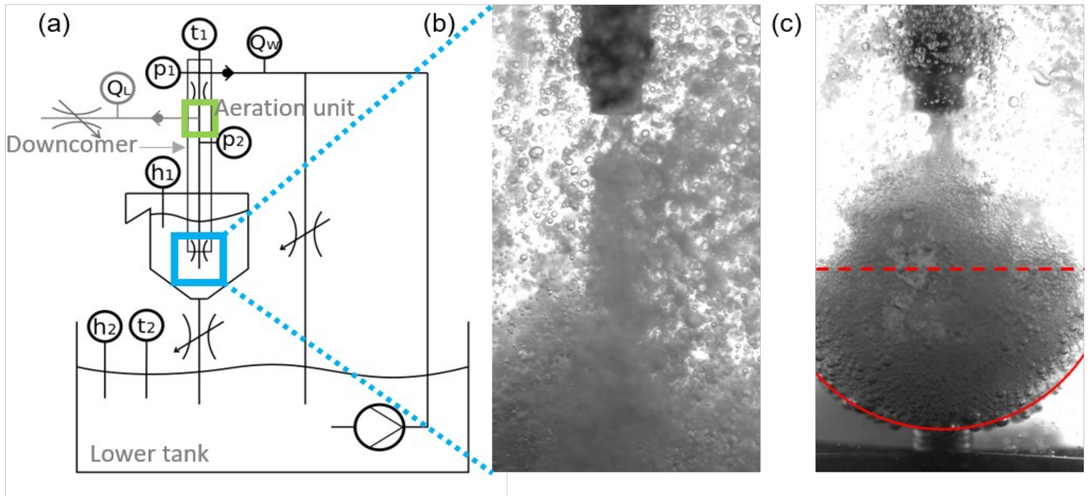


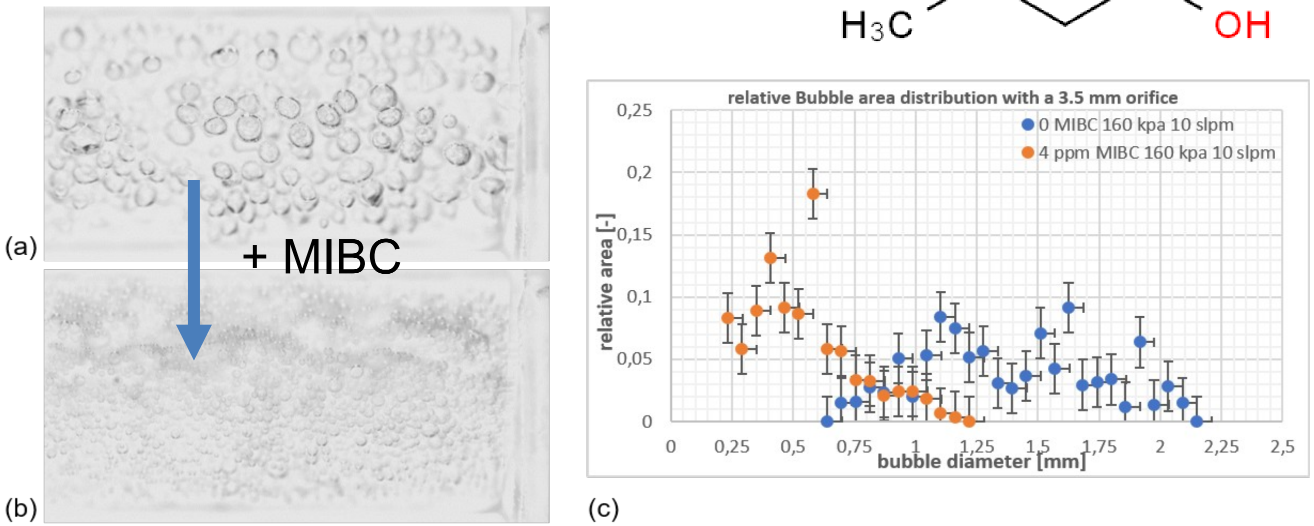
Frother

- Typical frother: methyl isobutyl carbinol - MIBC
- Hydroxy-group is polar, but not charged (=hydrophilic)
- Molecule is unpolar, otherwise (= hydrophobic)
- → generates small bubbles
- → generates meta-stable froth



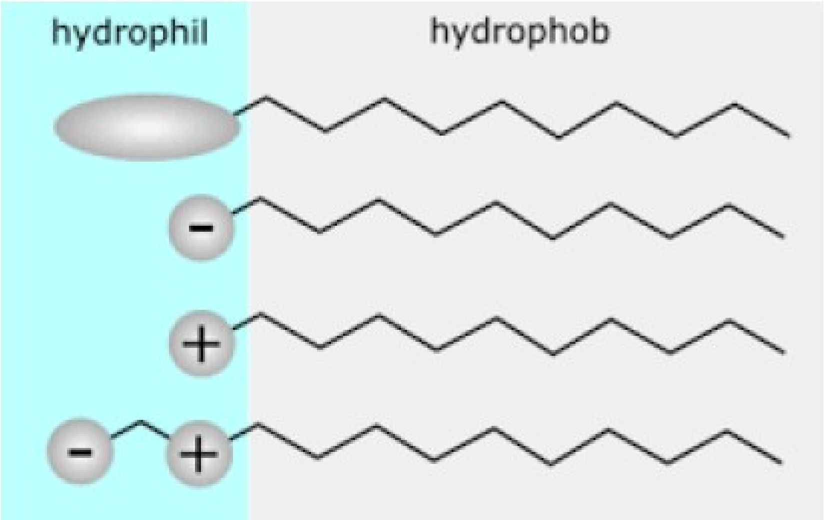






Frother vs. Collector

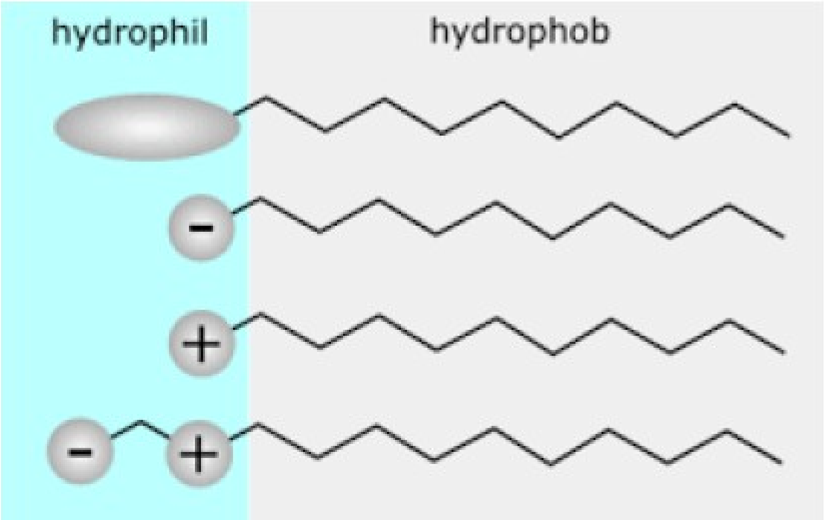
- Both are surfactants
- Purposely designed molecules for different classes of ores/minerals



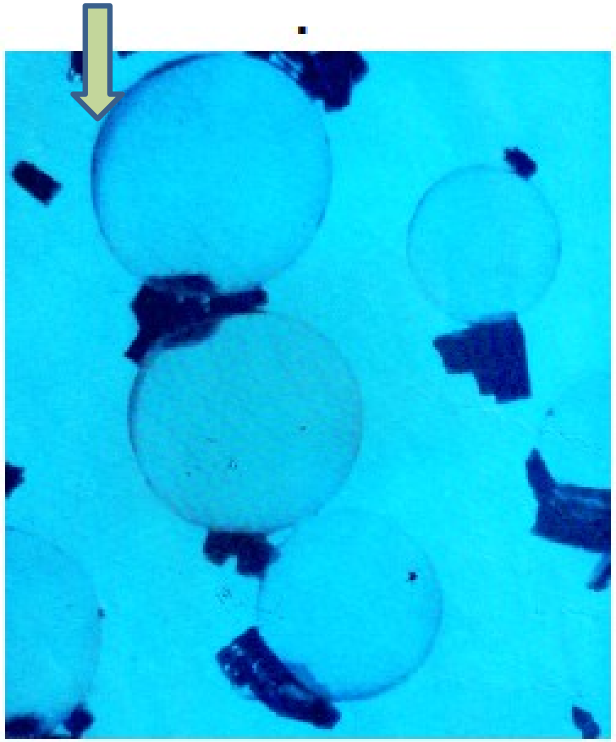
	Collector	Frother
Type	Ionic surfactants, charged head group	Non-ionic surfactants, polar head group
Function	- Adsorbs at solid-liquid interface - Hydrophobizes mineral particles	- Adsorbs at air-liquid interface - Creates metastable froth - Hinders bubble coalescence

Frother vs. Collector

- Both are surfactants
- Purposely designed molecules for different classes of ores/minerals

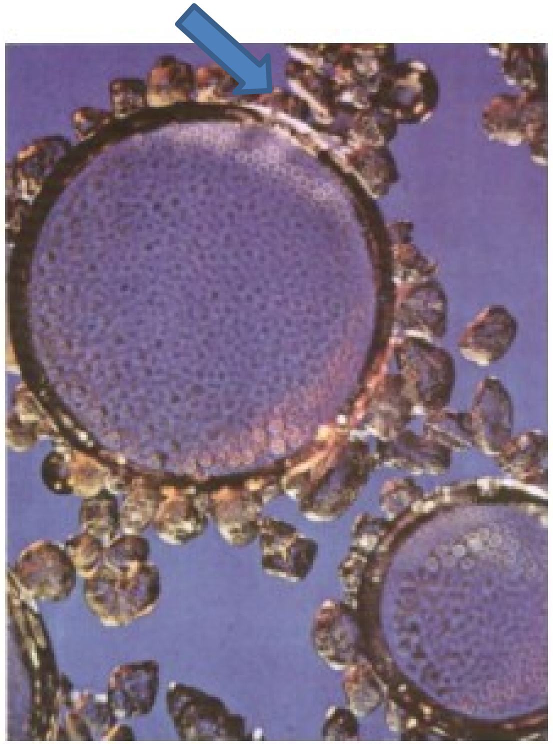


Frother



Quelle: Gaudin, Flotation

Collector



Quelle: FLSmidth

Structure

- Review lecture 11
- Mineral flotation
- Surfactants in Flotation
- Particle attachment
- Froth zone
- Cell design
- Related applications

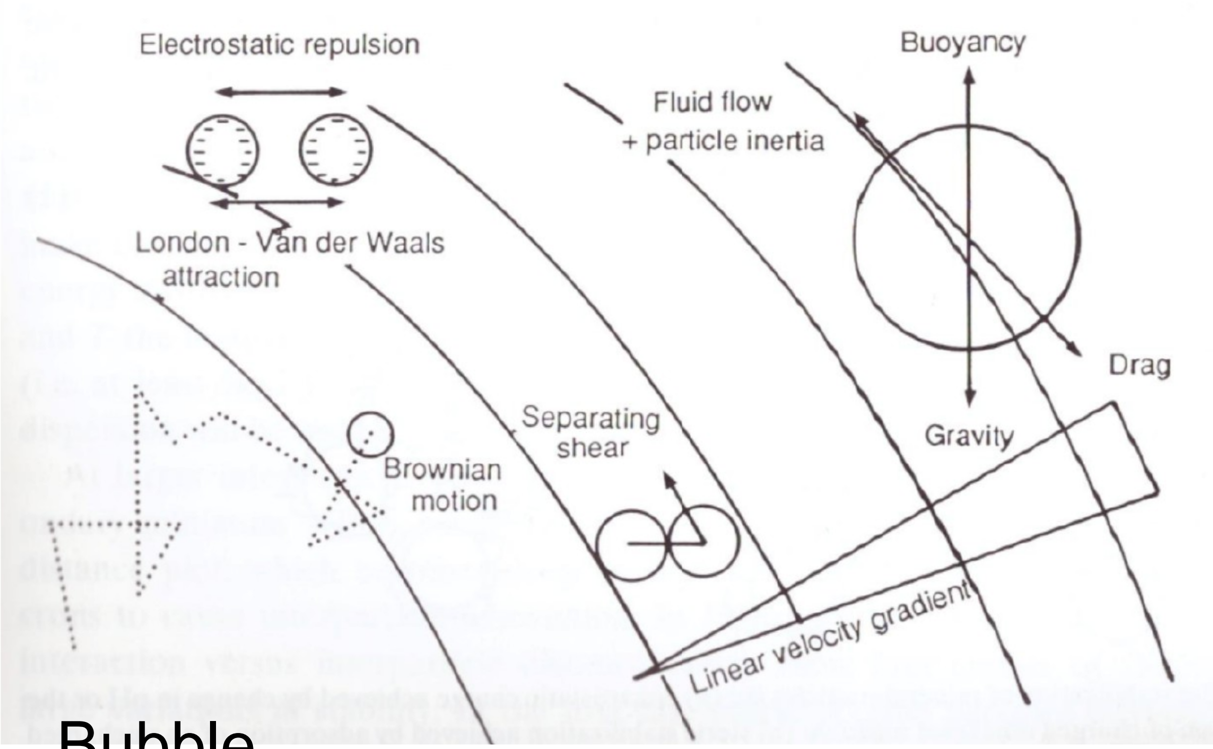
Particle-bubble collision

- I) Collision controlled by:
  - Long-range hydrodynamic forces:

    → inertia, drag, buoyancy, gravity, shear
  - Short-range hydrodynamic forces

    → modified stokes drag [Nguyen & Evans, JMF, 2002]
- II) Attachment controlled by
  - Short-range surface forces

    van-der-Waals, electrostatic, hydrophobic interaction
  - Brownian motion

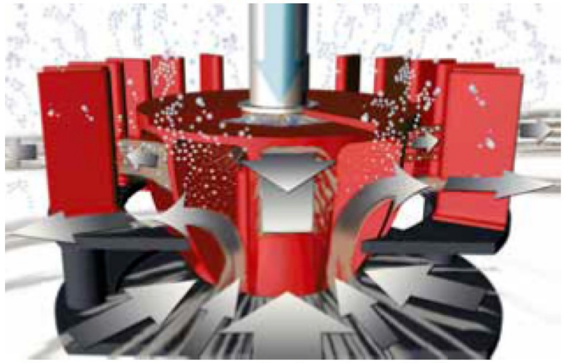


Bubble

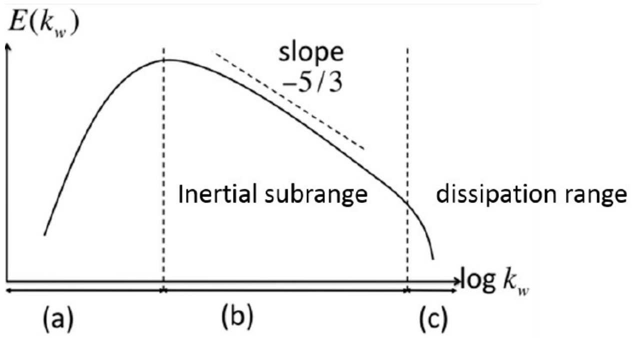
Long range hydrodynamics

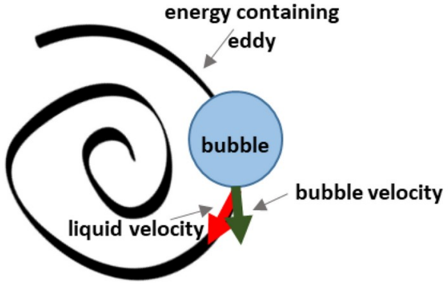
- Controlled by relative velocity between particle and bubble
- Depends on local turbulence
  - Turbulent kinetic energy, spectrum, dissipation

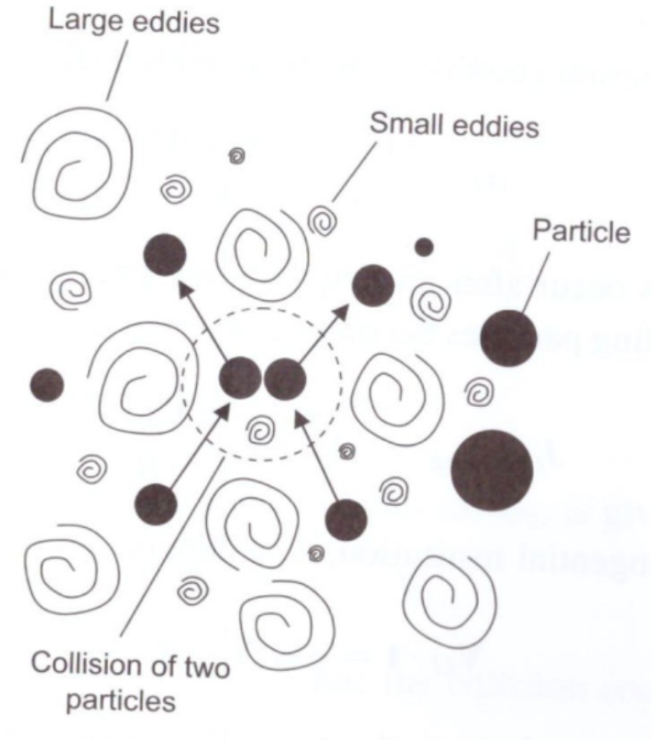
- Classification into two eddy sizes:
- I) Eddy > bubble
  - → influences bubble movement
- II) Eddy < bubble
  - → influences movement of particles near bubbl



Rotor stator unit in detail (Outotec Flotation technologies)







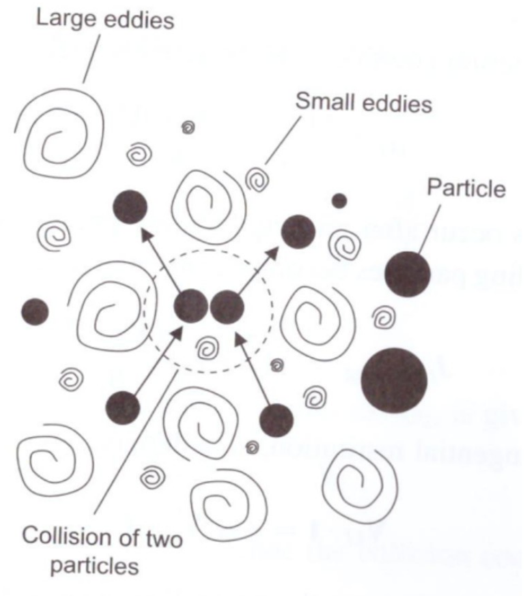
Yeoh et al.

Particle transport

- Stokes-number: $St = \frac{\tau_p}{\tau_f}$ $\qquad \tau_{f,laminar} = \frac{d_b}{u_b}$ $\qquad \tau_{f,turbulent} = \frac{1}{f_{turbulence}}$

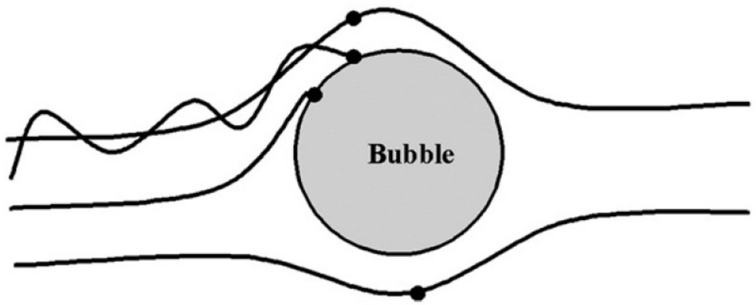
- Particle acceleration:

$$F = m\frac{du_p}{dt}, \frac{\rho_f}{2} {u_{rel}}^2 C_D \frac{\pi}{4} d_p^2 = \frac{4\pi d_p^3}{24}\rho_p \frac{du_{rel}}{dt} \rightarrow u_{rel} = Ue^{-t/\tau_p} \qquad \tau_p = \frac{4\rho_p d_p^2}{3\mu_f C_D Re_p}$$



Yeoh et al.

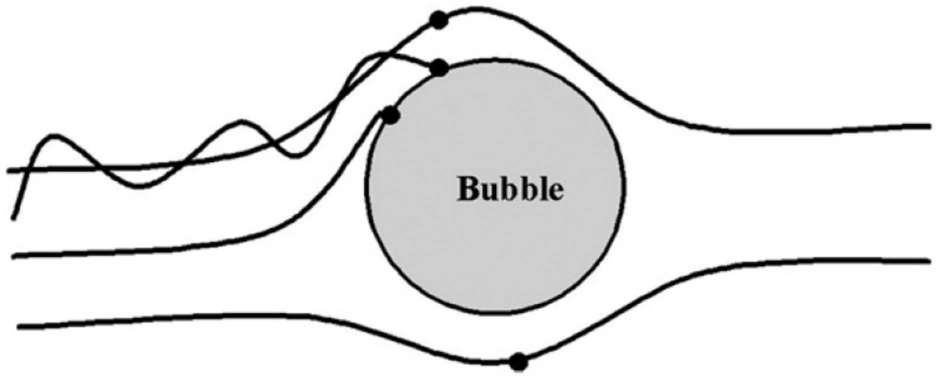
- Stokes-number << 1 (small particles)
- → Particle follow the fluid streamlines – low collision probability

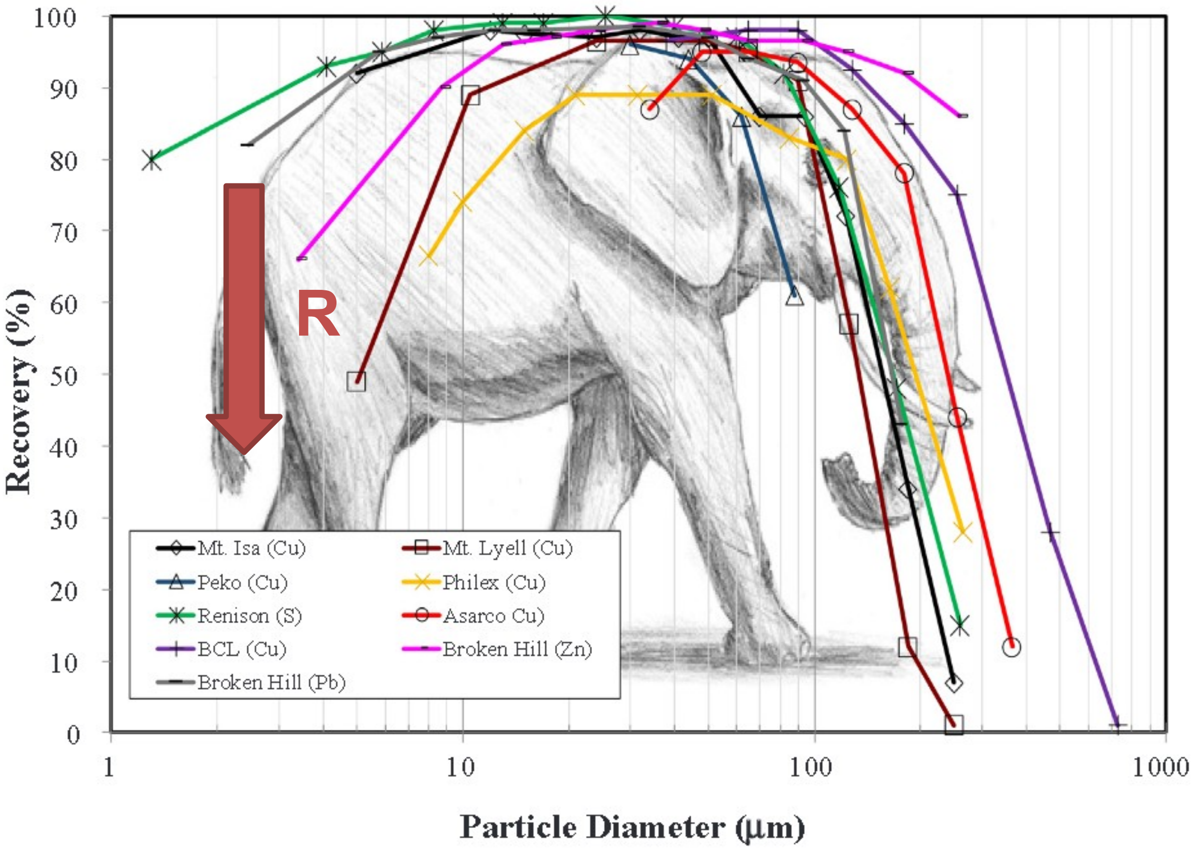


- Stokes-number >> 1 (large particles)
- → Particles deviate from streamlines – high collision probability

Fine particle flotation

- Fine particles: d < 20 μm
- nearly inertialess
- low Stokes number
- following of fluid streamlines
- low collision probability

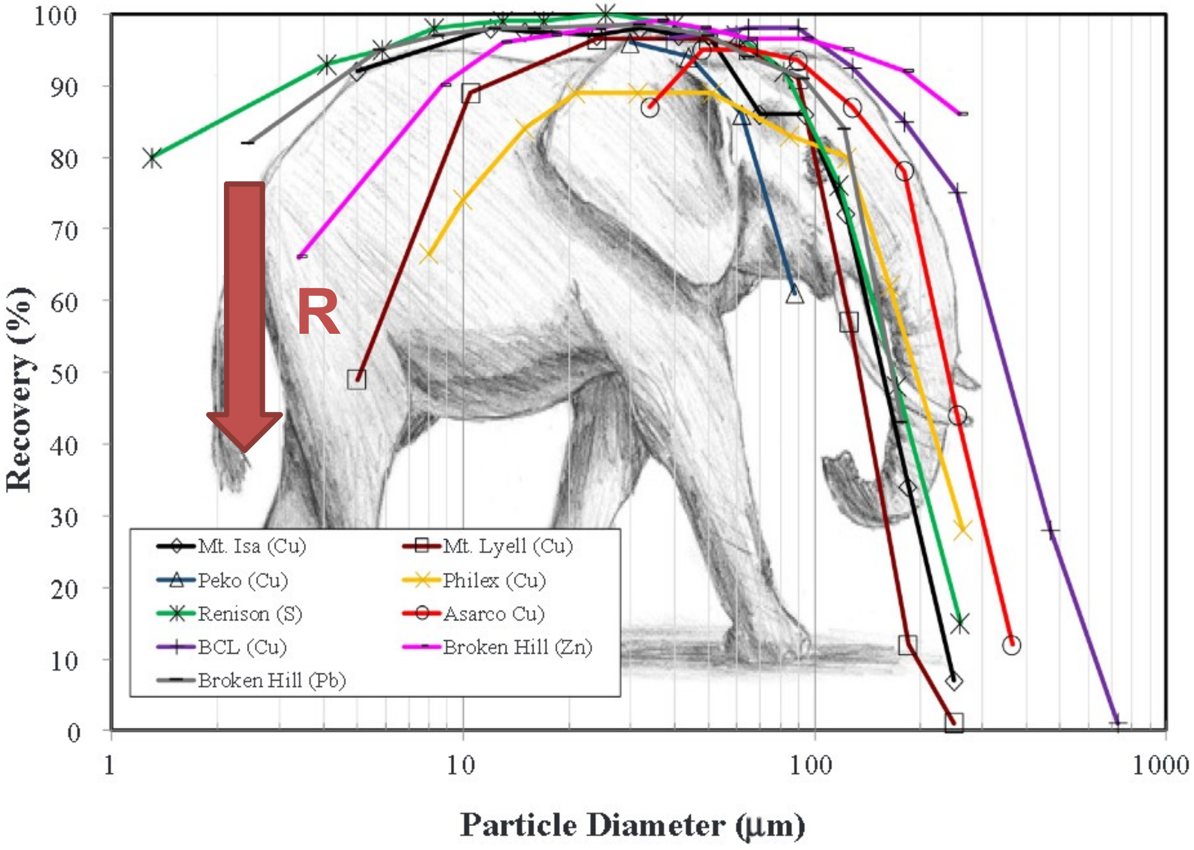




$$St = \frac{\tau_p}{\tau_f} \qquad \tau_p = \frac{4\rho_p d_p^2}{3\mu_f C_D Re_p}$$

Fine particle flotation

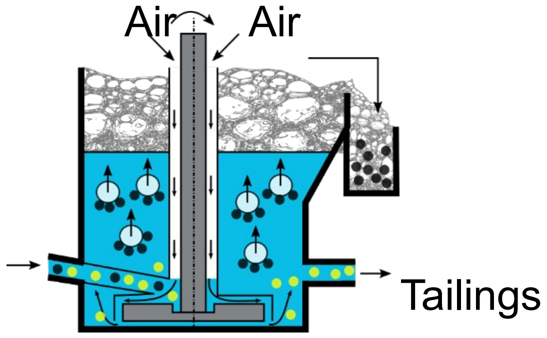
- High demand of minerals → more fine grinding
- → requirement of sorting fine particles!



Quantifying flotation efficiency (= recovery of valuables)

- Flotation is a rate processes: $$\frac{dN_p}{dt} = -kN_p = -Z_{pb}E_{coll}$$

  N_p: numbers of particles k – rate constant



- Aim: understanding recovery from first principles:
- Collection efficiency E_{coll}:

$$E_{coll} = P_c \times P_a \times (1 - P_d)$$

Encounter frequency Z_{pb}:

$$Z_{pb} = 5N_pN_b(d_p + d_b)^2 \cdot \sqrt{(\bar{u}_p)^2 + (\bar{u}_b)^2}$$

[Abrahamson, 1975, Chem. Eng. Sci.]

- Collision probability P_c: e.g.

$$P_c = \frac{3}{2}\left(\frac{d_p}{d_b}\right)^2\left[1 + \frac{3}{16}\left(\frac{Re}{1 + 0.249Re^{0.56}}\right)\right]$$

[Yoon, Luttrell, Min. Process Extr. Metall. Rev. (1989)]

rms-value of particle velocity fluctuations:

$$\bar{u}_p = 0.4\frac{\epsilon^{4/9}d_b^{7/9}}{\nu^{1/3}}\left(\frac{\rho_p - \rho_l}{\rho_l}\right)^{2/3}$$

[Liepe, Möckel, 1977]

Design goals for flotation cells

- High turbulence:
- → High turbulent Fluctuations (u_p'), (u_b')

$$Z_{pb} = 5\, N_p N_b (d_p + d_b)^2 \sqrt{(u_p')^2 + (u_b')^2}$$

- → High dissipation of turbulent kinetic energy

$$u_p' = 0.4 \frac{\epsilon^{4/9} d_b^{7/9}}{\nu^{1/3}} \left(\frac{\rho_p - \rho_l}{\rho_l} \right)^{2/3}$$

- → Small bubbles

$$P_c = \frac{3}{2} \left(\frac{d_p}{d_b} \right)^2 \left[1 + \frac{3}{16} \left(\frac{Re}{1 + 0.249 Re^{0.56}} \right) \right]$$

$$We_{crit} \approx 1 < We = \frac{\rho u_c^2}{2\gamma / r_b}$$ ⇒ Bubble break-up

$$u_c \sim \frac{\partial u}{\partial r} r_b$$

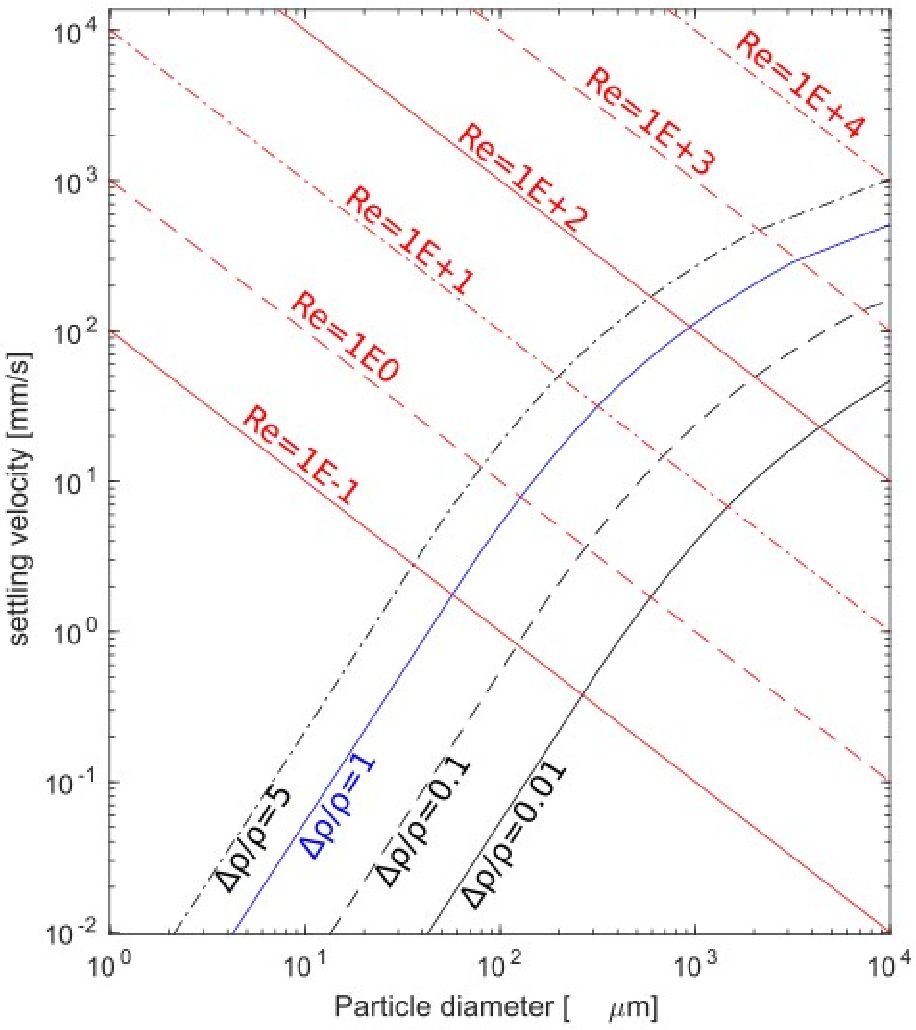
- BUT: Energy consumption! Desorption!

$$E_{coll} = P_c \times P_a \times (1 - P_d)$$

Exercise: Settling and rising velocity

- Bubble with 1 mm diameter, round particles, ρ_p=3000kg/m³
- → Rising/settling velocity?
- → Dwelling time (h=1m)

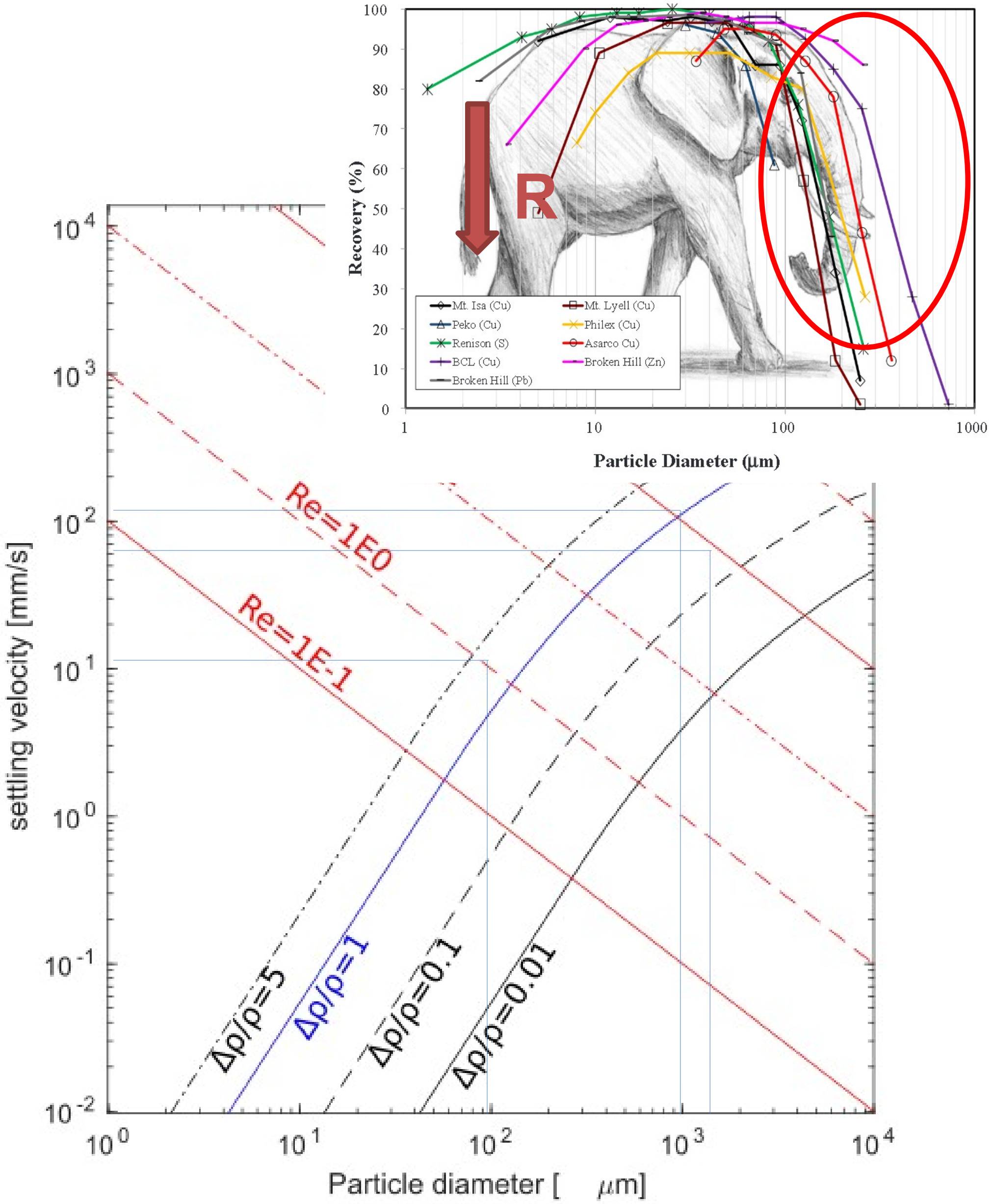
- A) single bubble
- B) Bubble with 5 particle of 0.1 mm diameter
- C) Bubble with 3 particle of 0.5 mm diameter
- D) Particle with 0.1 mm diameter (no bubble)



Exercise: Settling and rising velocity

- Bubble with 1 mm diameter, round particles, ρ_p=3000kg/m³
- → Rising/settling velocity?
- → Dwelling time (h=1m)

- A) single bubble → 100 mm/s □ T=10s
- B) Bubble with 5 particle of 0.1 mm diameter
- → $\Delta\rho/\rho = 0.985$ → 100 mm/s→ T=10s
- C) Bubble with 3 particle of 0.5 mm diameter
- → $\Delta\rho/\rho = 0.182$ → 60 mm/s → T=17s
- D) Particle with 0.1 mm diameter (no bubble)
- → $\Delta\rho/\rho = 2$ → 10 mm/s → T=100s

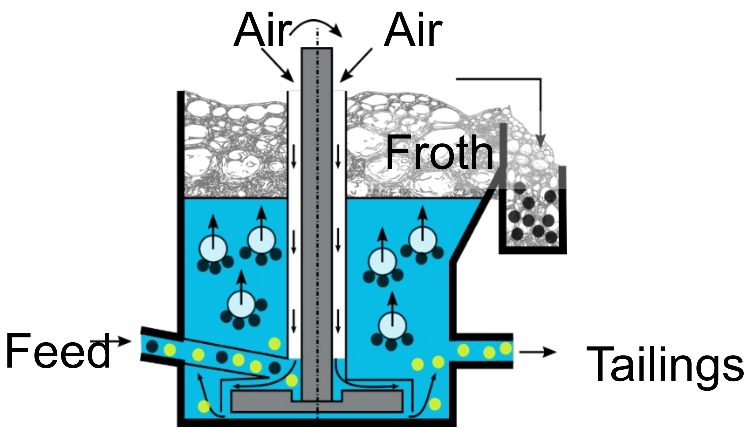


Structure

- Review lecture 11
- Mineral flotation
- Surfactants in Flotation
- Particle attachment
- Froth zone
- Cell design
- Related applications

Froth zone in flotation

- Meta-stable foam, typically large bubbles
- High solid/liquid ratio
- Launders to collect foam efficient



Processes in the froth

- Drainage, liquid fraction gradient
- Coalescence (film rupture) due to
  - hydrophobic particles
  - low frother concentrations
  - non-ionic frothers
- Froth life-times of seconds (gas diffusion negligible)
- Coalescence ⇒ particle clustering, particle drop-back

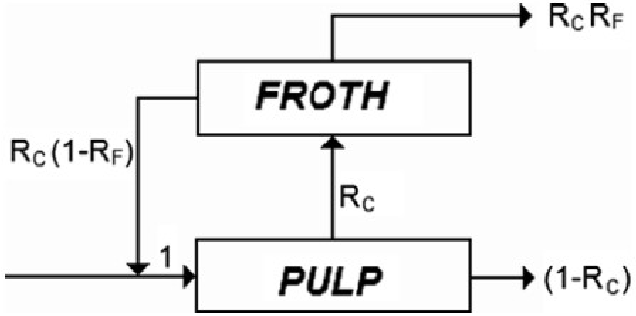
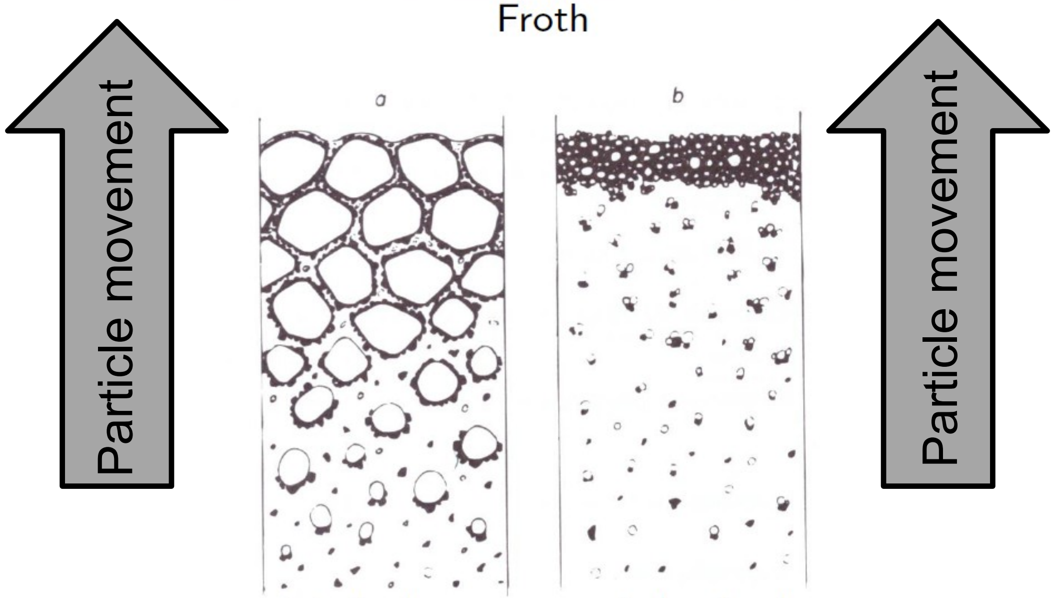


Fig. 2. Pulp and froth recovery model.


Froth

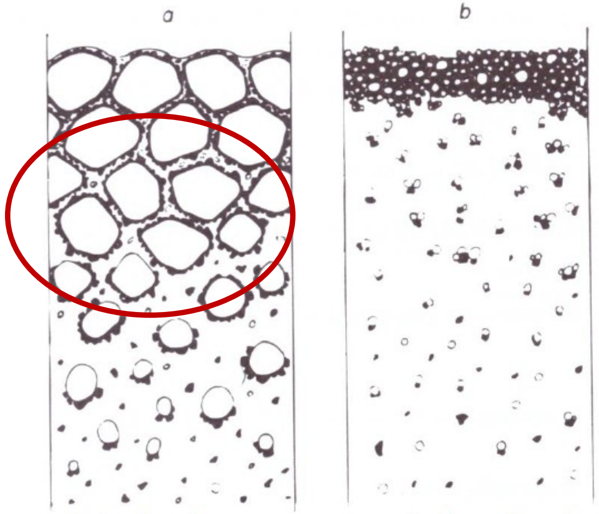


Typical structure of the froth

Wash water addition

- Entrained gangue particles in the froth
- Water addition to the froth, draining down
- Washing out non-attached particles
- Dirty environment – robust solution required

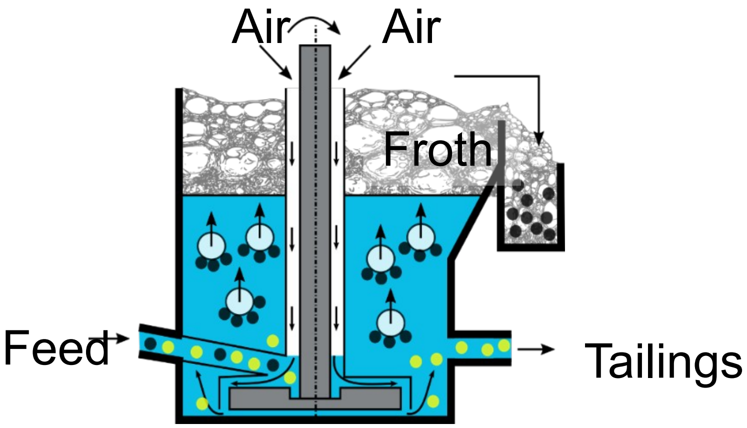
Froth



Typical structure of the froth

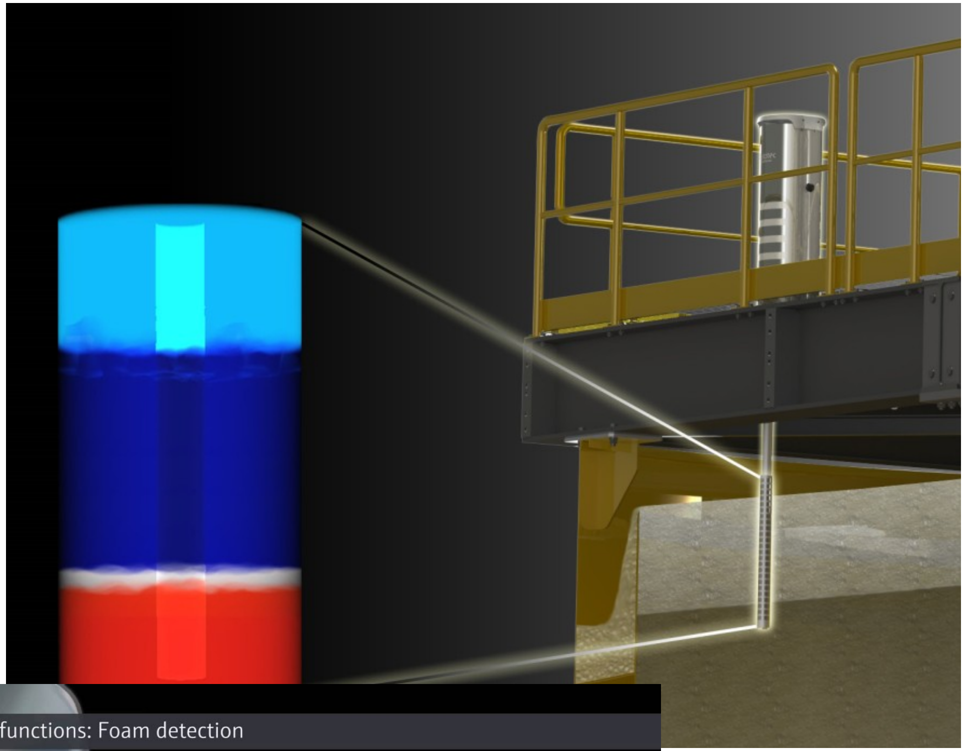
Froth measurement

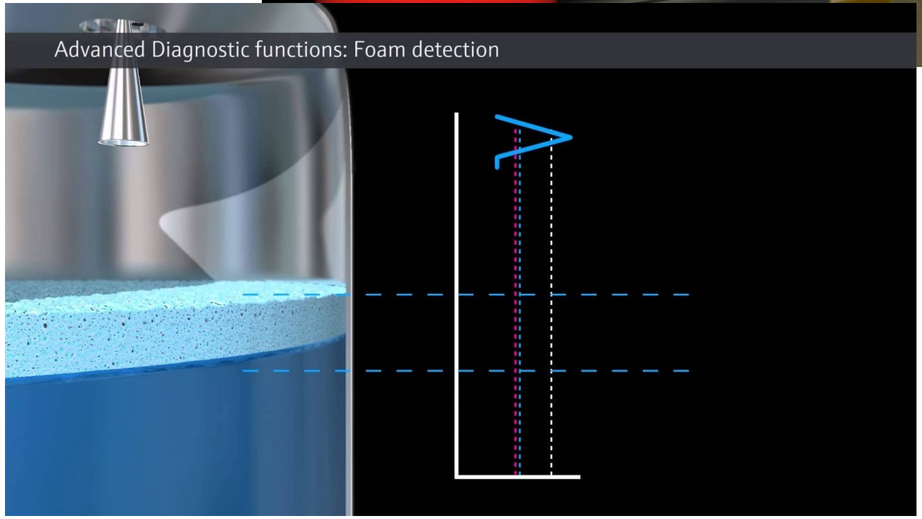
- Crucial to control/optimize flotation process
- Opaque foam, dirty environment
- Nearly no measurement techniques/devices available



Froth measurement

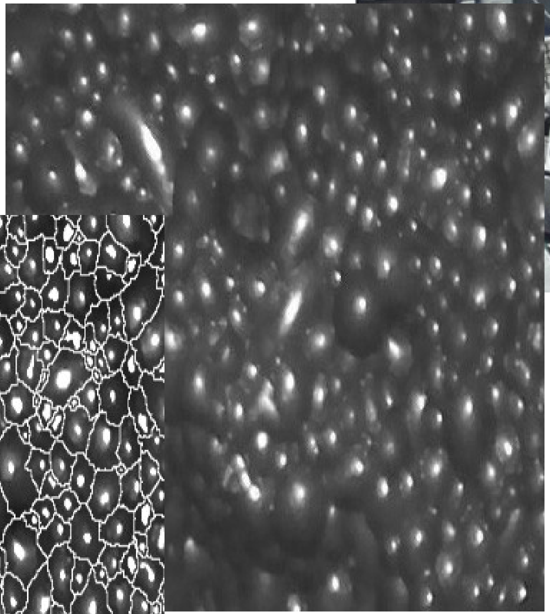
- Level measurement
- → measurement of level of pulp and froth, froth height
- Electric conductivity,
- Ultrasound time-of-flight
- Radar

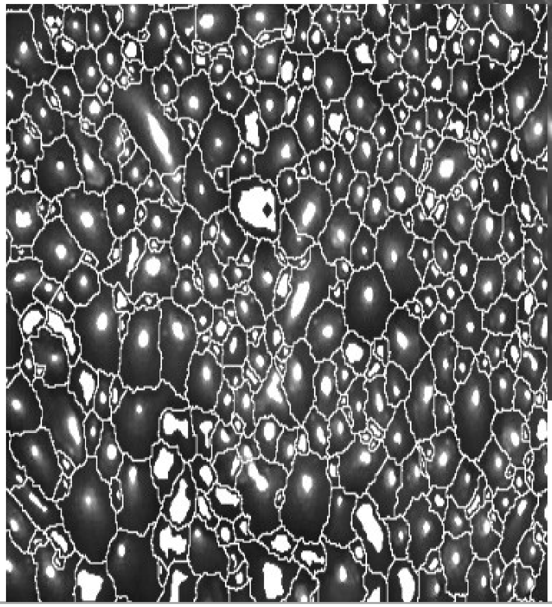




Froth measurement

- Froth imaging
- → measurement of bubble size, froth movement
- → Particle content by color?
- No information about the inside of the froth

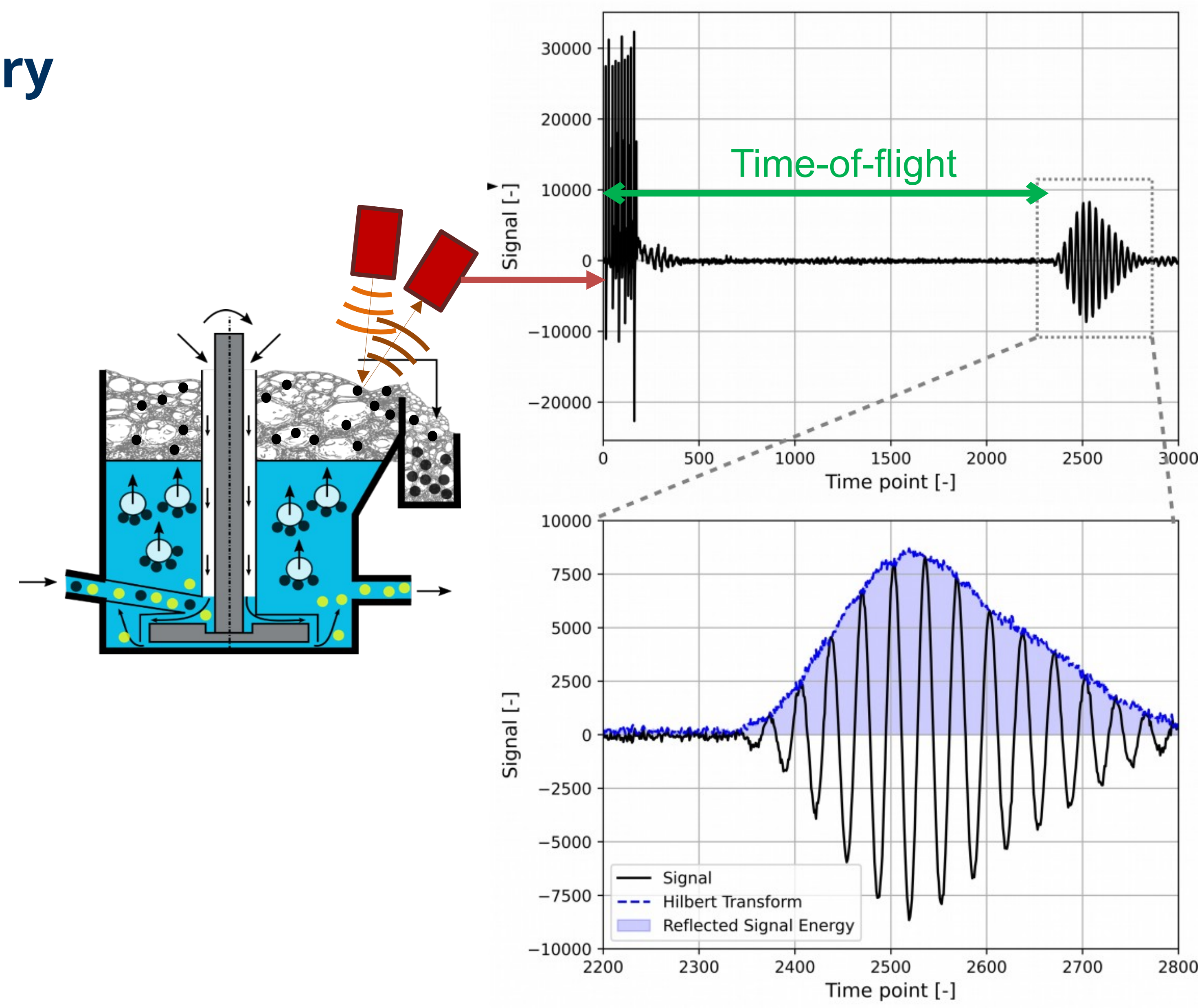




Ultrasound reflectometry

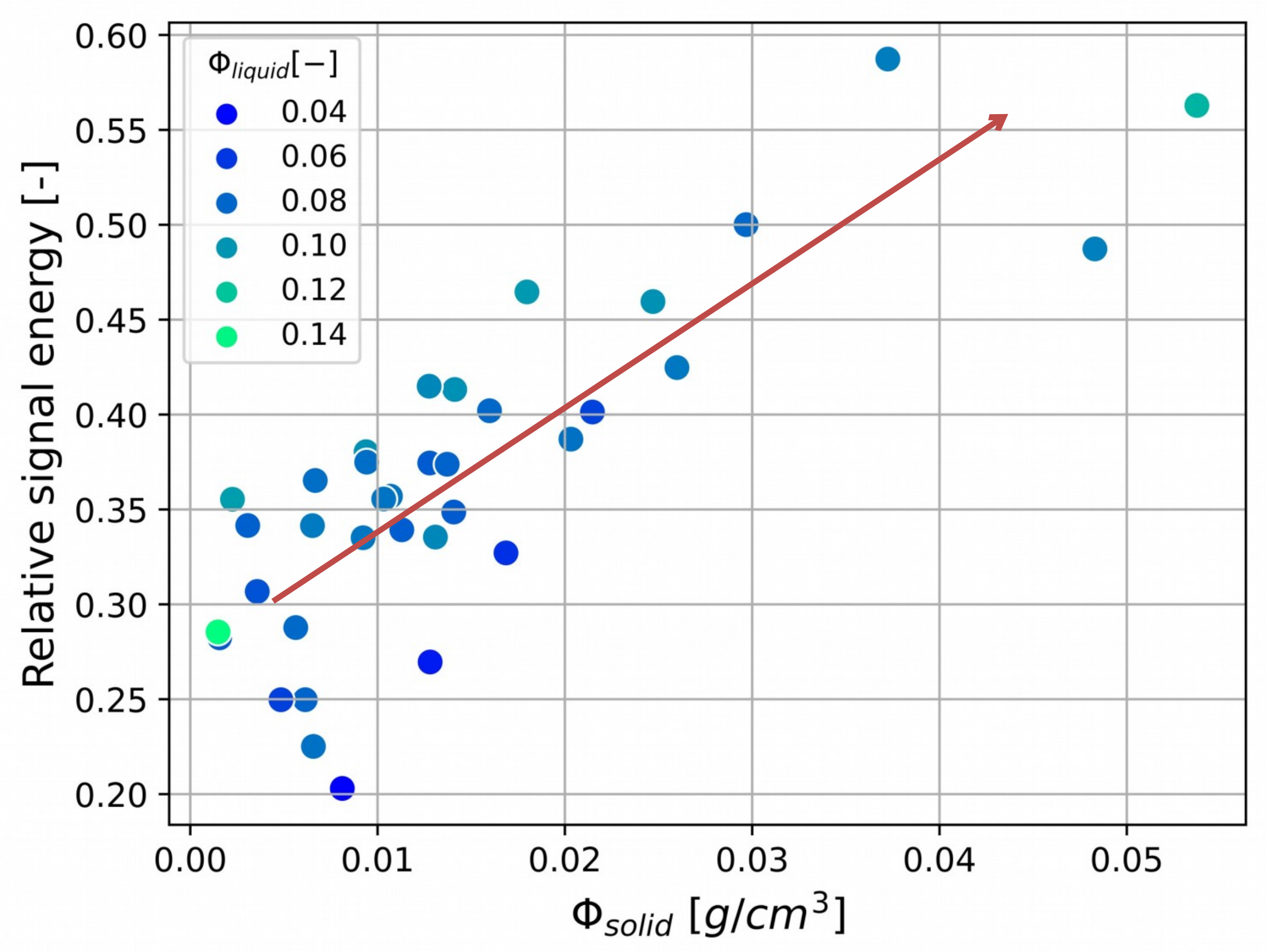
- Ultrasound-Pulse (130 kHz)
- Reflection at the froth surface
- Echo signal recorded

- Echo intensity → Particle fraction
- Time-of-Flight → Froth height



Results

- Echo intensity ~ solid fraction
- Influence of liquid fraction?



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Different cell designs

- Mechanical flotation cell
  - Rotor-Stator configuration
  - Compressed air

- Pneumatic flotation cell
  - No moving parts
  - Compressed air or self-aspirating

Column flotation

Reactor-Separator flotation cells

Jameson cell

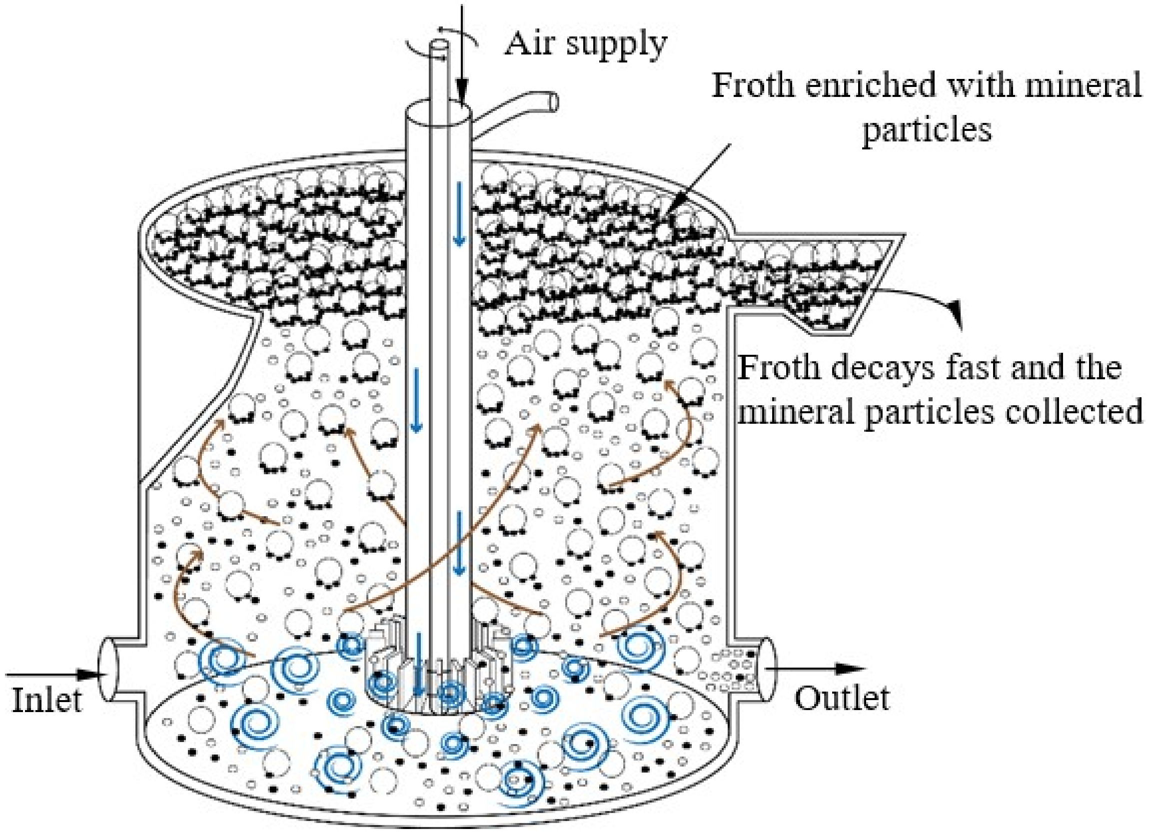
ImhoFlot

Tubular injector cells

→ Paper recycling

Mechanical flotation cell

- “Work horse” of froth flotation



Froth zone

→ Concentrated mineral particles

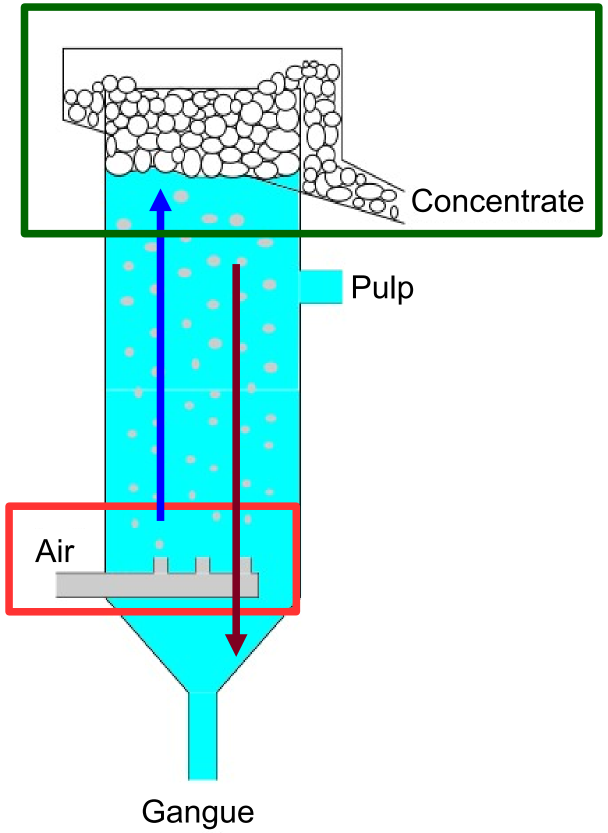
Pulp zone

→ Bubble-particle clusters

Mechanical flotation cell

- Different sizes, up to 800 m^3

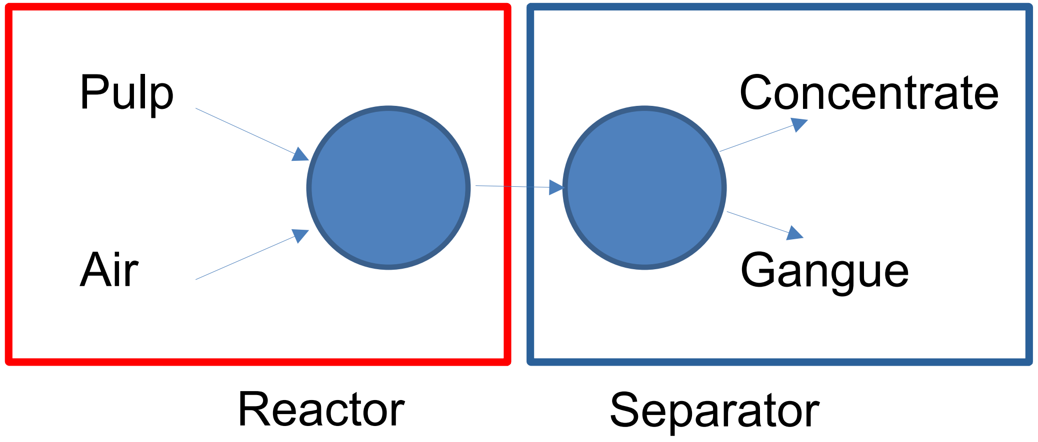
Column flotation

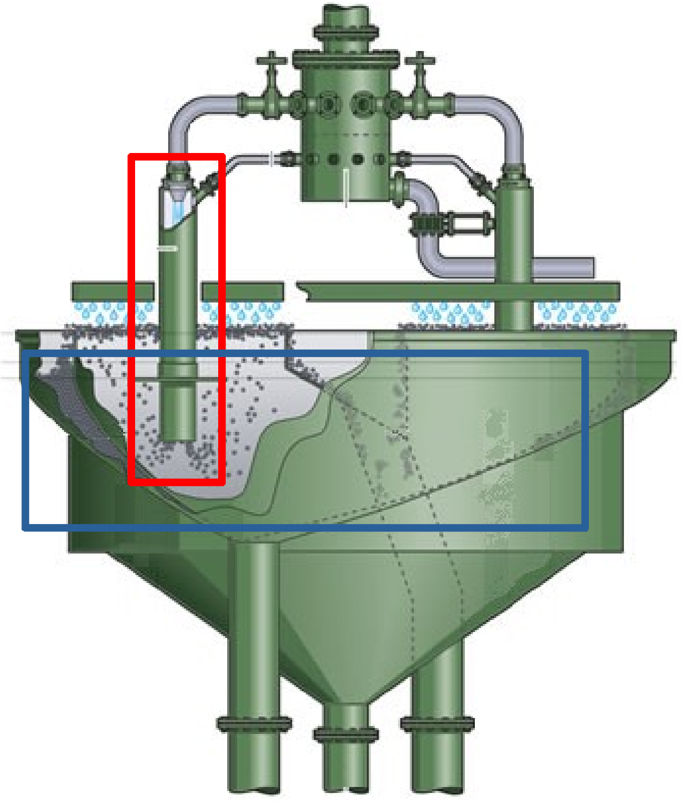


- Low turbulence
  → low recovery rate
- Bubble generator
  → gas flow and bubble size
- Air and pulp in counter-current
  → effective contact
- Deep froth
  → high grade of the extract
  → improved by wash water

Reactor-separator approach

- Approach for fine particle flotation



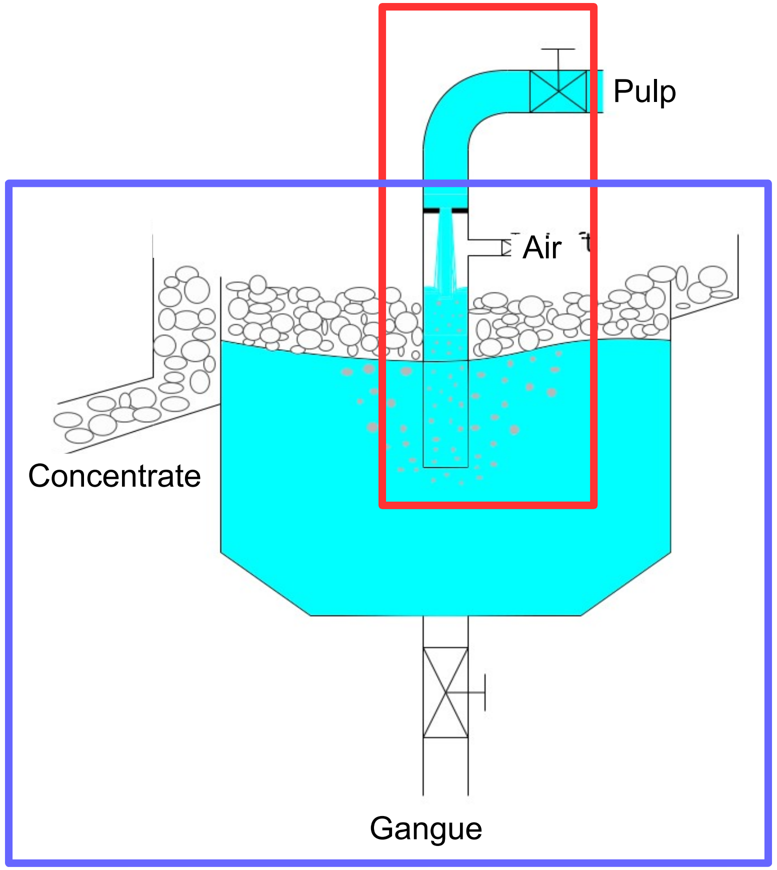


- Decoupled optimization of reactor and separator
- High turbulence, shear in reactor
- Quiescent flow in separator

$$E_{coll} = P_c \times P_a \times (1 - P_d)$$

Quelle: Jameson, G. J,

High-Intensity Flotation Cells: e.g. Jameson Zelle



Downcomer
- Turbulent flow
- Particle-bubble-contact
- (self aspirating)

Tank
- Separation process
- rising of bubble-particle clusters
- Settling of gangue particles
- Typically smaller than mechanical or column flotation cells

Jameson Cell reactor

- Approach for fine particle flotation

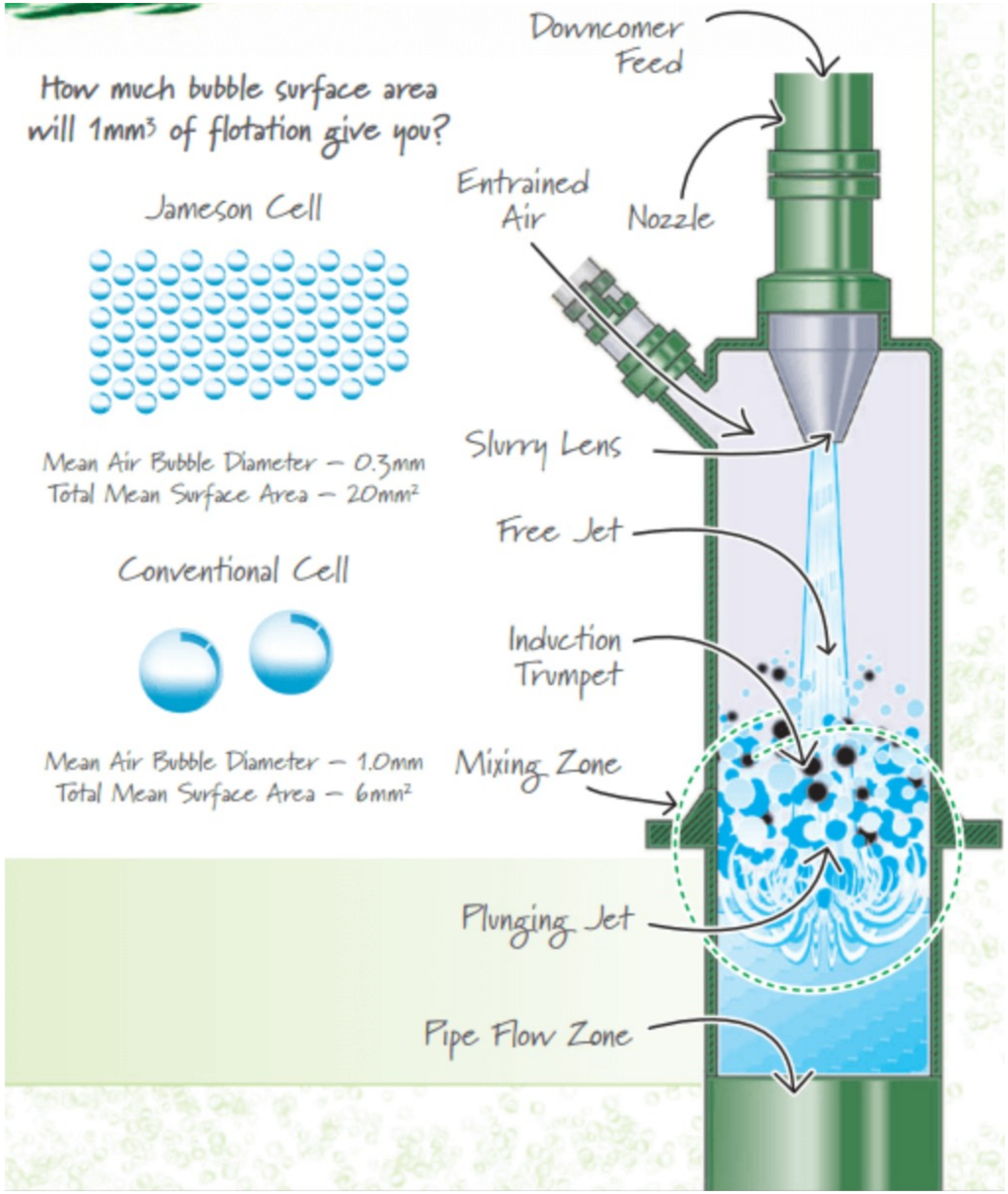
$$\frac{dN_p}{dt} \propto \frac{N_p Q_g \; d_p^2 \; G^{3/2}}{d_b^2}$$

Small particle diameter d_p → reduced recovery rate

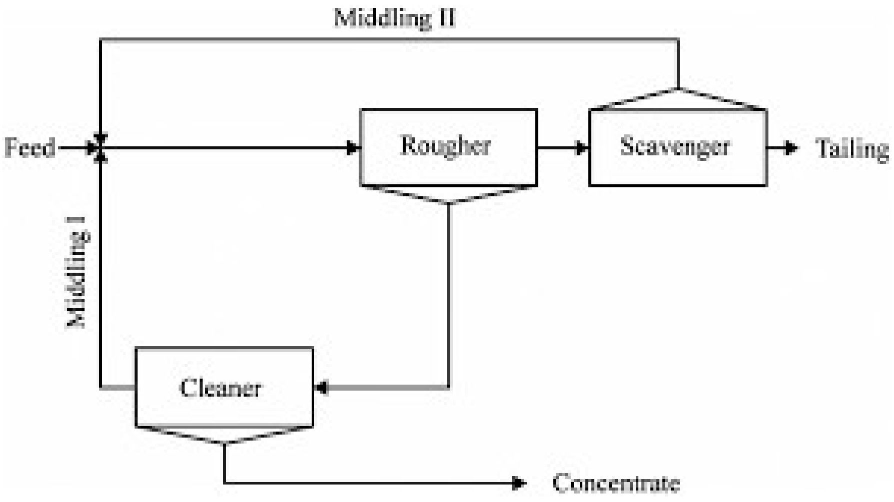
N_p and Q_g defined by the process

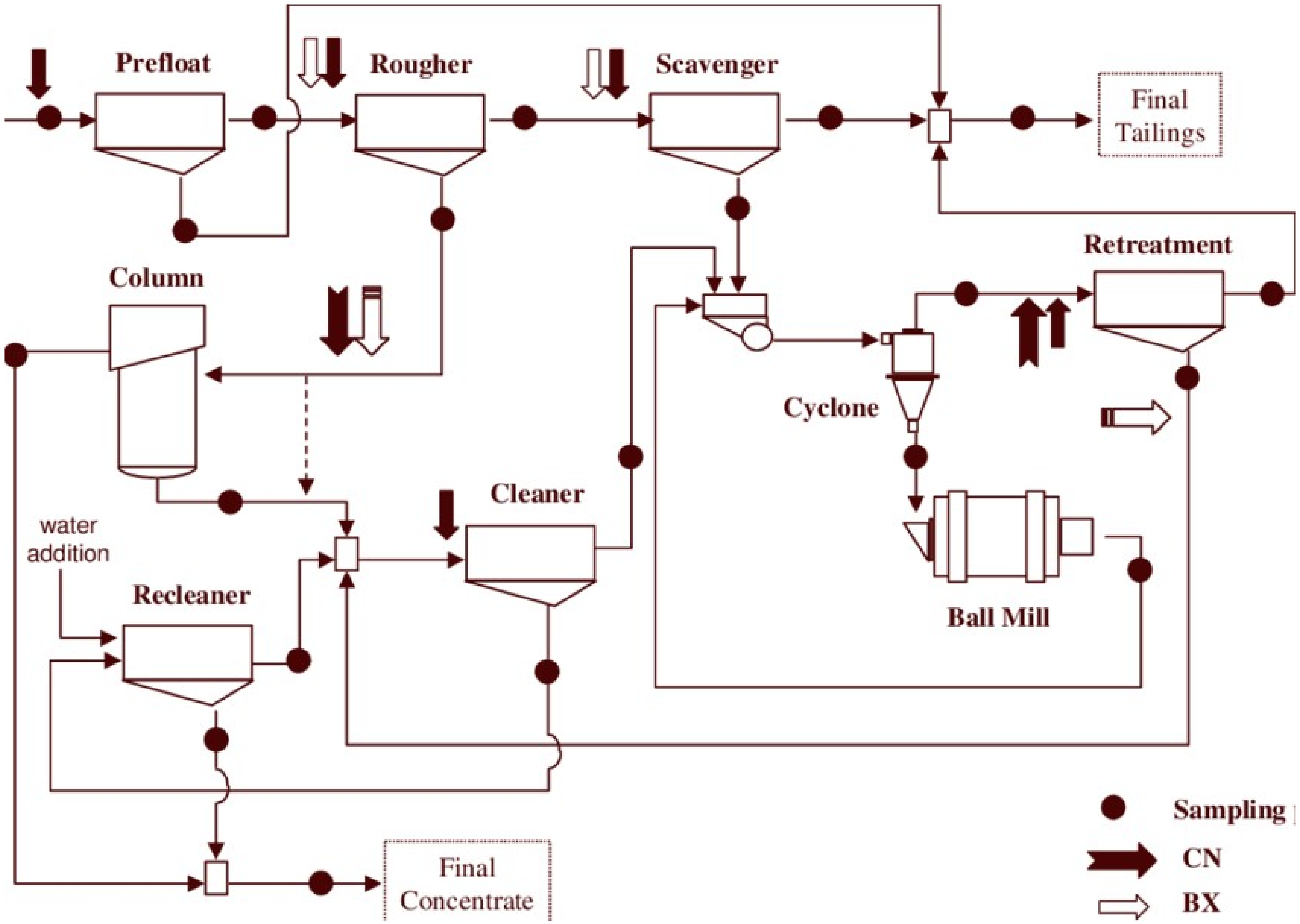
→ Increased shear rate G!

→ Reduced bubble diameter d_b!

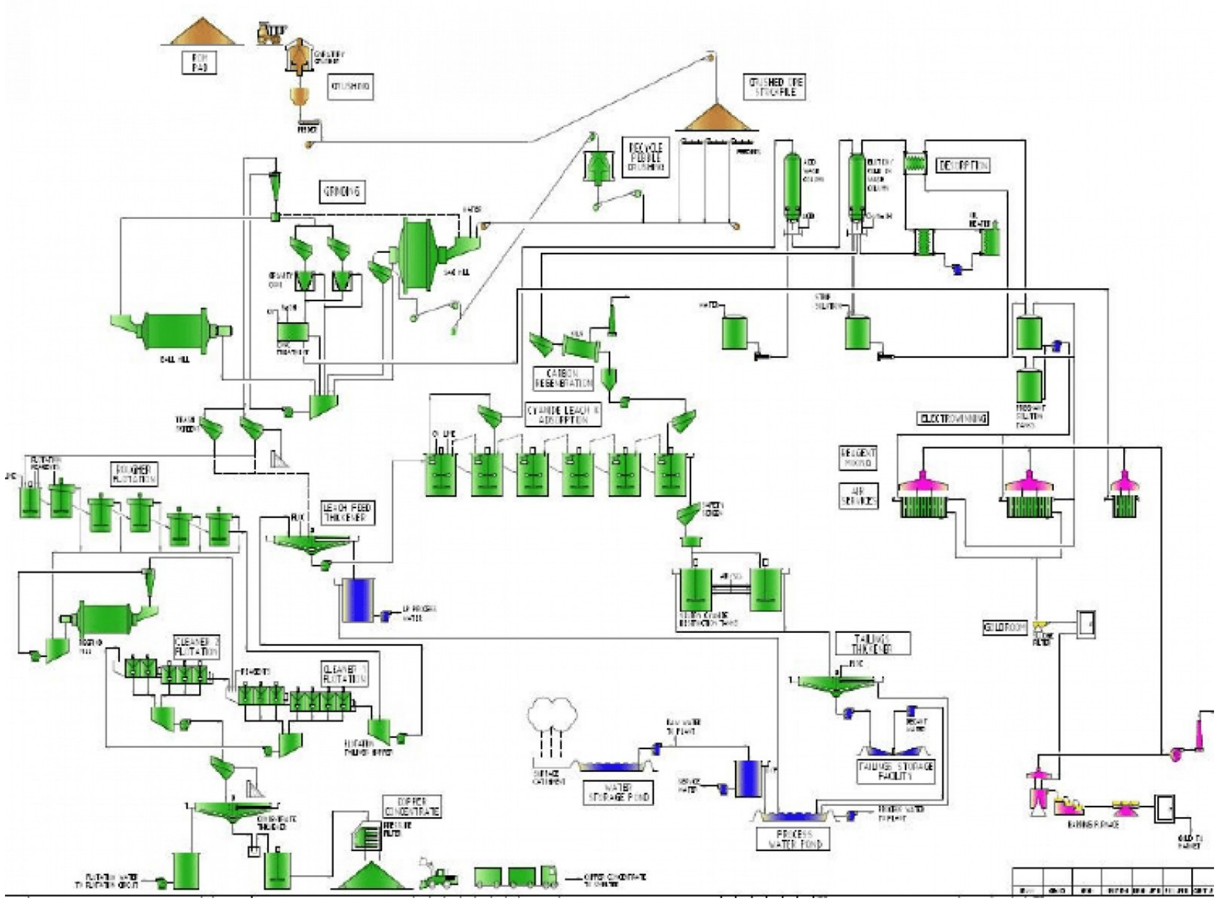


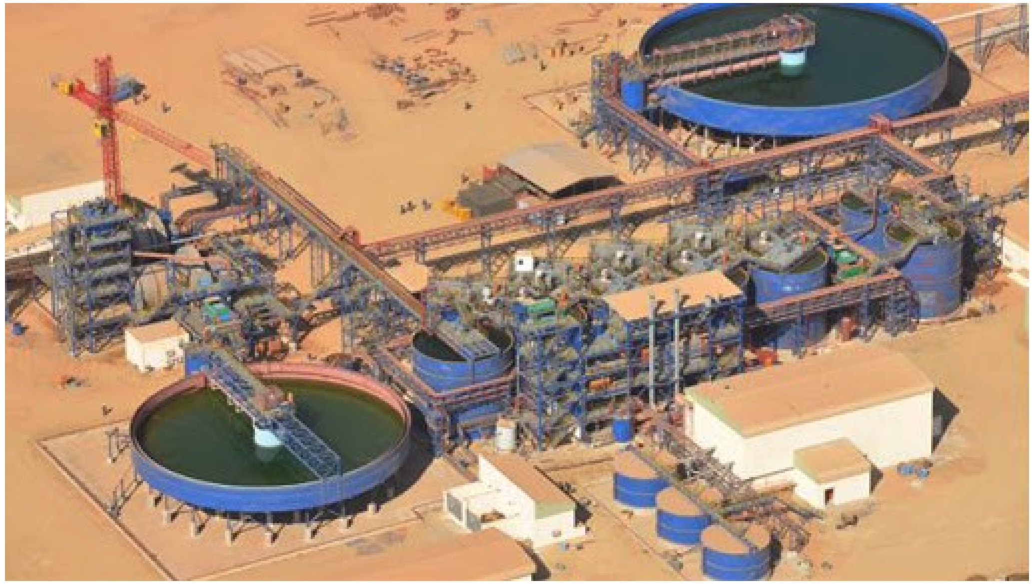
Flotation plant design





Flotation plant design



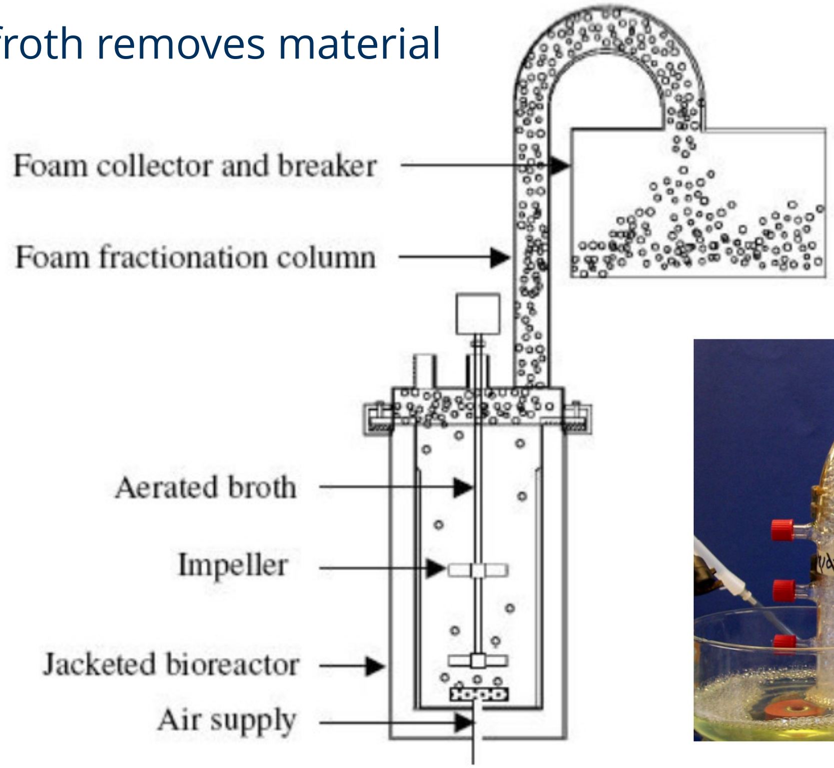


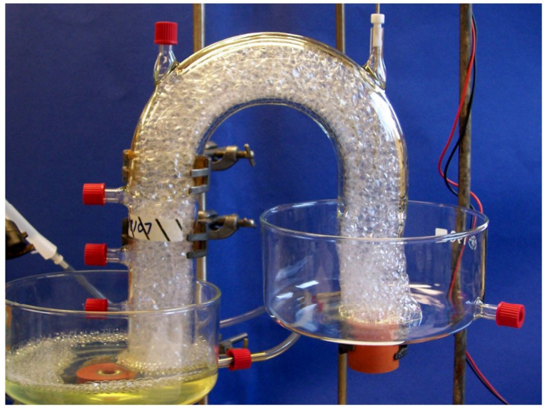
Structure

- Review lecture 11
- Mineral flotation
- Surfactants in Flotation
- Particle attachment
- Froth zone
- Cell design
- Related applications

Foam fractionation / Adsorptive bubble separation

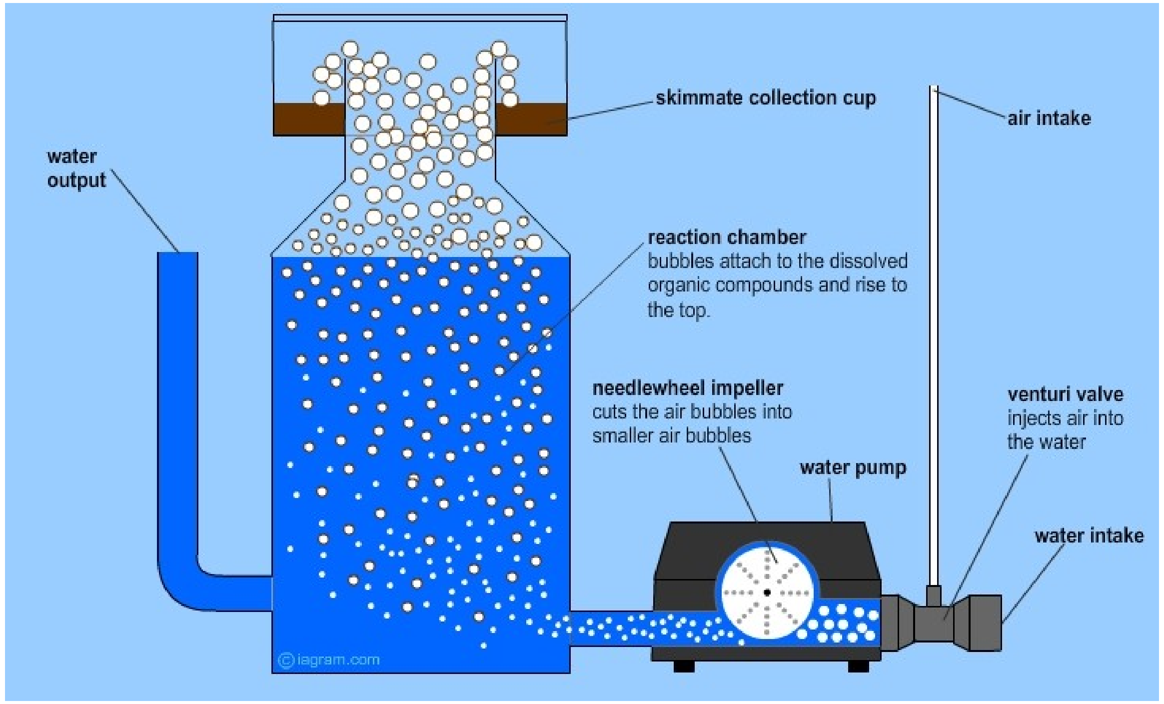
- Removal/recovery of hydrophobic material from solution
- Rising bubbles pick up material
- Froth generation at the surface
- Overflowing froth removes material





Protein skimmer

- Removal/recovery of hydrophobic bio-substances (proteins, bacteria, biosurfactants)
- Application in biochemical industry researched, but not yet full potential
- Application in fish tanks



De-inking process

- Removal of old ink to produce recycled paper
- Sodium hydroxide (NaOH)

  → swelling of the fibres

  → ink-film breaks

- Surfactant (Fatty acid)

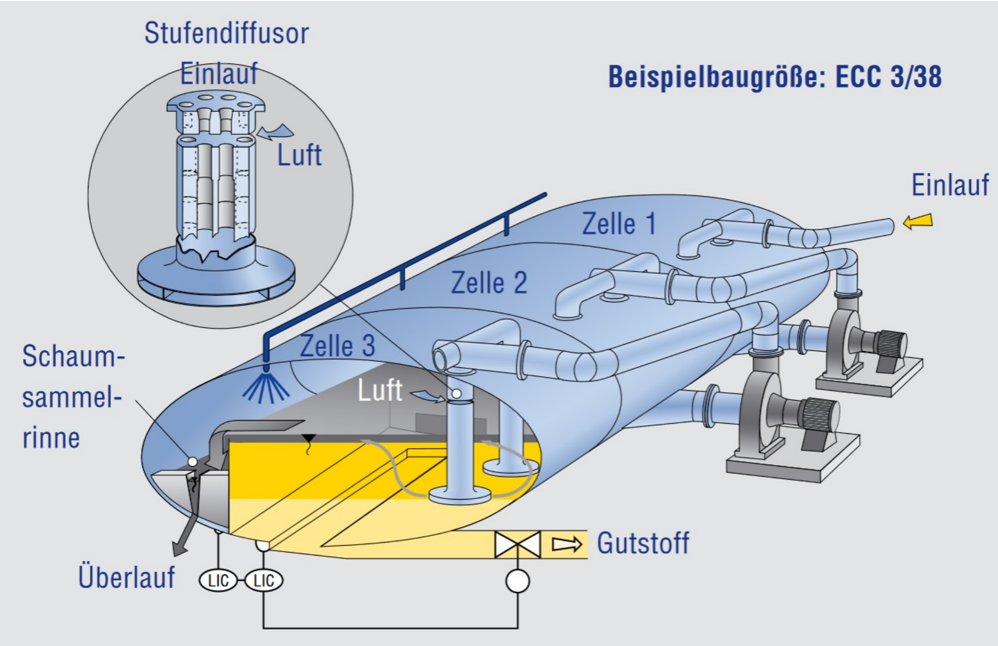
  → hydrophobizes ink droplets

- Sodium silicate

  → coagulation

- Hydrogen peroxide

  → bleaching



Dissolved air flotation (waste water treatment)

- Water, saturated with air at several bar
- Saturated air enters flotation cell,
- Microbubbles form on the surface of hydrophobic particles