

## Module 4: "Surface Thermodynamics"

### Lecture 24: "Froth Flotation"

The Lecture Contains:

- ☰ Froth Floatation
- ☰ Hydrophobicity and Contact Angle
- ☰ Stablizing Agent for Foam

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## Froth Flootation

Separation of solids from heterogeneous mixtures can be achieved by techniques utilizing their physical and chemical properties:

Property	Separation Method
Specific gravity	Gravity concentration
Shape or size	Screening
Surface properties	Froth floatation
Magnetic susceptibility	Magnetic Separation

Here we will utilize the surface properties in separation by froth flotation. Froth flotation is usually used for separation of minerals mined from the earth's crust. These minerals are mixture of mostly crystalline and occasionally non crystalline.

Flotation uses two surface properties surface energy and potential. The difference in interfacial tension allows partial wetting and non-wetting of some minerals by one fluid, usually water. This relative differentiation allows non-wetted solids to separate out in froth if the non-wetter solid is contacted with air bubbles.

Separation process utilizing surface properties of solids allows relative ease for controlling surface parameters when compared to other solid/solid separation processes. This makes froth flotation more versatile process than other industrial processes. Chemical additives are used to vary interfacial tension easily as compared to physical parameters like specific gravity or magnetic susceptibility.

Metallic ores of Cu, Zn, Co, etc., which exists as sulfides, oxides or carbonates are concentrated using flotation processes. About  $\sim 2 \times 10^9$  tons of ores are concentrated annually using flotation processes.

Froth flotation is used in many other industries as a part of separation chain. The following examples could be listed as:

1. Deinking of recycled paper.
2. Recovery of metallic silver from photographic residues (Kodak Company).
3. Recovery of heavy crude oil from tar sand in river deposits.

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Froth flotation is a method to separate or enrich an ore from which metal has to be extracted. It is an extremely important unit operation in mineral processing industry for removal of undesired foreign materials. The basis for flotation is difference in wettability of different minerals. Ore consists of both hydrophilic and hydrophobic particles. Air is bubbled through the slurry of ore and water from the bottom. Hydrophobic particles get adsorbed on the air bubbles and move upward because of buoyancy leaving dirt and other impurities (hydrophilic) in the slurry. Foam enriched with the hydrophobic particles gets accumulated on the top of the slurry which is then skimmed off and dried to get the required mineral.

Geometry of such a system is shown in the figure. As the size of the bubble is assumed to be large as compared to the metal particle (assumed hydrophobic), it can be assumed that the particle is adsorbed on flat surface of air. Gravity effects too can be neglected as the particle size is small.

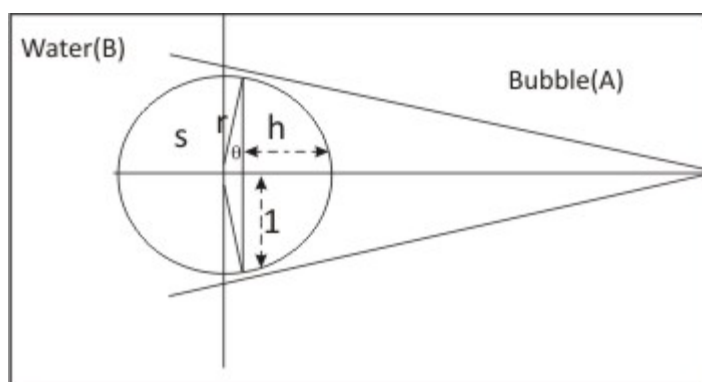


Fig: 6.13: Preferential Adsorption of Particle in Bubble or Water

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$\pi l^2$  = area destroyed by penetration or adsorption of particle

$$A_{SA} = 2\pi r h$$

$$A_{SB} = 4\pi r^2 - 2\pi r h$$

Area occupied by particle on bubble (interfacial area)

$$= \pi l^2 = A_l$$

but

$$l^2 = r^2 - (r - h)^2$$

$$A_l = \pi(2rh - h^2)$$

$$\Delta G = \gamma_{SA} 2\pi r h + \gamma_{SB} 4\pi r^2 - 2\pi r h - 4\pi r^2 \gamma_{SB} - \pi l^2 \gamma_{AB}$$

$$\Delta G = \gamma_{SA} 2\pi r h + \gamma_{SB} 4\pi r^2 - 2\pi r h - 4\pi r^2 \gamma_{SB} - \pi(2rh - h^2) \gamma_{AB}$$

$$\frac{\partial \Delta G}{\partial h} = 0 \Rightarrow 2\pi r \gamma_{SA} dh - 2\pi r \gamma_{SB} dh - \pi \gamma_{AB} 2r - 2h dh$$

$$\gamma_{SA} - \gamma_{SB} = \gamma_{AB} \left(1 - \frac{r}{h}\right)$$

$$\cos \theta = \left(1 - \frac{r}{h}\right)$$

This equation is similar to Young's equation for the following system.

$$\gamma_{SA} = \gamma_{SB} + \gamma_{AB} \cos \theta \quad (6.11)$$

Thus,  $\theta$  is the equilibrium contact angle for this system as  $\frac{\partial \Delta G}{\partial h} = 0$  gives angle at equilibrium condition.

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## Hydrophobicity and contact angle

Case 1:  $\theta = 0^\circ$

When we have  $\theta = 0^\circ$ ,  $h = 0$ . Liquid wets the particle completely then particle will remain in liquid and there will no penetration. This situation arises when the particle is completely hydrophilic and hence particle remains entirely in liquid phase.

Case 2:  $\theta = \pi/2$

At  $\theta = \pi/2$  we have  $h = r$ . In this case, the particle is half inside the water phase and half inside the bubble.

Case 3:  $\theta = \pi$

For  $\theta = \pi$  we have  $h = 2$  i.e. particle penetrates totally inside the bubble. This is possible when particle is completely hydrophobic.

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Hydrophobicity of the particle is the basis of flotation. So for good floatation, particle surface should be as hydrophobic as possible. The problems faced in using flotation technique are:

- 1. The ore contains different metal particles so froth at the top may contain mixture of these particles.
- 2. Mineral may not be hydrophobic which may hinder adsorption.
- 3. Bubble may collapse resulting in loss of mineral particles.

To avoid such problems some additives are added to the slurry which enhance hydrophobic property of the desired mineral particle. These additives are generally divided into 3 categories :

(1) **Collectors**: They adsorb on mineral particle surface and form a thin film of hydrophobic hydrocarbon and make them hydrophobic, so it greatly increase the contact angle so that bubbles will adhere to the surface.

Collectors are classified depending on their ionic charge:

- Nonionic-hydrocarbon oils (they do not dissociate in water) are cheap and effective.

Eg: kerosene, fuel oil etc.

- Anionic-Anionic collectors are weak acids or acid salts that ionize in water.

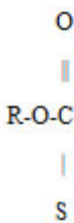
They decompose to give negatively charged end that will attach to the mineral surfaces.

Eg: oxyhydrl(carboxylic, sulfates, sulfonates)

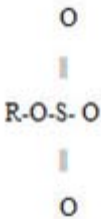


(Carboxylic)

Sulfhydryl (Xanthates,Dithiophosphates)



(Xanthates)



(Sulfonates)

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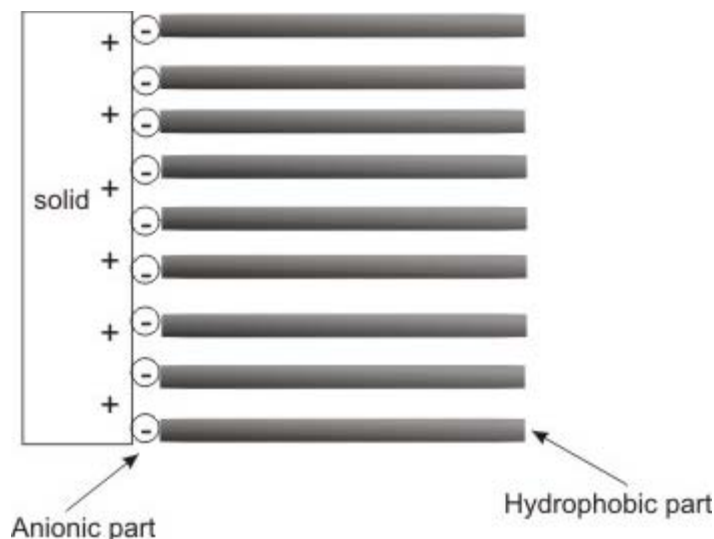


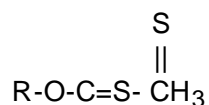
Fig: 6.14: Schematic of a Collector

- **Cationic:** Positively-charged amine group acts as cationic collector. They are mainly used for flotation of silicates and certain rare metal oxides. Eg: primary, secondary and tertiary amines.

(2) **Activators:** These are added to enhance selective adsorption. They also support the adsorption of collectors on the mineral particle surface. For example,

- Copper Sulfate acts as an activator for sphalerite ( $\text{ZnS}$ ) flotation with xanthate collectors. When untreated, xanthate cannot attach to the sphalerite surface because it forms a zinc-xanthate.
- Silica ( $\text{SiO}_2$ ) has a strong-negative surface charge and it has little affinity for anionic collectors such as oleic acid. Calcium ions adsorb on surface of silica reverse the charge of silica, then it is possible for the anionic collectors to electrostatically attach to the calcium-activated silica surface.

(iii) **Depressors:** They are added to suppress the hydrophobicity of undesired particles. Eg.: For silica, lead and copper, Xanthates are generally used.



Where **R** is  $\text{C}_2 - \text{C}_6$

- Zn ores are not floated by Xanthates directly so ore is pretreated with dilute copper sulfate which results in deposition of copper on Zn particle which then can be supported by Xanthates.
- Separation of iron, zinc and lead is done through dilute cyanide treatment, which inhibits adsorption on iron and zinc but not on lead.

- Cyanide ( $\text{CN}^-$ ) is used as depressant in sulfide mineral flotation.
- A large number of organic compounds are used as flotation depressants.  
Eg: “reverse flotation” of silica from iron ore. Starch acts as a depressant for iron oxide in this process, preventing it from being floated by the cationic collector.

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## STABILIZING AGENT FOR FOAM

Surfactants are used to stabilize foam.

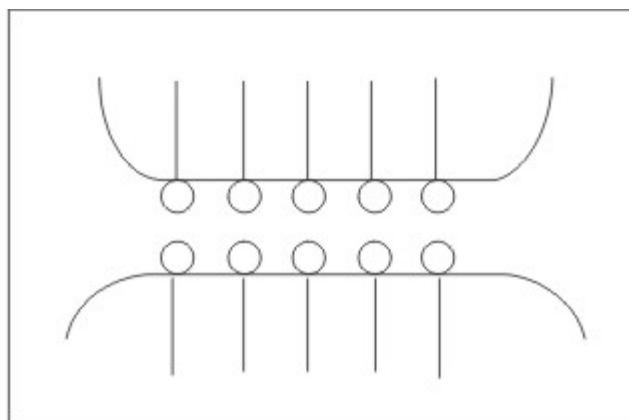


Fig. 6.15: Stabilising Agent

- Drainage of liquids is reduced by surfactants.
- Repulsion between hydrophilic heads also stabilizes the foam by increasing the surface viscosity.

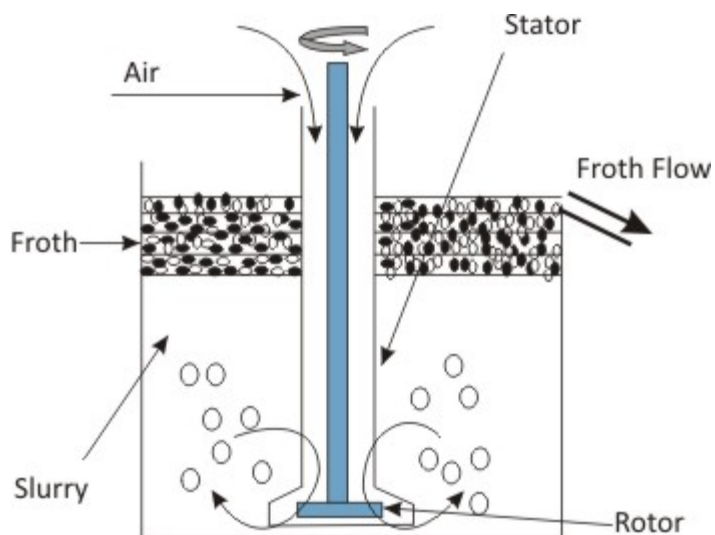


Fig. 6.16: Schematic representation of flotation cell

## References:

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