

# Flotation as an Operation of Macromolecular Mass Transfer

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## ABSTRACT

The present work presents a new theoretical interpretation of the flotation process, which can also be applied to other mineral processing physical unit operations. This interpretation is part of the 'Modelo Operacional' (Operational Model) that was developed as an attempt to establish a new theoretical basis for mineral processing unit operations. In the case of flotation, a book was edited by one of the authors in Brazil (*Mass Concentration by Froth Flotation*, in Portuguese and Spanish).

The model establishes a link between a natural phenomenon (migration of particles from the pulp to the froth) and a real industrial phenomenon (mass concentration by operational interference). In this model, flotation is viewed as a phenomenon of macromolecular mass transport (of particles) between froth and slurry phases. Mechanisms for mass transport and particle flow between phases as a function of the hydrophobic potential in each phase are discussed. By establishing the so-called *equilibrium distribution curve* between phases it is possible to calculate macroscopic balances that are related to metallurgical results, which in turn are a function of the *operational line* that is required by the process itself. The *number of cleaning stages* and their efficiencies can also be determined by simple laboratory-scale experiments.

## MACROMOLECULAR MASS TRANSFER

### New approach

In chemical engineering, mass transfer is described as the modification of solutions or mixtures of different chemical composition by means of methods that do not necessarily include chemical reactions (Treybal, 1970). Generally these operations are related to the separation of a substance from its components. In the case of *mineral particle* mixtures, separations can be entirely mechanical, as in certain unit operations, such as filtering and classification by screening. Separation of particles based upon differences in density, magnetic properties and also separation of mass by froth flotation, among others, promotes changes in chemical composition between products or separated phases. Therefore, as they include changes in flow composition, those operations can be defined as being macromolecular mass transfer operations.

In an analogous way, macromolecular mass transfer can be accomplished by flotation. Collector reagent is adsorbed into the surface of interest particles, creating or increasing their hydrophobicity. Gas addition to the slurry phase and capture of hydrophobic particles characterises macromolecular desorption, removing mass from slurry to the gas phase and keeping the ascending flow to the froth layer. Water addition to the froth surface (froth washing) drags hydrophilic or less hydrophobic particles back to the slurry phase, characterising a macromolecular absorption and creating a double draining mechanism in the froth phase.

### Transport mechanism

On a molecular scale, mass transfer is the result of a concentration gradient that induces the movement of molecules from a region of high concentration to another of low concentration. In flotation, a

particle does not move by itself, but is attached to air bubbles, from slurry to mineralised froth where it is dragged after being lifted to the average portion of froth flux. Desorption continues in the froth phase by macromolecular diffusion in laminar flow (not turbulent), and thereby a continuous concentration gradient from the froth/slurry interface until a froth surface is established. In a steady state the froth/slurry interface is a theoretical representation of contact between phases. When equilibrium is reached, particle transfer finishes and the final interface becomes physically well established, allowing final separation of products or phases.

### Gradient and driving forces

The average speed of particles depends on their hydrophobicity. The most hydrophobic ones have a higher affinity with air bubbles, giving rise to stronger froth that will quickly be transported to the surface of slurry. Free particles of a certain size range will respond better to the process. In the slurry phase, the contact bubble/particle is quickly produced by means of mechanic or pneumatic agitation, while keeping the necessary homogeneity of this phase. The speed of macromolecular transfer is very high, mainly in mechanical cells. The mass flow of the substance of interest ( $N_x = \text{mass/time}$ ) can be defined by means of the following expression:

$$N_x = \text{Transfer Coefficient} \times \text{Contact Area} \times \text{Gradient}$$

The hydrophobic difference between particles is the transport gradient, which can be related to particles' individual grade or liberation (and then best reagent adsorption and more hydrophobicity). The transfer coefficient possesses the same flow units divided by the gradient and the area ( $\text{mass}/[\text{time} \times \text{area} \times \text{gradient}]$ ). Let  $a$  be the average grade of the substance  $x$  in the slurry being fed to the process, and  $r_f$  the average grade of particles in the interface between slurry and froth, as illustrated in Figure 1. Knowing that:  $N_x = K_p \times A \times (a - r_f)$  where  $K_p$  is the transfer coefficient in the slurry phase. The gradient ( $a - r_f$ ) is the driving force (only an analogical supposition) that promotes macromolecular desorption in the slurry phase (particle capture from the pulp to air bubbles). The phenomenon that happens in the slurry phase is called *natural flotation*, or simply *flotation*. In the froth layer, due to their hydrophobicity, particles are spontaneously transported until the point of lowest contact angle with water – or lowest pressure. That is, until the surface of the froth layer comes in contact with the atmosphere.

For the froth phase, the following relation is defined:

$$N_x = K_E \times A \times (c - c_f) = K_p \times A \times (a - r_f)$$

**CONCENTRATION**                      **FLOTATION**  
**FROTH**                                      **SLURRY**

where:

$K_E$  is the transfer coefficient in the froth phase, with the same units of  $K_p$

$c$  is the average concentrate froth grade

$c_f$  is the interface particles grade

In a similar way to what was defined for the slurry phase, the gradient ( $c - c_f$ ) is the driving force that promotes particle transfer from the interface to the main froth concentrate flow. The phenomenon that happens in the froth phase is called *concentration*.

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