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# A compartment model for the mass transfer inside a conventional flotation cell

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**Abstract**

A model is developed by taking into account the simultaneous mechanisms of true flotation and entrainment in a conventional flotation cell. The total volume of the cell is divided into three compartments: pulp collection zone, pulp quiescent zone and froth region, with the mechanisms being modeled as occurring at the same time but originating at different places: true flotation from the collection zone and entrainment from the quiescent one. A particle is referred to as suspended in water or attached to an air bubble, depending upon its original state before crossing the pulp–froth interface (whether or not it remains in that state all the way to the concentrate launder). The model is obtained by solving a set of equations describing the mass conservation of solids and water between adjacent compartments. The principal mass transfer factors are identified as: the flotation rate constant, the mean residence time in the collection zone, the froth recovery of attached particles, the degree of entrainment through the froth and the water recovery from the feed to the concentrate. The development presented here allows the intricate nature of the mass transfer in a flotation cell to be reduced to one single equation, overcoming the need of numerical methods for simulation purposes. Moreover, it is shown that reliable prediction of grade and recovery can be obtained without detailed information on the pulp hydrodynamics or on any froth sub-process either than drainage, bubble bursting and bubble coalescence.


*Keywords:* flotation modeling; mass transfer; true flotation; entrainment; pulp hydrodynamics

## 1. Introduction

### *1.1. Overview of the mass transfer inside a conventional flotation cell*

It is well established that the pulp in a conventional flotation cell must be thoroughly agitated in order to promote solids suspension as well as effective bub-

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ble–particle collision (Degner, 1985). Excessive agitation, on the other hand, not only wastes power but also impairs metallurgical performance by increasing the probability of bubble–particle detachment in the impeller vicinity (Jameson, 1977; Jowett, 1980; Ahmed and Jameson, 1989). At the proper range of impeller speed, there is circulation of suspended particles through the pulp and the turbulence drops swiftly away from the impeller blades (Fallenius, 1987; Gosman et al., 1992). The efficiency of bubble–particle collision, however, is also known to decrease with the turbulence in the pulp (Jameson, 1977; Dobby and Finch, 1987). Therefore, the efficiency of bubble–particle collision in a conventional cell is a function of spatial position, dropping from the impeller blades towards the pulp–froth interface (Inoue, 1984). Unfortunately, such a function cannot be quantified without mapping the pulp hydrodynamics for specific cell geometries and operating conditions, which is not a trivial task.

The efficiency of bubble–particle attachment must also be considered, as not all particles colliding against a bubble will attach to it (Dobby and Finch, 1987; Crawford and Ralston, 1988). In this sense, as a bubble travels through the impeller vicinity, it tends to collect the most hydrophobic particles in its path, this being the primary source of flotation selectivity. However, depending on the pulp chemical environment, several physico-chemical processes may occur that will affect the efficiency of bubble–particle attachment, such as "ageing" of particle surfaces and agglomeration between hydrophobic and hydrophilic particles (Greene and Duke, 1962).

With increasing distance from the impeller blades, there is a transition to a less turbulent or *quiescent* zone, which is essential for the stability of the pulp–froth interface. Cell manufacturers have recognised that the quiescent zone, "being less turbulent, permits the upward migration of mineral-laden air bubbles with minimal opportunity for bubble–particle separation (Smith et al., 1982)". At the pulp–froth interface, air bubbles ascending from the quiescent zone cause water and suspended particles to become entrained in the froth, irrespective of particle hydrophobicity (Smith and Warren, 1989). Despite the fact that fine valuable particles can also be recovered by entrainment (Engelbrecht and Woodburn, 1975), this mechanism is a drawback in terms of the selectivity of separation, always resulting in lower concentrate grades (Johnson, 1972; Trahar, 1981).

Particle detachment within the froth is caused primarily by bubble bursting and bubble coalescence (Feteris et al., 1987; Falutsu, 1994). The detached particles become suspended in the voids between the remaining air bubbles, together with the particles that entered the froth by entrainment. A high proportion of the particles suspended in the voids (entrained and detached particles) are rejected to the pulp due to water drainage. The suspended particles that survive drainage and the ones still attached to the air bubbles are transported to the concentrate launder by the ascending motion of the froth (Moys, 1978; Yianatos et al., 1988). Additional to bubble bursting, bubble coalescence and water drainage, other sub-processes have been postulated (without supporting experimental evidence) to take place within the froth, including selective detachment of weak hydrophobic particles that would be caused by friction with the water draining from between the bubbles.

The fact that increasing froth depth leads to higher concentrate grade in a cleaner cell is sometimes invoked as proof for the significance of selective detachment. However, that fact can just as well be explained by a simple sequence of events: (a) unselective detachment of both weak and strong hydrophobic particles due to increased bubble bursting and bubble coalescence in the froth; (b) drainage of the detached particles back to the pulp; (c) faster reattachment of the strong hydrophobic particles in the pulp; and (d) rejection of the particles that did not reattach to the tail of the cell, the majority of which being weak hydrophobic. This not only explains the increase in grade but also the drop in recovery. Against the significance of selective detachment, it can certainly be argued that most of the weakly attached particles will detach in the turbulent impeller vicinity, long before the aggregate reaches the pulp–froth interface. In addition, a study of the forces acting upon the aggregates in the froth shows that attachment is about three orders of magnitude stronger than the friction generated by water drainage (Falutsu, 1994). Moreover, in one of the rare cases where the grade of attached particles was measured directly, there was no grade variation in going from the pulp to the froth or within the froth itself (Falutsu and Dobby, 1992). This clearly indicates that selective detachment was not