



A phenomenological model of entrainment and froth recovery for interpreting laboratory flotation kinetics tests



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ABSTRACT

There is currently no standard approach to laboratory flotation testing and interpretation. The deficiency stems, in part, from the difficulties in quantifying the recovery of mineral particles by hydraulic entrainment (R_e) and the recovery of collected mineral particles across the froth zone (R_f) of a laboratory flotation cell. For lack of alternatives, most practitioners ignore entrainment ($R_e = 0$) and assume that froth recovery is 100% ($R_f = 1$). Consequently, differences in test scraping frequency or froth characteristics can lead to large differences in the inferred collection kinetics.

This paper proposes resolving the problem by incorporating a phenomenological solution for R_e and R_f . By considering the test water balance, incorporating hindered settling theory, and making some simple assumptions regarding the pulp, interface, and froth phases, it can be shown that the entrainment recovery of any mineral can be calculated solely from the particle size and specific gravity. A similar approach can be used to estimate the froth recovery as a function of time.

The method is applied to a data set of flotation tests conducted with different scraping rates, and it is demonstrated that it yields similar flotation rate constants regardless of the scraping rate.

1. Introduction

There is no accepted standard for calculating the residence time requirements for a bank of industrial flotation cells from laboratory flotation kinetics tests. In the western hemisphere base metal industry (which accounts for much of the authors' experience), most engineering companies still rely on empirical methods such as the time multiplier method. Loosely stated, this means that the plant recovery will equal that of the laboratory test when the plant retention time is equal to that of the laboratory, multiplied by some factor, usually between 2 and 3. In this method, the value chosen for the time factor is based on experience. Therefore, the tests must be conducted in identical fashion—scraping frequencies, frother dosages, froth stability, and the equipment type (cell type, impeller speed, air flow rate) must all be standardized so as to avoid scale-up bias. Indeed, it is probably this standardization that explains why the 70-yr old Denver flotation cell is still the most popular laboratory cell for froth flotation test work, despite the availability of much more sophisticated (and instrumented) alternatives.

The limitations of this kind of standardization are significant because it means that the flotation cell geometry, frother type and dosage,

impeller type, diameter and rotational speed, scraping frequency, and other test parameters must be faithfully duplicated between laboratories and technicians. If they are not, then it creates a potential for scale-up bias (Fig. 1), thereby imposing a significant risk for the large, capital-intensive flotation plants common in western base metal mining.

For these reasons, many practitioners have turned to phenomenological models for flotation circuit simulation. The most widely adopted phenomenological model is the “compartmental” model, which discretizes the flotation system in two compartments and applies sub models for the relevant mass transfer vectors that occur in each one. The three main ones are:

1. Mineral recovery in the collection zone, R_c , which applies to the hydrophobic minerals and follows a pseudo first order plug-flow kinetics model.
2. Mineral recovery in the froth zone, R_f , which applies to the hydrophobic particles that have been recovered in the collection zone.
3. Mineral recovery by entrainment, which applies to uncollected hydrophilic and hydrophobic particles in the collection zone.

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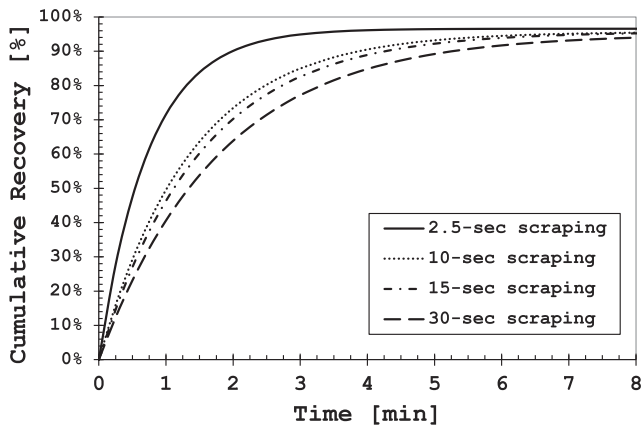


Fig. 1. Cumulative chalcopyrite recovery versus time for four different laboratory scraping rates [$K_c = 1.81$; $R_\infty = 95.6\%$].

Fig. 2 shows a representation of the two-compartment model (Finch and Dobby 1990). The model is applied to both batch (laboratory) and continuous (plant) cells.

The following equations describe the system (Finch and Dobby 1990):

$$R_{float} = \frac{R_c(t)R_f}{R_c(t)R_f + 1 - R_c(t)} \tag{1}$$

where, R_{float} is the overall recovery by flotation and R_c is the recovery by collection. For batch tests, collection recovery follows the plug-flow equation first proposed by Garcia-Zuñiga (1935):

$$R_c(t) = R_\infty [1 - \exp(-kt)] \tag{2}$$

For continuous flotation, the collection recovery follows the continuous stirred tank reactor (CSTR) model (Levenspiel 1962; Dorenfeld 1962; Arbiter and Harris 1962):

$$R_c(t) = R_\infty \left[1 - \frac{1}{(1 + kt)} \right] = R_\infty \left[\frac{kt}{1 + kt} \right] \tag{3}$$

It has been recognized for some time that recovery by entrainment is proportional to the size of the particle and the water recovery of the flotation cell (Johnson et al., 1972). By defining the degree of entrainment for a particle size class i (ENT_i) as the ratio of solids recovery by entrainment (R_e) to the water recovery (R_w), we define the recovery by entrainment for an entire mineral class as the sum of entrainment for all size classes:

$$R_e = m \sum_{i=1}^n \frac{ENT_i}{m_i} R_w \tag{4}$$

where m is the mass of the mineral class (i.e. the grade) and m_i is the mass of that mineral in size class i .

While Eqs. (1)–(4) offer an improved framework for the modeling of flotation systems, there are some important practical difficulties that must be overcome when applying them to the interpretation of laboratory kinetics tests. With current laboratory equipment, it is difficult to separately characterize the collection recovery and the froth recovery, and thus, most practitioners must assume that the froth recovery is 100% to simplify the equations and solve for the collection rate constants. In a previous work (Amelunxen et al., 2014), two of us examined the impact of laboratory scraping frequency on froth recovery. We found that for typical scraping frequencies of 10 to 15 s, the actual froth recovery is approximately between 30% and 40%. This can be a source of significant bias in the resulting collection rate constants, because if R_f is assumed to be 100%, then the value of k must be reduced to compensate.

Another common problem relates to entrainment. Because the relationship between the laboratory ENT and the particle size is not known, most practitioners ignore entrainment; i.e. they assume that $R_e = 0\%$. This can also cause bias in the resulting rate constants, because entrainment recovery of the less hydrophobic minerals is imputed to collection, and therefore the rate constants of those minerals must be increased to compensate.

These two caveats create a “catch-22” when performing and interpreting flotation kinetics tests. On the one hand, the practitioner can perform a test with fast scraping rates—say, every 1 to 3 s the froth is completely removed from the surface of the cell—and minimize the error associated with the assumption that $R_f = 1$. By doing this, the accuracy of the collection zone rate constants of the hydrophobic minerals will be better, but the test will also give much higher water and entrainment recoveries (Sandoval et al., 2014), resulting in over-estimation of the k and R_∞ of the slower-floating mineral. On the other hand, the practitioner can reduce the scraping frequency and improve the accuracy associated with the slower-floating minerals, but this approach will result in the under-estimation of the collection rate for the faster floating minerals.

It is likely for this reason that many current test standards (to use the term loosely), involve scraping rates of between 10 and 15 s (Amelunxen et al., 2014). It is precisely around this point that the froth recovery and entrainment recovery of the laboratory test are approximately equal to those of industrial roughing cells (Amelunxen 2015), resulting in differential kinetics—i.e. the kinetics of the fast-floating minerals relative to those of the slow-floating minerals—that are also

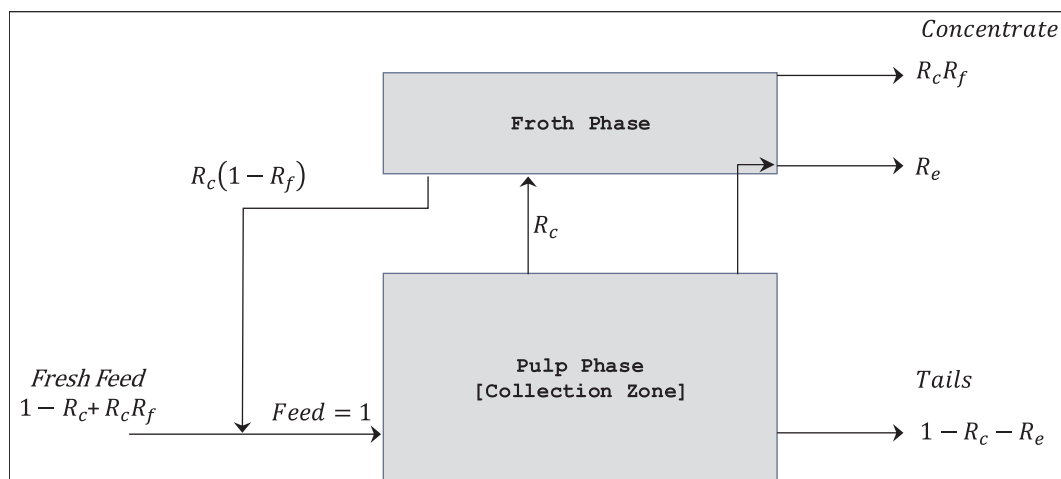


Fig. 2. Schematic representation of the two-compartment model of flotation.

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