Minerals Engineering 66–68 (2014) 191–196

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Bank profiling and separation efficiency

N. Singh [a,*], J.A. Finch [a]

[a] McGill University, 3610 University Street, Montreal H3A 0C5, Canada

ARTICLE INFO

Article history:
Received 25 December 2013
Revised 10 April 2014
Accepted 15 April 2014
Available online 10 May 2014

Keywords:
Froth flotation
Flotation machines
Flotation kinetics

ABSTRACT

Various authors have discussed methods of optimising a bank of flotation cells. In this paper, JKSimFloat is used to investigate the effect of recovery profiling and mass pull profiling (i.e., mass distribution to cells in a bank) on the separation efficiency between floatable minerals and against entrained gangue.

In the case of two floatable minerals, a balanced recovery profile was found to be optimal: supporting and extending previous analysis. In the case of separation of a floatable mineral from entrained gangue, the entrainment model that links water overflow rate to solids overflow rate was employed. When the value of b in the entrainment model is greater than one, a balanced mass pull profile was found to be optimum. The evidence for $b > 1$ is briefly reviewed; no example has been found where $b < 1$. Most of the profiles were controlled in the software by altering the bubble surface area flux distribution; a sensitivity analysis was performed using other variables.

Recovery profiling was tested as part of a bank optimisation campaign at a talc operation in Timmins, Canada. Using air and frother as manipulated variables, it was found that as the rougher bank was moved toward a balanced profile the final plant product showed improvement in grade and yield.

1. Introduction

Recovery in flotation may be attributed to either true flotation or entrainment. True flotation exploits the difference in the surface hydrophobicity of minerals to selectively recover one mineral (typically the valuable or pay mineral). Entrainment recovers particles indiscriminately in proportion to the amount of water recovered from the cell; a process that favours fine particles as they are unable to hydraulically settle (Lynch et al., 1981). Entrainment recovery lacks selectivity and is detrimental as it lowers the grade of valuable mineral concentrate. In flotation there are, therefore, three types of minerals which must be considered: valuable floatable mineral, floatable gangue (i.e., gangue that is recovered by true flotation), and entrained gangue.

Flotation cells are typically organised in series into banks (or rows or lines) to reduce the impact of mixing (Nesset, 1988). This configuration poses a curiosity: is it possible to reduce gangue recovery, whether recovered by true flotation or entrainment, by the way a bank is run? Various research groups have come up with different strategies (air profiling, peak air recovery, froth velocity profiling, and recovery profiling) (Cooper et al., 2004; Hadler et al., 2010; Maldonado et al., 2011; Runge et al., 2007). Of interest here is the work of Maldonado et al. (2011) who modelled recovery profiles to investigate separation of two floatable minerals. Their work is extended using JKSimFloat, which also permits entrainment to be analysed.

2. Theory

The modelling of floatable mineral recovery uses the well-established fully-mixed first order kinetic model and will not be reviewed here; rather the problem of modelling entrainment is considered. Entrainment recovery (R_E) is proportional to the amount of water recovered (R_W) (Lynch et al., 1981):

$$R_E = ENT \times R_W \tag{1}$$

where ENT is the entrainment factor. This understanding has motivated modelling water recovery. Many models have been developed, both empirical and phenomenological (Zheng et al., 2006). One of the models used by JKSimFloat is that developed by Alford (1990), which predicts the water overflow rate (Q_W) in terms of the solids overflow rate (Q_S):

$$Q_W = aQ_S^b \tag{2}$$

where a and b are fitted constants. To link with Eq. (1), Eq. (2) is re-written in terms of mass flow rate components:

$$\frac{Q_{E,C}}{Q_{E,F}} = ENT \times \frac{Q_{W,C}}{Q_{W,F}} \tag{3}$$

* Corresponding author. Tel.: +1 514 398 4755x00780.
E-mail address: nalini.singh@mail.mcgill.ca (N. Singh).

http://dx.doi.org/10.1016/j.mineng.2014.04.018
0892-6875/

where Q_E is the mass flow rate of entrained mineral, and the subscripts C and F denote the concentrate (overflow) and feed, respectively. The entrainment factor (ENT) and feed flow rates are constants and may be merged with the constant a in Eq. (2) after substitution in Eq. (3) to give a':

$$Q_E = a'Q_S^b \tag{4}$$

Eq. (4) gives the entrainment in a single flotation cell. To extend to a bank of n cells, as a simplification, it is assumed that each cell (i) in the bank has the same mass pull (i.e., $Q_{S,i} = \frac{Q_{\mathrm{Bank}}}{n}$). The total flowrate of entrained material is then the summation over all cells:

$$Q_{E,\mathrm{Bank}} = \sum_{i=1}^{n} a'\left(\frac{Q_{s,\mathrm{Bank}}}{n}\right)^b \tag{5}$$

Considering the summation for n cells Eq. (5) can be written:

$$Q_{ENT,\mathrm{Bank}} = \frac{Q_{E,\mathrm{SingleCell}}}{n^{b-1}} \tag{6}$$

Eq. (6) may be used to compare entrainment in a single flotation cell with entrainment in a bank of cells (of equal total volume). Eq. (6) gives two possibilities depending on the value of b: if $b > 1$, having a balanced bank will produce less entrainment than a single cell – in fact, the higher the value of b the greater the advantage to using a balanced bank; and if $b < 1$, entrainment would be less in a single cell than a bank. While the assumption of balanced mass pull was for mathematical convenience it is intuitive from Eq. (2) for the case when $b > 1$: if any cell in a bank over-recovers floatable solids, it would also over-recover water and by consequence over-recover entrained solids, which cannot be offset by other cells in the bank under-recovering floatable solids.

This analytical solution is analogous to that developed by Maldonado et al. (2011) for the separation of two floatable minerals (A and B). In that situation a balanced recovery profile (i.e., each cell has the same recovery based on feed to the cell) yielded the maximum separation efficiency for a given target recovery of the valuable (target) mineral (A) where separation efficiency is defined as the difference in recovery:

$$SE_{A/B} = R_A - R_B \tag{7}$$

One of the assumptions of Maldonado et al. (2011) is that the ratio (or relative magnitude) of the mineral rate constants S remains unchanged down the bank. It is not possible to determine whether this assumption of constant S will always hold: a secondary aim of this work is to extend the analysis of Maldonado et al. (2011) to include non-constant S.

In the JKSimFloat kinetic model each mineral has a unique rate constant, k, which depends on the intrinsic floatability of the mineral (P), the bubble surface area flux (S_b), and the froth recovery (R_f):

$$k = PS_bR_f \tag{8}$$

Thus, rather than $S = \frac{k_A}{k_B}$ as used by Maldonado et al. (2011), we can substitute $S = \frac{P_A}{P_B}$, the ratio of floatabilities.

Balanced recovery, as defined by Maldonado et al. (2011), is based on the feed to each cell in a bank, whereas in the balanced mass pull case discussed above it is based on the feed to the bank. In this paper, balanced recovery will always refer to recovery based on the feed to each cell in a bank, and a balanced mass pull will always refer to mass pull based on the bank feed.

3. Method

3.1. JKSimFloat simulations

JKSimFloat was selected because of its ability, through the Simulation Manager, to run multiple simulations. Floatability data collected by Welsby (2009) for galena and sphalerite was used to define mineral floatabilties (P) as a function of particle size class for the two minerals (A = galena and B = sphalerite). Mineral A was considered to be the valuable target mineral (grade = 8.6%) and mineral B (grade = 6.9%) represents floatable gangue. Entrainment recovery was set to zero for minerals A and B. For the third mineral class (E), representing materials recovered only by entrainment, the entrainment factors were based on the work of Smith and Warren (1989). While a small amount of mineral A and B would be recovered by entrainment, for these grades of A and B, the majority of entrained material will be type E. Assuming zero entrainment for the floatable minerals is consistent with Maldonado et al. (2011). The feed rate was set to 1275 tonnes per hour (dry solids) at 34% solids by weight.

Six profiles were compared. Five recovery profiles were devised for a target bank recovery of 75% of mineral A for a bank of 4 cells. These five recovery profiles also produce five mass pull profiles (combined mass of A, B, and E). The sixth profile was a balanced mass pull profile. The balanced mass profile was based on the average bank mass pull of the five recovery profiles, such that the final recovery of mineral A at the end of the bank was also 75%. This facilitates comparison between the six profiles. A bank of four cells was chosen as the performance of a short bank ($n < 7$) is more sensitive to the profile than a long bank (Maldonado et al., 2011).

The five recovery profiles are represented graphically in Fig. 1. Profiles 1 and 3 are, respectively, step-wise increasing and decreasing profiles starting from cell 1, with recovery equal in cells 2–4. Profile 2 is a balanced recovery profile. Profiles 4 and 5 are, respectively, monotonically increasing and decreasing profiles.

To evaluate the results the optimisation metric chosen was the separation efficiency used by Maldonado et al. (2011). Eq. (7) gives the separation efficiency between floatable minerals A and B, and the separation efficiency between floatable mineral A and entrained mineral E is given by Eq. (9):

$$SE_{A/E} = R_A - R_E \tag{9}$$

JKSimFloat was interfaced with Microsoft Excel such that the results could be interpreted and graphically represented. To create each profile, the bubble surface area flux was varied to obtain the target recovery for cell 1. This is analogous to changing the air rate (or bubble size) in a plant environment. The S_b of cell 1 was then fixed and the process repeated for the remaining cells in the bank to achieve the target bank recovery of A of 75%. As a base condition R_f was fixed at 60% for mineral A and 30% for minerals B and E; and in the water recovery model (Eq. (2)) a and b were set at 0.5 and 1.1, respectively. Setting R_f is analogous to changing froth depth.

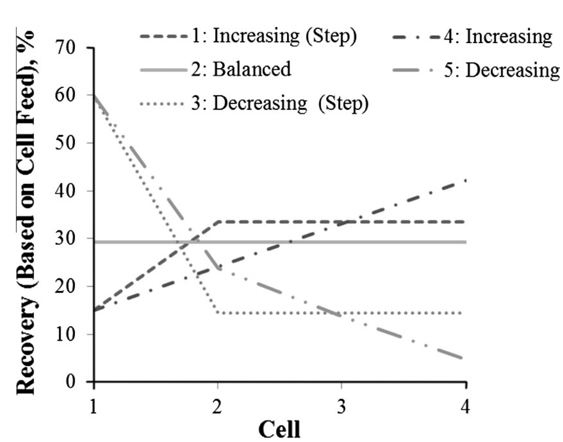

Fig. 1. Graphical representation of recovery profiles 1–5 for bank recovery of A of 75%.