Minerals Engineering 36–38 (2012) 132–137

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

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

The effect of surface liberation and particle size on flotation rate constants

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ARTICLE INFO

Article history:
Available online 27 April 2012

Keywords:
Flotation
Coarse particle flotation
Flotation kinetics
Flotation machines
Composites

ABSTRACT

The recovery of mineral particles by flotation is a strong function of particle size. As the size of floatable particles increases, the recovery increases also, until it reaches a maximum, before decreasing monotonically. Previous work has focused on liberated material or ore particles of unknown individual composition. Until recently, there has been no data on the size-by-size behaviour of partially liberated minerals.

This paper presents a re-interpretation of recent experimental results for the flotation of galena particles in an operating concentrator. The rate constants for each size fraction and liberation class were measured. Composites floated more slowly than liberated particles, but a fresh analysis of the data shows that the general shape of the distribution of rate constant with particle size is unaffected by liberation (composite formation). For each liberation class, the ratio of the rate constant k to the maximum rate constant for completely liberated particles k_{max}, was independent of particle size. A flotation liberation function $L = k/k_{max}$ can be defined, which is a function of the fractional liberation. For this ore, the liberation function is of the form $L = k/k_{max} = ax \exp(bx^c)$, where x is the fractional liberation ($0 \leqslant x \leqslant 1$), and a, b and c are constants. The liberation function is expected to depend on the ore type.

The effect of contact angle on the size-by-size recovery of fully liberated chalcopyrite particles in a mechanical cell has been examined. The recovery-particle size response for these particles followed the classical shape. A plot of k/k_{max} vs contact angle, where k_{max} is the rate constant at the greatest contact angle, showed that the flotation response was essentially independent of particle size.

The observed poor recovery of coarse particles cannot be attributed to lack of liberation. Partial surface liberation affects the rate constants of all particles in the same way, independently of size. The distribution of recoveries with particle size is determined by the response of fully liberated particles. The rate constants for coarse composites follow those for fully-liberated particles of the same size. The decline in recovery of coarse particles is related to the hydrodynamic conditions in the flotation cell.

1. Introduction

In the flotation process for the separation of valuable minerals from ores, it is well known that the flotation rate constant is a function of particle size. For a given type of flotation machine, the rate constant is low for ultrafine particles, but with increasing size, it increases until a maximum is observed, after which it declines monotonically. Such behaviour was has been seen in operating plants (Gaudin et al., 1931) and in experimental investigations (Jowett, 1980; Trahar, 1981).

In practical applications, the valuable mineral to be floated is initially embedded in a host rock, from which it must be liberated, by grinding. The degree of liberation is dependent on the ore type and grind size. Thus the feed to flotation can consist of particles that are fully liberated, predominantly the smaller particles, and others in which the mineral to be floated is contained within composite particles, along with unwanted gangue mineral. Although it has been surmised that the reduction in rate constant for coarse particles can be attributed to the formation of composites (see for example Runge et al., 2007), this aspect has not been confirmed by observation.

Until the advent of measurement techniques such as the QEM-Scan (Sutherland and Gottlieb (1991) and the Mineral Liberation Analyser (MLA) (Gu, 2003), it was impossible to measure easily, the surface liberation of a population of particles. Without this information, the particle size and liberation class of particles in the feed and concentrate cannot be determined, and accordingly, the effect on the recovery or rate constant of either of these two variables cannot be identified. Recently however, Welsby et al. (2010a) have quantified the feed and concentrate particles using the MLA in a way that allows us to investigate the true reasons for the decline in rate constant with increasing particle size. In another recent work, Muganda et al. (2011) have reported on the effect of

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http://dx.doi.org/10.1016/j.mineng.2012.03.011

Table 1
Data from Table 3, Welsby et al. (2010a).

k_{ij}, min^{-1}		Liberation class (mean percent)											
Size class		Mean (μm)	5	15	25	35	45	55	65	75	85	95	100
–	+												
Rate constants of floatable particles													
	+106	115.5	0	0.01	0.02	0.03	0.07	0.12	0.13	0.19	0.24	0.26	**1.39**
106	75	90.5	0.02	0.05	0.11	0.17	0.2	0.26	0.47	**0.63**	**0.77**	**1.26**	**2.52**
75	38	56.5	0.05	0.1	0.16	0.27	0.4	**0.63**	**0.77**	**0.83**	**1.12**	**1.99**	**3.83**
38	28	33	0.07	0.1	0.17	0.28	0.39	**0.6**	**0.78**	**0.96**	**1.62**	**2.69**	**4.36**
28	19	23.5	0.06	0.09	0.16	0.27	0.38	**0.63**	**0.75**	**0.98**	**1.64**	**2.74**	**4.23**
19	10	14.5	0.06	0.1	0.16	0.24	0.32	0.39	0.4	0.49	**0.68**	**1.07**	**2.13**
10	0	5	0.03	0.04	0.04	0.08	0.08	0.1	0.12	0.13	0.14	0.27	**0.67**
$m_{ij} \times 100$													
Mass of floatable mineral in each liberation class, percent													
	+106	115.5	0.65	0.65	0.47	0.38	0.17	0.13	0.09	0.07	0.05	0.1	**0.37**
106	75	90.5	0.22	0.17	0.14	0.16	0.14	0.13	0.07	**0.07**	**0.1**	**0.22**	**1.15**
75	38	56.5	0.32	0.32	0.28	0.28	0.25	**0.24**	**0.23**	**0.24**	**0.29**	**0.92**	**6.95**
38	28	33	0.07	0.07	0.06	0.07	0.07	**0.08**	**0.08**	**0.07**	**0.09**	**0.38**	**11.37**
28	19	23.5	0.07	0.07	0.06	0.06	0.08	**0.07**	**0.07**	**0.07**	**0.09**	**0.35**	**10.4**
19	10	14.5	0.07	0.09	0.08	0.08	0.12	0.11	0.11	0.12	**0.14**	**0.46**	**14.81**
10	0	5	0.05	0.12	0.11	0.11	0.12	0.13	0.17	0.18	0.22	0.35	**23.8**

contact angle on the flotation kinetics of single-mineral chalcopyrite, on a size-by-size basis. These papers provide detailed evidence concerning the flotation kinetics of pure and composite particles.

In this paper, the experimental evidence is reviewed, and used to investigate the effect of liberation fraction and particle size on rate constants in the flotation of a galena ore.

2. Liberation and particle size

In data obtained by early workers in the field, the particle size effect was reported in terms of the recovery. Presumably, it was simpler to report the overall recovery after a specified flotation time in a batch test, or residence time in a continuous flotation cell or bank of cells, than to calculate the rate constants. Naturally, the two are closely linked. The recovery is a manifestation of the rate constant of a given size particle, in the case of a pure mineral. For a collection of composite particles, the recovery will be the aggregate of the recoveries of particles in a given size band, with a range of fractional liberations, weighted according to the mass fractions of the particles in the feed. While the recovery is a valuable concept, especially from an operational point of view, the rate constant as a function of particle size and liberation class is more useful for interpreting the behaviour of a system with distributions of both particle size and liberation class.

Welsby et al. (2010a) described an investigation in which a ground ore was fed continuously to a 40-L pilot plant. The mineral was a galena ore from the Cannington deposit in Queensland, Australia. It was taken from the plant feed to the roughers, on site. Sodium ethyl xanthate was used as collector. Samples of concentrate were separated in a Warman Cyclosizer, and analysed by MLA. Rate constants were determined for each particle size band, and for eleven liberation classes. The data were analysed with reference to the Floatability Component Model (FCM), and the Physical Property Based Model, developed by the Julius Kruttschnitt Mineral Research Centre at the University of Queensland. Australia. The paper contains an excellent description of each of these models and the way they can be utilised. However, the extensive data reported in this paper has other uses. With further interpretation, some very interesting results emerge.

Table 1 shows the data reported in Table 3 of Welsby et al. The liberation classes in the original were reported as brackets of 10% by weight, but for present purposes, these have been replaced by the average percentages in each class, which are used in discussions as the "fractional liberation".

The authors separated the particles into the two groups because the floatability component model (FCM) assumes that all particles in the concentrate can be classified as slow floating, fast floating and non-floating (not shown here). We see that the fast-floating size-by-liberation classes (shown bolded in Table 3) contains particles that are there for two reasons: either they are highly liberated, or they are in a size class that, for whatever reason, happens to have high flotation rates. We can explore the flotation behaviour more deeply by plotting the rate constant as a function of the percentage liberation class and particle size, as shown in Fig. 1.

We see that although the rate constant decreases as liberation decreases, the shapes of the distributions remain approximately the same, suggesting similarity in the response to liberation. Accordingly, k/k_{max}, the ratio of the rate constant at a given particle size and liberation class, to the rate constant for fully-liberated particles of the same size, has been calculated as shown in Fig. 2.

It is seen that the rate constant ratio as a function of liberation is essentially the same for each particle size. The line of best fit shown in Fig. 2 can be described as a *flotation liberation function* $L = k/k_{max}$. In this instance it has the form

$$L = axe^{bx^c} \tag{1}$$

where $L = k/k_{max}$ and x is the fractional liberation ($0 \leqslant x \leqslant 1$); the constants have the values $a = 0.27$, $b = 1.30$ and $c = 10.80$. This relation is purely empirical. The constants will probably be a function of cell hydrodynamics and system surface chemistry.

The result shown in Fig. 2 is quite remarkable. It allows us to make generalisations about the effect of liberation on the rate constant in a way never before possible. More importantly, it suggests that the rate constant for a fully-liberated ore is determined solely by hydrodynamics and the surface chemistry of the system. If the chemical regime is constant, the peak in the k–d_p curve for fully liberated particles depends only on cell hydrodynamics. The rate constant of a particle of a given liberation class is firstly determined by that of the fully-liberated particle of the same size. A correction factor can then be applied to allow for the effect of liberation.

We can compare these results with the data for batch flotation of chalcopyrite reported by Sutherland (1989). The chalcopyrite data are for −38 + 32 μm particles, so data from Welsby et al. for the mean size of 33 μm have been used. Sutherland reported the recovery after specific time intervals, but not the rate constants.