A STUDY OF THE FLOTATION CHARACTERISTICS OF DIFFERENT MINERALOGICAL CLASSES IN DIFFERENT STREAMS OF AN INDUSTRIAL CIRCUIT

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ABSTRACT

Some researchers postulate that the floatability of a particle in the streams of an industrial flotation circuit is a function of only its size and liberation properties. They do not discount the importance of reagent or surface contamination on particle floatability but assume that the reagent coverage or surface contamination of the particle surfaces is essentially uniform for particles of similar size and mineralogical properties when subjected to a particular chemical regime.

In this paper, samples collected from batch tests performed on different streams of the Red Dog lead cleaning circuit have been characterised with respect to their size, mineral association and mineral surface exposure. An analysis of this data set indicates that particle recovery rate is significantly affected by mineralogical properties – in particular the degree of valuable mineral surface exposure.

However, through the use of a nodal analysis technique developed by the authors, it can be concluded that particles with the same size and mineral composition do not all float with the same rate, but with a distribution of rates. The characteristics of this floatability distribution do not change during the flotation process. It is suspected that the particles within a size mineralogical class in this study have varying degrees of surface oxidation and that this results in varying particle flotation rates. Thus basing particle floatability on size and mineralogical effects, alone, in a flotation model is not always valid.

Keywords: flotation, modelling, ore floatability, liberation, nodal analysis, oxidation

INTRODUCTION

Extensive research has been applied to the task of developing a mathematical model of the flotation process. The ultimate objective is to produce a model that predicts concentrate grade and recovery which can be used as a tool for flotation circuit design or for the optimisation of existing flotation circuits. This has proved difficult because of the vast number of variables that affect the flotation system.

Bubble particle collection in flotation is generally considered to be a first order rate process. Gorain et al (1997) studied the rate constant achieved in a variety of industrial flotation cells of different type and size run under a range of different air rates, impeller speeds and froth depths. They concluded that the difference in the flotation rate constant (k) achieved in these different cells was due to either a change in the ore floatability (P), the bubble surface area flux (S_b) generated in the cell or the loss in recovery across the froth phase (R_f).

$$k = R_f\, S_b\, P \qquad (1)$$

Ore floatability is considered to be a property of the feed stream to the process and not dependent on the operating conditions within the flotation cell. It is defined as the propensity of the particles in a stream to float. The particle properties that have been shown to affect the flotation rate constant of an ore significantly are size, mineralogical composition, reagent surface coverage, the degree of oxidation of the particle surface and the degree of aggregation of the particles in the system.

Previous work by the authors (Runge et al, 1997) and others (Imaizumi and Inoue, 1963) have shown that the ore floatability of a stream cannot be described by one number but by a distribution. A flotation stream contains a large number of different particles with different properties. Because of these different properties, they do not all react with the bubbles in the flotation process with the same rate. A process stream therefore exhibits a distribution of flotation rates.

At present there is insufficient knowledge to enable the exact shape of this ore floatability distribution to be derived fundamentally. Within the literature, there are three distinct methods for approximating the shape of this distribution for use in flotation models.

These are as follows:

- *Empirically Derived Shaped Distributions*: The floatability distribution is assumed to be of a particular shape, defined by a small number of parameters that can be derived from experimental data. Distribution functions proposed within the literature include the gamma (Imaizumi and Inoue, 1963), rectangular (Huber Panu et al, 1976), triangular (Harris and Chakravarti, 1970), sinusoidal (Diao et al, 1992) and normal (Chander and Polat, 1994) functions.
- *Empirically Derived Floatability Components:* The mass of the particles in the feed is broken up into a discrete number of floatability components each with a mean ore floatability constant. The mass and ore floatability of each component are derived using fitting techniques. The classical two component model (Kelsall, 1961) is an example of this method.
- *Property Based Floatability Components:* The feed is fractionated into classes based on some physical property of the system. Each class is assumed to float with a discrete ore floatability. The recovery of each class in a flotation system is used to determine the rate constant or ore floatability of that class. Properties used to divide the feed include size (Tomlinson and Fleming, 1965; Thorne et al., 1976; Kawatra et al., 1982), mineral association or liberation (King, 1976; Sutherland, 1989, Niemi et al., 1997; Savassi, 1995; Gorain et al., 2000) and chemical surface coverage (Niemi et al., 1997).

Empirically derived floatability components have the advantage that they do not presuppose a shape to the floatability distribution (a disadvantage of the empirically derived shape distributions) and have been used successfully to model flotation systems where the ore floatability is not subjected to a change (Harris, 1998; Runge et al, 1997). Both empirically based approaches have the disadvantage that their floatability distribution parameters are not related to the physical properties of the particles in the flotation circuit streams. It is therefore difficult, when using these types of models, to model flotation circuit processes that change particle properties and result in a change in the ore floatability distribution. Such processes include grinding of the feed, regrinding of internal flotation streams, feed reagent addition and staged reagent addition, to name a few.

Property based floatability component models are more expensive and time consuming to develop than the empirical based models because their calibration usually requires sizing, liberation analysis and, potentially, chemical surface analysis of particles in flotation circuit streams. The advantage of this approach, however, is that the components have physical properties which could be used within reagent addition or grinding models to predict the ore floatability distribution after one or other of these processes within a flotation circuit.

To use a property based floatability component model to represent ore floatability in an industrial flotation circuit, the following two conditions must be satisfied:

- All particles in a stream with a known set of measurable properties float with the same ore floatability
- Unless subjected to reagent addition or regrinding, the ore floatability of this group of particles does not change in the different processes of the flotation circuit

In this paper, batch laboratory flotation tests have been performed on samples of different streams in an industrial flotation circuit. The concentrate and tails from these tests were subjected to assay, size and mineralogical liberation analysis to enable the solids in each stream to be fractionated into different particle property groups. The recovery rates of these different particle groups in the different streams of the process are studied to test whether the two conditions stated above can be shown to be satisfied in an industrial flotation environment.

EXPERIMENTAL

The experimental testwork for this study was undertaken within the lead cleaning circuit of Cominco's (now Tech Cominco's) Red Dog operation on the 11th April, 1996. Figure 1 shows the Red Dog circuit configuration at the time of the testwork and denotes the streams investigated during the study.

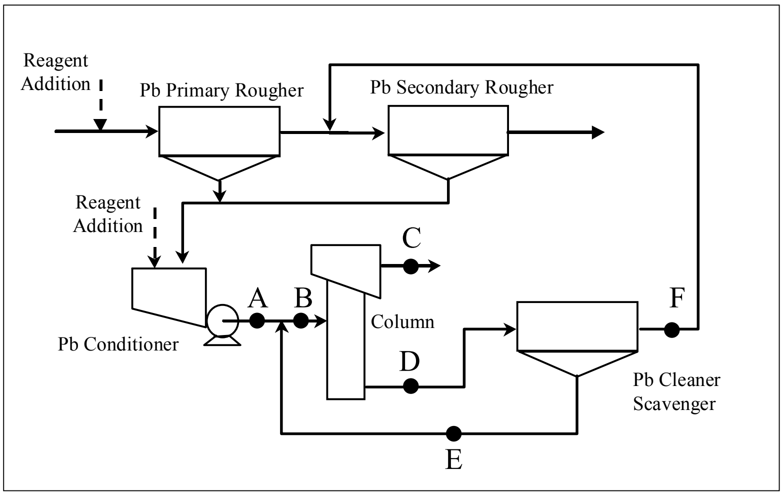

Figure 1. Red Dog lead circuit denoting streams sampled for batch flotation tests.
A – Combined rougher concentrate; B – column feed; C – column concentrate; D – column tailing;
E – cleaner scavenger concentrate; F – cleaner scavenger tailing.

The cleaning circuit consisted of a column unit and two conventional mechanical cells which acted as a cleaner scavenger. Feed to the cleaner circuit was the rougher combined concentrate. The solids in this stream had a P80 of approximately 20 microns and the major minerals present were galena, sphalerite and pyrite. For the purposes of this study, all the other gangue minerals present have been combined and will be referred to as non-sulphide gangue. It should be noted that the Red Dog lead circuit flowsheet has been altered since this testwork was completed.

The test program consisted of collecting a sample of approximately 4.8 litres from each major stream in the cleaning circuit and transferring this sample to a Denver laboratory flotation cell. Plant water dosed with an appropriate amount of frother (MIBC) was used to make up the volume in the cell to 4.8 litres when necessary. After adjusting the air rate to 4.8 litres/min and impeller speed to 1300 rpm, timed concentrate samples were collected. Concentrate removal was performed at a constant rate of one stroke every 10 seconds using a paddle. The paddle was designed to ensure the depth of concentrate removal remained constant. Froth depth was maintained at a reasonably constant level throughout each experiment by the addition of frother dosed plant water based on visual observation. Six or seven concentrates and a tailing sample were collected for each test.

For each stream in the process, the batch flotation test was carried out immediately after sampling. This procedure was adopted to minimise aging of samples during the time between sample collection and flotation. After all the major streams in the cleaning circuit had been floated, a sampling survey of the lead circuit was performed. This survey involved collecting a sub-sample of each major stream in the circuit at 10 minute intervals over a 40 minute period. Red Dog's on-stream analysis system indicated that the circuit remained at steady state during the entire sampling campaign.

All samples collected from the flotation tests and sampling survey were weighed wet, filtered, dried and weighed again. Sub-samples were analysed by a combination of atomic absorption spectroscopy and titration methods to determine their lead, zinc and iron content. Each dry sample was then split into seven size fractions. A sedimentation technique was used to remove the ultrafines (-4 micron) denoted as the CS7 fraction and a cyclosizer operating in series with a centrifuge was used to split the coarser fraction (+4 um) into six size classes (CS1, CS2, CS3, CS4, CS5, CS6) with mean sizes in the order of 28, 22, 17, 11, 8 and 5 micron, respectively. Each size fraction was assayed to determine lead, zinc and iron content. A sub-sample of the CS3 size fraction was submitted for mineralogical analysis using the JKTech Mineral Liberation Analysis (MLA) system. This system utilises grey level information from a back-scatter electron image to distinguish the mineral composition within and on the surface of particles mounted on a carbon resin. It should be noted that the data collected from the MLA system was not corrected for stereological error.

This data set was used to determine the mineral recovery in each stream of the circuit (based on the cleaning circuit feed) as well as the rate of recovery of various property-specific particle groupings in each of these streams in the batch flotation tests.

NODAL ANALYSIS

A mineral often exhibits different recovery rates in different streams of a flotation circuit. In Figure 2, galena is seen to exhibit different batch test recovery rates in the different streams of the Red Dog lead cleaning circuit.

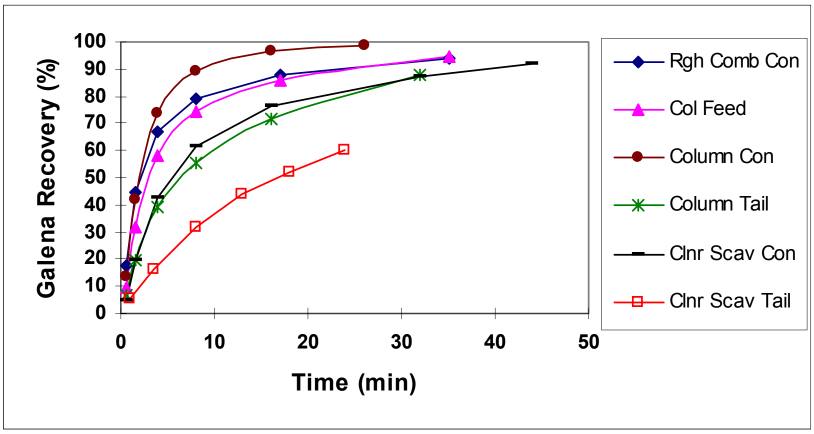

Figure 2. Galena batch test recovery rate in the different streams of the Red Dog lead cleaning circuit.

Many researchers have postulated that the turbulent aerated flotation environment in an industrial flotation cell would be conducive to particle attrition, deconditioning or oxidation and that these processes could all result in a change in the floatability of the particle system (Harris and Chakravarti, 1970). It is very possible that the difference in galena recovery rate measured in the six different streams of the Red Dog cleaning circuit is due to a change in particle floatability with time in the circuit, as a result of these processes.

Alternatively, the observed difference in galena recovery rate in the different streams may be due to floatability distribution effects. As noted in the introduction above, the particles in a stream may exhibit a distribution of floatabilities. For example, coarse galena particles would be expected to float faster than fine galena particles. The flotation process, by its very nature, concentrates fast floating particles into some (typically concentrate) streams and slower floating particles into other (typically tailing) streams. The difference in mineral recovery rate observed in Figure 2, could be due to the faster floating galena containing particles in the feed stream reporting to the concentrate streams and the slower floating galena containing particles reporting to the tailing streams in the circuit.

Nodal analysis, a technique proposed previously by the authors (Runge et al, 1997), can be used to differentiate between these two possible alternatives. Nodal analysis involves comparing the batch test recovery rates of streams before and after nodes in an industrial process. Where two or more streams are the feed or product of a node, they are mathematically combined based on their relative flow. For example, in the Red Dog case study, there are four nodes, one of which is the column node in which the column feed is separated into the column concentrate and column tailing stream. The floatability of the feed to this node is directly measured in the batch test of the column feed stream. The floatability of the product of this node must be inferred by combining the results of the batch tests of the column concentrate and column tailing streams using Equation 2. In Equation 2, $R_{\text{Galena}}^{\text{Stream name, t minutes}}$ is the batch test recovery of galena in a designated stream after t minutes of flotation and $F_{\text{Galena}}^{\text{Stream name}}$ is the mass flow rate of galena in a designated stream.

$$R_{\text{Galena}}^{\text{Column Product, t minutes}} = \frac{F_{\text{Galena}}^{\text{Column Con}} \times R_{\text{Galena}}^{\text{Column Con, t minutes}} + F_{\text{Galena}}^{\text{Column Tail}} \times R_{\text{Galena}}^{\text{Column Tail, t minutes}}}{F_{\text{Galena}}^{\text{Column Con}} + F_{\text{Galena}}^{\text{Column Tail}}} \qquad (2)$$

The galena batch test recovery rate measured in the column feed and calculated for the column product in the Red Dog lead cleaning circuit is displayed in Figure 3.

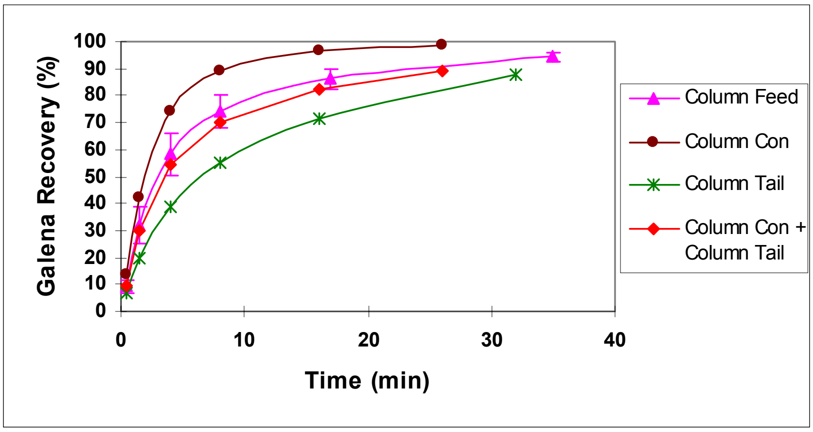

Figure 3. Results of nodal analysis around the Red Dog lead column.

In this example, the galena batch test recovery in the column feed is equal (within experimental error) to the galena batch test recovery in the column product and thus ore floatability can be assumed to be conserved across the node (i.e. ore floatability is not affected by the turbulence and aeration present within the column). It can therefore be concluded that the difference in the galena batch test recovery rates seen in Figure 2 are due to floatability distribution effects (i.e. not all particles containing galena in the feed to the circuit float with the same rate and are distributed between the different streams in the process according to their floatabilities). The same conclusion was obtained when carrying out nodal analysis on the cleaner scavenger bank and over the entire galena cleaning circuit (Runge et al, 1997).

Nodal analysis can not only be used to investigate the floatability of a *mineral species* across a node in a circuit but *any type of particle class grouping* characterised by one or more properties (eg. size or size and mineral composition). The batch test recovery of a particle class entering or exiting a node can be calculated using the general expression shown as Equation 3.

$$R^{\text{Combined Stream, t minutes}}_{\text{Particle Class}} = \frac{\sum_{s=1}^{n} F^{\text{Stream s}}_{\text{Particle Class}} \ \text{x} \ R^{\text{Stream s, t minutes}}_{\text{Particle Class}}}{\sum_{s=1}^{n} F^{\text{Stream s}}_{\text{Particle Class}}} \qquad (3)$$

In this paper, the samples collected from the batch tests have been broken up into different types of particle class groups and the batch test recoveries of these particle class groups have been calculated.

The following investigative approach has then been followed:

- Does a particle class group exhibit different batch test recovery rates in the different streams of the process?
- If no variation exists then it can be concluded that all particles within that particle class grouping float with the same rate and that this rate does not change during the flotation process.
- If there is a variation in the batch test rate in the different streams of the process, nodal analysis is applied to determine whether this variation in rate is due to particle modification within the process.
- If there is no modification in the flotation rate of particles within a process, but there is a variation in the rate of a particle class grouping in the different streams of the process, then it can be concluded that not all particles within the particle class grouping in the feed to the circuit have the same floatability and the particle class grouping is not suitable for use as a component in the property based flotation models.

ANALYSIS OF DIFFERENT TYPES OF PARTICLE CLASSES

Floatability as a Function of Size

It has been well documented that particle size affects flotation recovery rate. In the industrial flotation environment, flotation recovery exhibits a classical relationship with particle size (Morris, 1952; Imaizumi and Inoue, 1963; Trahar and Warren, 1976) - poor recovery of the fine and coarse particles and high recovery of the intermediate size fractions.

It is well accepted, however, that not all particles of a particular size float with the same rate. Flotation separation is based on the fact that different mineralogical species exhibit different degrees of hydrophobicity in the chemical environments employed in flotation circuits. It would therefore be expected that particles of different mineralogical composition within a single particle size class would exhibit different rates during flotation. This effect is observed within the Red Dog data set. Therefore, all subsequent analysis has been performed on particle class groups all of one size – the CS3 size fraction.

Floatability as a Function of Mineral Composition

Imaizumi and Inoue (1963), Steiner (1973) and Sutherland (1989) have all concluded that the greater the proportion of hydrophobic mineral in a particle, the higher its flotation rate constant. Sutherland (1989) also noted that floatability did not depend only on the proportion of the most floatable mineral in the particle but also the floatability of the other minerals in the particle. For example, a particle containing 30% chalcopyrite and 70% of another copper mineral floated faster than a particle containing 30% chalcopyrite and 70% pyrite.

The chemical conditions within the Red Dog circuit are designed to render the galena surface hydrophobic. In addition, galena in the Red Dog lead circuit exhibits a significant degree of association with other minerals. Using the mineral liberation data collected from the batch test samples, batch test recovery as a function of time was calculated for different mineralogical classes within the CS3 size fraction in the different streams in the Red Dog lead cleaning circuit.

The proportion of galena in a particle of this size has a significant impact on its recovery rate in a batch laboratory flotation cell (Figure 4(a)). The floatability of a galena mineralogical class is also a function of the floatability of its associated mineral/s. Liberated sphalerite exhibits higher recovery rates than liberated pyrite in the batch floats and the recovery rate of galena-sphalerite binaries is greater than galena-pyrite binaries (Figure 4(b)). These findings corroborate the findings of other researchers in this area.

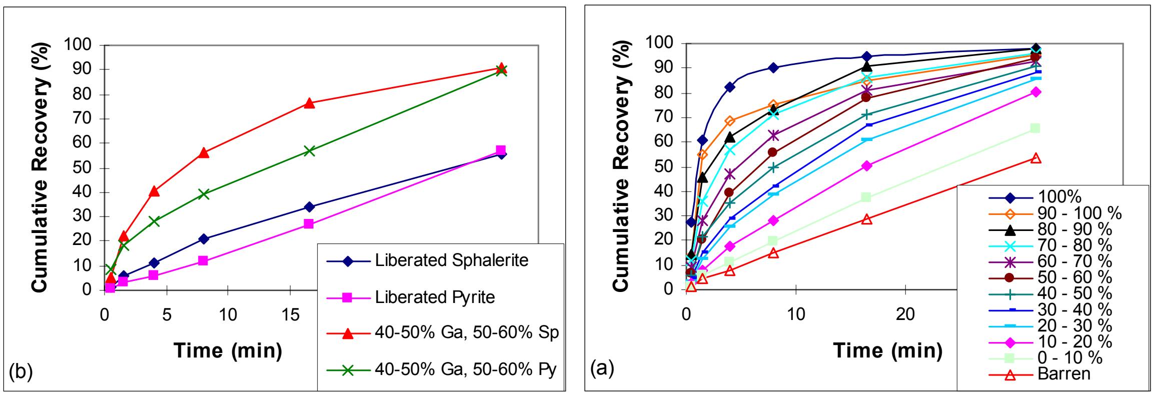

Figure 4. Batch test recovery of particles classes with defined mineral composition (CS3 size) in the rougher combined concentrate – feed to lead cleaning circuit. (a) as a function of galena content.(b) as a function of mineral composition.

The batch test recovery rates of these various mono-sized mineralogical classes in the different streams of the process were then compared to determine whether particles of similar size and mineral composition can be described by a single floatability constant. It was found that the different mono-size mineralogical classes exhibit very different rates in the different streams of the circuit. Figure 5 shows a typical example in which liberated galena of size CS3 floats significantly faster in the concentrate streams than it does in the tailing streams. The difference between the flotation rate constant of the fastest floating liberated galena and the slowest floating liberated galena in the CS3 size fraction is in the order of a multiple of 10.

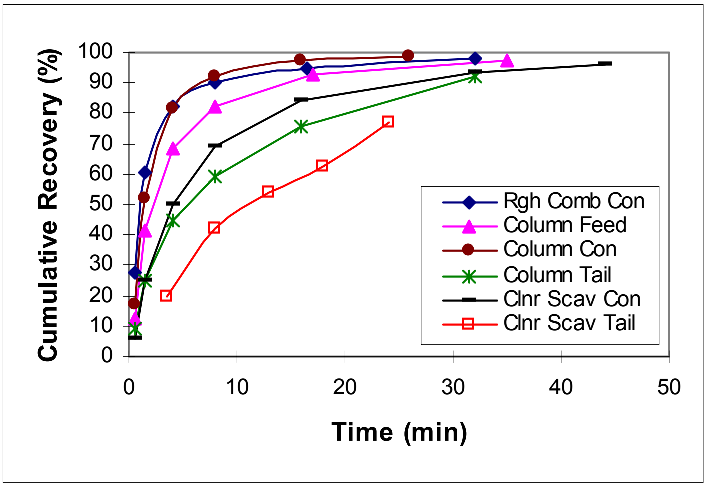

Figure 5. Batch test recovery of liberated galena of size CS3 in the different streams of the Red Dog lead cleaning circuit.

Nodal analysis is then used to determine whether this variation in rate is due to particle modification within the process or floatability distribution effects. Figure 6 shows the results of nodal analysis for the liberated galena in the CS3 size fraction in the four nodes in the Red Dog cleaning circuit – the overall circuit node, the column, the cleaner scavenger bank and the column feed sump.

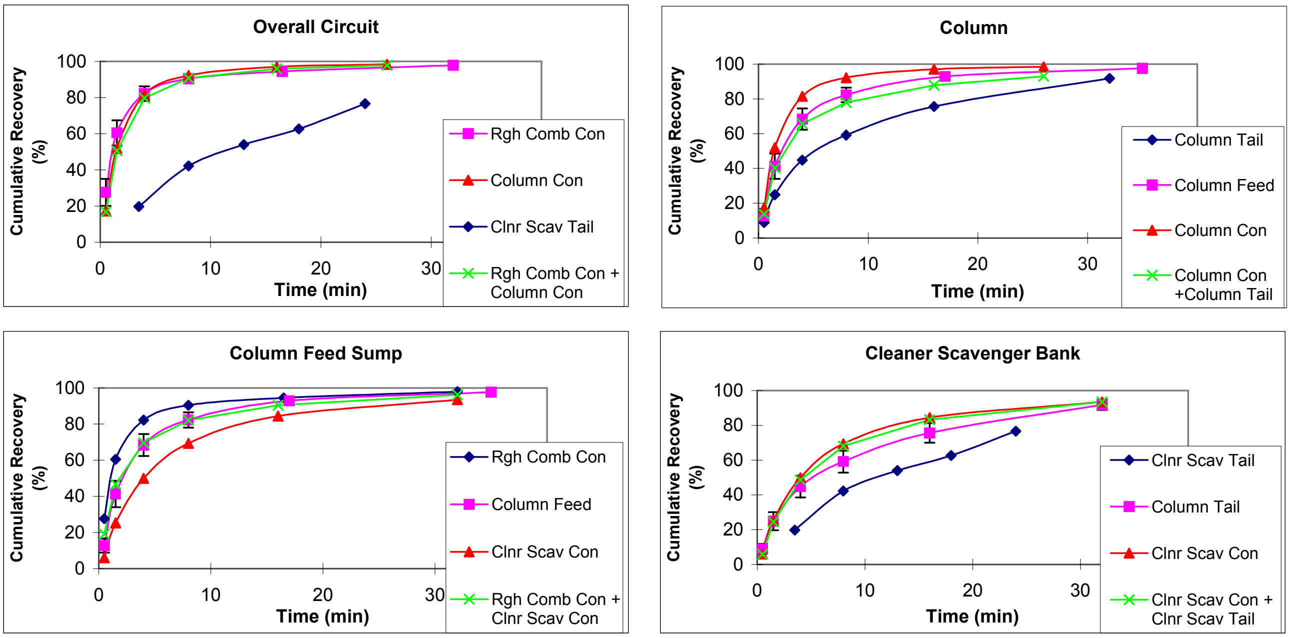

Figure 6. Batch test recovery rate of liberation galena (CS3) before and after the nodes in the Red Dog lead cleaning circuit.

It is clear that, although this size mineralogical class is exhibiting very different flotation rates in the different batch tests, the floatability of this particle class before each node in the process is equivalent to the floatability of this particle class after the node. This same type of result is achieved for all the different types of mono-sized mineralogical classes (eg. 40% Galena and 60% sphalerite particles CS3 in size) examined in the circuit. It can therefore be concluded that the variation in floatability of this type of particle class is due to a distribution of floatabilities within the particle class. Hence there is a property other than size and mineralogical composition that has a significant effect on flotation rate of particles in the Red Dog circuit. This property might be mineral surface composition, which is investigated in the next section.

Floatability as a Function of Mineral Surface Composition

Flotation is a consequence of interaction between bubbles and mineral surfaces. Mineral surface composition is a particle property that should influence floatability even more than volumetric mineral composition. Thus two particles with identical mineral composition but different mineral surface composition would be expected to float at different rates in a flotation system. This is observed within the Red Dog batch test data set. Figure 7 shows that particles with greater surface composition of galena float faster than particles of the same galena composition by volume, but with a lower proportion of galena on the surface (mineral surface composition was calculated as the percentage of particle perimeter in the images obtained from mineral liberation analysis)

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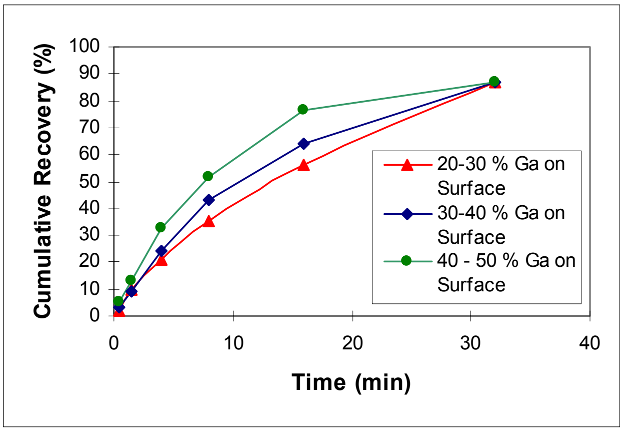

Figure 7. Batch test recovery in column tailing of different surface compositional particle classes of particles CS3 in size and 40-50% galena composition.

The batch test recovery rates of different particle size mineral surface compositional classes were studied to determine whether this surface effect is the reason for the floatability distribution observed for the different particle size mineralogical classes. Floatability of particles in a stream is a strong function of the proportion of galena at the surface of the particles (Figure 8(a)) but surface compositional classes exhibit a variation in flotation rate in the different streams of the circuit (Figure 8(b)). The floatability of a surface composition class is not significantly different to the floatability of the corresponding mineral composition class. This is in agreement with the findings of Sutherland (1989).

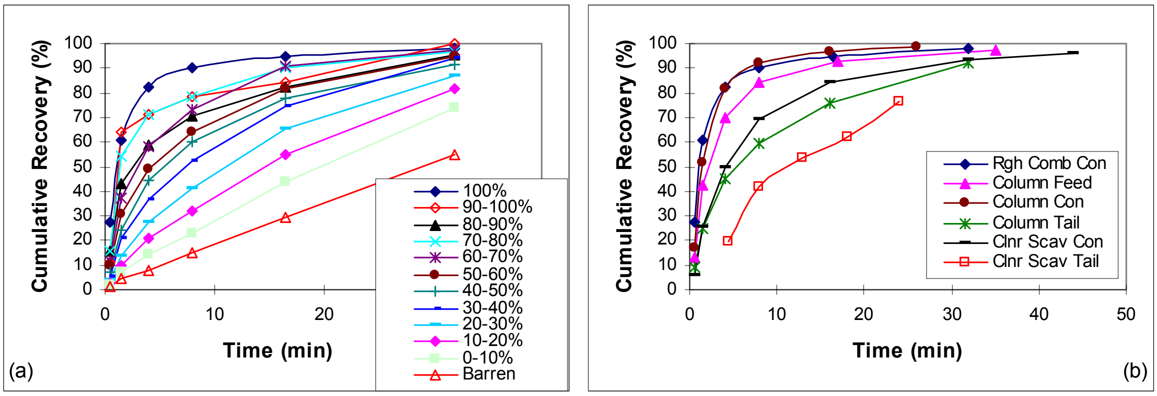

Figure 8. Batch test recovery of particles classes with defined surface composition (CS3 size) as a function of galena surface composition in the rougher combined concentrate. (a) of the Red Dog lead cleaning circuit, for particles of 100% galena surface composition. (b) in the different streams

Nodal analysis suggests that the floatability of these various surface mineral composition classes is conserved across the various nodes in the Red Dog lead cleaning circuit. In fact, none of the different types of particle classes studied in the Red Dog data set show a change in floatability across the nodes in the circuit.

Figure 9 shows the batch test recoveries of different types of particle classes (based on size, size by mineral composition and size by mineral surface composition) before and after the different process nodes in the circuit. The intercept and slope of the line of best fit for this data set are not very different from zero and one, respectively. Therefore it can be concluded that the ore floatability before a process is equal to the ore floatability after a process in this circuit.

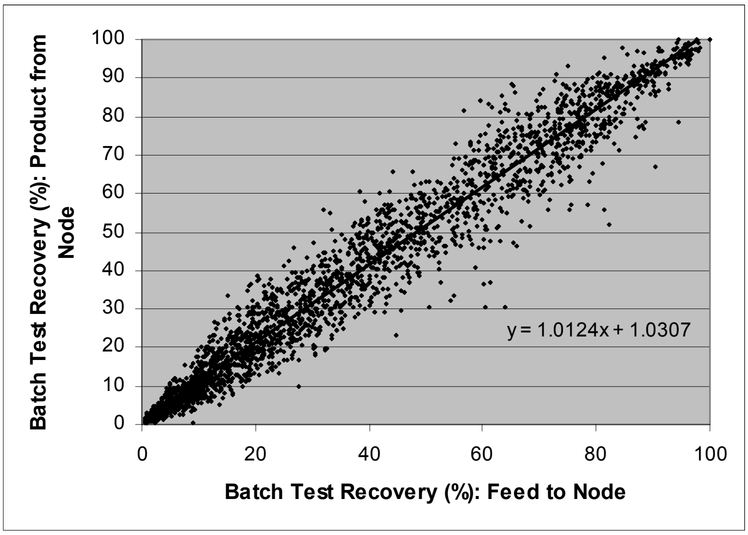

Figure 9. Comparison between the batch test recoveries before and after the nodes in the Red Dog lead cleaning circuit, of different particle classes with different size, mineral and surface composition properties.

DISCUSSION OF RESULTS

The flotation rate of a particle in the Red Dog lead cleaning circuit has been found to be affected by its size and mineral surface composition. Particles with the same size and mineral surface composition, however, did not exhibit the same flotation rate in the different streams in the Red Dog circuit. This variation in rate, investigated using nodal analysis, was not due to a change in floatabilities within the flotation circuit. Hence it is concluded that a distribution of floatabilites is present even within a size mineral surface composition class in the feed to the Red Dog lead cleaning circuit. Flotation results in the faster floating particles of a class reporting to concentrate streams and the slower floating particles of this same class reporting to the tailing streams.

Thus there must be another particle property affecting flotation in the Red Dog cleaning circuit. This particle property which gives rise to the observed distribution of floatabilities within a size mineral surface composition class could include:

- *Non-uniform collector coverage.* Chander and Polat (1994) found that at low collector dosages or collector starvation conditions a size liberation class exhibits a range of flotation rate constants whereas at high collector dosages a size liberation class can be described by a discrete flotation rate constant.
- *Non-uniform hydrophilic surface coatings.* Imaizumi and Inoue (1963) showed that liberated mono-sized pyrite displays a distributed rate constant after being subjected to oxidising conditions. Particles with hydrophilic oxidation coatings are observed to float more slowly than particles with clean surfaces (Smart, 1991). The degree of oxidation of particle surfaces in industrial plants is often found to be greater in tailing streams than in concentrate streams (Smart, 1991; Rumball and Richmond, 1996).
- *Non-uniform galena sliming of surfaces.* Chander and Polat (1994) noted that aggregation of particles results in a significant widening of the floatability distribution of a mineral in a size class and commented that this is due to particles being in a multitude of different "effective" size classes and therefore exhibiting different rates. Lange et al (1997) observed aggregation of sphalerite in a flotation system and found that the extent of aggregation has an effect on flotation kinetics.

It is suspected that the floatability of particles in the Red Dog lead cleaning circuit is not only a function of size and mineral surface composition but also a function of its hydrophilic surface coating.

Ethylene diaminetetraacetic acid (EDTA) was used to solubilise metal sulphide oxidation products from the surface of particles in the lead cleaning circuit feed stream. Solution analysis of these samples indicates high proportions of lead and iron hydroxyl species present on particle surfaces. X-ray photoelectron spectroscopy (XPS) analysis of solutions collected from the different streams in the Red Dog lead cleaning circuit during the survey indicates that surface oxygen exposure is greater in the concentrate than the tailing stream samples (Skinner, 1997). Skinner (1997) comments that "this result indicates a better flotation selectivity between less oxidised, hydrophobic surfaces and more oxidised, hydrophilic surfaces".

The above results from Red Dog would seem to be similar to those reported by Rumball and Richmond (1996). These researchers found that galena and iron hydroxyl species were present on particle surfaces in an industrial galena flotation circuit. These surface species formed rapidly (i.e. in the first stages of flotation) and had a significant effect on flotation, with the level of oxidation of galena in the concentrate being far less than that of galena in the tailings.

As for using property based flotation component models to represent the ore floatability within the Red Dog lead cleaning circuit, nodal analysis has indicated that only one of the two conditions required to develop a property based model has been satisfied, namely the fact that the ore floatability of any type of particle class does not change within the Red Dog lead cleaning circuit. The problem, however, is that no set of "measurable" properties were found with which all particles with those properties float with the same rate.

This type of analysis needs to be repeated at other industrial sites to confirm whether the observations noted in this paper are the norm or the exception. The fact that a number of studies have demonstrated that similar particles in the tailing of an industrial flotation circuit are more highly oxidised than in the concentrate streams indicates that the results obtained in this study may not be unique. If this proves to be the case, property based ore floatability representation in its current form will prove inadequate for use in predicting response in a flotation circuit model. Future research will need to concentrate on developing a hybrid ore floatability model. Empirical fitting techniques could potentially be used to determine both the components that best represent ore floatability for a particular system and the physical properties of these components.

CONCLUSIONS

The flotation rate of a particle in an industrial flotation environment is a strong function of its size and the mineral composition of its surface. It is a function not only of the proportion of the most floatable mineral on its surface but of the floatability of the other minerals on its surface as well.

In this paper, the properties of size and mineral surface composition are found to be insufficient to account for the distribution of ore floatability detected in the Red Dog lead cleaning circuit. It is suspected that non-uniform hydrophilic surface coatings also significantly affect the flotation of the particles in the circuit.

Nodal analysis, a technique that can be used to determine if the ore floatability of a particle class is changing within an industrial flotation circuit, shows that the floatability of a number of different types of particle classes within the Red Dog circuit did not change significantly during the lead cleaning stage. Hence it may be concluded that the surface phenomenon which is affecting flotation rate occurs prior to this stage of flotation.

There is a need to develop a new ore floatability distribution model that accounts for the variation in the chemical speciation on particle surfaces but incorporates mineralogical and surface properties to enable estimation of the recovery of a group of particles within a flotation process but also the change in floatability of a group of particles after reagent addition or grinding.

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