THE MFT: A STANDARDIZED METHODOLOGY FOR SCALE UP OF BATCH FLOTATION RESULTS.

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ABSTRACT

Scale up of batch flotation results to full plant performance is a difficult challenge because of several complicating factors such the difference in flow regime, mass transfer through the froth and the configuration of the industrial circuit. The MFT allows the measurement of true flotation kinetics based upon a rigorous experimental procedure and parameter extraction methodology. This paper describes the key aspects of the test and the phenomenological modeling applied to it.

KEY-WORDS: Flotation, Modeling, Batch Testwork, Scale-Up.
1. INTRODUCTION

Unlike physical properties such as particle size and liberation, the flotation rate constant is in fact an index that can assume different values depending upon the methodology applied for measurement. The MFT is a batch flotation test that allows ore type effects to be represented by a small set of kinetic parameters. The MFT is often used in conjunction with the FLEET simulator, both of which being based upon the same phenomenological models. The rational behind a rigorous experimental procedure and coherent model structure is to inhibit any operator interference upon final results. The flotation rates are thus standardized, providing a reliable basis for lab results to be translated into industrial plant performance. The MFT-FLEET methodology has been successfully applied for circuit optimization and production planning projects worldwide, encompassing copper, nickel, iron, gold, lead, zinc and coal operations (Dobby and Savassi, 2005; Bulled and McNees, 2005).

The basis for the MFT scale up approach is that the kinetics of bubble-particle collection is the primary source of flotation selectivity in both lab and industrial cells. The main objective of the test is to generate parameters that represent the true flotation mechanism in the collection zone of the batch cell, rather than trying to replicate the performance of the industrial circuit in the lab.

The standard MFT cell is equipped with a froth crowder to prevent the formation of a dead zone behind the impeller shaft. The compressed air line must have a main valve ahead of the flowmeter, so that the air flowrate can be set prior to the testwork. A t-shaped paddle allows uniform scraping action that is independent of the operator. Upon scraping, the paddle stands at 10 mm above the pulp level mark, so that the operator can only scrape the froth that is above a minimum froth layer. If the froth layer is thinner than that, there will be no concentrate being produced. The MFT is thus conducted with more frother than the nominal plant dosage to ensure strong froth structure as well as proper bubble size distribution in the pulp.

In order to assess the kinetics true flotation in the collection zone of the batch cell it is necessary to maximize the mass transfer through the froth, so that the particles that become attached to the bubbles in the pulp will end up in the concentrate, without any significant drop back from the froth. This situation, which is modeled as one of full froth recovery of attached particles (Savassi, 2005) is the reason for the standard froth removal rate during the MFT being relatively high: one scrape at every 2 seconds. Obviously the high scraping rate will also increase the degree of entrainment through the froth (Johnson, 1972, Trahar, 1981, Dobby and Finch, 1990). This problem is solved by means of a phenomenological model that allows true flotation and entrainment recoveries to be decoupled based upon the behavior of the gangue. The model also takes into account the differences in the flow regime (batch / perfect mixing) from the lab to the collection zone of the industrial cells.

In summary, the MFT aims at determining kinetic parameters, rather than trying to replicate plant performance in the lab. The standard experimental procedure has been designed to prevent any significant interference from the operator. Froth removal is relatively high in order to ensure that all particles that become attached to the bubbles in the pulp will report to the concentrate. True flotation and entrainment recoveries are decoupled by means of a phenomenological model. The upcoming sections provide more details about the MFT methodology.
2. EXPERIMENTAL PROCEDURE

A schematic of the MFT standard procedure is shown in Figure 1. As can be seen, four individual concentrates are collected at consecutive time intervals, with feed, combined concentrate and tail being divided into four size intervals. The combined concentrate is obtained by mixing the samples of the individual concentrates in proportion. Note that it is not necessary to conduct size analysis on individual concentrates.

Assigning kinetic parameters to metals does not always have physical meaning in terms of the separation of ore particles by flotation. For instance, iron metal in a copper ore can be part of chalcopyrite, pyrite and hematite, each of those mineral floating at a different rate. Therefore, the metal assays are converted to minerals before mass balancing the MFT experimental data. The conversion model is in general very simple, based upon mineral stoichiometric formulae.

Operating MFT conditions (chemical environment, airflow, impeller speed, etc) are determined by preliminary testwork. Time settings must be such that 30 to 50% of the valuable mineral is recovered in the first concentrate and about 70% in the second. As shown in Figure 2, the third and fourth concentrates are collected by the same length of time, with the valuable mineral reaching a plateau toward the end of the test. The top screen opening must be selected to retain around 5% of the mass of the combined concentrate. The fine screen opening is usually 38 microns. Finer screens or cyclone sizing are needed in case the feed is too fine. Once the settings have been determined, they must remain fixed for all subsequent tests in a project.
A key aspect in batch flotation testwork is the definition of the zero time, that is, the instant at which start marking the time. In the MFT procedure the operator must wait for a moment after switching on the air until the froth structure is fully develop. Zero time is defined as the instant the paddle first passes over the cell lip.

After noting the wet weight of the pulp at the start of the test, the cell is placed under the rotor, the impeller is switched on (with the air still off) and two feed sub-samples are siphoned out for assaying. While siphoning, the tip of the hose is moved all over the pulp volume to ensure the most representative samples. At the end of the test, another two sub-samples are siphoned out from the tail and the pulp wet weight noted again. Further details of the standard procedure can be found elsewhere (SGS MinnovEX web site).

3. PARAMETER EXTRACTION

3.1. The k-distribution

The principal objective of the MFT parameter extraction is to determine the k-distribution of the minerals in the ore. The k-distribution (Figure 3) is based on classes of particle flotation rate, similar to the way in which the Rosin-Rammler distribution is based on classes of particle size. Each class in the k-distribution, however, contains particles of different size and liberation. Ultrafines and poorly liberated particles belong to the slowest flotation class, while fully liberated particles to the fastest one (King 1976).

The k-distribution of a given mineral is described by three kinetic parameters:

- $R_{\text{max}}$: the ultimate recovery the mineral can achieve by true flotation.
- $K_{\text{avg}}$: the weighted average flotation rate, excluding unfloatable particles.
- Alpha: a measurement of the spread in the k-distribution.

As shown in Figure 3, the percentage of unfloatable particles (zero flotation rate) corresponds to $100 - R_{\text{max}}$, while $K_{\text{avg}}$ is the flotation rate at the mid point of the floatable range. Alpha is
usually between 1 and 5 for hydrophobic minerals and up to 10 for non-sulphide gangue. Clearly, a sharp difference in the k-distributions of gangue and valuable minerals is essential for separation both in lab and plant cells.

3.2. Decoupling true flotation and entrainment

The overall recovery values shown in Figure 2 arise from both true flotation and entrainment mechanisms. To be representative, however, the kinetic parameters must refer to true flotation exclusively. In the MFT parameter extraction the non-sulfide gangue (NSG) is used as a hydrophilic tracer to decouple true flotation and entrainment (Savassi, 2005). A partition curve is used to describe the effect of particle size upon the degree of entrainment. The entrainment parameters of the NSG are numerically adjusted to meet the following criteria:

- Most, if not all, of the NSG in the fourth concentrate is recovered by entrainment only.
- Most, if not all, of the NSG in the finest size interval is recovered by entrainment only.

The entrainment parameters of any other mineral (either hydrophobic or hydrophilic) are estimated from those of the NSG and the specific gravity of the mineral using a conversion model. Given the overall recovery of the mineral and the recovery by entrainment, allows the true flotation recovery to be estimated by difference, as shown in Figure 4.
3.3. Quantifying the impact of changes in the grind

When starting the MFT from dry rocks (for instance, a drill core sample in a production planning project), the grind that will be attained in the industrial plant is not usually known at the time the MFT is conducted. Therefore, in order to reconcile lab and plant data, it is necessary to quantify the impact of changes in the grind upon the true flotation recovery. The traditional approach to obtain such information is to conduct a series of tests at different grinds, which is rather undesirable from the perspective of cost, testwork duration and drill core consumption.

A significant feature of the MFT is the ability to calculate the impact of the grind upon flotation kinetics from one single test. This is based upon the assumption of first-order kinetics, according to which there is no competition for attachment on the bubble surface as long as the air is in excess in relation to the hydrophobic particles. Therefore each particle interval behaves independently of the others, allowing $R_{\text{max}}$ and $k_{\text{av}}$ to be estimated as weighted averages.
4. VALIDATION

Table 1 summarizes the results of MFT testwork conducted by different operators on the same test sample. All operators, except the fourth, had previous training on the standard MFT procedure. The test sample consisted of rougher feed collected in the plant using four separate buckets. Both the experimental procedure and subsequent parameter extraction were conducted independently for each sub-sample. The results obtained by the first three operators demonstrate that the MFT is highly reproducible, provided that the operator has the necessary level of training and the standard procedure is followed strictly.

Table 1: Reproducibility of the MFT

<table>
<thead>
<tr>
<th>Operator</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuSulf</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{\text{max}}$</td>
<td>90.5</td>
<td>91.2</td>
<td>89.5</td>
<td>84.3</td>
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<tr>
<td>$K_{\text{avg}}$</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.1</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>2.4</td>
<td>2.2</td>
<td>1.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Pyrite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{\text{max}}$</td>
<td>45.6</td>
<td>50.0</td>
<td>50.6</td>
<td>47.2</td>
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<tr>
<td>$K_{\text{avg}}$</td>
<td>0.7</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>5.8</td>
<td>1.7</td>
<td>3.3</td>
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<tr>
<td>NSG</td>
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<td></td>
</tr>
<tr>
<td>$R_{\text{max}}$</td>
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<td>6.9</td>
<td>5.7</td>
<td>6.7</td>
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<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
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<td>$\alpha$</td>
<td>10</td>
<td>10</td>
<td>10</td>
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Figure 6 shows size-liberation data obtained from benchmarking an industrial rougher bank. Each dot represents a size-liberation particle class, ordered according to the mass of mineral per interval of flotation rate. As can be seen, the entire dataset can be fitted by only three kinetic parameters per mineral, with the advantage of reduced experimental cost and implementation time. More important, the same family of curves can be used to describe true flotation kinetics of both gangue and valuable minerals.

![Figure 6: The k-distribution of valuable and gangue mineral measured directly from size-liberation data and fitted by the MFT kinetic parameters](image-url)
5. INDUSTRIAL APPLICATION

A total of ten surveys were conducted in a gold flotation plant over a period of fixed ore type characteristics (measured by MFT testwork). As usual in gold operations, the flotation circuit was very complex, aiming at maximum recovery. Cell dimensions at some stages were close to 30 times smaller than the roughers, as a consequence of the valuable mineral occurring in trace quantities. After mass balancing each one of the ten surveys individually, the weighted averaged assays were used to represent the base case of plant metallurgical performance. The strong relationship between base case and calibration results shown in Figure 7 demonstrates that the MFT-FLEET methodology is able to describe the plant with a high level of accuracy.

Figure 7: Calibration results for a complex gold plant

Benchmarking of an iron ore plant (reverse flotation of silica) was conducted in the midst of plant lay-out modification, resulting in the rare situation, shown in Figure 8, where parallel lines of industrial cells treated the same ore using different circuit configuration. This offered a unique opportunity for model validation by comparing model predictions against actual plant results. Both circuits were benchmarked, with the MFT being conducted on the plant feed. The FLEET simulator was then calibrated for Line 1 and the performance of the other lines simulated for three different surveys. As shown in Table 2, the MFT-FLEET model was able to successfully predict the impact of circuit reconfiguration from line 1 to lines 2 to 4.

Table 2 – Effect of circuit reconfiguration

<table>
<thead>
<tr>
<th>Survey</th>
<th>Model</th>
<th>Fe Recovery</th>
<th>SiO2 % Con</th>
<th>Actually Observed</th>
<th>Fe Recovery</th>
<th>SiO2 % Con</th>
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<td></td>
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<td>line 2-4</td>
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<td>91</td>
<td>3.7</td>
<td>2.3</td>
<td>88</td>
</tr>
</tbody>
</table>
Figure 8: Reconfiguration of an industrial flotation circuit

6. REFERENCES

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