Minerals Engineering 66–68 (2014) 2–12

Contents lists available at ScienceDirect

Minerals Engineering

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

Modern practice of laboratory flotation testing for flowsheet development – A review

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ARTICLE INFO

Article history:
Received 9 January 2014
Revised 18 April 2014
Accepted 24 April 2014
Available online 22 May 2014

Keywords:
Process Mineralogy
Sampling
Flowsheet development
Flotation testing

ABSTRACT

The flotation testing of sulphide ores for flowsheet development, or for the improvement of existing flowsheets in operations, has been practiced for a century or so. This practice has evolved at both laboratory and operations scales, as a result of contributions by various workers in this field. In this review, two major contributions to improved practice are discussed, viz Process Mineralogy and representative sampling. A description of modern best practice is proposed, particularly in the context of circuit changes or reagent selection and the use of mixed collectors. Process Mineralogy has contributed significantly by way of powerful information that reveals process implications such as those resulting from grinding strategies or flotation selectivity challenges. Only recently has the best practice of sampling been connected to flotation testing. High Confidence Flotation Testing, which incorporates appropriate sampling models, was proposed in 1995, and used Gy's minimum sample mass and Safety Line models. Statistical Benchmark Surveying, a method for extracting representative suites of survey samples from an operating plant, was added in 2005. A new addition is the small scale evaluation of floatability using the JKMSI, which enables the testing of small samples such as of drill core, and is demonstrating good agreement with operations data. Two generations of improved practice are reviewed. The first is when this practice was retrofitted to serve existing concentrators that had been conventionally designed, in a reactive approach. The second is serving new design opportunities before commissioning, where predictive value is added to the project with a more complete understanding of the process implications drawn from the sampling and characterisation of drill core. It is shown that when these connections are made and modern quality controls are applied to the flotation testing, much clearer conclusions are drawn, and tighter metal balances achieved, with better metallurgical performance. This all results in a lower level of error in the metallurgical test data, reducing project risk, offering significantly shorter project schedules, and better startup performance for the project, and also, as the results are more precise, allowing comparison of options with smaller recovery and grade gains.

Contents

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http://dx.doi.org/10.1016/j.mineng.2014.04.023
0892-6875/

1. Introduction

1.1. The project requirements of laboratory flotation testing

This review discusses flotation testing at the 1–2 kg batch scale. The metallurgical engineer arranging the flotation test programme typically wants clear, unambiguous results showing "before" and "after" test conditions that are significant, cogent, reproducible, and have a good probability of successful scale-up. All too often, however, much attention is paid to the flotation test treatment details, little is paid to the replication thereof, less is paid to the metal balances across the flotation tests, and regrettably even less, to the representativity of the ore sample being tested. Much of this situation is driven by limited budgets and demanding schedules, and is exacerbated by a limited understanding of what it takes to be able to claim that the ore being tested is a true sample – and not a specimen. Equally, it is a challenge to justify replicate flotation tests when the project manager does not see how the averaging process from the Central Limit Theorem works to his advantage (Box et al., 1978).

1.2. The milestone

Many regard the work of Henley (1983), as the turning point when conventional mineral processing and more modern mineralogy together engaged the overall perspective of geology, mineralogy, and implications for mineral processing, together with the ongoing advancement of mineral processing itself. This was largely enabled by the development of the QEM*SEM (later, the QEMSCAN) by Grant et al. (1976), and others such as Gottlieb; and of the MLA by Gu (2003), and others. The quantitative information that these instruments provide by way of mineral processing implications has made a significant difference to the focus of the mineral processor. However, the reliability and value of these measurements by the QEMSCAN and by the MLA are dependent to a large extent on the representativeness, or trueness, of the samples presented for measurement, and on the skill and experience of the mineralogist. Whilst several such as Gottlieb and Gu worked on advancing the capabilities of the QEMSCAN and the MLA respectively, others turned to investigating the importance and methodology of the sampling and reproducibility for both plant surveys and flotation testing (Restarick,1976; Hartley et al., 1977; Lotter, 1995a,b; Lotter, 2005). A theory of mixed collectors for synergy in flotation was consolidated and proposed by Bradshaw (1997) and Lotter and Bradshaw (2010), and was validated in a plant trial at the Eland Platinum operations in South Africa (Lotter et al., 2011). Others such as Wightman and Evans, 2012, developed new liberation models for grinding strategies. Together with many other significant contributions to the best practice, when consolidated and used as an integrated toolbox, flowsheet diagnosis and flotation testing became empowered with more effective capabilities. The overall outcome has been to shift the balance of technical activities away from reactive and more towards predictive.

1.3. 1st Generation: opportunities in conventionally-designed concentrators

Conventionally designed concentrators offer the modern Process Mineralogist much opportunity in plant performance improvement. This is because the fuller process implications from the mineralogy of the orebody, including variability, were not apparent or available at the time of design. The early generation of Process Mineralogy thus had to take a reactive approach to these opportunities so as to gain traction and credibility. The Mount Isa history is a good example of this.

An excellent example of the value of the practical application of Process Mineralogy comes from the Mt Isa operations from 1980s onwards has been reported extensively (Johnson et al 1998; Pease et al., 2006; Pease, 2010). From 1982, over a period of ten years as the ores became progressively more finely grained. Fig. 1 shows the resulting reduced Zn recovery as a result of decreasing sphalerite liberation, and Fig. 1 shows typical composite minerals responsible for the Zn tailings losses.

The insight to the reasons for the losses lead to the development of the IsaMill and inclusion of fine grinding in the circuit gave a substantial benefit to Zn recovery, as seen in Fig. 1.

The engagement of the Process Mineralogy toolbox with existing concentrators requiring performance improvements was well-demonstrated by Martin et al. (2003), in the case of the Lac des Iles expansion project in Ontario, Canada. The operation was expanded from a 2400 tonnes per day (tpd) operation to a much larger 15,000 tpd business. This required a new concentrator, which was designed from a prefeasibility study. One major difference between the two flowsheets was the 80% passing size (d80) size of the float feed, presumably recognising the need for a finer grind to liberate the discrete PGM. The change in d80 size was from 150 to 75 μm. Additionally the flotation residence time was increased from 19 to 55 min. The collector suite used was a mixture of Potassium Amyl Xanthate (PAX) and di-isobutyl dithiophosphate. A new heavy (750 g per tonne (g/t) milled) dose of talc depressant as Carboxy-Methyl Cellulose (CMC) was used in the rougher float. This was another change in the practice. Methyl Isobutyl Carbinol (MIBC) frother completed the reagent suite. Primary concentrates were reground in vertimills to a d80 size of 20 microns before cleaning in two separate cleaner circuits. Shortly after commissioning in October 2001, it became apparent that, whereas the concentrate grade was almost in agreement with the design value of 170 g/t Pd, the recovery of Pd was short of design. Actual Pd recoveries amounted to 67.5%, as compared to the design requirement of 82%.

Several plant surveys ensued, supported by mineralogy as well as size-by-size paymetal analysis of streams, each delivering clues to flowsheet improvement. The survey methodology was not