Minerals Engineering 116 (2018) 196–202

Contents lists available at ScienceDirect

Minerals Engineering

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

Sampling – A key tool in modern process mineralogy[☆]

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ARTICLE INFO

Keywords:
Sampling
Particulate materials
Minimum sample mass
Safety line
Semivariogram
Liberation

ABSTRACT

The powerful modern toolbox of hybrid Process Mineralogy for flowsheet development uses best practice sampling as one of its tools. In this paper, the three key components of best practice sampling are reviewed with case studies. These three components are:

1. Minimum sample mass.
2. Rules of unbiassed sampled extraction.
3. The safety line.

These excellent models and rules are not commonly taught in undergraduate programmes. In this review paper, which is intended as an introductory reference for those practitioners in Process Mineralogy who have not had exposure to the sampling models, simple and practical explanations are presented for reference. It is shown that finer particle size distributions lead to smaller minimum sample mass requirements.

While sampling theory allows us to estimate the error involved obtaining a mass of sample for mineralogical analysis it is also useful to account for errors in the process mineralogy measurements themselves. Examples of the confidence intervals on liberation measurements made on high- and low-grade samples are provided to illustrate the importance of sample size—specifically measuring sufficient numbers of particles—in these analyses.

1. Introduction

The best practice of sampling in mining and metallurgical engineering places the project or operation on a sound platform with reliable data which may be used for business decisions. This best practice works on a basis of the criteria that divide "samples" from 'specimens". In his 1979 seminal work on sampling of particulate materials, Gy stated that in most cases where a mining venture failed, the causes can nearly always be traced to unaccountable sampling errors because of the confusion between samples and specimens. He defined these two terms as:

- "**Sample**":
  - A part of the lot, often obtained by the reunion of several increments or fractions of the lot, and meant for representing it in further operations. A sample is not just any part of the lot; its extraction must respect certain rules that the theory of sampling intends to establish. The following key rules must be satisfied in order to declare material to be a sample:
    - The mass of dry solids in a sample must be equal to or more than the minimum sample mass, as determined by Gy's minimum sample mass models, with sufficiently low fundamental variance.
    - Any particle in the lot, of whatever size class, must be able to enter the primary sample with an equal probability of being excluded from the primary sample.

In other words, a sample differs from the lot only in mass. It has an identical composition to that of the lot.

- "**Specimen**":
  - A part of the lot obtained without respecting these (sampling) rules.

In short, best practice sampling amounts to three criteria:

1. How much primary sample must be taken
2. How the increments to that primary sample are extracted

☆ Originally Presented to MEI Process Mineralogy '17, Cape Town, March 2017. Edited New Revision (July 2017) submitted to the Minerals Engineering journal after peer review.

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http://dx.doi.org/10.1016/j.mineng.2017.07.013
Received 13 April 2017; Received in revised form 15 July 2017; Accepted 19 July 2017
Available online 27 July 2017
0892-6875/

3. How the primary sample is crushed and subsampled to a workable mass and size.

In a recently published monograph entitled "Process Mineralogy", numerous chapters describing relevant case studies in the practice of Process Mineralogy are provided (Becker et al., 2016). The reader is advised to add this reference to his or her reading.

This paper does not report any new material in the field of sampling. Its purpose is to set out a simple reference using prior published articles for the practitioner of Process Mineralogy, who probably has not had the opportunity of reading and understanding the basics of Gy's sampling models. Based on the observation of Minnitt, 2007, that details of Gy's sampling theories are only recently entering the undergraduate syllabi at universities, many professionals working in areas of the mining industry where sampling is important may not have been exposed to the details of these concepts. This view was supported by Holmes, 2010, who observed that the main reason sampling practice in an operation fails to meet with best practice is that the sampling responsibility is often left to people who do not have an appreciation of the significance and importance of sampling. It is acknowledged that since the seminal works of Gy, 1979, there has been a considerable amount of other excellent work performed by a number of workers, who have advanced his platform with suitable refinements describing relevant case studies. It is not the purpose of this paper to review this large volume of work in detail. Rather, a brief summary of these follows, to keep the article short and readable, for the reader's benefit.

A chapter entitled "Process Control" was written by Bartlett and Hawkins, 1987, in the SAIMM monograph entitled "The Extractive Metallurgy of Gold in South Africa". This chapter summarises the main components of the sampling models, and offers a few case studies. The entire sampling theory of Gy was re-explained in detail by Pitard, 1993. His book contains numerous case studies. A more recent publication summarises the essentials with case studies (Lotter, 2016).

1.1. Minimum sample mass M_s

One of the primary criteria for a sample is the minimum sample mass, or M_s. The entire set of sampling models written by Gy operate in the centimetre gramme second unit system (cgs). The primary sample mass must equal or exceed M_s for a selected fundamental variance, which is generally 8%, as recommended by Bartlett and Hawkins, 1987. The minimum sample mass and the fundamental variance are related to each other *by the sampling constant K as* in Equation (1).

$$M_s = \frac{K}{f_v} \tag{1}$$

where

M_s = minimum sample mass, grammes
K = the sampling constant, g/%^{2}
f_v = the fundamental variance, %^{2}

In this method, the fundamental variance f_v equates to the fundamental error. In order to relate this to the error resident in the mean assay grade $\bar{a}$, the square root of the fundamental variance is taken, providing the standard deviation. This standard deviation is then divided by the mean grade and expressed as a percentage of that mean error.

The sampling constant is obtained for a particular ore by an experiment in which the particulate material to be characterised is sampled and sized into a series of bound size classes, then weighed and assayed per size class. At the time of taking this sample, the sampling equation is unknown, so it cannot be declared to be a true sample until the testwork is done, the sampling equation becomes known, and the minimum sample mass declared and quantified. The equation for K is deliberately written in a form that is sensitive to variance of the paymetal grade in the sample. The form for the sampling constant K is shown in Equation (2).

$$K = \left(\left(\frac{g\cdot\bar{v}}{M\cdot\bar{a}^2}\right)\left(\sum_{i=1}^{n}\left((a_i-\bar{a})^2\cdot\left(\frac{M_i^2}{v_i}\right)\right)\right)\right) \tag{2}$$

where

M_s = representative sample mass, grammes
$\bar{d}$ = weighted mean particle diameter (or d_{50} size), cm
M_i = the ith fractional mass corresponding to d_i
v_i = volume of the ith ore particle, cm^3
$\bar{v}$ = mean particle volume in sample lot, cm^3
M = the lot mass, grammes
$\bar{a}$ = weighted mean sample grade of paymetal, expressed as grammes per
tonne of ore, or percent metal in ore
a_i = the grade of metal in the ith size fraction
d_i = the ith particle diameter, cm
f_v = the fundamental variance
g = the size range factor

The size range factor is the ratio between the d_{50} size and the d_{95} size, as in Equation (3). Both values are easily estimated from a cumulative percent passing size plot. It is thus obvious that the domain of g is confined to $0 < g < 1$.

$$g = \frac{d_{50}}{d_{95}} \tag{3}$$

Note that all of these equations use the centimetre gramme second system of units (cgs).

In the case of metallurgical plant process streams, which have undergone comminution and classification to liberate the valuable mineral(s), Gy's fifty-piece experiment has to be modified in order to obtain estimates of variance and thus a sampling equation. In this modification, the metallurgical process stream sample tested is screened over an appropriate set of test sieves into bound size classes, then each size class weighed, assayed, and measured for dry solids density. Each size class is then regarded as a "piece" in the experiment.

1.2. Rules of unbiased sample extraction

The following is a summary of the typical sample extraction rules recommended by Pierre Gy in his 1979 publication:

For cross-stream sample cutters, which extract primary samples of slurry from a continuously flowing (process) slurry stream, these rules are:

1. The sample cutter must be non-restrictive and self-cleaning, discharge completely.
2. The geometry of the cutter opening must be such that the cutting time at each point in the stream must be equal. For linear-path cutters, the cutter edges must be parallel, while for cutters travelling in an arc or circle (e.g. Vezin cutters) the cutters must be radial.
3. No materials other than the sample must be allowed to enter the cutter, e.g. dust or slurry must be prevented from accumulating in the cutter when in the parked position.
4. The cutter must intersect the stream in a plane normal to the trajectory of the stream.
5. The cutter must travel through the stream at a uniform speed. In this regard electrically-driven cutters are best.
6. The cutter aperture must be not less than three times the nominal topsize of the stream being sampled, with a minimum size of 10 mm for slurries for cases where the topsize is less than 3mm.
7. The cutter must have sufficient capacity to accommodate the increment mass at the maximum flowrate of the stream.