Minerals Engineering 46–47 (2013) 112–118

Contents lists available at SciVerse ScienceDirect

Minerals Engineering

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

"Memory loss" during mineral processing: Application to base metals traceability

Julie Machault [a,b,*], Luc Barbanson [a], Thierry Augé [b], Laurent Bailly [b], Alexandre Felicio [c]

[a] Institut des Sciences de la Terre d'Orléans (ISTO), Université d'Orléans/CNRS-INSU/BRGM, UMR 7327, 1A rue de la Férollerie, 45071 Orléans Cedex 2, France
[b] Bureau de Recherches Géologiques et Minières (BRGM), Direction des Géoressources (DGR/MIN), 3 Avenue Claude Guillemin, BP 36009, 45060 Orléans Cedex 2, France
[c] SOMINCOR, Minas Neves Corvo, Santa Barbara de Padroes P-7780-909, Portugal

ARTICLE INFO

Article history:
Received 19 November 2012
Accepted 27 March 2013
Available online 3 May 2013

Keywords:
Traceability
"Memory loss"
Mineral processing
Target minerals
Neves Corvo

ABSTRACT

Traceability of concentrates is required to introduce transparency in the trade of raw minerals. In this context traceability may be considered as a kind of inversion process: studying the product sold (i.e. the concentrate) in order to identify the original ore, in terms of ore deposit-type and if possible, location. The difficulty of making this inversion from concentrate toward bulk ore corresponds to the "memory loss" of the crude ore which occurs during mineral processing. Based on textural characterization and the chemical composition of the material at different steps of processing, as well as the minimum residence corresponding to each step, an estimation of this "memory loss" is proposed and the relations between memory loss and global kinetic rate of flotation are established.

"Memory loss" calculations are applied to the Neves Corvo plant. Throughout the process, the parameter of memory loss increases respectively from 0 to 195.06 for Cu; 0 to 46.15 for Zn and 0 to 0.43 for Fe. The "global memory loss", namely as the "experimental memory loss". For the Neves Corvo plant at the moment of the study this "experimental memory loss" was 14,146 min for Cu, 3408 min for Zn and 36 min for Fe. The results show that "memory loss" is greater for Cu than for Zn, thus emphasizing the importance of secondary elements for traceability purposes.

1. Introduction

The demand in mineral resources is increasing rapidly, but there is a lack of transparency in the trading of concentrated raw mineral materials. This is a concern of the French Ministry of Ecology, Sustainable Development and Energy (http://www.developpement-durable.gouv.fr/La-politique-des-ressources.html#s_curit; Braux and Christmann, 2012; Christmann et al., 2012). Traceability of raw material is also an issue for the automobile manufacturer Renault (Schulz, 2012).

Control of trade in the mineral industry would be facilitated by traceability of concentrates. Further, as pointed out by Kvarntröm and Oghazi (2008), traceability can also play an important role when a mixture of bulk ore from different mines, each with different characteristics, is treated: in some cases the use of such mixtures complicates subsequent mineral processing.

The traceability problem may be considered as a kind of inversion process: studying the product sold (i.e. the concentrate) to identify the original ore. The determination of the origin of a concentrate implies to involve up from the concentrate to the bulk ore, taking into account the transformation during mineral processing. In this study a new method, namely the "memory loss" method, is proposed to estimate the difficulty of realizing such an inversion that is to say which quantifies the loss of identifiable characteristics during mineral processing. In other words, the "memory loss" indicates the difficulty to realize an inversion from the concentrate toward the bulk ore. The "memory loss" method may also be useful, alongside other methods, as a tool to characterize a given mineral processing operation.

First, the "memory loss" method will be presented. Then its relation with sampling and flotation kinetics will be emphasized. Finally, an example taken from the Neves Corvo (Portugal) mineral plant will illustrate the use of the "memory loss" method.

2. The "memory loss" method

It could be useful first to recall some concepts concerning sampling for granular materials. A sampling method is described as equiprobable if, in a lot L, consisting of N fragments, all possible combinations of p fragments ($p < N$) have the same probability to form the sample E (Gy, 1996). This would occur if fragments were collected one by one and at random, and may also be achieved if the batch is homogenized (for example by mixing).

If an equiprobable sample is used to determine a characteristic of the lot, there will remain an incompressible error related to intrinsic properties of the material. This is the fundamental error of sampling related to the Constitution Heterogeneity (Gy, 1988).

* Corresponding author at: Institut des Sciences de la Terre d'Orléans (ISTO), Université d'Orléans/CNRS-INSU/BRGM, UMR 7327, 1A rue de la Férollerie, 45071 Orléans Cedex 2, France. Tel.: +33 (0)2 38 49 27 64.

E-mail address: j.machault@gmail.com (J. Machault).

0892-6875/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mineng.2013.03.021

According to Gy (1988), Constitution Heterogeneity is defined as the variance of h_j, where h_j is a parameter related to the fragment j and expressed as: $h_j = (\frac{a_j - a}{a}) \cdot (\frac{m_j}{\bar{m}})$ with a_j the value of the characteristic within the fragment j, a the value of the characteristic within the lot, m_j the mass of the fragment j and $\bar{m}$ the average mass of the N fragments. In Section 2.2, an analogy between "memory loss" and the parameter h_j of Gy's theory of particulate sampling theory is proposed.

The flow sheet of a mineral processing operation is always complex and is sometimes confidential. In order to compare either different treatments applied to similar ores or similar treatments applied to different ores, it is necessary to simplify the processing chain and extract the most crucial parameters. The proposed method does not attempt to describe the whole range of the numerous and complex phenomena involved in the mineral valuation process, but to provide a simplified holistic representation of the mineral treatment.

The mineral processing of a given ore can be considered as a process in which the memory characteristics of the bulk ore are removed. At a given step, namely i, of the process, this "loss" can be evaluated by a "memory loss" parameter (pml_i). For a given treatment the total estimated "memory loss" (ML) is defined. The "memory loss" calculated from the experimental data, will be called the experimental "memory loss" (ML_{exp}).

2.1. Definition of "memory loss" parameter pml_i

Let us consider a mineral processing operation of n steps. Each step is denoted with subscript i. t_i is the minimum residence time at step i and T_i is the value of a characteristic of the material flowing in the plant at this step. The characteristic can be: the metal content (primary or secondary, valuable or penalizing); the content in a main useful mineral or in gangue mineral; the grain size of a main useful mineral; or the content of chemical elements associated with the concentrated fraction. Finally, T_{BO} and T_{C} are the respective values of the characteristic in the bulk ore and concentrate. Note that when $i = 0$, $t = 0$ and $T_0 = T_{\text{BO}}$, and when $i = n$, $t = t_n$ and $T_n = T_C$.

We can define a parameter that estimates the "memory loss" of the bulk ore characteristic at step i for a given mineral processing operation:

$$\text{pml}_i = \left(\frac{T_i - T_{\text{BO}}}{T_{\text{BO}}}\right)^2 \quad (1)$$

To evaluate the "loss of memory" we choose to use a limited number of characteristics selected to facilitate the necessary measurements. In the parameter "memory loss", the overall mass flow at each stage of the processing is not considered. However the chemical composition at each stage in the mineral processing is taken into account; indeed, according to Eq. (1), it is a part of the definition of "memory loss" at a given stage of the mineral processing.

For $i = 0$, $t = 0$, $T_0 = T_{\text{BO}}$ and then $\text{pml}_0 = 0$.

For $i = n$, $t = t_n$, $T_n = T_C$ and then $\text{pml}_n = (\frac{T_C - T_{\text{BO}}}{T_{\text{BO}}})^2$.

It is worth noting that, for an effective mineral processing operation, the value of the "memory loss" increases during treatment. In the ideal case, the content of useful metal within the concentrate is equal to the metal content in the useful mineral. We also use a minimum residence time, because each grain may remain in the circuit indefinitely. The minimum residence time corresponds to the nominal time of a given stage. A graphical representation of the "memory loss" parameter during mineral processing is given in Fig. 1.

During comminution, only the characteristics of fragments (i.e. size and shape) may vary. Oghazi et al. (2009) proposed a monitoring evolution of these characteristics for the case of iron ore grinding. Texture analysis provides information about the distribution and release of minerals for the different fractions (Oghazi et al., 2009).

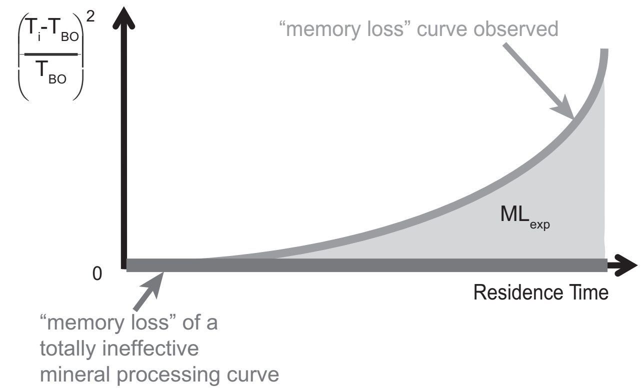

Fig. 1. Schematic plot illustrating the «memory loss» ML_{exp} parameter versus the residence time.

2.2. Perfectly ineffective mineral processing, sampling theory and loss of memory

To compare different mineral processing, or similar mineral processing applied to a different ore, it is necessary to have an invariant reference whatever the treatment and/or the ore considered. This reference could be a perfectly ineffective mineral processing defined as: $\forall i$, $T_i = T_{\text{BO}}$, which imply: $\forall i, \text{pml}_i = (\frac{T_i - T_{\text{BO}}}{T_{\text{BO}}})^2 = 0$. Note that a perfectly ineffective mineral processing is a perfect sampling process. Indeed at each stage of processing, the considered parameter is identical in the "tailings" and "concentrate" fractions.

According to the sampling theory of granular materials of Gy (1975), the contribution of a grain, namely j, to the value T_{BO} of the characteristic in the bulk ore can be estimated by: $h_j = (\frac{T_j - T_{\text{BO}}}{T_{\text{BO}}}) \cdot (\frac{m_j}{\bar{m}})$ where T_j is the value of the characteristic in the grain j, m_j is the mass of the grain, and $\bar{m}$ is the average mass of grains. Then h_j is the product of a first term, which represents the departure between the grain j and the bulk ore with respect to the considered characteristic, and a second term taking into account the importance of the grain j within the bulk ore. The "memory loss" parameter (pml_i) equals the square of this first term of h_j.

Choosing the perfectly ineffective treatment provides a reference that is: (1) unambiguously defined, (2) easy to use, and (3) consistent whatever the processed ore or the considered mineral processing. Using a measured characteristic reference in the concentrate would be less convenient, because the deduced value always varies from one ore to another. Finally, selecting a reference involved in Gy's theory will allow further developments taking into consideration the sampling theory of granular materials of this author.

Whatever the residence time, a perfectly inefficient mineral processing operation is characterized by a null "memory loss"; the metal contents in the bulk ore, the concentrate and the residue are all equal by definition. In plot of Fig. 1, the values of the parameter of "memory loss", at each stage i, are therefore distributed along a horizontal line (Fig. 1).

2.3. Definition of the "memory loss" (ML) of the bulk ore characteristics during mineral processing

The "memory loss" (ML) of a bulk ore characteristic during a mineral processing is defined as:

$$\text{ML} = \int_0^{t_n} \text{pml}_i \cdot dt = \int_0^{t_n} \left(\frac{T_i - T_{\text{BO}}}{T_{\text{BO}}}\right)^2 \cdot dt \quad (2)$$

where t is the minimum residence time. For $t = 0$, the value T of the studied characteristic is T_{BO}; at time t, the value T of the studied