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Evaluation of sampling systems in iron ore concentrating and pelletizing processes – Quantification of Total Sampling Error (TSE) vs. process variation

Karin Engström[a,b,*], Kim H. Esbensen[b,c,d]

[a] Quality Development Engineer in Sampling and Test Methods, Luossavaara-Kiirunavaara AB (LKAB), Kiruna, Sweden
[b] Aalborg University, Denmark
[c] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[d] Université du Québec à Chicoutimi, Quebec, Canada

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ABSTRACT

Process sampling is involved in grade control in all parts of the production value chain in mineral processing. Reliable sampling and assaying is essential to ensure final product quality, but the need for representative sampling is not always taken into account. By continuous control of the variability of sampling systems, a comprehensive understanding of the relationship between the sampling and process variability can lower the risk for overcorrections of process parameters due to sampling variability rather than process changes. Variographic characterization of process sampling makes it possible to assess all combined sampling and analytical errors from only 40–60 routine analytical values. The objective of this study is to evaluate total sampling variability in relation to process variability in the concentrating and pelletizing process sampling at LKAB. The results from the variographic analyses will form a basis for suggestions of possible improvements. The results show that variographic analysis is a powerful tool to evaluate both process variations and the variability of the sampling systems employed. The extensive access to time series data allow variographic characterization (quality control) of all critical measurement systems and locations. At the same time, periodicity and small changes in process variation can be detected and counteracted early, minimizing the risk for producing products out of specification.

1. Introduction

Process sampling is used for grade control in all parts of the production value chain in the minerals industry. Samples are extracted from slurry pipes, blender tanks, conveyor belts, stock piles and more, not always taking into account the need for representative sampling however. The process of sampling and assaying in all stages of sorting, concentrating and pelletizing is essential to ensure correct quality of the final product. One important aspect to reach correct quality within customer specifications is to be able to control the production process without overcorrecting for variability that derives from the sampling system rather than the process. The risk for this rises as the specification limits closes in on the variability of the sampling system itself. By continuous control of sampling systems, through variographic analysis, a comprehensive understanding of the relationship between the sampling - and process variability can lower the risk for overcorrections leading to unnecessary process changes (Minnitt and Pitard, 2008). Without meaningful data there is little point in trying to draw correct and reliable conclusions (Esbensen and Paasch-Mortensen, 2010). Cost, rather than the request for representative samples, is often the driving force for decision making by company management (Holmes, 2004, 2010). To be able to make these decisions correctly, there is however a need to fully understand the performance of the current process sampling systems in relation to the process variability.

There is no possibility to assess if a particular sample is representative by only looking at the sample itself (DS 3077, 2013), only the sampling process can be graded as representative or not. For one dimensional lots, i.e. process streams (Pitard, 1993), Theory of Sampling (TOS) offers variographics to fully characterize both process variability as well as all combined sampling and analytical errors generated by the complete sampling system. The variographic characterization of the process sampling makes it possible to assess the Total Sampling Error (TSE) from only 40–60 routine process analytical values (Esbensen et al., 2007).

* Corresponding author at: LKAB, SAK Lab, 981 86 Kiruna, Sweden.
E-mail addresses: karin.engstrom@lkab.com (K. Engström), khe.consult@gmail.com (K.H. Esbensen).

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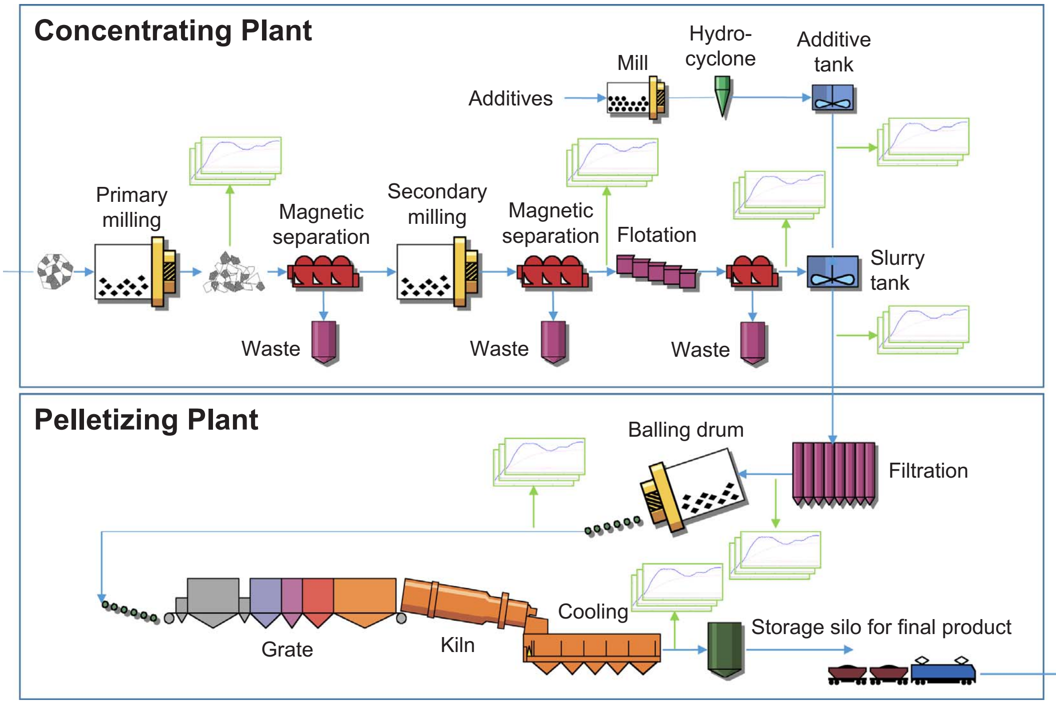

Fig. 1. Overview of the LKAB concentrating and pelletizing process. Sampling locations evaluated through variographic characterization are indicated.

1.1. Objectives

Luossavaara-Kiirunavaara limited company (LKAB) is a state owned mining company in the north of Sweden. The core business is producing high quality iron ore pellets for blast furnace and direct reduction steel making. Quality control in all parts of the concentrating and pelletizing process is important and continuous sampling and analysis is performed at all important process steps. Important quality characteristics for process control include iron and silica grade, moisture content and pellet size distribution.

The objective of this study is to evaluate TSE in the concentrating and pelletizing process sampling at LKAB with variographic characterization, see Fig. 1. By the use of existing process data, the performance of the sampling systems will be evaluated with regards to sampling variability in relation to process variability and control. The results from the variographic analyses will form a basis for suggestions of possible improvements of the evaluated sampling systems. The general theoretical methodology for variographic characterization, as well as the calculation of the relative semi variogram is fully described by e.g. Minnitt and Esbensen (2017), Esbensen and Paasch-Mortensen (2010), Minnitt and Pitard (2008), Pitard (1993), and will therefore not be described in detail here. The objective of the present study is to exemplify the practical application of variographics in a large-scale mineral processing industry; iron ore concentrating and pelletizing, illustrating the possibilities for improved process interpretation and control.

The main processes of LKAB is described by Fig. 1. Three stages of milling and magnetic separation is followed by floatation to remove phosphorus. A final magnetic separation stage is performed to reach desired iron grade. The magnetite slurry is mixed with specific additives dependent on final product and filtered to correct moisture content for successful balling in balling drums. After sieving, the correct size distribution of raw pellets is sintered in the grate-kiln oven. The final product is stored in silos and loaded to trains for delivery to the harbour and further sea transport to customer.

2. Theory

Variography is a powerful tool for the study of serial datasets. With the use of the relative semi-variogram all forms of heterogeneity fluctuations or variability present in the data can be quantified, short range (random discontinuous term), long range (trend term) and periodic (cyclic term) variabilities (Pitard, 1993). Variographics allow separation of variability stemming from the sampling system from the true process variability. The so called nugget effect of the variogram is defined by extrapolation to the y-axis intersect of the variogram. This value is an important parameter as it is a estimation of the total error variance of the current measurement system (Minkkinen, 2013; Gy 1999). The nugget effect is termed V(0) and is often calculated by extrapolation of the variogram to the intersect of the y-axis. In chronostatistics, i.e. the process variogram, the nugget encompasses the short range random variability from sampling, preparation and measurement (Pitard, 1993). These total measurement system error contributions can be subtracted from the observable process variability in order to gain insight into the true process variability.

A telling aspect of the variogram is the ratio between the nugget effect and the sill, expressing the fraction of the observable process variability made up by the measurement system error (Esbensen and Paasch-Mortensen, 2010). If the sampling system accounts for a major part of the total variability (above 20–25%), the possibilities for successful process control are reduced, as the actual process variations are increasingly covered by the variability (noise) of the sampling system (Minnitt and Esbensen, 2017; Minnitt and Pitard, 2008). The most important parameters of the semi-variogram are presented in Table 1.

The method of variographic characterization of sequential data, including calculation of relative semi-variograms has been described in numerous reference publications, see e.g. Minnitt and Esbensen (2017), Esbensen and Paasch-Mortensen (2010), Minnitt and Pitard (2008) and Pitard (1993) and need no detailed description here.

In this study, relative variograms have been calculated for existing process control data with the purpose of evaluating precision of the sampling systems in concentrating and pelletizing plants at LKAB and to assess the possibilities to control the process with the use of current sampling systems. Possible improvements or necessary further