SAMPLING IN MINERAL PROCESSING – REVIEW OF PRACTICES

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ABSTRACT The past few decades have witnessed a significant progress in the development of various sampling and control methods, sampling equipment, and standards. Sampling of various product streams in mineral processing plant is an extremely important process in providing information that allows the management and optimisation of the operation in a processing plant. In order to obtain a representative sample of the lot, we must ensure that all material in the process flow should have an equal probability of being sampled. The primary reasons for sampling in mineral processing plants, as well as some basic statistical concepts are discussed in this paper. However, the main aim of this review is to explore and summarise the various types of sampling equipment (mechanical, manual and on-line), sampling procedures (methods), and practices carried out in modern mineral processing plants.

Keywords: sampling, sample, mineral processing, practices, procedures

ОПРОБВАНЕ ПРИ ОБОГАТЯВАНЕТО НА ПОЛЕЗНИ ИЗКОПАЕМИ – ПРЕГЛЕД НА ПРАКТИКАТА

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РЕЗЮМЕ. През последните няколко десетилетия се наблюдава значителен прогрес в разработването на различни методи за опробване и контрол, както и стандарти и оборудване за осъществяване на процеса опробване. Опробването на различни технологични потоци е много важен процес, осигуряващ информация, чрез която управляваме и оптимизираме работата на обогатителната фабрика. С цел осигуряване на представителна проба, трябва да гарантираме, че всички части на материала който се опробва, трябва да бъдат равнопоставени по отношение на вероятността да попаднат в крайната проба за анализ. В настоящата разработка са разгледани главните причини, поради които се осъществява процеса опробване в обогатителните фабрики, както и някои основни статистически понятия. Основната цел на този преглед е да се проучат и обобщят разнообразните опробващи устройства (механични, ръчни и онлайн устройства), практики и процедури (методики) на опробване, прилагани в съвременните обогатителни фабрики.

Ключови думи: опробване, проба, обогатяване на полезни изкопаеми, практики, процедури

Introduction

According to Gy (1982) and Pitard (1993), the fundamental rule for correct sampling and sample processing is that all parts of the ore, concentrate or slurry being sampled must have an equal probability of being collected and becoming part of the final sample for analysis; otherwise, bias is easily introduced and the sample will not be representative.

Before doing into detail concerning the processes of sampling practice, measurements and procedures, it is worth mentioning some of the terms commonly used in this field. Authors such as Morrison et al. (2008) suggest the following definitions:

- Best practices – The most precise method of performing a measurement with the information and equipment available at that time;
- Bias – The difference between the mean result of one or more measurements and the true value of the quantity being measured;
- Cross-Stream Sampler – A mechanical sampling device that is used to collect an increment from a falling stream of material either from a conveyor or particulate material or from a slurry stream;
- Increment – A quantity of material collected in a single operation of a sampling device;
- Lot – A defined quantity of the material being measured to which the mass and analysis is applicable. For accounting purposes, a weighed average sample of all the production or shipment batches making up that lot is prepared and submitted for analysis;
- Representative – A sample can be said to be representative of the lot from which it was taken if the mean square of the total sampling accuracy is less than some standard of representativeness;
- Sample – A subset of population chosen in such a way that it can be taken to represent the population with respect to some characteristics.

Overall, sampling procedures cover the practice of selecting representative quantities of test material in the field in order to evaluate bulk materials. Examples of the test materials are bulk granular solids, slurries, sludge, grains, and solid fuels. It is necessary to be able to sample bulk materials during shipment and during processing operations.

Taggart (1945) defined sampling as: "The operation of removing a part convenient in size for testing, from a whole which is of much greater bulk, in such a way that the proportion and distribution of the quality to be tested (e.g. specific gravity, metal content, recoverability) are the same in both the whole and the part removed."

After the primary sampling stage, the increments taken by the mechanical sampling system are usually processed on-line to reduce the sample mass that is taken back to the laboratory for final sample preparation and analysis. Primary increments are either processed individually or combined into a sub-lot or gross sample in a number of stages of crushing, division and drying if necessary (Morrison et al., 2008).

Very important decisions, such as process flowsheet developments, methods of improving recoveries and grades, and reducing losses etc., are usually made in a metallurgical plant thanks to the results obtained from sampling processes. Logically, this confirms the need for reliability of the samples and the methods used in obtaining them, as well as careful control and quantitative determination (Chibwe et al., 2005).

Morrison et al. (2008) highlight the principal steps in establishing a sampling regime and they are listed below:

- Determine what needs to be sampled – a shift production, a stockpile or a shipment;
- Specify the purpose of sampling and the required precision – the purpose of sampling is particularly important as it determines the overall precision required;
- Identify the nominal top size of the material to be sampled and, hence, the dimensions of the sample cutter and mass of increment;
- Characterise the variability of the material being sampled for determining the number of primary increments needed to obtain the required sampling precision;
- Determine the sampling intervals in tonnes for mass-basis sampling and in minutes for time-basis sampling;
- Establish the procedure for combining increments into sub-lot samples or a gross sample in order to achieve the required overall precision of sampling, sample preparation and analysis.

The sampling intervals mentioned above are usually based on time or mass principle, i.e. mass-basis and time-basis systematic sampling. Morrison et al. (2008) suggest that when mass-basis sampling is adopted, the increment masses extracted need to be of almost uniform mass to ensure that each increment caries the correct weighting information. This could be achieved by using a variable speed cutter, discussed below, that adjusts its speed increment-by-increment so that it is proportional to the flow rate at the time of taking the increment, thereby ensuring that the increment masses are almost uniform. On the other hand, when time-basis sampling is adopted, the increment mass must be proportional to the flow rate, so a fixed speed cutter needs to be used. Both mass-basis and time-basis sampling are equally acceptable, although time-basis sampling is easier to implement and does not require measurement of flow rate and control of cutter speed.

Sampling in concentrators

Holmes (2010) suggests that the most appropriate location for sampling a process stream in a mineral processing plant is at the discharge point of a conveyor belt or chute where the complete stream can be intersected at regular intervals.

This article begins with a look at the manual, mechanical and on-line sampling techniques, requirements, and instruments that are most widely used in practice.

Manual Sampling

According to Morrison et al. (2008), the requirements for manual sampling of a process stream are very similar to those for mechanical sampling, even though manual sampling can only be conducted at relatively low flow rates.

Smith (2004) points out that the most important and influential aspect of sampling, in the Gy sense, is the correct sampling equipment which is also used properly. Conversely, the incorrect equipment commonly results in biased samples. Another essential conclusion, according to Smith (2004), is that the sampling equipment may not perform well in practice even though it is designed correctly. Operators (those taking the samples) may not be properly trained in correct sampling. Without correctness, sampling bias is introduced and sampling variation is increased, sometimes substantially, beyond the unavoidable statistical sampling variation. Since samples are only as good as the sampling systems that generate them, incorrect sampling will remain undetected without an examination and evaluation of the sampling systems.

Fig. 1. Sampling from the top of conveyor belt (Holmes, 2010)

Taking a manual sample from the top of conveyor belt (Fig. 1) is undesirable, because the material at the bottom of the conveyor is ignored, therefore the representativeness of the sample is not provided. Furthermore, sampling from the top of railway wagons (Fig. 2A) or from the side of a stockpile (Fig. 2B) it is not recommended due to the segregation which occurs in stockpiles because the coarser particles tend to rill down the outside leaving the finer particles in the centre of the stockpile, thus introducing unsatisfactory results.

Fig. 2. Taking samples from the top of railway wagons (A) and the side of stockpiles (B) (Morrison et al., 2008)

According to Petersen et al. (2005) due to the material heterogeneity, the Grouping and Segregation Error (GSE) is usually inevitable in any sampling practice. The GSE mostly depends on the level of fragment segregation which strongly depends on the material differences in particle size, shape, and density. Segregation usually occurs when dealing with particulate materials, both stationary and in motion.

Figure 3 illustrates the effect of sampling a segregated (Fig. 3A) and mixed material (Fig.3B). The authors (Peterson et al., 2005) suggest that it may be appreciated how compositing a number of small samples gives a much more representative sample than extracting only one large sample of the same mass/volume. In order to minimise the grouping and segregation error, mixing or blending the material before primary or/and secondary sampling should be carried out; if this is not possible, a composite sampling is the most appropriate action that must be taken.

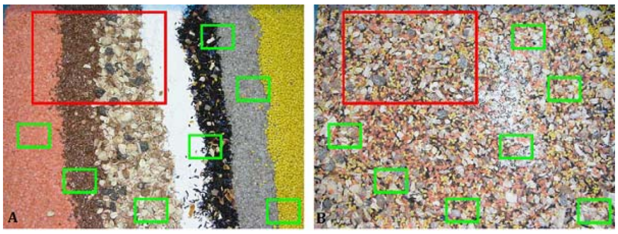

Fig. 3. Illustration of segregated (A) and mixed (B) material (Peterson et al., 2005)

Mechanical Sampling

Sample cutters are known as devices for taking samples from a broad range of locations in the mineral processing plant, and the portions of material extracted by a single operation of a sample cutter are referred to as ‘‘increments’’. Holmes and Robinson (2004) suggest that the two main classes of sample cutters are ‘‘cross-stream cutters’’ which pass a bucket or a chute through a stream of falling material, and ‘‘cross-belt cutters’’ which remove material from a conveyor belt by passing a device across the belt, generally by having it rotate around an axis that is parallel to the belt.

Cross-Belt Cutters

As reported by Morrison et al. (2008), cross-belt cutters are widely used in the resource industries, especially as cutters that take samples in-situ from conveyor belts, as well as for ore, concentrate, and particularly coal sampling rather than falling stream cutters. Generally, the cross-stream cutters are cheaper to install and the increment mass is smaller than for falling stream cutters.

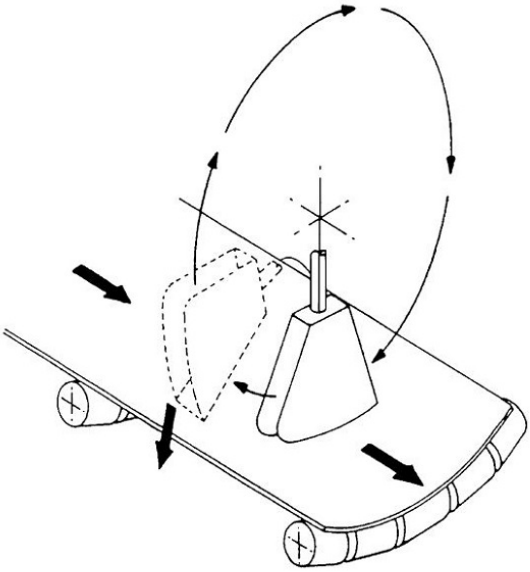

Fig. 4. Cross-belt sample cutter illustration (Holmes and Robinson, 2004)

The most appropriate cross-belt cutters (Fig.4) should comprise cutter blades which delimit the sample but use other parts of the cutter to extract the sample, as reported by Holmes and Robinson (2004). However, even the best designed cross-belt cutters are likely to undersample any material, therefore they are not recommended for metallurgical accounting for the following reasons (Morrison et al., 2008):

- Generation of considerable turbulence when passing through the stream, resulting in loss of material that should have been included in the increment, as well as in the introduction of other material into the increment that should not be included;

- Cross-belt cutters could leave a layer of material on the conveyor belt if the profile of the belt does not match the cutter path and/or if the skirts at the bottom of the cutter are not correctly adjusted. An example of an incorrectly designed cross-belt cutter installation where the conveyor profile does not match the cutter trajectory is shown in Figure 5 (Docherty, 2005);

- It is virtually impossible to check visually whether a cross-belt cutter is performing correctly in terms of correct increment delimitation and increment extraction because considerable turbulence is created as the cutter traverses the stream.

Fig. 5. Cross-belt sample cutter- the conveyor belt profile does not match the trajectory of the cutter (Docherty, 2005; Morrison et al., 2008)

Gy (1992) considers the “Pollock samplers”, “hammer samplers”, “strip samplers”, and “swing samplers” as having “definitely incorrect extraction” because they undersample the material which is near the belt.

Linear Falling Stream Samplers

The appropriate design of sample cutters is of a great importance with respect to obtaining representative samples from process streams. The installation of the falling stream linear sampler (Fig. 6) at the discharge end of a belt conveyor is the internationally preferred method of sampling the conveyor. Correct design of the cutter shape and positioning is critical to obtaining a correct representative sample (http://www.flsmidth.com, 2018).

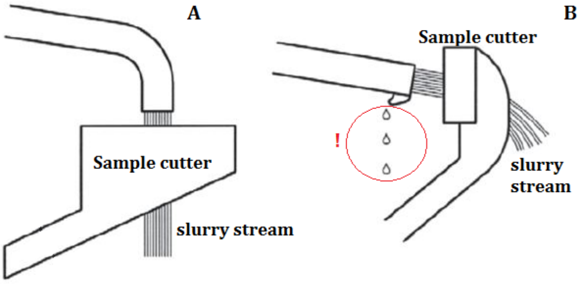

Fig. 6. Correct (A) and incorrect (B) slurry stream sampling (Holmes, 2010)

One of the world’s pioneers in the design and manufacture of sampling and sample preparation equipment is the Australian company Essa which was acquired by FLSmidth in 2011. Now Essa Australia Limited are worldwide distributors of a range of electric motor driven ball screw samplers that find particular application in collecting representative samples from the material stream being discharged over the head pulley of a belt conveyor. These are setting new standards of performance and reliability that traditional chain, pneumatic, and hydraulic drive samplers can find difficult to match.

Fig. 7. Ball Screw Linear Cross Stream Sampler - Essa® Sampling Systems (http://www.flsmidth.com, 2018)

For cross-stream cutters (Figures 7, 8), the commonly accepted conditions for correct sampling are based on Gy’s consulting experience and on trials discussed by Gy and Marin (1978). As mentioned by Holmes (2015), the cutter aperture must be at least 3 times the nominal top size (d) of the material being sampled, i.e. 3d, to prevent preferential loss of the larger particles, subject to a minimum of 10 mm for fine dry solids. The cutter speed is also an important design requirement for falling stream cutters and according to Gy (1982) must not exceed 0.6 m/s

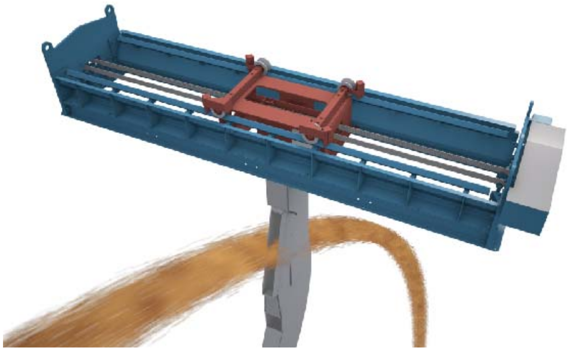

Fig. 8. Belt Drive Linear Cross Stream Sampler - Essa® Sampling Systems (http://www.flsmidth.com, 2018)

The synchronous belt drive samplers (Fig. 9, SBD), engineered and manufactured by FLSmidth (Essa®), are used where the sampler drive has to be mounted below the discharge point. A single electric motor drives two synchronised toothed belts located at either side of the ore stream. This allows the sampler drive and cutter to operate on the same plane across the falling ore stream.

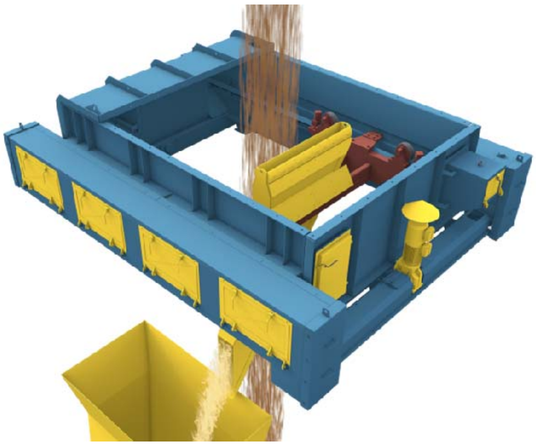

Fig. 9. Synchronous Belt Drive Linear Cross Stream Sampler - Essa® Sampling Systems (http://www.flsmidth.com, 2018)

On-line sampling and analysis

Wills and Napier-Munn (2006) suggest that the key to effective control is online chemical analysis which produces real-time analysis of the metal composition of process streams. On-line X-ray fluorescence (XRF) analysers provide elemental assays from process flow streams and are now considered standard hardware on large scale flotation plants (Garrido et al., 2008). Furthermore, various measurement techniques have been used for on-line particle size analysis of slurries. The main analytical procedure in comminution circuit performance measurement is the determination of the size distribution of the solids in the samples taken during surveys. Many techniques exist for particle size analysis (Napier-Munn et al., 2005). Grinding circuit reduces particle size to a desired distribution. It is important to measure the grinding product particle size for grinding circuit monitoring and control. On-line particle size measurement is the industry practice today.

Fig. 10. Courier® slurry analyser system (www.outotec.com, 2018)

Nowadays, many mine sites use analysers to replace the time-consuming and labour-intensive laboratory methods for routine process control assays. One of the main suppliers of advanced process automation systems, control solutions, and intelligent instruments to the mineral and metal processing industries is the well known Finland Company Outotec Oyj. One of the primary uses of on-stream slurry analysers is in flotation control. Outotec's Courier analyser (Fig. 10) family, for example, can measure elemental content in each stream of the flotation process.

The Courier range of analysers includes Courier 5X SL, Courier 6X SL, and Courier 8 SL (Table 1). It cannot be sufficiently specified how essential it is to choose the most suitable analyser since this entirely depends on your application and on the primary process control goal (Outotec SEAP Customer eNewsletter, 2018).

Several points of the process can be sampled with some modern XRF analysers handling up to 24 streams and with most machines capable of analysing for several elements and solids content. The time to analyse a single sample can range from 15 s to a minute, and the sampling cycle time is between 10 and 20 min — depending on the number of sample points attached to the analyser (Laurila et al., 2002; Bergh and Yianatos, 2011).

Table 1.
Various courier analyser details

	Courier 5X SL	Courier 6X SL	Courier 8 SL
Source	X-ray tube (35 W)	W-ray tube (200 W)	Laser
Detector	WDXRF / EDXRF	WDXRF / EDXRF	LIBS
Elements	Ca and heavier	Ca and heavier	Li and heavier
Measurement time	30 – 120 s	15 – 60 s	60 – 300 s
Sensitivity	0.01 %	0.003 %	0.05 %
Samples	Up to 12	Up to 24	Up to 12
Typical applications	Base metals, Fe ore, rare earths	Base metals, Fe ore, rare earths, precious metals, PGMs	Fe ore, phosphates, Ni concentrates with Mg/Si impurities, sulphide (Au), $CaCo_3$, coal

It is well-documented that different particle size measurement techniques will yield different results. This is due to the fact that each technique measures a different dimension of a three-dimensional particle. For on-stream particle measurement, the focus is on repeatability, precision, and reliability of the equipment (Kongas and Saloheimo, 2008).

An example of a commonly used analyser that provides real-time, accurate particle size distribution measurements is the PSI 500i Particle Size Analyser manufactured by Outotec. Usually, PSI 500i is used in: monitoring grinding circuit products with wide or bimodal distributions; monitoring regrind circuits; controlling thickeners for optimum water recovery; monitoring mine backfill and tailings disposal; monitoring feed to slurry pipeline product quality measurement for industrial minerals.

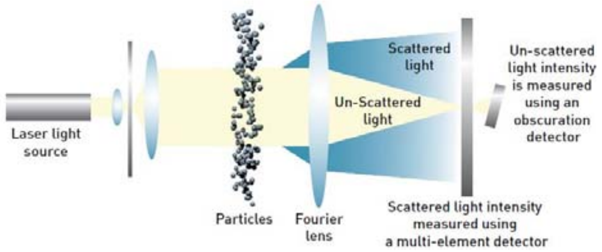

Fig. 11. Principle of laser diffraction measurement (www.outotec.com, 2018)

Laser diffraction (Fig. 11) gives a consistent volumetric particle size analysis result without any external calibration which is a significant advantage. There is a small difference to the particle size analysis measured by other methods, such as sieve analysis. However, the repeatability and precision over a wide particle size range are the most important features in process control applications. Plant results have shown that laser diffraction is a viable method for the on-line particle size analysis of wet slurries in mineral processes (www.outotec.com, 2018).

Conclusion

The objective of all sampling is to obtain a representative sample. This is an ideal concept which is rarely realised in practice. As mentioned above, the fundamental rule for taking representative samples is that all parts of the material sampled must have an equal probability of being collected and becoming part of the final sample for analysis. There is little point in using the latest metallurgical accounting package to improve metal balancing if the data used are unreliable in the first place. As pointed by Holmes and Robinson (2004) and Morrison et al. (2008), the financial consequences can be huge, ranging from sub-optimum utilisation of ore resources to poor recovery in the processing plant and loss of revenue from product sales. Therefore, it is vital for accurate metallurgical accounting that sampling be carried out correctly to ensure that samples are representative; otherwise the entire measurement chain is corrupted at the outset.

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