Investigating the significance of sample extraction methods on multiplexing process streams for online elemental analysis

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Multiplexing process streams with a common elemental on-stream analyser has been common practice for decades. This study investigates two aspects that directly determine the success of multiplexing and the subsequent validity of measured results. The first aspect is the choice of upstream slurry sampler type. Online analysis is typically associated with 'good enough sampling for process control'. The precision difference between sample extraction and full-stream sampling methods will be discussed. The second aspect is the number of multiplexed streams assigned to a single analyser. The decision to measure 'as many streams as possible with one analyser' was driven by the perception that more value would be gained from the same amount of dollars spent. On larger plants the direct implication is much longer sample lines which typically increase increment extraction errors. The value gained from having more analysers with shorter sampling lines will be discussed.

INTRODUCTION

Theory of Sampling (TOS) is well understood and accepted within the mining industry. It has however been associated mostly with metal accounting practices. This paper focuses on the application of sampling theory in elemental online analysis.

There are two types of analysers on the market: in-line single stream analysers and traditional multi-stream analysers with upstream multiplexers.

The focus of this paper will be on the traditional multi-stream analyser with an upstream multiplexer. Two sampling errors associated with this type of analyser will be discussed. The first error is the increment delimitation error that takes effect with primary sampling of the process line and the second is the increment extraction error associated with the sample lines routed to the multiplexer.

Lastly, the effect of aliasing with an increasing number of streams measured per analyser will be discussed.

BACKGROUND

Online elemental analysis includes several analytical techniques including prompt gamma neutron activation analysis (PGNAA), laser induced breakdown spectroscopy (LIBS), energy dispersive X-ray fluorescence (EDXRF), wavelength dispersive X-ray fluorescence (WDXRF) and diffuse reflective spectroscopy (DRS).

PGNAA is typically used for the measurement of light and heavy elements in material that has not been liberated such as Run of Mine material on a conveyor belt. LIBS can also be successfully applied in light and heavy elements but for liberated applications downstream from the comminution circuit. EDXRF is the most common technology used in the base metals industry and it measures heavy elements (Ca – U). EDXRF is also applied mostly downstream from the comminution circuit as it requires the material to be liberated. WDXRF has similar capabilities to that of EDXRF but can measure specific heavy elements at higher resolution and at lower concentrations. DFS is an optical method that is also used for downstream measurements but is not limited to elemental analysis. It can for example make a distinction between Cu associated with oxides and Cu associated with sulfides.

DRS can be applied to in-line slurry applications through a robust interface such as sapphire. LIBS can also be applied to a single stream but without any physical contact with the process stream.

In-line single stream analysers have the advantage that they measure a single stream in real-time without the complexities of extracting a sample prior to measurement.

The downside to in-line measurement (other than LIBS) is the physical interface between the analyser and the slurry stream that is affected by the line velocity and the type and particle size of the material measured. When damage occurs on the physical interface during operation, immediate isolation is not always possible to prevent damage to the analyser.

Another downside of in-line measurement is the calibration of the analyser. By definition, a calibration sample should be representative of what was measured by the analyser during the calibration sequence. It is difficult to extract a representative sample from the main process line where a measurement was made on the side of the pipe. The success of such a calibration will be greater for concentrate streams where a large range in grade has been included in the calibration set. The purpose of such an analyser would then only be as an indication of an upwards or downwards trend for control purposes.

Multi-stream analysers have the advantage of measuring multiple process streams with a single analyser and have a good integrated calibration sampler.

The downside of the multi-stream analyser is the often poorly-designed sample lines between the primary sampler and the multiplexer and the tendency to want to measure too many streams with a single analyser, resulting in aliasing.

PRIMARY SAMPLER SELECTION

It is widely documented that samples are only truly representative of the process stream they are sampled from, if every particle in the process stream has an equal opportunity to be included in the collected sample. This is only possible if the entire process stream is sampled. Described in other terms (Gerlach and Nocerino, 2003), error will be introduced if the sampling device selects or includes particles from any part of the lot with unequal probability.

This aspect plays a significant role in selecting a primary sampler feeding the multiplexer of a multi-stream analyser. In addition to preparing a sampled process stream for measurement, most multiplexers on the market also have the added advantage that they can collect a composite sample for metal accounting. If this functionality is used, it is critical to select the correct primary sampler.

Primary sampling devices can be broken down into two groups: samplers and extractors.

Samplers are free from the delimitation error in that they have been designed to allow the volume collected at the sampling point to have boundaries that allow equi-probalistic sampling (Pitard, 2019). Figure 1 illustrates the movement of the cutter through the entire stream at constant speed. It is also critical that the cutter starts and stops outside of the slurry flow.

Examples of samplers are crosscut samplers, vezin samplers and moving pipe samplers. All these cuts through the entire sample stream and fully adhere to the TOS.

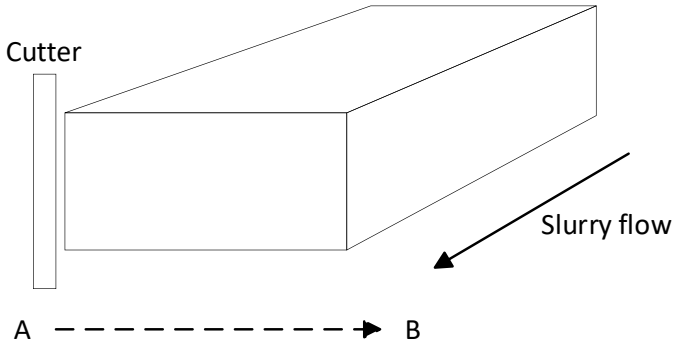

Figure 1. Sampler design considerations to avoid increment delimitation error.

Extractors on the other hand are not free from the delimitation error and have been designed to extract a sample from a process line in a pragmatic way to get an indication of the grade. Unfortunately, the idea of a 'good enough' sample for process control has become well adapted in the metallurgical field. Extractors are generally cheaper and easier to retrofit into plants and have become an attractive choice.

Examples of extractors include pneumatic extractors, pressure pipe extractors (Figure 2) and shark-fin extractors. None of these extractors adhere to TOS and should be used selectively.

Under certain circumstances extractors should not be considered at all. These include, firstly, process streams with a low line velocity (approaching settling velocity) as this results in a lower chance of extracting a representative sample. Secondly, process streams with a low grade as well as a small grade variation, such as tailings or feed streams, should also not be sampled with an extractor. Errors associated with these lower grade streams are typically much higher than for concentrate streams.

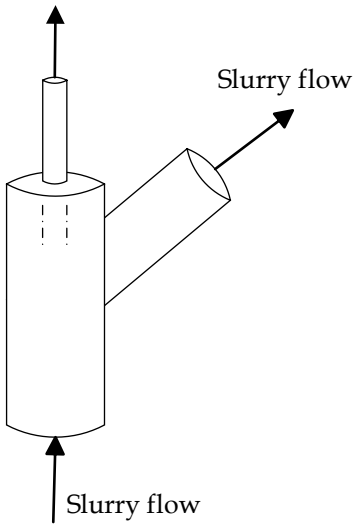

Figure 2. Example of pressure pipe sampler that has a delimitation error.

Quantifying the delimitation error for a specific extractor would be very difficult as the sample extracted is arbitrary.

SAMPLE LINE DESIGN

Where the increment delimitation error involves the physical sampler/extractor selected for a specific application, the increment extraction error refers to how the sample is recovered from the sampling system.

Typically referred to under the increment extraction error are the dimensions and properties of the cutter used to extract the sample. This paper will elaborate on an aspect less frequently discussed but very relevant to a multi-stream analyser where sample lines feed the central multiplexer from variable distances in the process.

Commonly, the battery limits of the supply of a multi-stream analyser and multiplexer excludes the design of the sample lines between the primary sampler and the multiplexer. Multi-stream analysers are frequently sold to measure 12 to 24 process streams. This leads to long sample lines that are known for blockages. The blockages are caused by the line velocity dropping below the transitional velocity due to friction losses in the pipes. Sagging of pipes and many bends increase the chances of blockages. These poor designs lead to large increment extraction errors. Blocked sample lines often lead to multi-stream analysers being under-utilised or not used at all.

To minimise the increment extraction error so that the sample stream collected from the primary sampler is recovered in the multiplexer, the line velocity of the sample stream in the pipe plays a critical role. For the sampled slurry stream to reach the multiplexer and still be representative of what was sampled, the flow regime in the slurry line must be a pseudo-homogeneous suspension.

Factors to consider in the design of the slurry sample lines to ensure this flow regime is achieved consistently are length of the pipe, the slope and the pipe diameter.

The location of the multiplexer on site should be selected to minimise the slurry line distances. The longer the pipes, the higher the friction losses (requiring a higher line velocity for the same flow regime) and the higher the residence time between the measurement and the actual process.

The slope of the pipe plays a significant role as an incline introduces an axial component to the forces that resist motion and require higher flow velocities to prevent settling (Jääskeläinen and Roitto, 2014).

The pipe diameter should be selected by firstly determining the transition velocity, V_{M2}, often regarded as the minimum transport velocity for settling slurries (Perry and Green, 1998). Durand's formula is used (Schiller and Herbich, 1991) and incorporates factors such as the particle size, density (solids and liquid), and viscosity.

$$V_{M2} = F_L[2gD(s-1)]^{0.5}$$

where g = acceleration of gravity
D = pipe diameter
s = ratio of solid to liquid density
F_L = a factor influenced by particle size and concentration

Figure 3 is Durand's empirical correlation for FL as a function of particle diameter and volume fraction of solids C_s:

$$C_s = Q_s/(Q_s+Q_l)$$

where Q_s = Volume of solids
Q_l = Volume of liquid

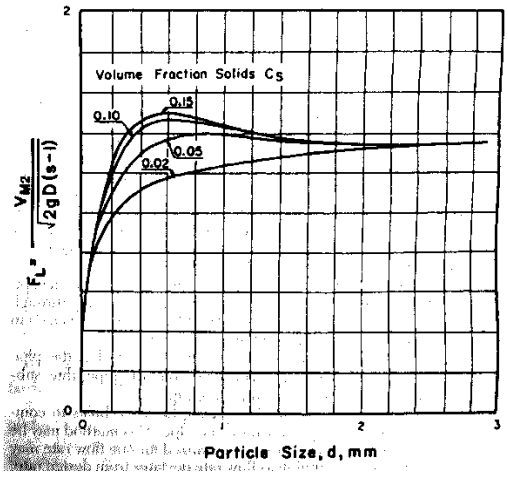

Figure 3. Durand factor for minimum suspension velocity.

Once the transitional line velocity is known, the diameter of the pipe is calculated for a flow higher than the transitional velocity. The selection of the diameter at this point must also accommodate any incline in the sample line.

In the base metals industry, a transitional velocity between 0.5 – 1 m/s is common. Operating at line velocities lower than this will cause settling of solids in a horizontal pipeline.

NUMBER OF STREAMS MEASURED AND ALIASING

The distinction between data suitable for process control and data subject to aliasing only becomes quantifiable with the availability of real-time measurement of a particular process stream (Keet and Du Plessis, 2012). A study was conducted to quantify the sample frequency required for a feed, tails and concentrate stream of a typical base metal sulphides flotation circuit. The result indicated that the dynamics of the concentrate stream were a lot faster and required measurement as frequently as every two minutes to combat aliasing. For the feed and tailings process streams, the dynamics were much slower, only requiring measurement at 15-minute intervals for process control.

Each process stream measured by the multi-stream analyser has an adjustable measurement time of around two minutes, followed by a washing cycle of another 1-2 minutes. It is therefore not uncommon for a six-stream multi-stream analyser to see an updated measurement only every 20 minutes for a particular process stream. Although this information is still very valuable, it might be problematic for closed loop process control.

CONCLUSION

Two aspects relating to sampling and extraction of process streams for online multi-stream elemental analysis have been investigated.

The choice of primary sampler determines the extent of the increment delimitation error at play. Pneumatic, shark-fin or pressure pipe 'samplers' are referred to as extractors as they do not adhere to TOS and should be used selectively (i.e., not at all for process streams with low grades and small grade variations).

Crosscut, vezin and moving pipe samplers adhere to TOS and have a negligible associated increment delimitation error.

A larger increment extraction error is associated with a higher number of multiplexed streams assigned to a single multi-stream analyser. The reason is that there are longer sample lines between the primary samplers/extractors and the multiplexer. The design of these lines is typically poor without proper attention given to important parameters such as length, slope and diameter.

A higher number of process streams measured by a multi-stream analyser also increases the risk of aliasing where the dynamics of a particular process stream are not captured by the frequency of measurement.

RECOMMENDATION

The selection of primary samplers should be considered at greenfield level. This will ensure that the spatial arrangement makes provision for equipment that adheres to TOS with a minimised incremental delimitation error.

Multi-stream analysers for control of critical streams should not be used for the measurement of more than six process streams. Where possible, no more than four streams are recommended, especially for concentrate streams which are known to have faster dynamics.

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