Pitfalls in Vezin sampling for finely crushed materials

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Synopsis

Anglo American Platinum has adopted a strategy of best practice principles (BPP) for sampling, mass measurement, analysis, and metal accounting for more than a decade now. When new plants are designed, the most suitable sampling equipment and sampling protocols are implemented and material flows and plant layouts are designed around sampling strategies. A few years ago, a crushing plant for a high-grade matte stream was commissioned.

The design called for the high-grade material to be crushed to 95% passing 2 mm, and the design allowed for a single-cutter primary Vezin sampler taking increments from a gravity flowing stream at regular intervals while filling a tanker for pneumatic offload at the base metal refinery. This was a *single point of sampling* and analysis that would measure the wanted output from the smelting complex and the input to the refineries. In addition, the design incorporated the functionality to collect increments in an 'interleaved' fashion from the Vezin sampler for internal precision checks.

The metal accounting strategy for Anglo Platinum involves the ongoing measurement of all inputs, outputs, and stock levels for all operations for platinum group metal (PGM) and base metal (BM) content. Included are yearly stocktakes, usually done on 1 February, across the smelters and refineries (at least the base metal refinery). In the accounting period immediately following the introduction of the new crushing and sampling facility, a trend was developing whereby the absolute difference between the physical stock and theoretical stock (PGMs predominantly) increased for the two respective sites on an ongoing basis. The smelter showed an increase in physical stock compared to the theoretical stock (sender) and the base metal refinery showed an increase in theoretical stock against physical stock. Because of this anomaly, an additional stocktake was held in September for the period in question, and it was confirmed through the physical stock measurement results that the PGM accounting problem was indeed pointing towards the evaluation of the high-grade matte stream.

This paper showcases parts of the process that took place to explain the poor accountabilities for the two sites. Previous results from the sampler ratification process (of the interleaved sampling design) were re-analysed, a physical inspection was carried out on the sampling system again, and the sampler performance was monitored (quality control parameters) for the period.

From these investigations, it was found that *airflows inside the Vezin* introduced the sampling bias. A change in sampling protocol was introduced, as well as certain physical changes to the sampling equipment, to eliminate the airflow and thus the bias conditions significantly. The accounting period that followed the phased upgrading process showed that the accounting between the smelter and base metal refinery had been restored to within statistical limits (difference between physical and theoretical stock below 5% relative to theoretical stock).

Keywords
sampling, metal accounting, Vezin sampler, sampler bias.

Introduction

The first step and best defence against any sampling bias is the correct mechanical design of the sampling rig and the correct sampling protocol to be followed. From Anglo American Platinum's smelting operations a single stream output of convertor matte goes to the base metal refinery. When Anglo Platinum optimized the metallurgical process at the refinery, it resulted in a process change whereby the crushed matte particle size changed from 95% passing 27 mm to 95% passing 2 mm. It also involved building a new crushing plant and storage silo at the smelter operation.

This process change provided the opportunity to design and incorporate a new sampling facility for this material stream. Previously, this material with the nominal particle size of 27 mm was sampled at the discharge end from a conveyor belt feeding into a silo at the refinery. The primary sample that was collected was in the range of 1 t, and material handling and sub-sampling was a challenge.

The new process design would require the pneumatic offload of finely crushed matte into the new mill feed silos. From past experience, sampling material under pressurized conditions was not an option for consideration.

The new plant allowed for a product bin (storage silo) at the smelting operations to discharge under gravity, through a Vezin sampler, into a tanker that can pneumatically offload the material at the refinery. Mass measurement and sampling for grade analysis forms the basis of the transfer of this metal accounting stream.

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 ISSN 2225-6253. This paper was first presented at the, Sampling and analysis: Best-practice in African mining Conference, 4–6 June 2013, Misty Hills Country Hotel and Conference Centre, Cradle of Humankind, Muldersdrift, South Africa.

The sampling rig also allowed for interleaved sampling i.e. retrieving two samples for each batch (tanker) of matte dispatched. The initial ratification process for this sampling rig indicated that the sampling system was sound and conformed to best practice principles (BPP). However, the accounting period following the introduction of the new rig showed a trend whereby the relative difference between physical stock and theoretical stock was increasing month-on-month and was outside accepted tolerances.

Original sampler design

A schematic of the sampling rig design can be seen in Figure 1.

Mechanical design considerations for samplers

Vezin sampler mechanical design

Applying the principles of Pierre Gy, the following considerations were applied to the Vezin sampler's mechanical design, which also included BPP from Anglo Platinum in conjunction with its suppliers.

- ➤ The sample cutter rotates in a horizontal plane perpendicular to the falling stream
- ➤ The cutter collects increments by cutting a complete cross-section of the material stream
- ➤ The cutter travels through the stream at constant speed (the cutter head should be driven by a gearbox with a synchronous motor)
- ➤ The cutter speed at its extremity should not be greater than 0.6 m/s
- ➤ The park position of the cutter should always be furthest away from the stream
- ➤ The distance between the discharge pipe and cutter opening should be less than 10 mm (or as dictated by larger particles sizes)
- ➤ The cutter length should exceed the inlet by 15% minimum on either side
- ➤ The minimum critical cutter width must be 10 mm or three times the diameter of the largest particles of the stream
- ➤ An inspection port should be available to enable inspection of the cutter blades and the presentation of the stream to the cutter
- ➤ The capacity (volume) of the cutter head should be at least three times the sampler increment size
- ➤ The depth of the cutter at any point along its length should be at least three times the diameter of the largest particle to be sampled and in all cases not shorter than 30 mm
- ➤ All surface slopes should be ≥ 70°
- ➤ The park position should have a 'cap' when sampling dusty materials; a thicker section of rubber or plastic inserted under the Vezin lid to cover the Vezin cutter opening and prevent the ingress of dust. The maximum clearance between the cap and the cutter blade should be 1 mm
- ➤ The cutter opening must be radial towards the point of rotation
- ➤ The critical cutter width (where the inner part of the stream is cut by the sampler) should be a minimum of $3d + 10$, where d is the diameter of the largest particle of the stream. In the case of fine materials the width of the cutter at this point should be a minimum of 10 mm.

Rotary (secondary) splitter mechanical design

- ➤ The material to be sub-sampled/split should be fed slowly and carefully into the feed hopper to avoid dust losses
- ➤ The revolving speed of the turntable should be constant and should not exceed 0.6 m/s at the point where the cutter intersects the stream
- ➤ Each sample cup should take a minimum of 30 cuts over the duration of the sampling campaign i.e. the turntable should complete more than 30 revolutions during the sampling campaign
- ➤ Material movement and discharge should be evenly forward
- ➤ The distance between the exit of the feeder and the top of the sample cups should be minimized to prevent dust loss
- ➤ The vibratory speed of the feed launder must be optimized for efficient splitting time but negligible dust loss
- ➤ The total capacity of the sample cups should be sufficient to contain the entire sample portion to be subdivided.

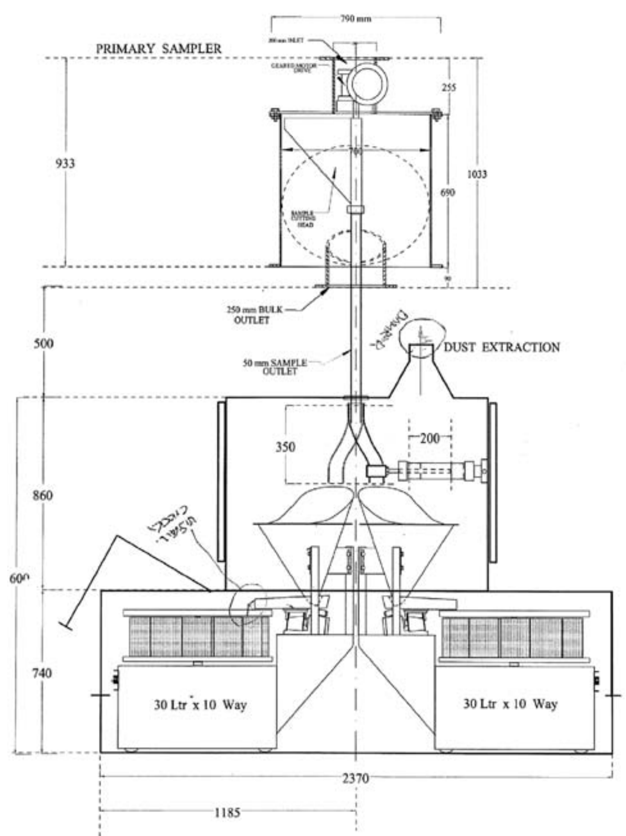

Figure 1—Schematic design of Vezin sampler and the two rotary splitters used to collect the interleaved increments from the Vezin

Description of sampling system

The matte is rich in PGMs as well as BMs, with Pt grades between 1 300 g/t and 1 700 g/t. Matte ingots are cooled down and broken into smaller portions. This material is then crushed to <3 mm and loaded under gravity into a road tanker for transport to the base metal refinery. During loading the material is sampled by a primary Vezin sampler (Figure 2), and the primary increment can be collected in an interleaved fashion, each increment of which can be sub-sampled by two secondary 10-way rotary splitters. The sampler has a single primary Vezin-type cutter that operates intermittently. Individual primary increments are diverted in an interleaved fashion to one of two hoppers using an oscillator to direct a flexible tube carrying the sample to one or the other of the hoppers (Figure 3). The two sets of accumulated interleaved increments are individually divided in dedicated 10-way splitters (Figure 4). The sampling system for the matte includes a dust extraction cabinet that extracts dust from the whole cabinet region above the hoppers receiving the primary increments. Dust collected (if any) is directed to the tanker receiving the batch for transport to the base metal refinery.

A minimum of 2 kg sample from the rotary splitter is bagged. The full contents of a splitter cup will be collected and no scoop or dip sampling will take place. When a sample from each road tanker (for the day) has been collected, the variable split sample divider (VSSD) will be used to make up a daily weighted composite of 2 kg. The weighted composite sample is then rod milled to 95% passing 75 μm. After milling, the sample is split 10 ways to render 200 g aliquots for analysis at the laboratory.

Original ratification of the sampling rig

The methodology included quantification of the total uncertainty in sampling this material by making use of interleaved sampling. In addition, the contribution of the analytical uncertainty was also determined. A sampling constant programme was also developed by Dr Geoff Lyman for Anglo American Platinum in order to determine the effect of the intrinsic heterogeneity during sampling of this material.

Figure 2—Primary Vezin sampler

The methodology and data analysis discussed in the following section was provided by sampling consultant Dr Geoff Lyman.

Sampler ratification methodology

The analytical relative standard deviation (RSD) is calculated by analysing twin stream data. All samples were analysed in twin stream, generating an A and a B assay. This information shows how much the analysis contributes to the difference between the two daily weighted composite samples (compiled with the two interleaved sub-samples). The analytical RSD was calculated as follows (note: WCM is the material code for the matte stream):

$$Analytical\ SD = \sqrt{\frac{\sigma^2_{A-B}}{4}} \qquad [1]$$

$$Analytical\ RSD = \frac{Analytical\ SD}{\overline{X}_{A\&B}} \times 100 \qquad [2]$$

Figure 3—Oscillator to direct a flexible tube channelling the sample into the respective hoppers

Figure 4—10-way splitter used for the sub-sampling of the interleaved samples

The combined analytical RSD for both the WCM2 and WCM3 sample was calculated as follow:

$$Analytical\ RSD_{WCM2\&WCM2} = \sqrt{\left[(n_1) \times RSD^2_{WCM_2}\right] + \left[(n_2) \times RSD^2_{WCM_3}\right]} \qquad [3]$$

The SD for the interleaved sampling (between WCM2 and WCM3) was determined. Because the combined analytical RSD was compared with the SD of the difference, it was multiplied by √2.

$$SD \text{ of twin stream data} = \sqrt{2\times\left(\frac{Analytical\ RSD_{WCM_2\&WCM_3}}{100}\right)} \times \bar{X}_{A\&B} \qquad [4]$$

The F-test was also conducted to determine if there was a significant difference between the analytical SD and the SD between the two samples. At 95% confidence the difference will be significant only if the probability value (p-value) is less than 0.05.

Summary of ratification results

The analytical RSD for platinum (Pt) for the WCM2 sample was 0.72% and for the WCM3 sample 0.78%. The combined analytical RSD was 0.75%.

There was little difference between the analytical uncertainty (RSD of 1.06) and the interleaved sampling (1.12%). The F- test also indicated that there was no significant difference. Thus the distributional heterogeneity and the analytical variance are similar. Modifying the sampling system by, for example, increasing the number of cuts would not improve overall precision.

The sampling constant showed a RSD of 0.146% (Lyman, 2010)) which is much lower than the distributional heterogeneity (1.12%) and the analytical uncertainty (1.06%). Thus the effect of the intrinsic heterogeneity on the overall uncertainty in WCM material was of very little significance and collecting a 2 kg weighted composite sample at 3 mm was sufficient.

Thus, the ratification process concluded that the sampling rig produced representative samples and no further optimization was needed. The results could, therefore, be used with confidence. This was subsequently contradicted by the accountabilities seen for the respective sites after the introduction of the new sampling rig.

The variance in stock (physical – theoretical) as a percentage of plant throughput was +5.2% for the smelter and -2.0 % for the base metal refinery on Pt.

Physical inspection and investigation into the Vezin sampling rig

A literature review was conducted on Vezins in general and a physical inspection of the Vezin sampling rig carried out. Part of this process entailed an examination of historical quality control data of the sampling rig where the percentage sample cut is monitored. Sampler proportionality is determined by calculating the percentage cut of sample relative to the total mass in the road tanker. If the sampler is proportional, this percentage cut should be consistent and its RSD should not exceed 2% (Lyman, 2010), but in practice the target of 2% is ambitious, especially where the sample size is very much smaller than the bulk batch. If the sampler proves to be proportional, then bulk weighted compositing can be used to make up the daily weighted composite. By weighing all the sample cups of the rotary splitter, the total mass of the primary sample can be determined. If this value is then divided by the total mass of material in the road tanker, the percentage cut for the primary sample can be obtained. The percentage sample cut (before and after modifications to the sampler) will be discussed further in the next section.

$$\%\ cut = \frac{\text{Sample mass}}{\text{Mass in road tanker}} \times 100 \qquad [5]$$

$$RSD = \frac{SD_{\%\ cut}}{Average_{\%\ cut}} \times 100 \qquad [6]$$

Literature review

Cleary and Robinson (2009) indicated that closer scrutiny of the conditions inside the Vezin was required. Pitard (1989) suggested that Vezins sometimes need to run at 0.3 m/s or 0.45 m/s rather than 0.6 m/s as specified by Gy's rules. It was for that reason that they investigated the effects of several factors on extraction ratio and sample bias. They conjectured through discrete element modelling (DEM), having investigated other possible bias mechanisms, that the observed bias could be due to the effects of air motion generated by the Vezin rotation on very fine particles.

Physical audit

A physical inspection revealed that a 'vacuum' exists inside the Vezin. It was difficult to lift the inspection lid while sampling and loading of the tanker took place. This was confirmed when the inspection was extended to the open discharge end of the flexible sample hose. Through normal observation, each sample increment appeared to be discharging without any difficulty into the respective receiving hoppers of the 10-way rotary splitters.

However, on closer inspection it was found that the material fall through the Vezin sampler caused the back-suction of fines from the sample increment. With the entrapment of air within the material stream as it passes through the Vezin, a vacuum is created inside the Vezin. This imbalance can be rectified only by allowing air back into the Vezin. This additional air cannot enter through the closed and dust-sealed Vezin inspection lid or from the product silo itself. The only other open circuit is the cutter and sample discharge pipe with an open-end discharge.

For each increment that was taken, a percentage of the very fine material was sucked back into the Vezin through the sample pipe and cutter, with the coarser, denser particles continuing to the sample. This confirmed the existence of a bias in the matte sampling due to sampler design and airflow conditions.

From the investigation and scrutiny of quality control data (Figure 5), a change in trend for the percentage sample cut is apparent well before any changes to the Vezin were made. It was established that the dust extraction system connected to the retractable loading spout (below the

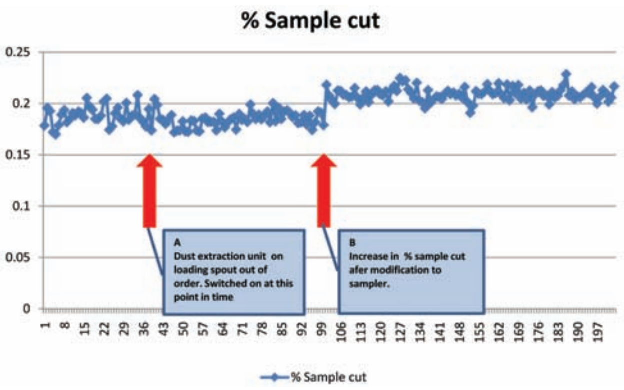

Figure 5—Changes in percentage sample cut due to event changes

sampler) was off-line. When this was repaired, it created additional suction below the Vezin and increased the vacuum inside the Vezin. The percentage sample cut (before and after modifications to the sampler) will be further discussed in the next section. The changes introduced to the Vezin sampler design also resulted in a step change in quality control data trend for the percentage sample cut.

The discharge of each increment into the hoppers also led to dusting and loss of fines from the sample. This aggravated the situation.

Particle size distribution and size-by-size analysis

Table I indicates the grade variation for the size fractions associated with this crushed matte product. It is clear that the very fine particles have a significantly lower Pt grade. If the fines are removed from the sample increment, the sample will be significantly biased and the evaluation of this material stream will overstate the PGM grade (as the lower grade particles are removed from the sample).

Design changes to the Vezin sampling rig

With this newly acquired knowledge, that the airflow (inside the Vezin and through the cutter head and sample discharge pipe) was causing the selective removal of fine particles from each sample increment, thus biasing the sample, modifications were introduced to eliminate the impact.

- A vent was installed in the primary Vezin sampler lid to act as a breather (Figure 6)
- Only single-point sampling would be conducted. Interleaved sampling would no longer be required. Original ratification between the two interleaved samples showed no significant sampling error. The reason for this was that the error (removal of fines) was relatively similar for both interleaved sample increments. Thus, the rig design for interleaved sampling was flawed
- An intermediate hopper (Figure 7) was installed between the Vezin and the 10-way rotary splitter. It has a manual outlet valve and the objective is to collect the whole primary increment while loading the tanker. On completion of primary sampling, the valve will be manually opened to discharge the primary sample into the feed hopper of the 10-way rotary sampler. The long-term plan is to automate the hopper outlet valve in conjunction with the relevant interlocks
- The discharge of the sample into the hopper was no longer open-ended. An airtight lid has been installed (Figure 8) to prevent any dusting from the sample.

Table I

Size-by-size analysis for crushed matte stream

Sieve size [µm]	PGM grade [g/t]	[%] Mass retention
+1.18 mm	1527	20.73
+850	1625	22.03
+600	1828	9.92
+425	1887	8.16
+212	1902	20.29
+106	1454	11.53
-106	528	7.32

Figure 6 – Vent / breather in Vezin lid

Figure 7—Intermediate hopper between primary Vezin and 10-way splitter hopper

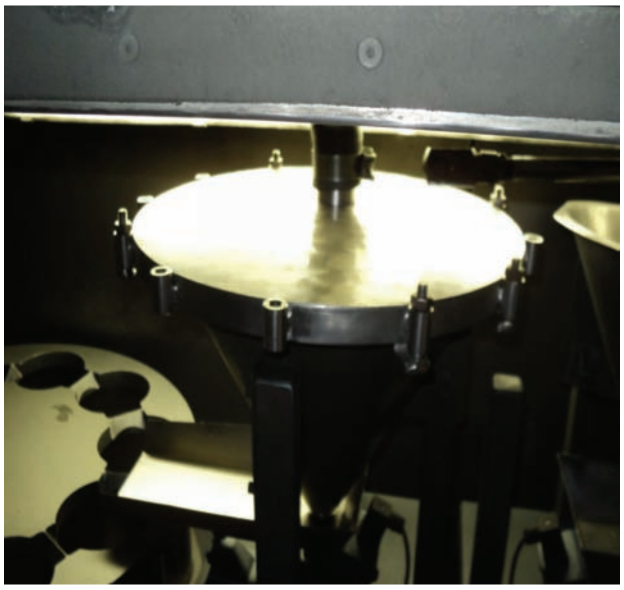

Figure 8—Airtight lid to prevent any dust loss/ingress

Results from the modifications, as indicated by percentage sample cut

From Figure 5, it is easy to identify two step changes in the percentage sample cut. For step change A, it was established that the dust extraction unit connected to the loading spout was not operational. When the dust extraction unit was switched on, it created additional suction and increased the vacuum inside the Vezin and aggravated the sampling error. It is for that reason that the average sample mass reduced from that point onwards, until step change B.

At step change B, the modifications to the Vezin sampler (vent) and the new sampling strategy were introduced. The installation of a vent and operating the sampling system as a closed circuit resulted in the sample mass increasing by 12% from 61.099 kg to 69.477 kg. After implementation of the changes the percentage coefficient of variation improved as shown in Table II.

Conclusion

A new sampling rig had been implemented for the sampling of a high-grade matte material at Anglo American Platinum. Prior to installation a full ratification campaign was undertaken and passed. Subsequent to installation of the new rig, a significant variance in the smelter and base metal refinery accountabilities was noted, indicating that a bias existed. Following investigation, it was confirmed that a bias existed in the matte sampling due to airflow conditions within the sampler.

It is not suggested that this was the only factor contributing to the sampling bias experienced; however, it is believed that it was the biggest contributing factor.

Designing sampling equipment is complex, and material characteristics must be carefully investigated to understand the relationship between the equipment, equipment design, the material itself, and flow characteristics.

The first step would be to investigate the material properties. The impact of dusting and grade association with particle size was known beforehand, but the effect of air flow inside the Vezin was not recognized up-front. Additional characteristics such as flowability, moisture, particle size, and stream size, to name only a few, must be investigated to ensure the correct equipment and plant design is matched with the material. The correct sampling equipment and equipment set-up must be identified and the plant equipment designed around these requirements. Attempts should not be made to fit sampling equipment into spaces 'left open' during plant design.

The next step would be the graphical design and calculations to ensure the correct sizing of the sampling equipment and that it conforms to sampling theory. Factors such as the sampling constant must be determined to ensure the correct quality assurance is in place (sampling protocol). Ensuring the engineering around the sampling rig allows for the equipment to operate within the design specifications.

The third step is to inspect the equipment prior to installation to ensure that the manufacture conforms to specifications and sampling theory.

The fourth step is cold (if possible) and hot commissioning. This is where most projects stop.

The fifth step (and probably the most important) is to conduct an intense ratification process with a sound experimental design and the monitoring of results over an adequate period. It is difficult to measure for bias because the luxury of installing two different sampling systems for the same material stream is too expensive. It is for this reason that quality control parameters must be put into place, which should be trended on an ongoing basis. In conjunction, the analytical / metal accounting data should be monitored to determine if there is any reason to doubt the sampling equipment.

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Table II

Improvement in coefficient of variation

	Average sample cut, %	Standard deviation	Coefficient of variation. %
Before	0.183	0.039	21.497
After	0.210	0.010	4.941