Eliminating sample preparation bias: The evolution of the rotating plate divider to overcome delineation errors

C.P. Bester and W.P. Slabbert

Multotec Process Equipment (Pty) Ltd, South Africa

The rotating plate divider (RPD) is a versatile equipment used for dry sample taking, subsampling and sample preparation over a range of throughputs, particle size and mineral commodities. The RPD is compact, uses minimal moving parts, performs reliably due to the large fly wheel design, boasts exceptional availability, and has low operational power consumption. The sampling accuracy and precision achieved by the (old) RPD equipment is challenged with a specific application of potash sampling with a large particle size distribution. Through partnership with the end user, the sources of bias were identified, investigated and mechanisms hypothesised as below:

- Segregation of fine and coarse material, given the tensile strength of potash and its unique material behaviour down the feed chute of the equipment.
- The feed chute to cutter interaction and alignment allowed some bouncing coarse material to be under-sampled.
- The rectangular cutter opening, instead of radial tapering on a rotary equipment resulted in classic delineation error and bias.

The sampling equipment manufacturer (SEM) improves the necessary features of the design, making the equipment more compliant over a larger range of minerals and applications. The improved design RPD was put into practise through employment on large PSD bauxite material that is sticky, elastic and poses real operational challenges. The sampling system has undergone independent bias tests in the past two years and has produced positive results confirming that the SEM has eliminated the source of delineation through compliance to Theory of Sampling design principles, resulting in improved precision of the RPD across minerals and materials sampling.

Keywords: Theory of Samplmg, TOS, rotating plate divider, sample preparation, delineation error, sample bias

INTRODUCTION

Sampling as a specialised field has been emphasised now for many years resulting in sampling knowledge gaining traction throughout the industry. Purchasing samplers is not just a random selection anymore but driven by users with increased sampling knowledge due to forums, training and guidance provided. Papers written, standards produced, ISO documents, conferences and dedicated training has exposed the world of correct sampling to many individuals globally, resulting in compliance and sampling correctness becoming a requirement for manufacturers and suppliers to the market.

The Theory of Sampling (ToS) has moulded designers into a different way of thinking when designing sampling equipment, resulting in continuous compliance improvement and developments in line with the standards and requirements set.

The rotating plate divider (RPD) is a versatile equipment used for dry sample taking, subsampling and sample preparation over a range of throughputs, particle size and mineral commodity applications. The RPD is compact, uses minimal moving parts, starts direct online (DoL), performs reliably in the most challenging operations due to the large fly wheel design, boasts exceptional availability, and has low operational power consumption.

The RPD could be regarded as a vertical vezin type sampling unit for dry sampling applications; ultra-simple and reliable operation with minimum maintenance and no finicky parts requiring attention. The cutters are mounted on a vertically rotating plate that retains rejects at the front, and allows a sample taken to enter the rear of the plate and report to the sample container or next process (Figures 1 and 2). In their continuous operation, RPDs readily achieve more than 20 sub cuts of the preceding sample increment. Their performance exceeds minimum ISO 8685 requirements of six sub cuts per preceding increment and will result in an improved sampling precision level. The cutters are interchangeable and can accommodate different apertures for different sample sizes to adapt to sampling regime requirements/amendments.

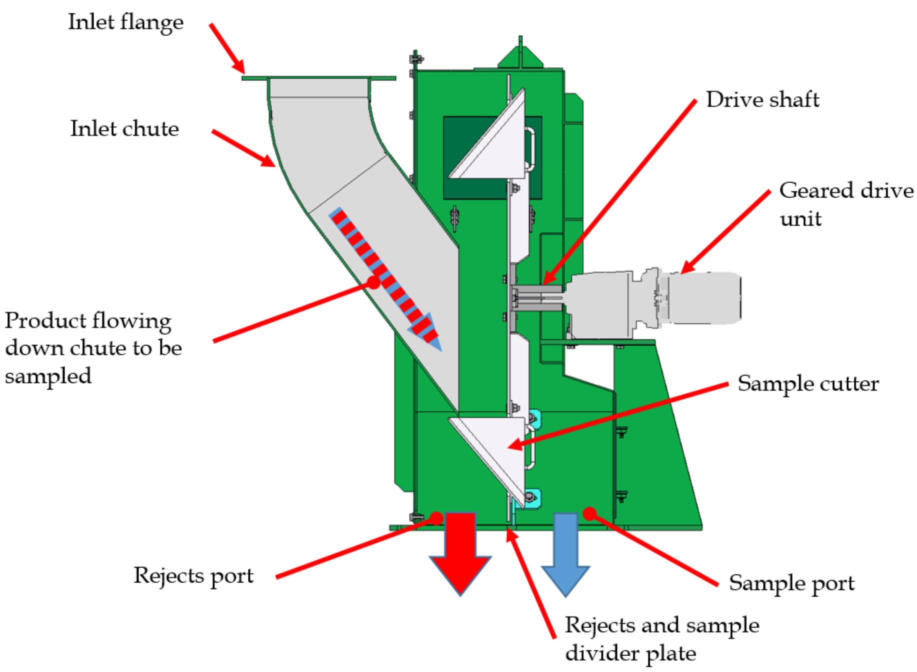


Figure 1. Sectional view of the RPD feed pipe (left) presents a sample increment to the cutter (middle) to sub-sample (blue particles) the stream and generate rejects (red particles) on the feed side of the plate. Sample and rejects report to separate, isolated chutes.

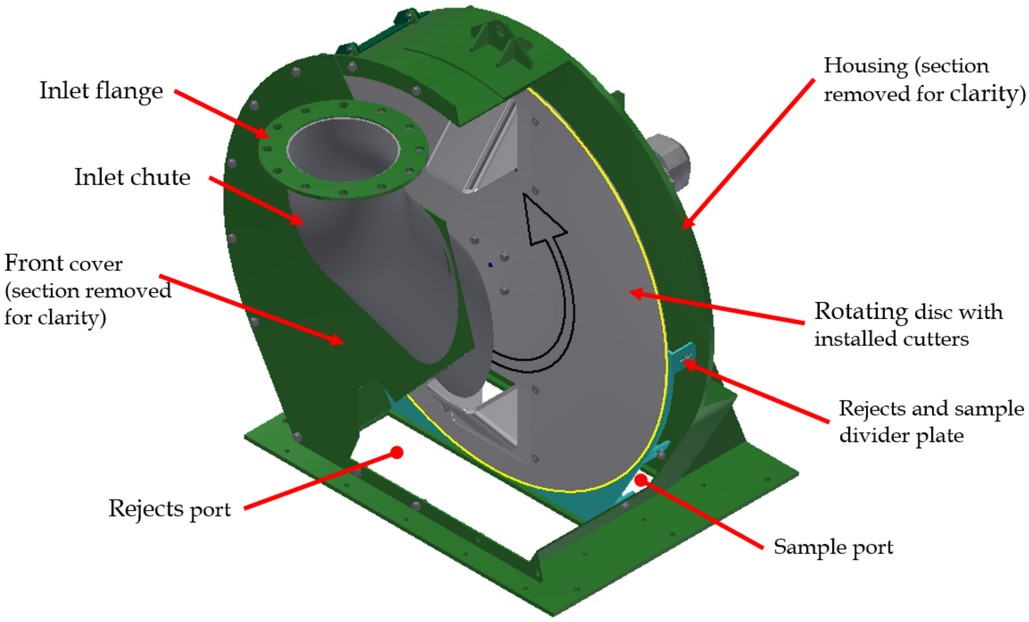


Figure 2. 3D image, identifying components and illustrating the working of the sampler.

To optimise the sampling process and requirements, the RPD can operate on a continuous or timed based frequency, by using an electromagnetic sensor to identify the park position and disengage power to the motor.

The reliability and general sampling accuracy and precision achieved by the (old) RPD equipment has proved to be biased for a specific application of potash sampling with a large particle size distribution. Through partnership with the end user, the sources of bias were identified.

The range of RPD equipment received a redesign to incorporate new requirements and features to improve the sample quality by eliminating delineating errors and bias. The revised version was installed in a bauxite application, and passed two separate bias tests successfully, contributing to successfully extracting samples fit for metallurgical accounting purposes.

LITERATURE REVIEW

Steinhaus and Minnitt (2014) explain the responsibilities of sampling sampling equipment manufacturer (SEMs) to understand the requirements and best practices of sampling equipment design and how partnership with end users and engineering clients aims to collaboratively eradicate previous non-compliant designs to better align with TOS. They continue to state that: "SEMs gain specialised experience and practical mechanical sampling knowledge out in the field that is complementary to the sampling theory in the literature, and both are relevant to new sampling projects. A SEM cannot design equipment that is compliant, unless it takes both these aspects into account. For SEMs to gain applications knowledge, they need to make continuous improvements to their designs to make them more versatile and reliable. Each material characteristic, location, material stream, and throughput application present a whole new set of challenges. SEMs rely on their collective knowledge to date and their experience in those applications to provide better informed recommendations and solutions into the future. They acknowledge the fact that equipment must conform to approved design parameters and clearly defined requirements as laid out by sampling consultants and approved literature. A SEM could become an authority in its own right, by producing equipment suitable for various metallurgical applications, while also being mechanically reliable. Some application knowledge is unintentionally also gained at the 'University of Hard Knocks'."

SEMs do not usually have the facility to test the equipment with various material properties, characteristics, parameters and importantly: at the production flow rates. The equipment is designed for transferring previous experience, client feedback and gained site knowledge into a sampler or sampling system worthy of correct sampling and complementary to TOS and accreditation by sampling specialists. Internal audits and site visits by a dedicated maintenance team can also provide solid feedback, to review design and allow for improvement. Independent bias testing also provides concrete evidence on the working and compliance of the installed sampler.

Cleary and Robinson (2009) investigated the internal workings of a vezin sampler to ensure compliance as well as impact of cutter speed and deviation from the standard 0.6 m/s as specified in Gy's rules (1982). The proposal from Pitard (2005) of 0.3 m/s or 0.45 m/s opened the door for more versatility on the RPD, and for the new design we opted for a cutter speed of 0.54 m/s at the centre of the inlet pipe to accommodate standard gearbox ratios.

Kruger (2014) explains that the design of sampling equipment is a complex exercise and to understand the relationship between equipment, equipment design and flow characteristics, the material characteristics must be fully understood. He provided some guidelines and considerations for the design of mechanical equipment. Some of these guidelines for dry fines vezin samplers were also found to be relevant to the RPD. The guidelines included:

- Cutter to collect each increment by cutting a complete cross-section of the material stream.
- Cutter to travel at constants speed.
- Cutter length to exceed the inlet by 15%.
- Minimum cutter opening to be at least three times the particle size.
- Cutter must be radial towards the point of rotation.
- Sample should be fed slowly to reduce or avoid dust loss.
- Material movement and discharge should be evenly forward.

PROBLEM STATEMENT: REPORTED BIAS

Material Properties

Despite the versatility and generally perceived compliance and precision performance of the (old) design RPD, a client (Morris, 2016) proved a sampler bias for an application with the following characteristics:

Table I. Physical properties of sylvite and halite minerals

Mineral	Density (g/cm³)	Young's Modulus (GPa)	Lattice Constant (Å)	Crystalline Structure
Sylvite (KCl)	1.984	29.63	6.29	Face-centred cubic
Halite (NaCl)	2.165	39.96	5.64	Face-centred cubic

Our client reported that based on the above visual changes in geological composition of material and physical characteristics, the material has been observed to behave differently when approaching the cutter through the radiused and sloped inlet pipe of the RPD. The analyte to be sampled in a potash process is not homogenous. Up to 80% of the ore can be halite and approximately 20% can be sylvite. During primary comminution the ore is fractured along the crystalline face, and results in some particles 10 mm in diameter being either pure halite or pure sylvite. The kinematics of the of the falling ore particle in material handling and multistage sampling system chute work are different due to the different material properties as indicated in Table I.

The sylvite is more elastic and has a lower density then the halite, thus the force of the particle-chute impact will be relatively less for the sylvite particle to that of a comparable halite particle. Ore that visually appears homogeneous in nature, can still introduce a bias during chute impact and material with different particle sizes. Differences in density leads to segregation or grouping phenomena which is always prevalent in mineral ores and particulate systems to a certain extent.

Equipment Layout, Method and Results

The sampling system consists of a primary linear cross stream sampler at the head pulley of a conveyor belt; the sample taken is discharged via a chute to a small vibrating feeder that will trickle feed the RPD to ensure multiple sub cuts are taken. The RPD was evaluated by taking multiple cuts and comparing the size fractions in the rejects and sample side. This was done at random intervals for a month. The collected ore fractions were then screened on a rotap vibratory screen and the cumulative present passing was calculated. In addition to screening, the individual size fractions were analysed using an x-ray diffraction for mineral content.

Based on the results produced during the sampling campaign there was nearly 50% more +4 mesh material that reported to the sample side, as opposed to the rejects side. Table II below lists the mass split and cumulative mass split to sample and rejects as well as the grade by size assay in the respective streams. The grade bias is evident with the sample frequently measuring higher potassium grades than the rejects.

Table II. Sampling campaign test results

Tyler Mesh	% Cumulative - Rejects	% Cumulative - Sample	% Direct - Rejects	% Direct - Sample	%K_2O - Rejects	%K_2O - Sample
+4	8.9	17.2	8.9	17.2	7.59	10.30
+6	17.0	30.2	8.1	13.0	10.81	9.56
+8	28.0	44.1	10.9	14.0	9.97	11.28
+12	40.3	57.7	12.3	13.6	10.08	11.73
+16	53.7	70.5	13.5	12.8	11.09	12.18
+20	65.7	80.4	11.9	9.9	11.16	12.87
+28	76.4	88.2	10.7	7.8	12.78	12.71
+40	85.2	93.2	8.8	5.0	12.64	13.02
+50	92.6	97.0	7.4	3.8	12.33	14.00
+70	97.8	99.3	5.2	2.2	12.74	13.46
+100	99.6	99.8	1.8	0.5	12.59	14.14
Pan	100.0	100.0	0.4	0.2	12.03	13.98

DESIGN EVOLUTION OF THE RPD TO ALIGN WITH TOS REQUIREMENTS AND ELIMINATE BIAS-GENERATING MECHANISMS

Feed pipe

The presentation of the material to the cutter is critical to reduce the risk of a delineation error. A previous design had the cutter blades horizontal and parallel to each other, with the feed pipe entering the housing at 37° from the vertical. This created an opportunity for material to bounce down the rejects chute and not make contact with the divider plate and the cutter – and not be sampled. Deflecting material could also be presented to the cutter at an angle, and either bounce off the cutter blades into the rejects port or sample port contributing to the bias (Figure 3).

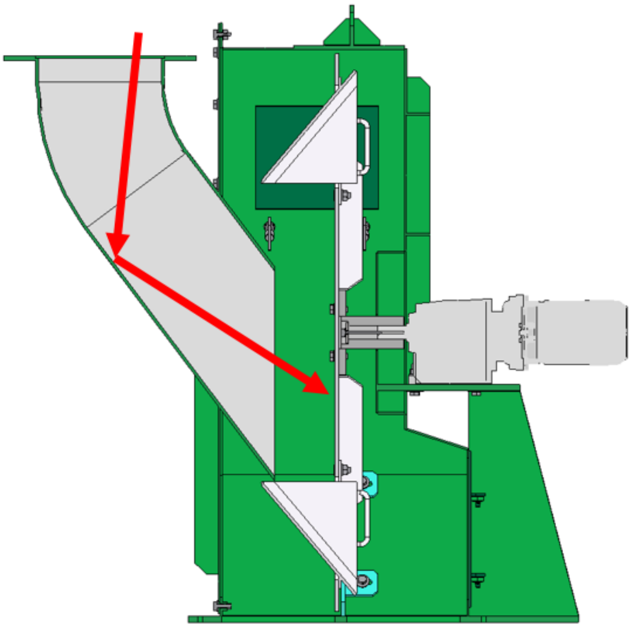


Figure 3. Sectional view of the (old) RPD; material in feed pipe could be deflected and not be presented to the cutter to enable every particle the same opportunity to be sampled.

The feed pipe design can be either round or square with rounded corners, depending on the abrasiveness of the material and if liners are required. The feed inlet design change allows for the cutter angle to be perpendicular to the feed pipe angle, eliminating the chance of material sliding down the feed chute and not being sampled (Figure 4).

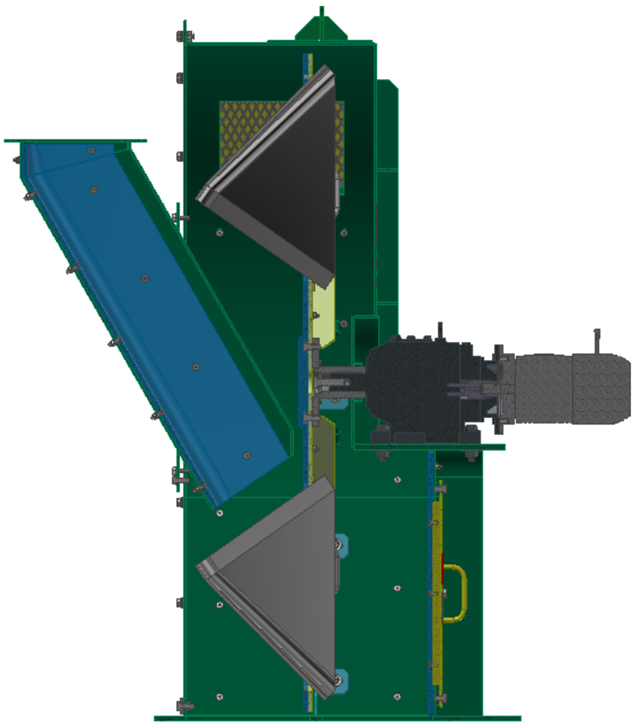


Figure 4. Sectional view of the new RPD; material presentation to the cutter has been revised to conform to sampling standards.

The RPD design allows for material to slide down the inlet chute in a more gradual and controlled way than that of a falling stream as seen in a dry vezin sampler. The controlled feed allows for a reduction of short-range quality variation, as the material is packed together and guided all the way to the cutter edges to be sampled.

Cutter

The cutter design incorporated two horizontal cutting edges that run parallel to the slanted bottom diverting section of the cutter assembly. A sample taken is diverted to the opposite side of the rotating plate that isolates the sample side from the rejects side. The cutter has been designed to protrude past the inlet pipe to ensure all dribblings are caught; the same principle as with the design of a vezin sampler. The maximum cutter aperture is restricted by the sampler design due to the cutter blades needing to clear the feed pipe while rotating. Cutters for applications are specified as either 3D or 4D and achieved by utilising a larger sampler in the range if required. The new design has kept the vertical cutter sides but also open to allow sample to pass through without restriction. The cutter blades are also radially tapered to the centre of the point of rotation. Radial taper allows equal probability of all particles to be sampled at a constant radius over tip speed ratio (Figure 5).

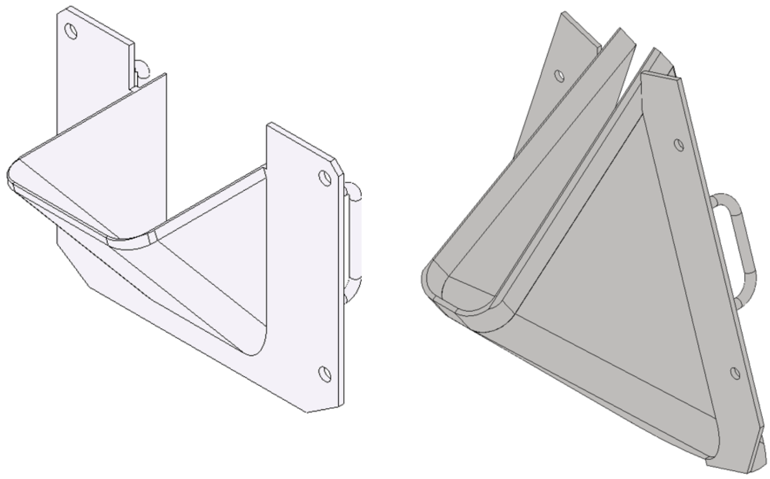


Figure 5. Conventional cutter design on the left, and the improved, revised design on the right.

Protruded Cutter Edges

Protruding cutter edges: although the old design can be considered to have protruding cutter edges, they were not engineered cutter boxes but rather rectangular cavities to intersect the feed stream. The vertical protruding edges of the cutter design aids in ensuring that the cutter aperture is always constant even when the cutter blades are subject to wear. This design feature aids in prolonging the life of the cutter as well as the sample integrity.

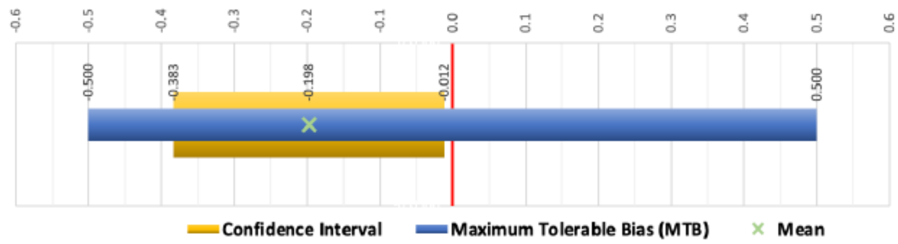
Cutter Speed

The rotating disc mounts directly to the extruding solid shaft of a helical gearbox and electrical motor combination; thereby eliminating the requirements for additional bearings and alignment complications. The electrical motor used is connected DOL and runs at a constant speed. The same principle has once again been adopted as with vezin samplers, and the cutter speed does not exceed 0.6 metres per second (m/sec) on the cutting edge. Based on test work conducted by Cleary and Robinson (2009) on a vezin sampler relating to acceptable cutter speed for sample taking, we have standardised on a maximum cutter speed to not exceed 0.6 metres per second. They state that sampler speeds are generally considered critical for sample performance based on the work of Gy (1982, 1992) and a small-scale falling stream test done.

RESULTS AND CONCLUSIONS

Following TOS recommendations as well as following the rules of symmetry, the revised RPD design, installed in a bauxite application, has proven to take representative samples. Four RPDs were installed in sampling systems and bias-tested by an independent company twice during the last two years. For the bias tests, reference samples were extracted from the stopped production conveyor as per standard industry practice and in compliance with ISO – 10226 aluminum ores – experimental methods for checking the bias of sampling. The composite chemical sample results were compared to the profile plate reference belt cuts over 60 sample sets (one set comprising the composite system sample and reference samples A and B). The bias test results can be seen in Figure 6.

Parameter	Significance of Bias		MTB Limit (%)	Confidence Interval (CI)
	Statistical Perspective	Practical Perspective		
Alumina (Al_2O_3) (%)	Significant	Insignificant	± 0.5	-0.198 ± 0.186



Parameter	Statistical Perspective	Practical Perspective	MTB Limit (%)	Confidence Interval (CI)
Silica (SiO_2) (%)	Significant	Insignificant	+ 0.2	0.124 ± 0.049

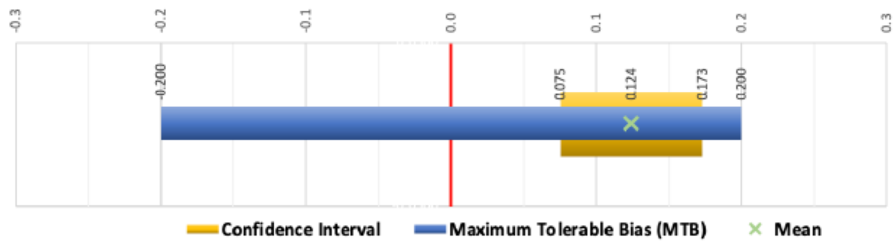


Figure 6. Bias testing (2021) results of the sampling scheme showing client-specified maximum tolerable bias level with the blue line, bias test results with the yellow line.

A bias from a statistical perspective is observed where the average and standard deviation (position and span of the yellow line) does not intercept zero. However, from a practical point of view the data renders the bias irrelevant since the confidence interval falls within the maximum tolerable bias (MTB) limits.

The bias test was performed again in 2022 with results depicted in Figure 7.

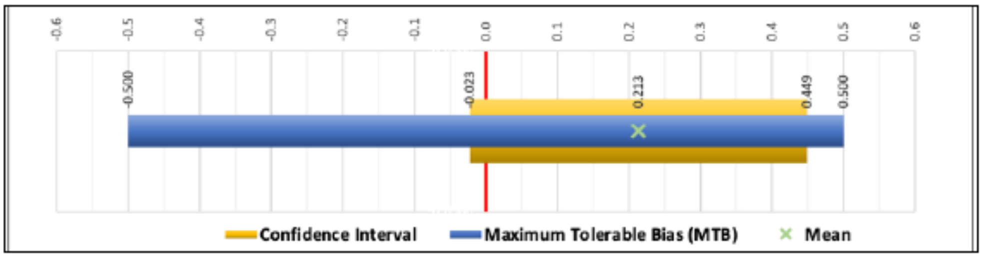
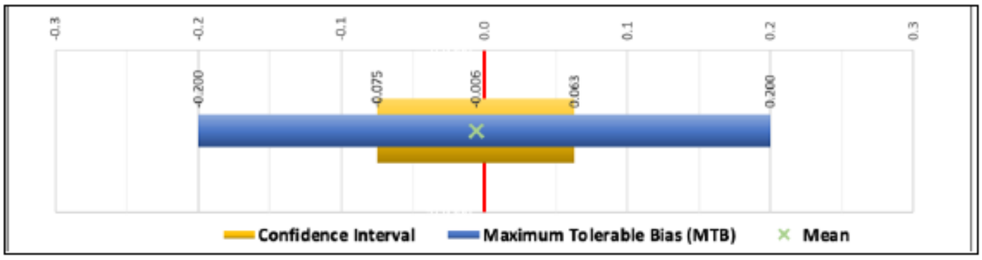
Parameter	Significance of Bias		MTB Limit (%)	Confidence Interval (CI)
	Statistical Perspective	Practical Perspective		
Alumina (Al_2O_3) (%)	Insignificant	Insignificant	± 0.5	0.213 ± 0.236
				
Silica (SiO_2) (%)	Insignificant	Insignificant	± 0.2	-0.006 ± 0.069
				

Figure 7. Bias testing (2022) results of the sampling scheme showing client specified MTB with the blue line, bias test results with the yellow line.

The repeat bias tests show no practical or statistical significance. It is important to note that the bias tests were conducted across a sampling system that employs a primary cross belt sampler, primary double rolls crusher, secondary RDP, secondary rolls crusher, tertiary RPD and sample storage carousel. It can therefore be concluded that neither the RPDs nor the system show a practically significant bias.

The positive results produced confirm that the SEM has eliminated the source of the delineation error experienced through compliance to TOS design principles, and with the added mechanical reliability the SEM has improved the precision of the RPD across minerals and materials handling.

REFERENCES

Cleary P.W. and Robinson G.K. (2009). Some investigations of Vezin sampler performance. *Proceedings of the fourth world conference of sampling and blending, Cape town, South Africa, 21-23 October 2009.* The Southern African Institute of Mining and Metallurgy. Johannesburg. pp. 219–229.

Gy P.M. (1982). *Sampling of Particulate materials*, Revised edn. Elsevier.

Gy P.M. (1992). Sampling of Heterogeneous and dynamic material systems mechanical sampling – a manufacturer's perspective. *Proceedings of the Theories of heterogeneity, sampling and homogenizing, fourth world conference of sampling and blending*, Elsevier.

International Organization for Standardization, (1991). *Aluminium ores – Experimental methods for checking the bias of sampling* ISO 10226:1991(withdrawn).

Kruger C. and Van Tonder E. (2014). Pitfalls in Vezin sampling for finely crushed materials. *Proceedings of the South African institute of Mining and Metallurgy.* The Southern African Institute of Mining and Metallurgy, Johannesburg. pp. 447–458.

Morris A. (2016). Information share – Sampler site performance – Intrepid Potash

Pitard F.F. (2005). Sampling Correctness – A Comprehensive Guideline. *Sampling and Blending Conference, Sunshine Coast, Queensland, 9 - 12 May 2005*. pp. 55-66.

Steinhaus R.C. and Minnitt R.C.A. (2014). Mechanical sampling – a manufacturer's perspective. *Proceedings of the journal of the South African Institute of Mining and Metallurgy: Vol 114.* The Southern African Institute of Mining and Metallurgy, Johannesburg. pp. 121–129.

Clinton Paul Bester

Product Manager
Multotec Process Equipment

28 years ago, Clinton was introduced to the world of sampling and sampling systems. This unique world combining science, theory and mechanical design was intriguing and captivating. As product manager at Multotec Process Equipment, he was involved with all the aspects of samplers, including assembly, installation, commissioning, design and was responsible for ensuring the sampling systems produced conformed to the Theory of Sampling and sampling best practices.