ISO 8685 Compliant Contractual Ship-Loading Export Facility: Bauxite Sampling Plant Process Design and Equipment Selection for Chemical Sampling.

W.P. Slabbert[a] and M. Nyokong[b]
[a]Email: willems@multotec.com
[b]Email: disen@multotec.com

The paper discusses the process design and mass balance for the minimum and maximum design case to illustrate the ISO 8685 compliance of a 2-year-running barge loading payment station sampling plant. The plant samples -100 mm, export quality, bauxite material from a barge-loading conveyor delivering 10 kton/h at 5.4 m/s. The green field operation does not know the Coefficient of Variation or the Size Range Factor as required inputs to calculate the Number of Primary Increments and Minimum Gross Sample Mass required. Therefore, informed assumptions were made given performance data of a neighboring sampling system that is in operation for over a decade. Without the available variation and size factor data the ISO-compliant scheme design could not commence. Where this data is not available for green field projects, it poses a risk that plant designs may not be compliant where variabilities could exceed assumptions on the input parameters.

The system is designed for various barge carrying capacities with lot size in mass. Operational quality assurance however requires samples more frequently and therefore sublot periods are 4 hourly time based. ISO 8685 compliance is achieved with sample increments taken at maximum throughputs and barge sizes to determine the time-based interval. At reduced throughputs, the fixed time interval regime results in the minimum ISO requirements to be exceeded and tied in well with client overall quality incentives.

Primary sample increments from a tailored cross belt sampler are crushed automatically in the sampling plant to 25 mm and then to 6mm using two stages of double roll crushers. The sample is then subdivided through secondary and tertiary sampling to produce a composite 4-hourly chemical sample. The 4-hourly sublot samples are collected in an ergonomic 4-way carousel with each composite sample representing 1-hour barge loading production – allowing the client quality assurance insights into their blending facility performance.

Keywords: ISO 8685 compliant, Sampling Plant, mass-based lot, time-based sampling interval.

Project Background

The client understood the importance of correct sampling as an important contributor to quality assurance of bauxite grade between port-and-buyer. Commercial payment terms were structured around ISO 8685: 1992[1] with specification of Aluminium and Silica grade maximum tolerable bias (MTB) levels. Compliance to ISO 8685 and sampling plant performance to sampling variance within the MTB levels are therefore important to defend commercial trade risks. The client identified the need for correct sampling and ensured that commercial trade conditions were written around the applicable commodity ISO sampling requirement. They did their part well, only to be let down by the executing engineering company and a Sampling Equipment Manufacturer (SEM) who proposed a single stage hammer sampler. Apart from mechanical design inadequacy, this single stage sampling system without comminution and subsampling would result in enormous composite sample masses forcing the operation to take too few sample cuts required for an ISO compliant sampling scheme. Thankfully, informed client technical adjudication role-players compared the single stage, primary sampler proposal against their experience with multi-stage sampling plants on iron ore, coal and manganese and probed the compliance of the offer with a different SEM. This SEM consulted and guided project stakeholders on: 1) sampling correctness, 2) adequate automated mechanical sampler design and 3) understanding the requirements for ISO compliance, given system parameters of particle top size, lot size, production throughputs and nomograms imbedded in the ISO standard that require crushing before subsampling to ergonomic sample sizes. However, increment variability and size range factor data were not known for the green field operation and sampling scheme design calculations could not be done. Under preliminary assumptions, the SEM explained that the primary sampler is only the first step into an overall sampling regime that requires a sampling plant infrastructure. Unknown system parameters would have to be obtained before the design can commence.

Further project constraints included production conveyors which were under construction and an onsite laboratory which was already built. SEM advice on sampling correctness of a cross stream primary sampler was explored but concluded that

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existing conveyor designs and transfer tower heights did not allow for belt end crosscut samplers to be fitted at the head pulley. A feasibility study was conducted, with conceptual equipment designs from the SEM, to determine the techno-commercial project implications to install cross stream samplers. The anticipated project costs and reworks on existing infrastructure rendered this option to be unfeasible. Suitable positions were identified for installation of a primary hammer (cross belt) sampler, despite structural engineering challenges on existing conveyor stringer load allowances that would have to be overcome. Despite other ISO sampling standards prohibiting the use of cross belt samplers, ISO 8685[1] does not exclude hammer samplers from use in Bauxite sampling applications. The run of Mine (ROM) material is crushed down to -100 mm export size using Mineral Sizers which are promoted to generate less fines and more regular shaped product both of which are suitable characteristics for representative cross belt sampler applications. The laboratory equipment was already installed and imposed constraints on composite sample top size of 6mm and sample mass of less than 10kg.

The client's mandate to be recognized as a reliable bauxite supplier overcame the technical and commercial hurdles to install a multi-stage sampling system with cross belt primary sampler as a "compromise" to cross stream samplers which are better regarded by sampling purists.

The responsibility was set on the SEM to design and supply a multistage sampling system for commercial trade that complies to ISO 8685, overcomes the engineering constraints and delivers correct sampling results within the MTB limits.

Literature Review.

Holmes (2010)[2] mentions that sampling must be given the necessary attention to produce representative samples for analyses. It should be noted that Holmes makes use of the word sampling not sampler, since a sampler is a piece of device, mechanical or not, that can be used to collect a sample from a moving stream or stationary lot. The word sampling is the science of collecting representative samples which includes, but is not limited to the sampler, number of increments the sampler takes, how the samples are collected, stored, and transported to the lab for analyses and ultimately how the samples are analyzed. It is important to understand that deviation from an ideal sampling scheme is a cumulation of incremental error contributions towards the total sampling error as defined by the Theory of Sampling (TOS). The degree of error accumulation and nature of the errors are ascribed to bias (accuracy deviation), precision (reproducibility) and ore variability. Therefore, the objective of any sampling system or protocol is to eliminate or minimize bias, standard deviation and minimize variance (Minnitt, 2007)[3]. Eliminating bias generating errors falls under the responsibility of the SEM. Where material variance information is available (i.e. in the form of a Nomogram), the SEM is also expected to design a sampling system that can sample the material variance to the required precision levels through sample increment frequency and sufficient sample mass. The nomogram information is not always available for the specific ore of concern, as a result, ISO standards are normally referred to as a guideline for sampling of various bulk commodities (Steinhaus & Minnitt, 2014)[4]. According to Steinhaus and Minnitt (2014)[4], SEMs need to familiarize themselves with the critical aspects of each ISO standard which relates to the minimum number of increments and the minimum sample mass to be collected per lot, the minimum number of sub-increments per preceding increment, quality variations, precision levels achieved relative to the material nominal top size, etc.

Recent advances on practical mineral process sampling of damp bauxite is published (Lyman, 2019[5]) and useful to future bauxite sampling projects. The release of the book lagged the project design of this paper with a year and this paper did not benefit from the valuable recommendations.

Mass versus time-based sampling and the weighting error

The Weighting Error is defined by TOS as the error that results when a sample increment weight is inconsistent despite consistent lot sizes (production weight intervals) it is supposed to represent - where the sampling rule of proportionality is not conserved. In the case of hammer samplers, the sampler can only sample the material loaded on the belt at the instance of increment extraction. Even if the cutter speed set point is changed in between consecutive increments, the sampling action will not result in a different sample increment weight because the hammer sampler will still sample the material burden on the belt (now only at different velocity through the stream). The increment mass extracted by a hammer sampler will only change if the velocity of the production conveyor it is sampling from changes and results in a lower loading (ton per meter) on the belt. If each hammer sample increment is intended to represent a constant production weight, where the sample cut is prompted by a cumulative weightometer input in a mass based scheme, there could be a discrepancy in the ratio of sample increment weight over constant production weight, between consecutive increments. For this reason, hammer samplers can only be used on a time basis.

Cross stream samplers however, can be controlled over a defined range by varying frequency drives to change their cutter speed before a cut is initiated and then cut through the stream at that instantaneous speed set point. This possibility allows a cross stream sampler, running on a mass based sampling scheme, to adapt its cutter speed to spend more or less time through the stream and result in a constant ratio of sample increment weight over constant production weight. Cross stream samplers can be used in mass- or time-based sampling regimes. For use in time-based regimes, the cutter speed must be consistent between cuts at a fixed set point irrespective of instantaneous throughput.

Theoretical design of the ISO compliant sampling scheme

Known input parameters

The design heuristic for a compliant bauxite sampling system is explained by the ISO 8685 sampling standard[6].The number of primary increments and the minimum gross (composite) sample mass are important design outputs from the ISO standard equations. The calculations require input variables for the parameters of the specific system being designed. The known input parameters for this system is listed in Table 1 below.

Table 1. System design parameters.

Parameter	Value	Units	Comments
MTB for Alumina content	±0.5	%	Measured as Al_2O_3
MTB for Silica content	±0.2	%	Measured as SiO_2
Lot size	13	kton	The client requirements extend beyond a chemical sample per barge load (mass based) and requires quality assurance of the blending and reclaiming (quality control) operations. A time based hourly chemical sample is required over the 1.5-3.5 hour barge load duration.
Lot duration	4	h	
Sub-Lot duration	1	h	
Nominal particle top size	100	mm	Produced from a Mineral Sizer known for producing cubic shaped particles with minimal fines generation.
Particle density	2 680	Ton/m^3	

Unknown input parameters

The greenfield operation has not produced any sampling results and the following two inputs parameters are unknown. The increment variance (V_I) is assumed to be 1.75. The sampling scheme design authority has access to a nearby operation's variance data from their more-than-a-decade operational sampling plant and can base this variance assumption on data from previous bias tests conducted at the preceding site. The assumption will have to be verified according to DS 3077 (2013[7]) against system produced data once the sampling plant is operational.

The coefficient of variation (C_V) for Aluminium and Silica grades is assumed by the client to be 15% for this "homogenous ore" and verified against neighboring sampling plant data as a reasonable assumption. The assumption will have to be verified against system produced data once the sampling plant is operational.

The risk of using unknown parameters into an inflexible plant design

Where data is not available, assumptions towards unknown input parameters required to design a compliant sampling scheme may be the designer's only option. The scheme design will dictate the equipment selection for the sampling plant. Once operational, the sampling plant must produce accurate results without bias. The accurate data from the sampling campaign will allow calculation of the variance parameters and the sampling scheme design must be verified for ISO compliance using the new variability data. The results may render the original sampling scheme non-compliant and larger sample weight and/or more frequent sampling may be required. It may also happen that production or in sampling plant crushers do not perform to their size reduction and large particles may have to be sampled. It is therefore important that the sampling equipment, crushers and plant throughout design capability be conservative on the first iteration and adaptable to accommodate the new throughput rates, sample weight and particle top size. Adaptability should come without major modifications and capital cost. Designing green field sampling plants to meet (not exceed) minimum compliance requirements is a great risk if reliable variance data is not available. Where major plant upgrades to a new sampling plant must be done post-commissioning, capital is not likely to be approved resulting in undersized and underperforming sampling plants (white elephants) which the industry should not tolerate.

Calculation of compliance requirements

The number of required primary sample increments (n) is calculated using the below equation from ISO 8685[8].

$$n = \frac{V_I}{\sigma_S^2}$$

n is the number of primary increments

V_I is the increment variance

δ^2_S is the desired sampling variance

The value for n is calculated to be 43.75 using V_I = 1.75 and using the more stringent 0.2% silica (SiO_2) sampling variance. Practically 44 increments for chemical assaying are required. The number of 44 increments for silica precision sampling transcends the requirement for Aluminium content sampling, at ±0.5% precision, by factor 6 and exceed minimum compliance requirements.

The number of sampling units (k) cannot be calculated in the design phase with too many variables (variance of sampling, sample preparation, measurement, overall variance and number of replicable determinations) not known before the sampling plant is commissioned. The plant is rather designed to collect and analyze 4 off 1-hourly samples according to the client's quality assurance requirements around their blending operations. Without the necessary data, the number of sampling units is set to 4 without strict compliance to the ISO determination. The design decision will have to be verified against system produced data once the sampling plant is operational.

The minimum gross sample mass required to achieve the desired relative sampling error is determined using (ISO 8685[9]):

$$m_G = \left(\frac{C_V}{\sigma_S}\right)^2 \rho g D^3 \times 10^{-6}$$

M_G is the minimum gross sample mass in kilogram

C_V is the coefficient of variation between particles of the quality characteristic under investigation.

δ_S is the required relative sampling error (standard deviation).

ρ is the particle density in ton/m^3 (not bulk density).

g is the size range factor.

D is the nominal top size in millimeter of the ore in the Lot

The size range factor was calculated from the data obtained during production scale test runs performed by the production mineral sizer original equipment manufacturer. Test work was also conducted to determine the crushing efficiency of the in-plant sample preparation, double stage rolls crushers. The necessary PSD data of the crusher test work is listed in Table 1 below.

Table 2. Crusher performance results at P_{95} and P_5 and determination of size range factor (ISO 8685[8]).

Sample Identification	D=P_{95} (mm)	D' = P_5 (mm)	D/D'	Value for g
ROM production	100	3	33	0.25
After first stage double rolls crushing (within sampling plant)	25	1	25	0.25
Wet material After second stage double rolls crushing (within sampling plant)	4	<1	>4	0.25
Dry material After second stage double rolls crushing (within sampling plant)	9	<1	>6	0.25

The minimum gross sample mass is calculated by using parameter values listed above to be 3769 kg. After size reduction to P_{95} = 25 mm, M_G decreases to 59 kg and at P_{95}=6 mm reduces to 0.81 kg. It should be noted that the tabulated result for secondary crushing test work of dry material (P_{95}= 9 mm) was not used in the calculation because crusher design modifications are made to ensure that -6 mm material would be produced under both wet and dry operating conditions (this is a laboratory top size constraint). All PSD values used in the above table must be confirmed during performance testing of the plant and design parameters verified as actual performance data.

From the minimum gross sample mass, the increment mass is calculated to be MG/n = 3769/44 = 85.7 kg.

The sample increment frequency is calculated as the lot duration divided by the number of primary increments required. For this system design, 44 increments must be taken in 4 hours' time which requires an increment every 5 minutes and 27 seconds.

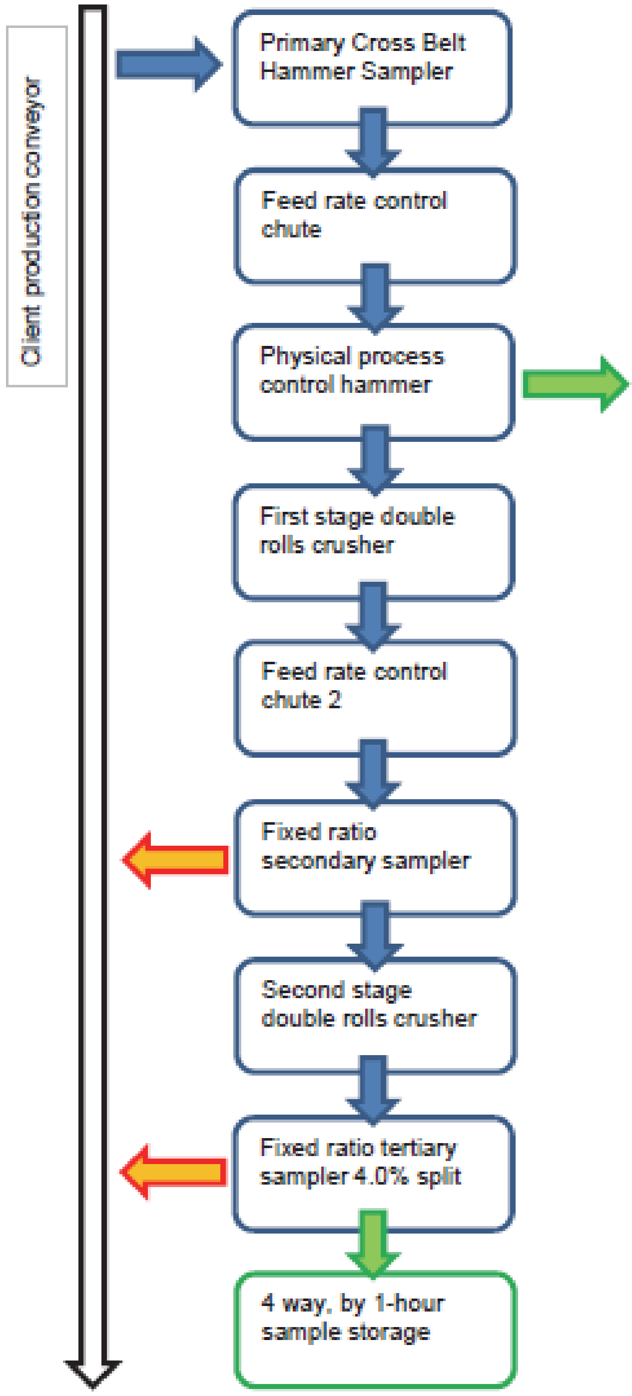
For chemical sample compliance, the sampling plant must take a primary cut every 5 minutes and 27 seconds to total 44 increments over a 4-hour lot period. Each increment must have minimum mass of 85.7 kg. The total composite sample mass over the lot must be 3769 kg at 100 mm particle size, 59 kg at 25 mm and 0.81 kg at 6 mm nominal top size.

However, there is a requirement for a process control physical sample to monitor the particle top size from the mining operation. To extract this physical indicative sample, a secondary hammer sampler is designed onto the sampling plant primary feeder conveyor. This sample is not required to be ISO 8685 complaint but the removal of material from the chemical composite sample stream affects the final sample weight rendering the plant non-compliant. The physical sampler would extract a single physical sample increment, per alternating primary sample increment. The mass of each physical sample increment was calculated to be 8 kg and 21 kg at minimum and maximum production loading, respectively. Over the Lot period consisting of 44 primary sample increments, it would mean that 462 kg of the total primary sample increment would be removed from the system and not report to the ISO 8685 complaint chemical leg of the sampling plant. To account for this removal of material 3 additional primary sampler increments (now totaling 47 increments) would be extracted to substitute (257 kg per increment times 3) 771 kg of primary increment through the system at 10 kton/h throughput rates. The same proportionality also applies at the minimum throughput rates of 3.75 kton/h. To allow the 3 additional sample increments over the Lot period of 4 hours, the increment time had to improve from 5 minutes and 27 to the final design 5 minutes and 11 seconds. Previous increment minimum- and composite sample masses remains unchanged.

Now that the theoretical calculations for the sampling scheme requirements are determined, the automated mechanical equipment that can fulfill the requirements must be designed by the SEM.

Practical design and equipment selection for the ISO compliant sampling plant

Figure 1 below provides the block flow diagram for the sampling plant design resulting from suitable equipment selection. The tabulated values for each stream list the particle size at that unit operation. The minimum and maximum sample masses (proportional to minimum and maximum production throughout rates) per single increment and over a 4-hourly lot period is tabulated. The subsequent text explains how the sampling plant meets the requirements of the sampling scheme design and continues to discuss relevant equipment design considerations.



Property		Per increment	Per 4-hourly composite
P95 (mm)		100	
Mass (kg)	Min	96.5	4,536
	Max	257	12,079
P95 (mm)		100	
Mass (kg)	Min	96.5	4,536
	Max	257	12,079
P95 (mm)		100	
Mass (kg)	Min	8	376
	Max	21	987
P95 (mm)		25	
Mass (kg)	Min	88.5	4,160
	Max	236	11,092
P95 (mm)		25	
Mass (kg)	Min	88.5	4,160
	Max	236	11,092
P95 (mm)		25	
Mass (kg)	Min	81.78	3,844
	Max	218.06	10,249
P95 (mm)		25	
Mass (kg)	Min	6.72	316
	Max	17.94	843
P95 (mm)		25	
Mass (kg)	Min	6.45	303
	Max	12.92	607
P95 (mm)		25	
Mass (kg)	Min	0.27	13
	Max	0.72	34

Figure 1. Sampling plant block flow diagram tabulating corresponding sample weight per increment and composite sample weight per Lot size listed against each unit operation.

Comparing Figure 1 listed sample mass to the sampling scheme design values form the previous section, it can be concluded that not only the primary increment masses of 257 and 88.5kg exceeds the minimum ISO 8685 requirement of 85.7 kg, but also the composite sample masses (after 47 increments) exceed the minimum requirements: 4536 against 3769 kg, 316 against 59 kg and 13 against 0.81 kg.

The resulting 34 kg of composite sample at highest throughput rate of 10 kton/h is split between four off 1-hourly sample bins and therefore still ergonomic and within laboratory constraints for 10kg per sample.

The sampling scheme design exceeds minimum ISO 8685 requirements while allowing ergonomic samples at the end of the Lot according to Lab constraints.

Primary Sampler.

The primary, cross belt hammer sampler was purposefully designed for the application with main components illustrated below (Figure 2).

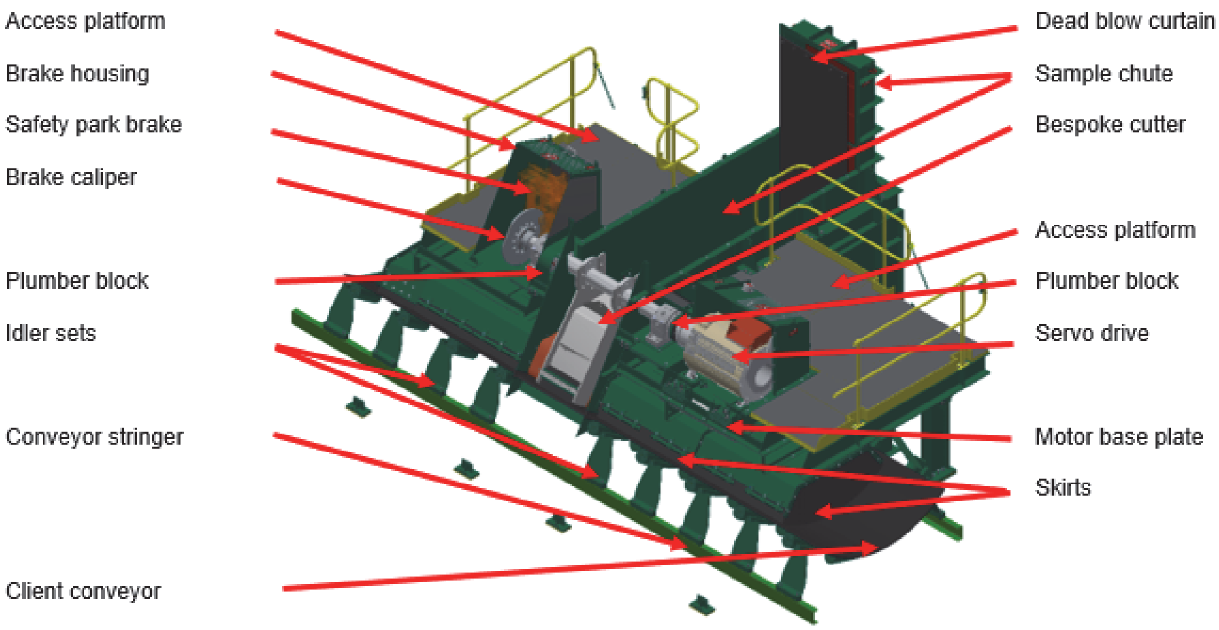


Figure 2. Main components of the hammer sampler seen from the drive end – sectional view without support frame. Handrails appear incomplete resulting from the sections made on the model to show the operational parts.

The primary sampler uses a 500 mm wide cutter and a unique servo drive system to provide the torque required to cut with constant speed across the 10 kton/h production stream, moving on a conveyor at 5.4 m/s. The sampler is purposefully designed for the application and has a number of design features implemented to minimize potential error generating mechanisms typically associated with commonly available cross belt samplers (Pitard, 2005[11]; Robinson, Sinnott, and Cleary, 2008[12]). A full technical paper on the details of this machine, designed and built under affiliated Licensor Siebtechnik GmbH, is published in the WCSB 10 proceedings ("Cross Belt Sampler Mechanical Design of the World's Largest Hammer Sampler for Bauxite Export Contractual Requirements" but not added to the reference list because it is not yet published).

The increment mass collected by this sampler (and listed in Figure 1 above) is calculated using:

$$M_I = \frac{q_m \times b_c}{3.6 \times v_{pc}}$$

M_I is the mass of the increment in kilogram.

q_m is the production throughout on the conveyor in ton/h.

b_c is the cutter aperture in meter.

v_{pc} is the production conveyor velocity in m/s.

It must be noted that the sample increment mass calculation above is not the same as the calculation for cross stream samplers; see ISO 8685:1992, page 10 for the required formula and parameter definitions for cross stream sample increment mass calculation.

Secondary and tertiary samplers

Secondary and Tertiary samplers are Rotating Plate Dividers (RPDs). These automated mechanical samplers use a large diameter rotating disc "fly wheel" design, that rotates at <0.45 m/s cutter tip speed, to drive a cutter through the feed inlet stream and isolate samples through the rotating plate into the sample chute while the sample rejects remains on the feed end of the rotating plate (Figure 3). RPDs run continuously, without stop starts or forwards/backwards movement, with significant inertia that results in ultra-simple and reliable operation with minimum maintenance and no finnicky parts that requires attention. RPDs are started direct online, uses a helical bevel gearbox and motor that drives a shaft, to drive the rotating plate. The cutters are mounted to the rotating plate. The equipment design includes sampling error combating features: a round and steep feed pipe to minimize segregation, perpendicular cutter-to-feed pipe interception, radially tapered cutter(s) with rounded corners to prevent material hang-up and seal arrangements between the rotating plate and stationary sample-rejects-chute intercept to prevent material misplacement. 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 6 sub cuts per preceding increment and will result in improved sampling precision level. The cutters are interchangeable and can accommodate different apertures for different sample sizes to adapt to sampling regime requirements/amendments. The rotating plate can allow up to 4 of the interchangeable cutters making the design flexible, at low cost, to adopt to sampling regime requirements.

The secondary sampler subsamples the -25mm material using two off, 3 times top size cutters of 75mm aperture. The division ratio of secondary sample weight out of total feed weight is 7.6% (the remainder is sample rejects).

The smaller tertiary sampler uses 1 off 50 mm cutter to sub sample the nominal -6 mm secondary increment in a 4% fixed ratio to produce the tertiary sample. A three times top size cutter of 18mm is not employed to allow ease of operation and unblocking which is impractical for smaller cutter apertures.

Figure 3. Sectional view of the Rotating Plate Divider feed pipe (on the right) presenting a sample increment to the cutter (middle) to sub-sample (blue particles) the stream and generate rejects (black particles) on the feed side of the plate. Sample and rejects report to separate, isolated chutes.

Crushers

The project design criteria call for impact hammer mill type crushers typically used on Australian Bauxite. However, test work confirms that impact hammer mills are not efficient in their reduction ratio of reducing Guinean bauxite material. The test results reaffirm the use of double rolls crushers on existing Guinean bauxite sampling plants. This material deposit has nodules of Aluminium-rich material with Mohs hardness of up to 7, embedded in a much softer substrate with Mohs hardness of 3 (Figure 4). Primary sampling plant crushing from 100 to 25 mm is achieved relatively easily, but once the hard nodules are released from the substrate material, the crushing of these nodules are more taxing. The standard double rolls crushers must be upgraded with regards to spring tension, bearings, stub-shaft material and diameter, drive power and material of construction of the rolls themselves requiring already work-hardened manganese alloy. Guinean Bauxite becomes very sticky at critical moisture contents and could choke up the stationary impact surfaces of impact hammer mills. Double rolls crushers aid to drive the material through the rolls and are less prone to operational blockages.

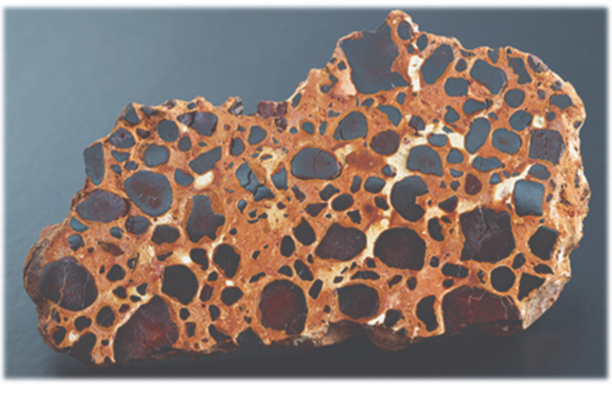


Figure 4. Bauxite material showing soft substrate material in brown and hard nodules in reddish-black. Nodules are typically liberated at 50 mm and have a diameter of 5-30 mm.

Equipment seal arrangements

The crusher inlet and outlet chutes are designed with overlapping rubber seal arrangements to prevent loss of fines (sample bias generator) while still allowing maintenance access.

All other chutes in the plant are designed as either bolt on chutes with seal gaskets or tailored overlapping rubber seal arrangements to prevent selective sample loss or sample contamination.

All sampling equipment are sealed to contain and prevent sample contamination.

Feed control chutes

Proprietary feed control chutes allow for mechanical adjustment of profile plates that forms the material burden width and height, manipulating the cross-sectional area through which increments are extruded thereby adjusting increment draw out rates. The chute design allows control towards subsequent sub sampling number of cuts. The chutes are designed with steep angles and proprietary geometry to prevent blockages. The generous chute volume acts as intermediate storage vessels from where samples are extruded by the underlying conveyor – minimizing segregation of material through the plant.

Feeder conveyors

Sample feeder conveyors are equipped with variable frequency drives to adjust their speed and throughput rate. This easily implemented-, adjusted in real-time flexibility ensures that samples are processed timeously through the plant, but also that crushers are not overfed when increased material hardness requires longer crusher “residence time”. Most importantly adjustable belt speeds allow the sample increment to be stretched out and achieve more than 20 sub cuts through downstream sampling. Conveyors are fully skirted to prevent sample loss, fully cladded to prevent sample contamination and include scrapers at the head end pulley to allow fines to report through the plant and be proportionally accounted in the composite sample.

Sample storage carousel

A 6-way sample storage carousel is designed to allow safe storage of the four 1-hourly composite samples, plus two spare slots for operational contingency. The carousel is equipped with a protruding feed pipe to ensure all fine material reports into the composite sample bin and does not flare over the drum rim and is lost. When the bin is indexed out of the receiving position, the top of the bin is sealed with a flexible gasket to prevent sample contamination while the bin is in storage. The carousel can be indexed manually from the control panel to allow the operator to remove all bins consecutively from the same door. Interlocks are provided to prevent the carousel from indexing while the door is open and operators can be exposed to moving equipment.

Rejects

The sampling plant includes automated rejects handling through rejects chutes after secondary and tertiary sub sampling onto a rejects conveyor that report back onto the production conveyor.

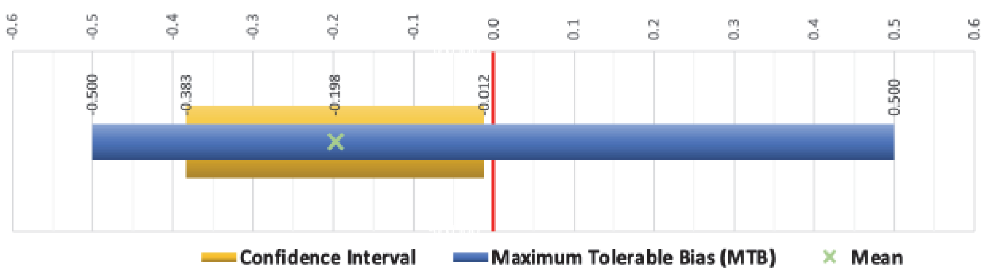
Material handling.

Bauxite is notoriously sticky at elevated moisture content but still below the transportable moisture limit. Over and above the sampling plant design, equipment selections should bear cognizance of potential blockage problems. All chutes with practical geometry are lined with low coefficient of friction, polymer liners. Special polyurethane tools (shovels, picks, spatulas) are required to clean the sampling plant where normal steel tools would scratch the liners and increase the surface roughness. Chute angles are designed to have minimum 70-degree angles and 65-degree valley angles which contributes to sampling tower height and capital cost. Most chutes are equipped with blocked chute detectors which upon detection would activate a PLC controlled vibration motor sequence to release the blockages. The system works well and clears blockages automatically, even under challenging conditions, without stops or operator intervention. Vibration transfer into the structure is prevented by suspending the chutes with chain from the ceiling since chutes cannot be bolted to equipment or the structure. Ultimately the additional blockage clearing system costs are worth the expense by preventing operational challenges, promoting plant availability and because sampling plant healthy operation is interlocked with the production conveyor running - production stoppages are a minimum.

Performance – bias testing

The sampling plant, sample preparation and analytical procedures were bias tested 6 months after commissioning, by an independent, experienced third party. The bias test results can be seen in Figure 5 below. The reference samples were extracted from the stopped production conveyor as per standard industry practice and in compliance to ISO – 10226 Aluminium ores – experimental methods for checking the bias of sampling[13]. The composite chemical sample results were compared to the profile plate reference belts cuts over 60 sample sets (one set comprising the composite system sample and reference samples A and B). No separate bias testing of the primary sampler was conducted – only the entire sampling plant performance was tested.

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

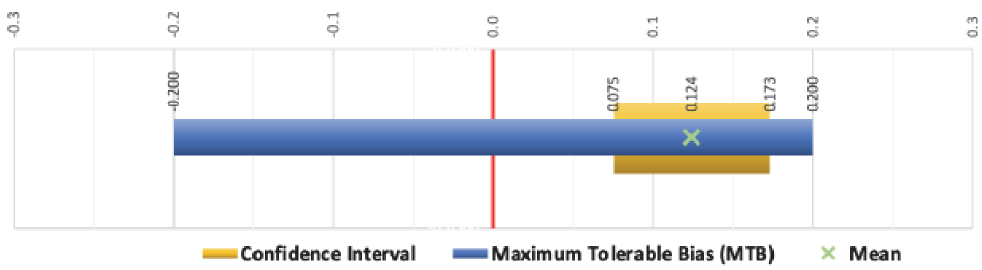


Figure 5. Bias testing results of the sampling scheme showing client specified Maximum Tolerable Bias Level (MTB) with the blue line, bias test results with the yellow line.

Bias detection was done in accordance to ISO – 10226[13]. A bias from a statistical perspective was 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 MTB limits set out by the client as applicable to their commercial trade parameters.

Silica grade is overreported against the reference samples. The client informed that the Silica grade reports in the fine fraction. This implies that fines are oversampled in their proportion in relation to the Aluminium bearing coarser material. This finding is in direct contradiction to claims that hammer samplers tend to leave fines on the belt. An isolated bias test on the primary hammer sampler only (not the entire sampling plant) would be a more conclusive basis to support this claim.

Aluminium grade was slightly underreported while Silica content slightly overreported against the "truth" (reference samples). If the seller of bauxite is faced with a contractual claim for quality (low Aluminium content or high Silica content), the under and over reporting of respective elements would act in the bauxite seller's favor to defend the claim when explaining that the sampling plant values are conservative on each quality parameter.

Conclusions

To allow ISO 8685:1992 compliance requirement calculations, this design leveraged off variance data available from a neighboring operation. Without the neighboring plant's reference data variance data required as input to ISO calculations would otherwise not be available. Daring assumptions towards such variance may leave the sampling scheme designer unfeasible against uninformed competitors that would propose non-compliant systems.

Crusher test work was paramount to determine some of the ISO compliance calculation parameters for particle size which otherwise would not allow the calculation of sample masses through the various sampling and subsampling stages of the sampling scheme design. Double rolls crushers are recommended for crushing of Guinean bauxite ore in sampling plant infrastructure.

Without the above two data sets, the client faces a risk of building a sampling plant, where if assumptions are not true, will result in significant capital investment to upgrade the plant and if not implemented will result in a non-compliant or non-operational sampling plant. Sampling results are needed before sampling variance can be calculated and only then can a compliant sampling scheme be designed. The interdependence of a sampling plant to generate reliable variance data – before it is built – so that a reliable sampling plant can be built is a catch 22 and makes ISO standard compliance difficult to implement practically where information is not available in the design phase.

For this system providing chemical ISO compliant samples and indicative physical oversize samples, primary increments are collected every 5 minutes and 11 seconds to total 47 increments over a 1-hour sublot, 4-hour lot period. Each increment must have minimum mass of 85.7kg, which was well exceeded with 96.5kg at 3750 ton/h and 257 kg at 10 000 ton/h production rates, respectively. The total composite sample mass over the lot must be 3769 kg at 100 mm particle size, 67 kg at 25 mm and 1 kg at 6 mm nominal top size. These values are also comfortably exceeded.

A bias from a statistical perspective is observed, but from a practical point of view, the standard deviation is low and falls within the minimum tolerable bias limits set by the client. The sampling scheme is ISO compliant, performs reliably with good availability and performs well for chemical grade sampling.

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