ISO 13909 Compliant Contractual Payment Station Coal Sampling Plant: Process Design and Equipment Selection for Chemical, Physical and Moisture Sampling

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

The paper discusses the process design and mass balance highlights to illustrate the ISO 13909 compliance of a 4-year-running contractual payment station sampling plant. The plant is used to sample -60mm coal supply to a coal fired power station infrastructure belonging to the South African National Power Utility. Payment parameters are proximate analysis (Calorific Value, Ash-, Sulphur content), physical (size and abrasion index) and moisture content. Over and above ergonomic physical samples and timeous moisture samples, the plant also delivers the crushed chemical sample in triplicate for buyer-, seller- and referee analysis.

The lot period was defined as 24 hours production while the system compliance was designed around mass-based sampling. Production varies over a wide range of throughout tonnages from 800-3600 ton/h as dictated by complex boiler and silo operational requirements. The plant required a unique operational philosophy to adapt the number of primary increments (and corresponding time interval) per sublot size to the varying production rates which over a fix lot period results in varying lot size. Furthermore, a contractual grade, calibrated, 6-idler belt scale is used to measure the instantaneous conveyor load which in turn controls the cutter speed via a programmable logic controller (PLC) prompted variable speed drive (VSD) setpoint to sample fixed increment mass to represent fixed production mass interval.

The primary belt end crosscut sampler boasts a unique articulated joint design sample chute to fit down the high sample tract; eliminating the delineation errors associated with the previous competitor design.

Keywords: ISO 13909 compliant, Sampling Plant, chemical-, physical-, moisture sampling, time-based lot, mass-based sampling interval.

Project Background.

One of the major National Power Utility Power stations in South Africa, which contributes to the South African energy grid, required a sampling plant payment station to be used in its off-take agreement with its fuel supplier.

Multotec supplied a full turnkey solution consisting of an ISO 13909 compliant sampling scheme design and custom-built sampling equipment. Since the project was not completed by the previously awarded competitor, there was already an existing building infrastructure onto which the sampling plant payment station had to be retrofitted and installed. Steinhaus and Minnitt (2014)[1] emphasize the difficulties encountered when implementing samplings solutions on an

doi: https://doi.org/10.1255/tosf.163

already existing processing plant. In addition to the brown fields engineering challenges of fitting new sampling equipment into constrained building layouts, the following was also critical to the design and success of the project:

1. Sampling measurements for contractual payment according to ISO-13909 for the collection of Chemical, Physical and Moisture composite samples.
2. Mass based primary sample increment compared to a time-based Lot period with extraction of constant primary increment mass within mechanical cutter speed design limitations and over a large range of throughputs.
3. Triplicate Chemical Composite Samples to be collected for the seller, customer, and referee.

Literature Review.

Holmes (2010)[2] mentions that sampling needs to be given the necessary attention to produce representative samples for analyses. It should be noted that Holmes (2010)[2] makes use of the words 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 stationery lot. The word sampling is the science of collecting representative samples which includes, but not limited to the sampler, number of times the sampler takes increments, how the samples are collected, stored, and transported to the lab for analyses and ultimately how the samples are analyzed. It is important to notice the above cumulative deviations from an ideal sampling scheme design can be summarized into 10 sampling errors as per Theory of Sampling (TOS). The degree of error accumulation and nature of the errors are defined by the 10 sampling errors and can be classified as bias (accuracy deviation), precision (reproducibility) and ore variability. Therefore, the objective of any sampling exercise or protocol is to eliminate or minimize bias, standard deviation and minimize variance (Minnitt, 2007)[3]. Bias generating errors falls under the responsibility of the Sampling Equipment Manufacturer (SEM), however, variance (precision) can also be the sole responsibility of the SEM, provided that the variance information is available (i.e., in the form of a Nomogram).

The nomograph 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)[1]. Coal and Iron Ore commodities consist of comprehensive standards which can be obtained from the ISO committee and local standard organisations. According to Steinhaus and Minnitt (2014)[1], the SEM needs to familiarize themselves with the critical aspects of each ISO standard which relates to minimum number of increments to be collected per lot or consignment, minimum mass to be collected per lot or consignment, minimum number of sub-increments per preceding increment, quality variations, precision levels achieved with each specific minimum mass collected per lot or consignment relative to the material nominal top size.

There are various standards applicable to the sampling of coal and coke which includes, but not limited to the below:

- ISO 13909:2016 which consists of 8 parts for coal and coke handling. Part 2, 3, and 4 relate to coal only, and Part 5 and 6 to coke only (ISO, 2016[4]).
- ASTM standards
    1. ASTM D 7430 – Standard practice for sampling of coal. The standard is normally used to calculate the number of primary sample increments to be collected per lot or consignment.
    2. ASTM D 2234 – Standard practice for collecting gross sample of coal.
    3. ASTM D 2013 – Standard for preparing coal samples for analysis.
- Australian standard – AS 4264, Coal and Coke Sampling procedures.

Design Scheme for Contractual Payment Station - Coal Sampling Plant.

The design scheme guideline as outlined in ISO (2016)[4] was used to design the contractual payment station sampling plant. The input parameters required for the design was obtained from operational personnel at the power station and is listed in Table 1.

Table 1. Sampling system design input parameters

Parameter	Value	Units	Comments
Throughput per Belt (Maximum)	1800	*tons/hour*	
Throughput per Belt (Minimum)	800	*tons/hour*	.
Material Top Size	60	mm	
Lot period	24	h	
Lot size (Maximum)	86 400	tons	
Lot size (Minimum)	38 400	tons	
Particle density	2.680	Ton/m^3	
Chemical sample particle size to the lab	6	mm	This is the size fraction that is required by the lab for analytical analysis
PSD precision level	2	%	This precision level was provided by operational personnel and listed as a requirement
Sampling frequency	240	tons	Provided by operational personnel
Chemical analysis precision level	0.2	%	0.2 % ash precision level is required. No other elements such as Sulphur for example were specified. The SEM is aware that these other elements can be important to consider in the design scheme.
Frequency of collecting moisture samples	8	hours	
Frequency of collecting Chemical and PSD samples			

Primary Sampler Sizing and Selection

The primary increments collected by two identical primary samplers are outlined in Table 2. This primary sampler boasts a unique articulated joint design sample chute to fit down the high sample tract; eliminating the delineation errors associated with the previous competitor design where a pendulum effect, resulting from the long cutter that had only been supported at the top, drive end. The articulated joint design (Figure 1) allowed additional supports, but more importantly facilitated triangulation of the main cutter and sample outlet pipe, making the sample length sturdier and allowing constant cutter speed through the stream (across the range of VSD set points).

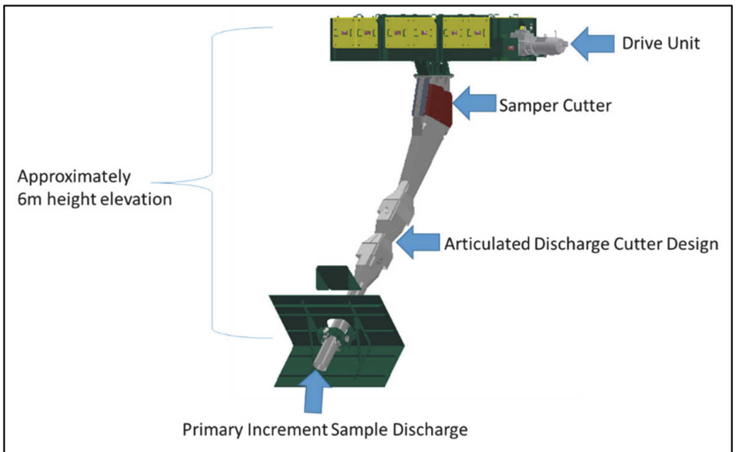

Figure 1. Primary Sampler Cutter with articulated discharge design

Table 2. Primary sampler specifications

Description	Units	Sampler 1/2
Sampler type	-	Falling stream
Cutter width	*mm*	180
Maximum Cutter speed	*m/s*	0.58
Number of increments per maximum Lot	*number*	360
Sampling frequency	*tons*	240
Primary increment size	*kg/cut*	310

The primary sampler increment mass can be calculated using equation 1, while the number of increments to be collected per 24-hour lot period was calculated using equation 2.

$$m_1 = \frac{Cb\times10^{-3}}{3.6V_c} \quad (1)$$

Where:

$m_1 = mass\ in\ kilograms$

$C = flow\ rate\ in\ tonnes\ per\ hour$

$b = cutter\ aperture\ in\ mm$

$V_c = cutter\ speed\ in\ meters\ per\ second$

$$N = \frac{t/d}{240t} \quad (2)$$

Where:

$N = Number\ of\ increments$

$\frac{t}{d} = Daily\ consignment\ (tons)$

$240t = Mass\ based\ sampling\ frequency\ (tons)$

The mass-basis operation was chosen for the sampling scheme by the client. Since it is mass-basis sampling operation, the primary increment collected should be constant mass irrespective of conveyor A and B instantaneous throughput at the 240t mark when it is time to take a sample increment. If the instantaneous conveyor loading is lower than the maximum loading, the cutter will be activated and traverse through the stream at constant speed with its sufficiently strong electromechanical drive system but result in an increment mass lower than the design increment mass and result in a weighting error. To achieve constant primary mass increment, each primary sampler is equipped with a VSD to adjust the sampler cutter speed – before the increment is initiated and then traverse through the stream at this predetermined set-point while maintaining constant velocity. Figure 2 shows the minimum cutter speed per belt throughput to achieve a constant primary increment of 310.0+-1% kg. The cutter speed is calculated by re-arranging equation 1 and making the cutter speed the subject of the formula.

Primary samplers were designed to ramp down to at least 0.13m/s minimum speed when the belt throughput is at 800tph, thus achieving 22% of the maximum speed. Below 20% of the full motor speed, the motor's cooling fan will not rotate fast enough to cool down the motor and can result in rotor winding insulation breakdown and motor failure. The minimum of 20% motor speed is ever more important where sampler drives are stopped and started drawing higher ampere than continuously running motor applications. To this extent a small forced cooled slave motor was added to the cowl cover of the master drive motor to ensure the motor is cooled. However, there is a throughput range lower limit below which the mechanical design rule of minimum 20% motor speed cannot be achieved and must be noted in sampling plant designs as a throughput range restriction.

According to ISO 13909, the mass variation on primary increment must be less than 20%, however, the sampling plant is designed to extract a constant primary mass increment at variable primary cutter speed down to 800tph as shown in Figure 2 below.

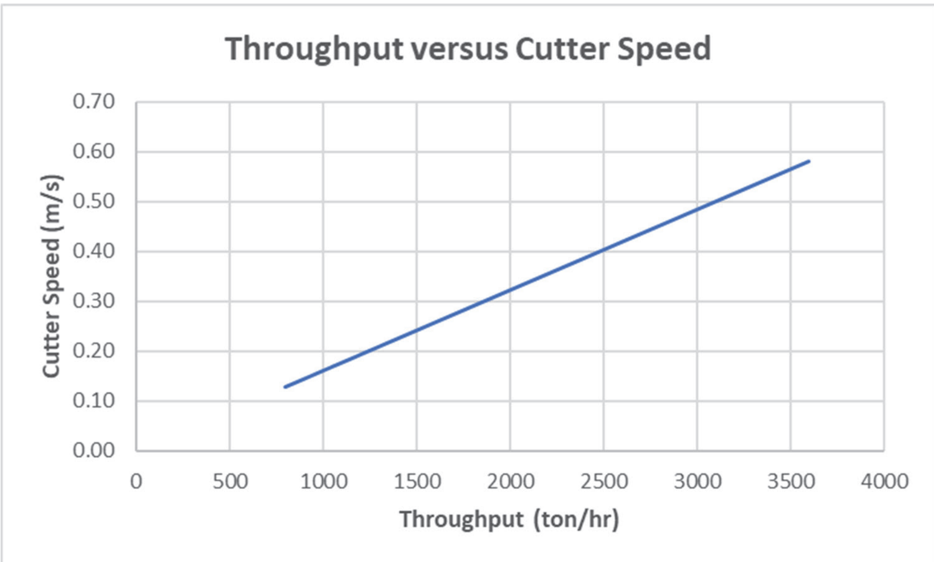

Figure 2. Primary Sampler Cutter speed versus Conveyor Belt Throughput

Process of combining increments into samples.

The primary increments collected by each primary sampler will be divided and transferred to the secondary sampler, a Rotary Tube Splitter (RTS), into three respective sample streams: chemical, moisture and Particle Size Distribution (PSD) in accordance with ISO (2016)[5].

Figure 3 shows the block flow diagram of the sampling plant with the various process streams;_chemical, moisture and PSD (Physical), including rejects handling by utilizing various sampling equipment which include rotating plate dividers (RPD), hammer mill impact crusher, turnstile divider.

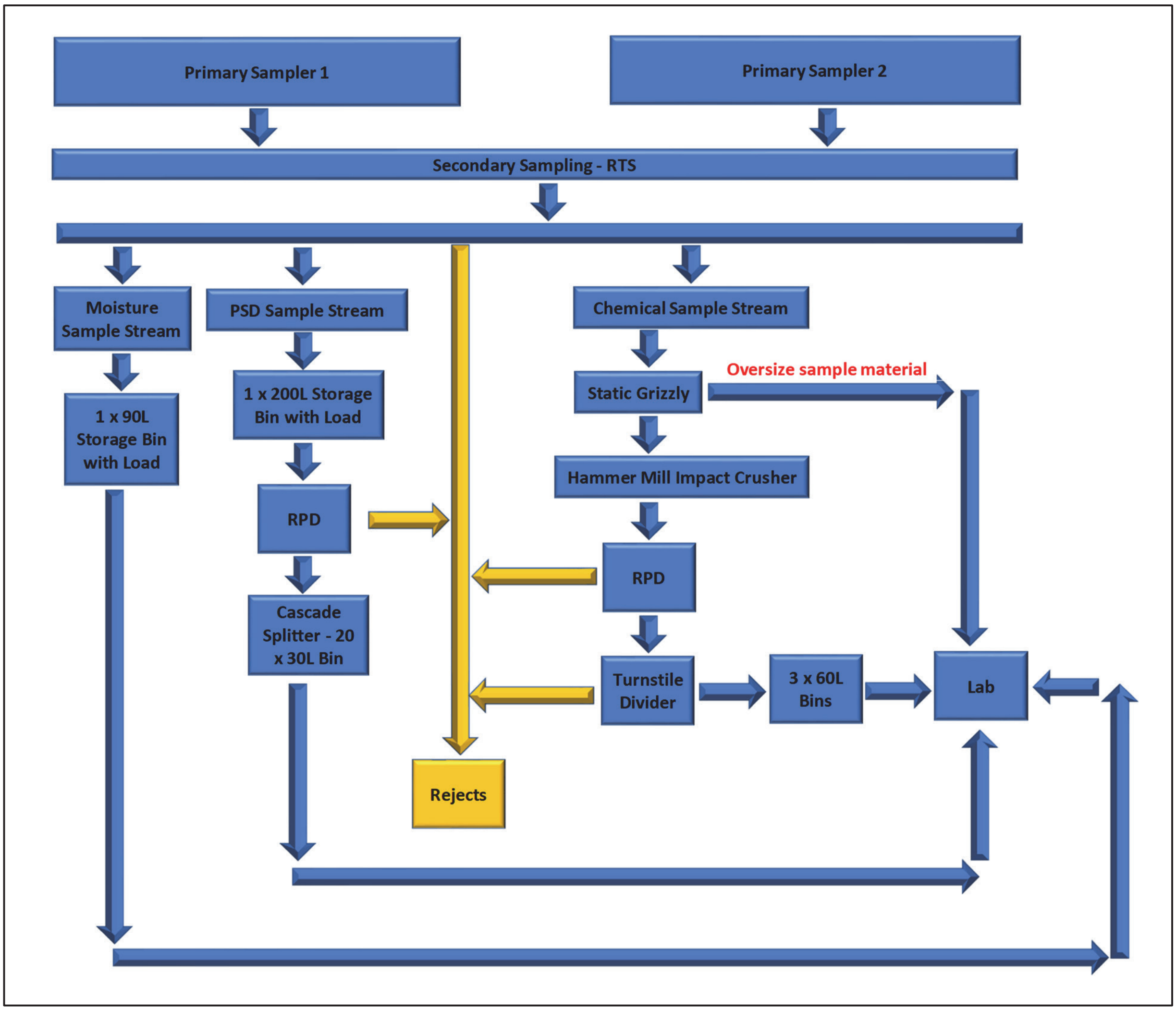

Figure 3: Sampling Plant – Block Flow Diagram

Secondary Sampling

Each alternative primary sampler increment from Primary Sampler 1 and Primary Sampler 2 will be transported via the Primary Sample Feeder to report to the RTS. The secondary sampler, RTS is equipped with 3 cutters of 240mm width each (to cater for the 80mm oversize material), cutter tip speed of 0.22m/s and a sample division ratio of 11.1%, will extract 2.85kg/cut per cutter, per primary increment. The RTS will take 12 sub-cuts per primary increment (exceeding ISO minimum requirements by 3 times) over a 2-minute processing time, yielding a 34.4kg secondary sample increment reporting to the physical, chemical, and moisture sample chutes. The remaining primary increment will report to the rejects chute. Both the physical and the chemical primary chutes are fitted with blocked chute detectors to prevent any potential material blockages, and thus facilitate material flow.

Physical Sampling for particle size

The physical sample from the secondary RTS will be further subjected to two sampling stages to achieve a manageable final sample size still maintaining the minimum sampling protocol requirements for ISO compliance.

The RTS physical sample discharge chute is fitted with a flopper gate. This flopper gate will send random sample increments, as selected from a random number generator algorithm in the PLC, to rejects. The number of physical samples received (not rejected) is a function of the hourly sublot's total production.

The secondary sub-increments reporting to the physical sample after the flopper gate are stored and accumulated in a 200L physical sample intermediate storage bin for 4 hours. From the 200L bin, the sample discharges onto the tertiary sample feeder and is fed to the tertiary rotating plate divider (RPD). The RPD is equipped with a 240mm cutter width and results in a sample division ratio of 11.2%. The tertiary RPD will subdivide the secondary physical sample increment to obtain a 4.13kg tertiary physical sample increment.

The tertiary sample from the rotating plate divider is stored in the cascade splitter weigh bin (600L) coupled with the cascade splitter vibratory feeder. The cascade splitter will further split the sample into 1.38kg per tertiary increment, to be accumulated in a 20 way by 30L canisters for ease of sample handling. A total of 496kg will be collected per 24 hours which exceeds the ISO minimum requirement of 210 kg (3 times 70kg for 2% precision).

The rejects from the rotating plate divider are directed to the rejects chute and flows to the power station's main product belts by gravity.

Chemical Sampling Stream.

The RTS chemical sample chute is fitted with an 80mm static grizzly screen plate and a blocked chute detector. The 80mm screen will prevent any particle larger than 80mm top size to proceed to the hammer mill impact crusher, thus minimizing blockages downstream. The oversize material will slide into the oversize tray and is retained until the end of the shift. It is important for the client to note the percentage of oversize material as a contractual penalty that affects their downstream pulverizing equipment. The mass proportion of oversize removed, compared to the linearly proportional total sample mass that passed through the grizzly as undersized, is calculated at the end of the shift. The oversize is manually crushed down in the laboratory and the proportionate oversize sample mass added to the plant generated composite sample mass. Composite chemical sample proportions (of over and undersized material) are maintained through the manual controlled laboratory procedure.

The undersize material is fed via the dedicated feeder belt to the hammer mill impact crusher. The crusher reduces the material size down to 95% passing -6mm in a single pass and discharges onto the chemical sample belt feeder designed to trickle feed the chemical sample RPD.

The sample from the chemical sample RPD is subdivided further by a quaternary turnstile divider (refer Figure 4) to produce 3 replicate composite samples to be stored in three 60L composite, lockable sample bins as per customer requirement: buyer, seller, and referee. A minimum of 4kg composite chemical sample is required (ISO 13909, 2016[2]) per replicate sample., hence, a minimum of 12 kg (3 x 4kg) is required. The 4kg of -6mm material marks the end of in plant sample preparation. The samples are collected by operators at the end of the shift and taken to the lab for pulverization, preparation, and analysis. The rejects from the chemical RPD and the quaternary turnstile divider is automatically directed back to the power station's main plant conveyor through the rejects stream chute. The inlet and outlet of the hammer mill impact crusher, as well as the sample discharge chutes of the chemical RPD are fitted with blocked chute detectors.

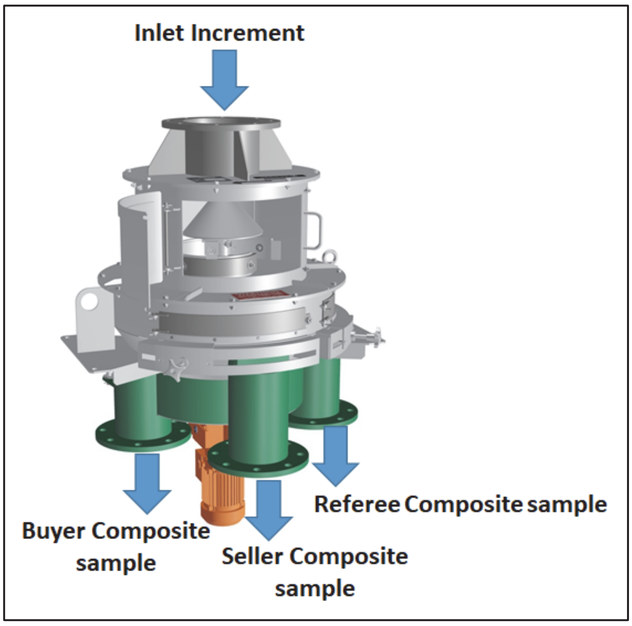

Figure 4. Triplicate Composite Samples for Buyer, Seller and Referee

Moisture Sampling Stream.

Moisture sample increments are isolated to the moisture sample bin or to the rejects chute using a random stratified PLC-controlled algorithm. Received samples are stored in a 90L collection bin (a maximum of 2 random secondary increments from the RTS to make up the 60kg minimum moisture sample required by the ISO 13909-2 standard). The moisture sample is isolated at first reasonable opportunity to prevent unnecessary moisture loss. Early extraction ensures reliable moisture preservation which would otherwise be lost to equipment internal surfaces if the moisture increments were extracted further downstream in the sampling plant. Despite 2-hourly collection recommendation, moisture samples are collected 8 hourly as per client requirements and resource availability. Excess sample increments will be fed to the rejects stream by the diverter to automatically return sample rejects.

Material handling.

The sampling plant is designed taking into consideration the flow of sample increments throughout the sampling plant. Interconnecting chute work design is not defined in ISO standard, however, Multotec's experience in the supply of coal sampling plants has established that 304 stainless interconnecting chutes with rounded 50mm radius corners and a minimum of 60-degree angles with 55 degree valley angles, is ideal for most coal types, surface moisture and size. Critical chute locations within the sampling plant are fitted with blocked chute detectors equipped with vibrating motors. If a blocked chute is detected, this will activate the respective vibratory motor to clear the blockage It should be noted that available space sometimes creates challenges to achieve the above chute design characteristics, therefore, feed-back loop type process is paramount between process designers, draughtsman, and site people to design the entire sampling station to be operator- and maintenance friendly.

Conclusions

The design of the sampling system needs to follow specific guidelines as outlined in the various ISO standards taking into consideration available space, headroom, material handling, experience with similar type of sampling systems to achieve the required precision levels. Specific to this coal fired power station sampling plant, it was important to follow the ISO 13909 and client's requirements in terms of sampling frequency, lot period, material size to be delivered to the lab (P_{95}=6mm), size analysis precision (2%) and 0.2% ash precision level for chemical analysis, to ensure that an ISO 13909 sampling plant is supplied. The sampling plant is expected to representatively sample the coal trade between power station and fuel supplier. As a result of its importance and the commercial value of coal passing daily, the power station, SEM and seller all provided inputs to the design and acceptance of the sampling plant

The available infrastructure created the necessity to design a custom primary cross-stream belt end sampler with articulated discharge joint to ensure that the sampler fits and operates in a 6m head room space. The minimum ISO 13909 requirements were exceeded by the design of the sampling plant which included minimum sub-increment cuts per preceding stage (more than 12 sub-cuts were achieved), minimum composite sample mases for chemical, PSD and moisture. Since the basis of the sampling plant was mass-based instead of time-based, this required that the primary increment collected by each primary sampler be constant irrespective of the instantaneous mass loading during increment collection. A VSD is incorporated into the design and operation of the primary sampler to ensure that the cutter speed of the sampler is automatically adjusted based on the instantaneous loading of the conveyor when the sampler takes a cut.

The preparation of the various increments was done via a four-stage sampling system consisting of a primary cross stream sampler, rotating tube splitter, rotating plat divider and turnstile divider sampling equipment, with the rejects produced from each sampling equipment returned back to the client's main production conveyors via 304 stainless steel interconnecting chute work. To minimize and eliminate any potential blockages, interconnecting chute work angles were 60 degrees or more.

References

1. Steinhaus, R.C., and Minnitt, R.C.A. 2014. Mechanical Sampling - a Manufacturer's Perspective. *The Journal of The Southern African Institute of Mining and Metallurgy*, vol. 114, January 2014. pp 121-130.
2. Holmes, R.J. 2010. Sampling Mineral Commodities – the good, the bad and the ugly. *The Journal of The Southern African Institute of Mining and Metallurgy*, vol. 110, June 2010. pp 269-276.
3. Minnitt, R.C.A. 2007. Sampling: The impact on costs and decision making. *The Journal of The Southern African Institute of Mining and Metallurgy*, vol. 107, July 2007. pp 451-461.
4. International Organization for Standardization. (2016). Hard coal and coke—Mechanical sampling – Part 2: Coal – Sampling from moving streams (ISO/FDIS 13909-2:2016(E)).
5. International Organization for Standardization. (2016). Hard coal and coke—Mechanical sampling – Part 4: Coal – Preparation of test samples (ISO/FDIS 13909-4:2016E)).