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PARTICLE SEGREGATION ASSOCIATED WITH SUB-SAMPLING OF FEED AT A TYPICAL UG2 CONCENTRATOR

by

Neressa Naicker

A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Metallurgical Engineering

Johannesburg, August 2017

Declaration

I declare that this dissertation is my own unaided work under the supervision of Professor V. Sibanda. It is in submission to the Degree of Masters of Science in Metallurgical Engineering to the University of the Witwatersrand, Johannesburg. This dissertation has not been submitted previously for any degree or examination to any other University.

…… ……..

Neressa Naicker Date

Executive Summary

A particular Upper Group 2 (UG2) reef ore treating Concentrator Plant has been historically under-accounting in terms of 4T (Platinum, Palladium, Rhodium and Gold) content. It has been postulated that the main reason for the consistent under-accounting is due to the correct sub-sampling of finer particles and consequently under sub-sampling of the coarser particles present in the feed slurry streams into the plant.

The test work presented involved a series of experimental studies designed to gain an understanding of the presence and extent of particle segregation in the intermediate hopper of a typical UG2 feed vezin sampling system. A total of three stages of test work were conducted, including vezin credibility and chronological sub-sample tests, tests on a re-designed nozzle and mechanical hopper.

The tests on sub-sampling of the feed material from the intermediate hopper performed on the current sampling arrangement (Stage 1, Test 1) demonstrated that segregation occurs in the intermediate hopper of the feed sampling system. A consistent bias was observed between the reject and official samples with the official samples having more fine particles and being higher in 4T grade than the reject samples. By means of a paired t-test, the calculated bias for % mass retained was deemed significant at the 95% confidence level. This outcome together with the size by assay analysis performed indicated that an under-accounting scenario would result.

Stage 2 test work involved the use of an alternative nozzle design at the outlet of the current intermediate hopper as a way of optimizing the current arrangement. The sub-sampling tests performed after this modification resulted in a more random distribution of fine and coarse particles in both the reject and official samples. The PSD's for the reject and official samples were similar across all test runs however the 4T grade was not consistent. The calculated bias for % mass retained was not significant at the 95% confidence level.

Stage 3 test work involved the application of a new hopper design which was equipped with an agitator in an attempt to reverse the segregation observed in the old hopper design. The

new hopper also necessitated the introduction of an alternative sampling protocol where multiple primary increments were collected and the sub-sampling to produce an official and reject sample while agitation transpires created the platform for better suspension of all particles. The particle segregation in the intermediate hopper was reduced and the calculated bias for % mass retained was not significant at most measurements at the 90% and 95% confidence level. The change in nozzle and hopper design seemed to not have an impact on the overall 4T grade of the official sub-samples generated over the sampling campaign.

There was a slight improvement in the % COV for the % +38µm from Stage 1 to Stage 2. With the inclusion of the new nozzle design to the mechanical hopper, the % COV for the % +75µm improved from 26.7% to 14.5%.

In general, it is believed that the particle segregation which was so evident in the baseline test was significantly reduced with the incorporation of the alternative nozzle design and mechanical agitation. Compressed air agitation alone does not seem to keep all particles of varying size and density in suspension in the intermediate hopper.

A future mechanical hopper prototype should be redesigned and fabricated from a cheaper yet robust material and should also be ergonomically improved. The incorporation of internal baffles inside the mechanical hopper should also be considered to reduce the impact of vortexing. An inspection port should also be integrated into the design to be able to view the agitator in operation and observe for vortexing of the slurry material or retention of residual solids in the hopper after sub-sampling takes place. Multiple air agitation points may also be considered in future designs of the mechanical hopper (for instance, an air agitation point above and below the pneumatic valve).

It is recommended that any future investigation or test work around particle segregation in the intermediate hopper be conducted in a controlled testing environment. In this way, any random variation due to the process can be disregarded and the true bias (if any) can be determined and confirmed.

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Nomenclature

μ	Viscosity of the Fluid (kg/m.s)
ρ_F	Density of the Fluid (kg/m^3)
ρ_S	Density of the Solid (kg/m^3)
v	Settling Velocity (m/s)
λ	Variance (g^2/t^2)
g	Gravitational Acceleration (m/s^2)
4T/4E	Trace Elements (Platinum, Palladium, Rhodium & Gold) (g/t)
6T	Trace Elements (4T, add on Ruthenium & Iridium) (g/t)
AE	Analytical Error
a_i	Grade of the Sample (g/t)
Au	Gold
Avg	Average
BP	Business Plan
BUH	Build-up Head (g/t)
CH	Constitution Heterogeneity
conc.	Concentrate
COV	Co-efficient of Variance (%)
Cr_2O_3	Chromium (III) Oxide
CRM	Certified Reference Material
Cu	Copper
d	Diameter of the dropped object (m)
DE	Delimitation Error
DEM	Discrete Element Modelling
DH	Distribution Heterogeneity
EE	Extraction Error
HIRA	Hazard Identification Risk Assessment
I/D	Inside Diameter (mm)
ISO	International Organization for Standardization
LTI	Lost Time Injury

N	Number of Pairs of Samples
Ni	Nickel
O/D	Outside Diameter (mm)
OEM	Original Equipment Manufacturer
Pd	Palladium
PE	Preparation Error
PGE (3E)	Platinum Group Elements (Platinum, Palladium and Rhodium)
PGM's	Platinum Group Metals
ppm	parts per million
PSA	Particle Size Analysis
PSD	Particle Size Distribution
Pt	Platinum
R	Radius (mm)
R_e	Reynolds Number
rpm	Rotations per Minute
RSD	Relative Standard Deviation
S	Sulphur
SAG	Semi-autogenous
SG	Specific Gravity
STDEV	Standard Deviation
THK	Thickness (mm)
UG2	Upper Group 2
V0	Random Variability (g^2/t^2)
V1	Total Process Variability (g^2/t^2)

1 Introduction and Research Objectives

A particular Upper Group 2 (UG2) reef ore treating Concentrator Plant has been historically under-accounting in terms of 4T (Platinum, Palladium, Rhodium and Gold) content. The 4T accountability takes into consideration the 4T sample head grade and 4T built-up head grade. The 4T sample head grade is a measured value obtained by taking an automatic sample with a vezin-vezin sampling system, preparing the sample and analysing the sample thereafter. The built-up 4T head grade is a value calculated based on the tonnage milled, concentrate mass, concentrate grade, tails mass and tails grade. Given that there was no reason to question the integrity of the latter information through a full plant audit conducted, the sample head grade was highlighted as the likely contributor to the observed 4T under-accounting trend. In addition, comparisons to the mining 4T head grade and qualitative discussions with mining colleagues indicated that the 4T sample head grade at the Concentrator plant was possibly being overstated resulting in an under-accounting scenario being observed.

Moreover, with the mechanical design and operational aspects of the primary and secondary feed samplers conforming to Best Practice, Theory of Sampling and the rules for sampling correctness (Pitard, 1993), it has been hypothesized that the main reason for the consistent under-accounting is due to the correct sub-sampling of finer particles and consequently under sub-sampling of the coarser particles present in the feed slurry streams into the plant. As particles of varying shape, size, 4T grade and density only have the opportunity to segregate in the intermediate hopper, it is believed that particle segregation may be playing a more dominant role in the intermediate hopper of the UG2 feed sampling systems than originally assumed. Intermediate hoppers typically have the design capacity to hold a single primary sample increment for a certain retention time until the entire primary sample increment is sub-sampled via a secondary sampler.

The primary aim of this research is to validate the presence and extent of particle segregation in the intermediate hopper of the UG2 feed vezin-vezin sampling system in an attempt to explain the under-accounting trend. UG2 feed sample size by assay analyses indicate that higher platinum and palladium grades are associated with the sub 75µm size

fractions as opposed to the coarser size fractions above 75µm (Ntlhabane, 2014). Indications are that because of the under sampling of coarse particles, the head grade of the feed into the plant is overstated leading to an under accountability of metal content.

In metallurgical accounting, it is vital that there is unbiased sampling of input and output streams (Bartlett, 2005). The ability to prove or disprove, and quantify the bias associated with particle segregation during sub-sampling in vezin-vezin sampling equipment on the UG2 feed streams will give insight into what contributes to the severe under accountabilities being observed.

The main research objectives were:

a. To investigate if particle segregation occurs in the intermediate hopper of a UG2 feed sampling system;

b. To determine how particle segregation, if present, can be overcome either by:
    (i) optimization of the existing sampling equipment;
    (ii) introducing an alternative sampling equipment design and/or sampling protocols;

c. To test the impact of optimization of existing sampling equipment, alternative sampling equipment design and/or sampling protocols on particle segregation.

The secondary research objectives were:

a. To conduct a ratification process with a sound experimental design to demonstrate that particle segregation has been eliminated or minimized;

b. To analyse the historical and present data relating to key performance indicators such as 4T accountability and sample head grades over an adequate period of time (inclusive of analytical and metal accounting data) to assess the effects of changes implemented as per main objective b. above.

The scope of the research entailed optimization of the feed vezin-vezin sampling system at the UG2 Concentrator, and focused on identifying and reducing particle segregation and bias in resulting particle size distributions. Experimental work in line with the research objectives were conducted in a production environment. The experimental work entailed three main stages of test work, namely:

- Stage 1 – Baseline test work to confirm if particle segregation is present or not, and if so, to what extent;
- Stage 2 – Optimization test work to reduce particle segregation (if present);
- Stage 3 – Equipment re-design test work to further reduce particle segregation (if present).

Results obtained from each stage of test work was analysed and discussed, and conclusions and recommendations are included in the following dissertation.

Currently, there is limited knowledge available regarding segregation of particles in the intermediate hopper of the vezin sampling system configuration that is used at the concerned plant. Through research, considerable focus has been placed on eliminating particle segregation during primary and secondary stages of sampling, and sample preparation through the correct design of automated and mechanical samplers, and the determination of minimum sample size required. Investigations into particle segregation in the kind of intermediate hoppers used at this plant is scarce and therefore the current research has an element of novelty. The success of this research and learnings can be extrapolated to all mineral processing plants that treat and sample material with characteristics that involve grade by particle size associations.

2 Literature Review

2.1 Overview

The importance of sampling in the mining industry cannot be over-emphasized, whether in exploration, in mining or in mineral processing, modern protocol demands excellence (Bartlett, 2005). The conventional wisdom is that sampling should follow the accepted rules for unbiased sampling as defined by numerous specialists. The measured parameter is biased if the mean of its distribution is not equal to the true value of the parameter. Thus, the bias can be positive (the measured value is more than the true value) or negative (the measured value is less than the true value). In sampling, there are two major areas where bias exists, namely, sampling and sample preparation. Sampling bias, for example, may include increments coinciding with cyclic events, or where only a portion of the stream is being sampled or where cutter specifications are not being adhered to or when sample containers are overfilled (Kruger & Millar, 2002). The concept is that if the rules for representative sampling are followed and the sampling equipment is in good order and procedures used by the operators are well defined and are followed, unbiased samples will be obtained and there will be no bias in sampling. This emphasizes the need for good design of the sampling equipment and adequate control and maintenance during its operation (Bartlett, 2005).

Platinum Group Metals (PGMs) are present as trace elements in the ore body. Sampling and analysis of such an ore body is not a simple task. Unlike in the coal industry where ISO standards for coal sampling are available, there are no ISO sampling standards for gold and platinum, both of which are extensively mined in South Africa. Reliance is thus placed on in-house standards developed by the mining companies involved (Steinhaus & Minnitt, 2014). There are often numerous practical and theoretical difficulties when sampling for precious metals and the ‘one shoe fits all’ ISO standard approach cannot do justice for particular minerals, especially considering mineral heterogeneity in most of the mined and processed ores. Optimisation of sampling protocols is therefore very vital as non-optimized protocols

can lead to poor precision and hence poor reconciliation between mine and process plants head grades (Pitard, 2005).

It is often implied in literature that a sampler is either good and does not produce biased samples, or bad and does generate biased samples. It has been demonstrated that a small improvement to sampling reproducibility in a mine-plant complex can result in additional profits being realized. Conversely, ignorance of sampling biases can result in losses of the same order of magnitude (Francois-Bongarcon & Gy, 2002).

In general, there are three recognized sampling approaches corresponding to different groups of automatic samplers:

1. Approach one: Taking a cut from part of a stream at specific time intervals e.g. internal pipe bleeder;
2. Approach two: Taking a cut of part of the stream all of the time e.g. in-pipe derivation, pressure bleeder;
3. Approach three: Taking a cut of the full stream at specific time intervals e.g. cross stream sampler (Francois-Bongarcon & Gy, 2002).

The third approach will ensure correct samples provided that the sampler is correctly installed and is used for the correct application.

Examples of *incorrect* samplers include:

1. Internal pipe bleeders – Pipe bleeders, pressure bleeders, sample valves and Archimedes screw extractors operate based on sampling approach one and two above and are not recommended;

2. Cross-belt sampler is a running belt sampler which consists of a rotary, articulated arm and collects a sample from the passing material on a conveyor belt. Sampling approach three is generally used for this application. This sampler is however deemed problematic for the following reasons:

a. In general, the selected part of the flow of material is directed towards the collection chute instead of being cut;

b. Representative proportions do not always contain the finest and coarsest fractions;

c. These samplers are often fitted with motors that are not powerful enough leading to notable variation in cutter speed during increment collection (Francois-Bongarcon & Gy, 2002).

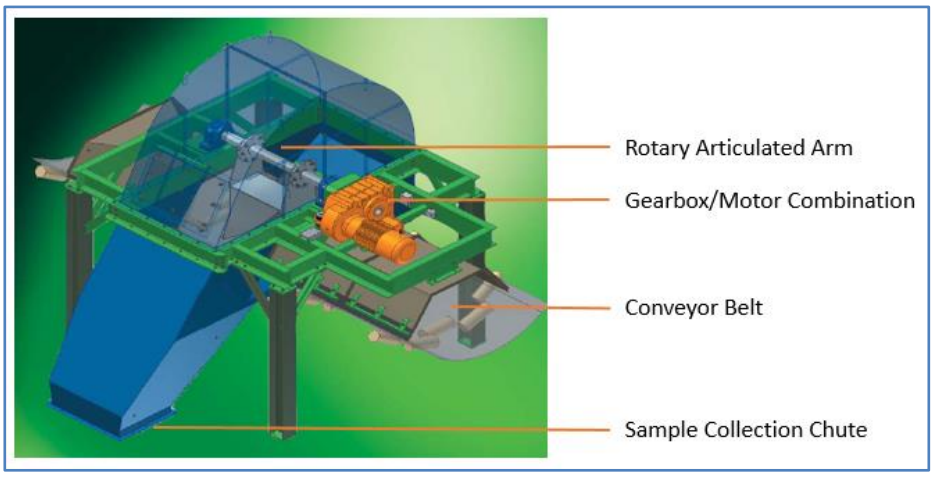


Figure 2.1: Cross-Belt Sampler Illustration.
(Kruger & Millar, 2002)

Examples of *correct* samplers include:

1. Cross-stream sampler – cross-stream samplers can include rectilinear cutters or rotary cutters with radial, revolving openings. Sampling approach three is generally used for this application. This type of sampling is preferred and is recommended in industry provided that the following conditions are met:

    a. The collection opening must be a minimum of 3d+10mm where d is the diameter of the largest fragment;

b. A maximum allowable speed can be determined and calculated from the retained opening (Francois-Bongarcon & Gy, 2002).

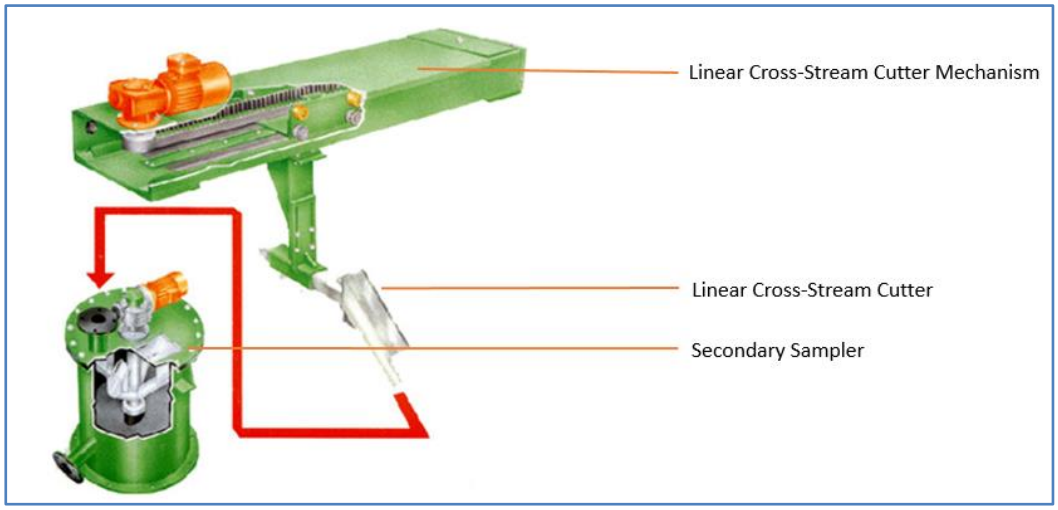


Figure 2.2: Linear Cross-Stream and Vezin Sampler Combination. (Kruger & Millar, 2002)

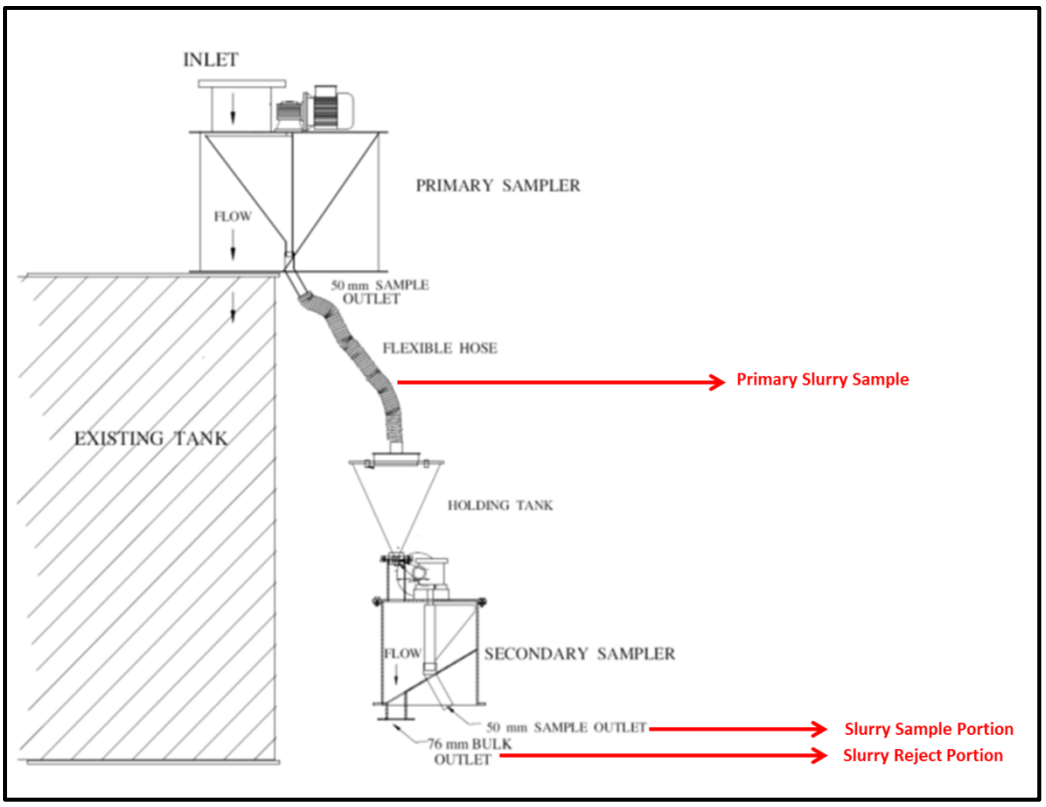


Figure 2.3: Vezin-Vezin Sampler Combination. (Kruger & Millar, 2002)

Sampling systems often comprise of a primary sampler and a secondary sampler as illustrated in Figure 2.2 and 2.3 above. The bulk stream that is sampled is generally

large and thus the primary increment obtained is often too large to further process or prepare. A secondary sampler is then incorporated as part of the overall sampling system to reduce the primary sample into a more manageable sub-sample size. A secondary sampler is generally in the form of a vezin sampler or rotary splitter. A vezin sampler is a multipurpose device that collects representative samples from materials that are free-falling from pipes, chutes or hoppers. Various versions of the vezin sampler are available in several sizes and from multiple manufacturers. This device operates by one or more cutters revolving on a central shaft, passing through the sample stream and collecting a fixed percentage of the total material (Trottier & Dhodapkar, 2012). A vezin sampler arrangement can comprise of 1, 2 or 4 cutter arrangement and the sample division or reduction ratios (by mass/volume) are generally in the region of 1:40, 1:20 or 1:10 respectively (Kruger & Millar, 2002).

The 'golden rule' for correct sampling is that 'all parts of the material being sampled must have an equal probability of being collected and becoming part of the final sample for analysis'. If this requirement is taken into account at the outset of designing a sampling system, then good progress towards obtaining representative samples is assured. On the other hand, if this rule is not respected, then sample bias is easily introduced (Holmes, 2010). Key design flaws that need to be eliminated include incorrect delimitation of increments (incorrect cutter/increment geometry), incomplete extraction of increments, preferential exclusion of specific size fractions, sample loss and sample contamination (Gy, 1982). Mechanisms for possible bias generation specifically in vezin samplers include: congestion at cutter aperture, bouncing off blades completely over the cutter aperture, particles rolling up the sampler surfaces and into the sampler and air effects. The evaluation of a sampler performance can be done via bias testing. Bias testing, whether physical or computational, requires comparison against an alternative sampling method which is more reliably unbiased than the sampling method to be tested (Clearly & Robinson, 2011). Testing a sampling system for bias with respect to particle size, is generally a more powerful method than testing for bias with respect to a chemical constituent, especially when the chosen analyte is present in small concentration.

Bias generation due to settling of coarser particles in the intermediate hopper followed by the sub-sampling with a secondary vezin has not yet been explored. Segregation of a particulate material usually leads to a local concentration of particles of high or low composition or particles of large or small particle size. It can generally be considered as a form of distributional heterogeneity (Kruger & Millar, 2002). This is generally the case with UG2 reef ore material. Errors in sampling of geological material are primarily caused by a combination of constitutional heterogeneity and distributional heterogeneity as illustrated in Figure 2.4 below. Constitution heterogeneity is the difference in the mineral or rock fragments present within the sample whereas distribution heterogeneity (better known as segregation) is the different distributions of these minerals or rock fragments (Barr, Woolam, Roux & Muzondo, 2016).

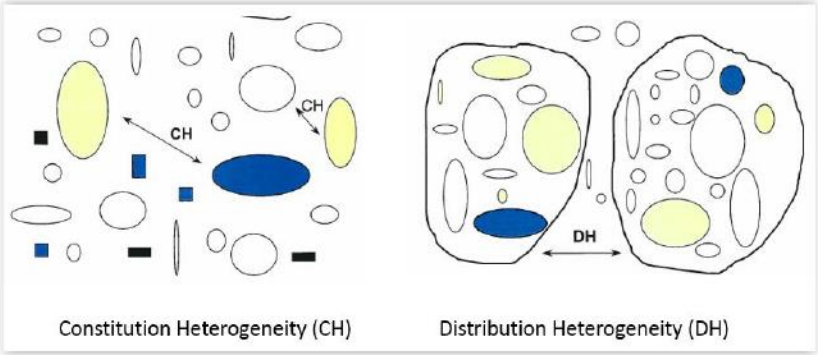


Figure 2.4: Constitution and Distribution Heterogeneity Illustration. (Barr et al., 2016)

The size by assay analysis of a typical UG2 reef feed sample is shown in Table 2.1 below (Ntlhabane, 2014).

Table 2.1: Chemistry Results per Size Fraction for Typical UG2 Feed Sample

Size Fraction (µm)	Mass (%)	Pt	Pd	Au	PGE (3E)	Cu	Ni	Cr2O3	S
		ppm				%			
< 10	18.6	4.10	2.21	0.07	6.38	0.03	0.10	13.38	0.09
> 10	6.7	2.73	1.82	0.04	4.59	0.02	0.10	14.49	0.08
> 25	13.0	2.01	1.33	0.04	3.38	0.01	0.09	15.36	0.05
> 53	9.8	1.24	0.83	0.02	2.08	0.01	0.08	17.39	0.04
> 75	12.9	0.87	0.63	0.02	1.52	0.01	0.09	19.27	0.03
> 106	25.6	0.72	0.40	0.01	1.13	0.01	0.08	19.63	0.02
> 212	13.4	0.53	0.36	0.02	0.91	0.01	0.07	12.95	0.03
Actual Head	d50 =	1.78	1.05	0.03	2.86	0.01	0.09	16.24	0.05
Recalculated Head	54µm	1.70	1.02	0.03	2.75	0.01	0.09	16.41	0.05

*Assay data contained in Table 2.1 has been factorized for confidentiality purposes.

The UG2 reef ore is a chromite cumulative texture ore whereby the sulphides and PGMs are found in the spaces of the texture dominated by euhedral chromite grains. The overall material has a grade that is in essence equal to the head grade of the ore. Chromite grains dominate the size fractions near 350µm and these fractions are relatively low in PGMs. The heterogeneity with respect to PGMs of the fractions above 350µm is low, but for sizes below 100µm, there is a radical increase in the heterogeneity (Gaylard, 2007).

It is more complex to get a representative sample if the heterogeneity is greater. It is for this reason that sampling protocols, procedures and equipment need to be designed and used appropriately to maintain sampling error within acceptable limits i.e. Gy's 10% safety limit guide, (Barr et al., 2016).

Gy's theory of sampling of particulate materials is acknowledged and widespread through various applications. On the contrary, however, Gy's theory of distributional heterogeneity of a material, detailing segregation effects is rarely discussed and is usually ignored in sampling calculations (Lyman, 1998). Mixing or blending is an often-used expression without a clear, textbook definition. Francois-Bongarcon et al. (2007) propose that 'mixing' should mean destroying the unwanted segregation of the element(s) of interest using stirring and movement. Francois-Bongarcon et al. (2007) indicate that there is no theory of mechanical mixing applied to the sampling field. At the present state of knowledge, it appears there is no usable theories of segregation mechanisms, nor universally acceptable models for it. Segregation is largely not entirely understood, and is very complex in nature (Francois-Bongarcon et al., 2007).

When sampling for slurries, the basic sampling rule where all particles have to have an equal chance of being sampled must also be applied. Understanding and knowledge of slurry properties and the behaviour of particles contained within the slurry is essential in ensuring suitable sampling strategies are applied. For instance, the minimum requirement for sampling slurry from a point in a tank or slurry flowing through a pipeline is the presence of a homogeneous suspension at the point of sampling. This is very much dependent on parameters such as particle size, size by assay distribution,

particle density, fluid density, viscosity, flowrate and pipe diameter. Turbulent flow generally provides mixing and is typically required to keep the slurry well mixed prior to any sampling taking place. It is also preferable to sample slurry from a vertical pipe so that particle segregation by gravity can be avoided.

The velocity of particles in a fluid medium is dependent on factors such as size, shape and specific gravity of the particles (Wills & Finch, 2016). Particle diameter has a strong influence on particle segregation by gravity since the settling velocity is proportional to the square of the particle diameter (McCabe, Smith & Harriott, 1993).

Assuming laminar flow, Stokes' Law can be used to describe how fast spherical bodies fall through viscous liquids:

$$v = \frac{1}{18}\left[\frac{(\rho_s - \rho_F)gd^2}{\mu}\right] \quad \text{....Equation 1}$$

Where v is terminal settling velocity

g is the gravitational acceleration

ρ_s is the density of the dropped object

d is the diameter of the dropped object

ρ_F is the density of the fluid

μ is the viscosity of the fluid

Newton's Law can be used to describe turbulent flow or turbulent resistance:

$$v = \left[\frac{3gd(\rho_s - \rho_F}{\rho_F}\right]^{1/2} \quad \text{....Equation 2}$$

The Reynolds Number R_e defines whether fluid flow conditions around a sphere are laminar or turbulent:

$$R_e = \frac{d v \rho_F}{\mu}$$

....Equation 3

Stokes Law is applicable for Reynolds numbers below 1. For Reynolds numbers above 1000, Newton's Law should be used. This is generally the case for particles larger than 0.5cm in diameter (Wills & Finch, 2016).

The role of gravity remains the same in Stoke's region however terminal settling velocities are significant enough to cause segregation (Wills & Finch, 2016). Gravity starts to play an important role at particle diameters greater than roughly 50µm. A large number of cuts (greater than 30) for both the primary and secondary samplers need to be extracted when the slurry contains substantial amount of particles above 50µm (Trottier & Dhodapkar, 2012).

The effect of particle sizes and solids concentration on the rheology of silica sand based suspensions was investigated by Mangesana et al. (2008). The flow curves seemed to be non-Newtonian and the rheograms that resulted showed a dilatant behaviour. Several models were fitted to the experimental data but the Herschel-Buckley model provided a suitable representation of the flow curves for all slurries. From this model, the apparent viscosity was determined. It was found that the apparent viscosity and yield stress increased with solids concentration and particle size at the different shear rates. These findings were explained by increased frequency of particle-particle interactions and increased inertial effects.

2.2 Particle Segregation

Particles tend to segregate during handling and motion as a result of slight differences in the characteristics of the particles and the carrier medium. Such characteristics may include particle size, particle shape, particle density or inter-particle friction, fluid density, viscosity and flowrate. The particles flow and collide repetitively with one another due to the free movement created by the increase in void fraction (Shimoska

et al., 2013). Mixing processes are the opposite of segregation processes as they result in particles being blended together to give a homogenized mixture.

The quantification of segregation of multicomponent particulate mixtures is a challenge due to a lack of well-developed equipment in industry. Particle segregation problems can be addressed in process design via two means: the process can be altered to allow for segregation patterns resulting from several mechanisms of segregation, or modifications can be made to the process itself to minimize the source of segregation. It is possible for several segregation mechanisms to occur simultaneously producing a complex overall segregation pattern (Johanson, n.d.). McCarthy (2008) mentions that "one might find as many as 13 differing segregation mechanisms quoted in the literature yet many of these are degenerate, relatively unimportant, or simply have not been extensively studied". The main mechanisms of segregation are discussed briefly below.

Main Mechanisms of Segregation:

- Sifting segregation (also referred to as percolation of fines) is a principal cause of separation during handling of differently sized particles. This type of segregation typically results in a radial segregation pattern where fines collect near the centre of a pile as opposed to the coarse material which accumulates at the edge of the pile (Johanson, n.d.);

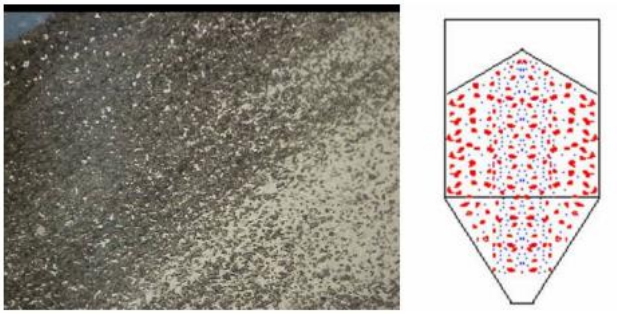


Figure 2.5: Example of Sifting Segregation. (Johanson, n.d.)

- Repose angle segregation as seen in Figure 2.6 below results from particles having differences in inter-particle friction and thus forms piles with different repose angles (Johanson, n.d.);

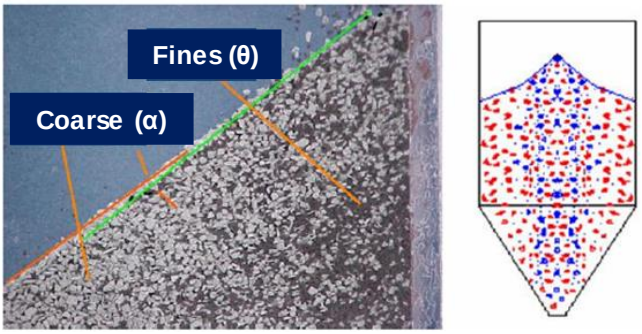


Figure 2.6: Example of Repose Angle Segregation. (Johanson, n.d.)

- Air entrainment segregation results from air currents during filling which may carry very fine material to areas where the air current decreases adequately to deposit the fine particles (Johanson, n.d.);

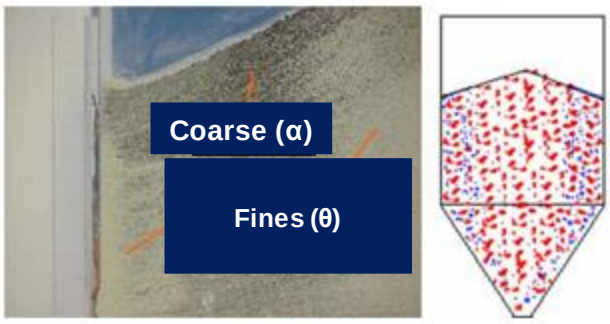


Figure 2.7: Example of Air Entrainment Segregation. (Johanson, n.d.)

- Impact fluidization segregation (also referred to as elutriation segregation) occurs when bulk material is fine and compressible, and becomes fluidized during the filling of a process vessel. During fluidization, a large volume of air is displaced by the bulk material. In such scenarios, the air velocity may exceed the terminal velocity of the smaller particles and may result in the fines being suspended while the coarse particles settle out (Johanson, n.d.);



Figure 2.8: Example of Impact Fluidization Segregation. (Johanson, n.d.)

- Trajectory segregation arises when particles are caused to move through air or when powders fall from the end of a conveyor belt. Groups of fine particles can travel farther than single large particles and the largest particle within a set of coarse particles will have a tendency to travel the farthest (Johanson, n.d.);

- Vibration segregation occurs if a mixture of particles of different size is vibrated. The larger particles will have a tendency to move upwards (rise) within a bed of smaller particles i.e. Brazil-nut effect, (Shimoska et al., 2013).

McCarthy (2008) states that it has been shown that segregation will result despite a material being otherwise identical when its particles differ in mechanical properties such as size, shape and density, leading to performance related issues. The content of the paper by McCarthy (2008) focuses on controlling and minimizing the extent of segregation in a number of model systems in industry as opposed to identifying particle segregation mechanisms and the kinetics of segregation processes. The solutions to such segregation problems are often aimed at efforts to be taken to avoid segregation in the form of best practice. These include device operation advice, device design heuristics and proposed adjustments to particle material properties.

McCarthy (2008) further mentions that studies in particle segregation is ongoing for over a century now and indications are that significant progress has been made in understanding the segregation problem in an effort to control segregation instead of

avoiding it. Two alternative approaches to the control and limitation of segregation in free-surface flows was explored in this article, namely, interparticle cohesive interactions and a dynamical-systems inspired flow perturbations technique. It is noted that in free-surface flows several mechanisms may be present with the dominant mechanism being percolation whereby the smaller and denser particles sink to the bottom with the larger and lighter particles rising to the top. The ability of interparticle cohesion to reduce the extent of segregation has been known for some time but the origin of the phenomenon has been indefinable and the presence of cohesion does not always translate to less segregation. Traditional ordered mixing involves the generation of a better-than-random mixture involving particles favourably sticking to different counterparts. The focus has now moved towards cohesion due to interstitial moisture by Kudrolli & Samadani (2000), where the degree of segregation in a poured heap was measured as the moisture content, interstitial fluid viscosity, and glass particle size ratio was varied. Kudrolli et al. (2000) noted that as the saturation increased, segregation in a heap monotonically decreased. It was also noted that the interstitial fluid viscosity impacts on the degree of segregation observed. This implied that the segregation kinetics are strongly affected by interstitial moisture. Although this is an interesting finding, there is still a lack in the understanding of the impact of differing modes of cohesion on the mixing and segregation kinetics.

Similar work to Kudrolli et al. (2000), was performed by Geromichalos et al. (2003) and the belief that all cohesion limits segregation was dismissed. They showed that at sufficiently low saturations first a decrease in mixedness is observed with increasing liquid content before reaching a “mixing” phase at higher saturations. In addition, it was determined that the lower bound on this “mixing” phase coincides with the point where the cohesive interaction becomes too strong for mechanical agitation to completely overcome. As opposed to the work done by the various authors mentioned above, McCarthy (2008), examined systems where particle size, density and surface characteristics such as degree of hydrophilicity may all vary, with focus on a single saturation level and the asymptotic behaviour of the system. This led to the development of discrete characterization tools for wet cohesive granular materials

where the characterization base and segregation models is determined by the competition between various forces acting on individual particles within a granular bed. Two ratios namely, cohesion vs. particle weight and cohesion vs. shear was discussed. It is suggested that cohesion be explored to lessen segregation by specific choice of binder fluid, material properties, and/or process operational parameters (for example shearing speed). In the second approach of time modulation of flow, the intensity of segregation as a measure of the mixedness was shown for variety of inversion frequencies, chute inclinations, particle density ratios, and bed heights. A distinct trend was observed for increased mixing for increasing inversion frequency. The technique for flow modulation has only been extended to tumbler and chute flows and the application or adaption of the idea are still to be explored.

Earlier studies around segregation in the coal industry were focused on by Brown (1939) and Mitchell (1938) and in the mining and metallurgy industry by Seaton (1960). Interestingly, segregation of particles in hopper filling and discharge was examined by Bauer & Denburg (1962). To the author's knowledge, a similar study of particles suspended in a slurry has not been conducted.

Five main mechanisms of segregation are identified by Carson et al. (1998) with sifting segregation being the most common phenomenon occurring as smaller particles move through larger particles. It is mentioned that a sifting segregation test for a binary mixture can be performed to determine the tendency of a material to segregate in this manner. A representative sample of particles was taken from the test and clusters are evaluated for particle size distribution, chemical content and other variables to determine the presence and degree of segregation. The particle size distribution was presented as cumulative percent retained against screening opening, and the distributions for the different clusters were plotted alongside each other. The authors go on to mention that fine or light particles are less permeable than coarse or heavy particles and so finer particles remain fluidized longer while coarser particles settle first (also referred to as sedimentation). A test for segregation by air entrainment is also mentioned in the article and it is suggested that if material has segregated by air entrainment in a tall cylinder then fines will be located at the top section of the

cylinder with the coarser and heavier particles present at the base of the cylinder. Particle size distribution, particle shape, cohesiveness and bin flow pattern mentioned to be likely variables that can affect the tendency of particles in a specific material to segregate.

Many industries such as the chemical, food, mining and energy industries are known to handle and process materials of varying particle sizes and it is often the case that the varying particle sizes have different chemical content. It is mentioned that prevention of segregation is dependent on the cause or source of the segregation. The paper showcases a method of measuring the magnitude of sifting segregation in a bulk material. A comparison of segregation due to sifting and repose angle mechanisms is also included in an attempt to show the difference between the two mechanisms. The work presented in this paper also showed the potential for isolation and quantification of particular segregation mechanisms. Johanson (1998) identified six segregation mechanisms qualitatively only. It is further noted that in real processes, a number of mechanisms can often occur and there is a real need for a general model to include physics. However, the development of the general model is not simple as segregation mechanisms is highly dependent on particle size and the cohesive nature of the bulk material.

2.3 Agitation and Mixing

Mixing can be defined as the mixture of two or more dissimilar portions of a material, resulting in a desired level of uniformity, either physically or chemically, in the final mixed product. The degree of mixing within a system is a function of two variables: the magnitude of eddy currents or turbulence formed and the forces tending to inhibit this formation (McCabe, Smith & Harriott, 1993).

The five most common mixing categories include solid-solid dispersion, solid-liquid mixing, liquid-gas, and liquid-liquid mixing i.e. mixing of miscible liquids and mixing of immiscible liquids. Solid-liquid mixing is commonly seen in suspension of solids or dissolving of solids.

There is a variety of aeration systems that are available in industry suited for specific applications. These include and are not limited to fine-bubble diffusers, coarse-bubble diffusers, and mechanical aerators. Computational fluid dynamics (CFD) programs are often used to simulate aeration operating conditions to determine optimization of flow turbulence in tanks for instance (Sanitaire Aeration Products, 2012). Agitators are used particularly when solvents need to remain in suspension. Liquid viscosity affects the flow created by a rotating agitator. Viscosity is the property of a liquid that causes flow resistance through internal forces and molecular attraction. In general, the more viscous a liquid, the more the energy required to produce an appropriate flow status. This is because high viscosity liquids dampen the mechanical energy transferred from a rotating agitator and therefore require higher power per unit volume for adequate mixing to occur. Low viscosity liquids show little resistance to flow and therefore require relatively small amounts of energy per unit volume for the same condition of mixing to occur (Jones Industrial Mixers. n.d.).

Dispersion is a process of mixing by breaking solid particles apart into a bulk liquid by agitation using a rotating saw-tooth blade or other special impeller designs. The blade or impeller produces high shear forces that break apart the particles. In any dispersion process, it is important to maximise cycling and minimise turbulence in order to achieve rapid and homogeneous dispersion (Jones Industrial Mixers. n.d.).

In dispersion processing, the major part of the effective work is developed in a region of a few centimetres away from the impeller edge. It is at this position that the major part of the applied energy is utilised. The remaining energy serves to force streaks of the treated material towards the walls of the tank to produce an upward flow near the wall. When the rising streaks of treated material reach the upper level of the batch, they flow inwards and towards the rotating shaft, then travel downwards to the impeller and are then exposed to a series of treatments in the acceleration region of the vanes. Material movement in a circulatory mode from the walls of the tank, towards the impeller shaft is referred to as cycling. However, when the circulation effect produced by the rotation of the impeller governs and the entire batch rotates,

this action is known as turbulence. Good cycling will result in high dispersion efficiency whereas turbulence, will result in very poor efficiency (Jones Industrial Mixers. n.d.).

Mixing low viscosity liquids may lead to vortexing if such liquids are vigorously agitated. Vortexing increases with impeller speed, until the vortex reaches down and moves through the impeller. Mixing efficiency is reduced for vortexing systems compared to non-vortexing systems, and baffles are then required. Baffles must be used with low viscosity mixing processes. Tanks that do not contain baffles will result in wide power variations, making predictable loading difficult and motor under-loading probable (Jones Industrial Mixers. n.d.).

2.4 Summary of Significant Work Done in Sampling Field

A significant amount of work has been done to test the bias of specific samplers. Pitard (2005) and Gy (1982) did some work around the effects of particle segregation in the flow to primary samplers, the segregation effects of a primary sampler cutting through the stream as well as the effects of segregation if the cutter speed is greater than 0.6m/s. Regulated compressed air is often introduced into the intermediate hopper of a two-stage sampling unit (e.g. vezin-vezin combination) to minimize the risk of chokes in the hopper. To some extent, the compressed air into the intermediate hopper provides some mixing and additional retention time by allowing particles to be suspended in the slurry mixture for a longer period of time. In these systems, the question that might be asked is whether all particles, both coarse and fine, are equally or sufficiently suspended to allow them to have an equal chance to be sampled throughout the entire sampling campaign. Specific investigations into possible segregation in intermediate hoppers of vezin-vezin type samplers in a UG2 reef environment has not received attention and hence some of the focus of this present study shall look at this phenomenon.

2.4.1 Crushed Material Vezin Sampling

Kruger & Van Tonder (2014) suggests that the first step in sampling, and the best defence against any sampling bias lies in the correct mechanical design of the sampling rig and adherence to the correct sampling protocol.

The paper by Kruger & Van Tonder (2014) showcases parts of the sampling processes that explain the poor accountabilities for the respective sites (Smelter material transfer to Refinery). At this particular site the crushed material from the product bin at the Smelter is discharged under gravity, passing through a vezin sampler and then into a tanker that can pneumatically offload the material at the Refinery. The grade and mass data associated with the material transfer is used for metal accounting purposes.

The sampling system was setup such that interleaved sampling was possible. Interleaved sampling allowed for the retrieval of two samples from each tanker dispatched from the Smelter. Figure 2.9 overleaf is a schematic of the sampling system described.

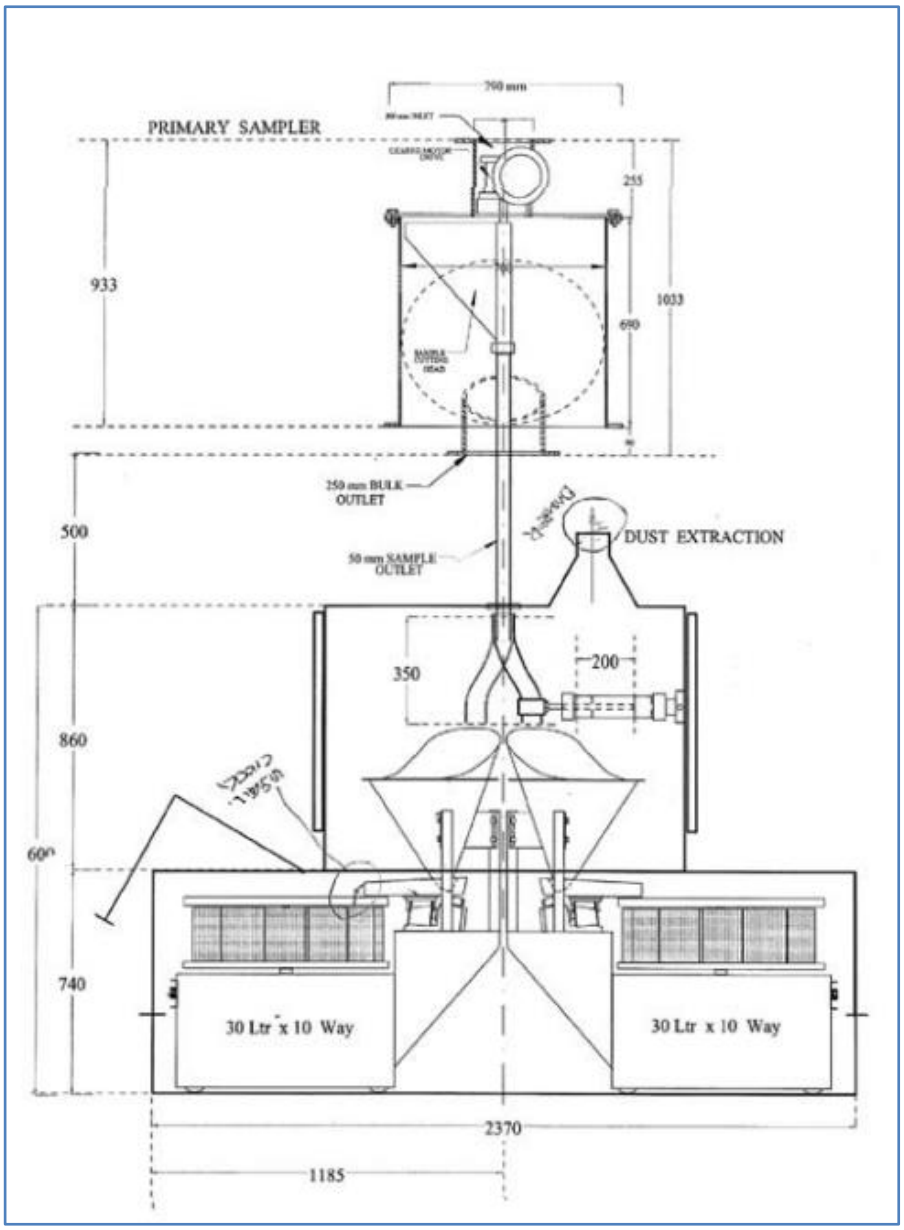


Figure 2.9: Interleaved Sampling Rig.
(Kruger & Van Tonder, 2014)

The material was sampled intermittently during loading of the tanker via the single primary vezin type cutter. The primary increment was collected in an interleaved manner with each increment being discharged into a dedicated splitter hopper and being sub-sampled by the respective 10-way rotary splitter. The sampling system was ratified and the ratification process concluded that representative samples were produced from the sampling system in question. It was therefore concluded at this point that the results could be used with a high degree of confidence. This was however soon contradicted by the resulting accountabilities and variances in physical

and theoretical stock for the respective sites (Smelter and Refinery). This called for further investigation and as a result a physical inspection and audit of the sampling system was then done. The % sample cut per batch loaded was trended to check for sampler proportionality and the relative standard deviation was calculated.

It was also established via a literature study that existing conditions within the vezin had to be addressed. It was suggested that the observed bias could be due to the effects of air motion generated by the primary vezin rotation on very fine particles. These investigations confirmed that a bias existed in the material sampling due to air flow conditions within the sampler. A physical inspection of the sampling system indicated that a vacuum existed inside the vezin and as a result during sampling, fines were being sucked up back into the vezin through the sample pipe and cutter, while the coarser and denser material proceeded to be sampled. Carson et al. (1998) mentioned that fine or light particles tend to remain suspended in air longer than coarser or heavier particles. It is also suggested that air currents can carry airborne fines and light particles away from a filling point to areas such as vents or dust extractors/collectors. Johanson et al. (2005), also state that air currents may carry fine particles to dormant regions of process equipment where they settle out of the air streams.

A change in sampling protocol was introduced together with certain physical changes to the sampling equipment. This resulted in the elimination of the airflow and in turn rectified the bias conditions significantly.

Table 2.2 overleaf shows the grade variation in parts per million (ppm) (g/t) for the size fractions associated with the crushed product (Kruger & van Tonder, 2014).

Table 2.2: Size by Size Analysis for Crushed Product Stream

Sieve Size (µm)	PGM Grade (g/t)	Mass Retained (%)
+1180	763.5	20.7
+850	812.5	22.0
+600	914.0	9.9
+425	943.5	8.2
+212	951.0	20.3
+106	727.0	11.5
-106	264.0	7.3

*Assay data contained in Table 2.2 has been factorized for confidentiality purposes.

It is clear from Table 2.2 that the very fine particles have a significantly lower Platinum Group Metals (PGM) grade. Removal of the fines (via air flows present in the vezin during sampler operation) from the sample increment would thus significantly bias the sample, and the evaluation of this material stream would overstate the PGM grade therefore affecting the PGM accountability.

Kruger & Van Tonder (2014) further suggests that designing sampling equipment is a complex exercise and that material characteristics must be carefully investigated to understand the relationship between the equipment design, the material itself, and fluid flow characteristics. The first step would be to investigate the material properties. In the case of the work by Kruger & Van Tonder (2014) the relationship of dusting and grade association with particle size was known, but the effect of air flow inside the vezin was not recognised upfront.

2.4.2 Bias Testing of Cross-Belt Samplers

Lyman et al. (2009) discusses the bias testing of cross-belt samplers of the original design and of the go-belt design. The application of individual t-tests to the results of testing a sampler on size distribution is debated and was deemed incorrect as this test ignores the correlation between the amounts in size fractions. T-testing when more than one analyte is used is also incorrect when the analyte contents in samples are correlated (as they usually are). The other bias testing protocol, the Hotelling T-squared test, correctly takes the correlation in the data into account when tests on

simple differences are used. It was noted that the Hotelling test is somehow sensitive to outliers and abnormal data. The Hotelling T-squared test intrinsically recognizes the correlation or co-variance between mass fractions in the various size fractions as is appropriate to the technical realities of the situation (Lyman et al., 2009).

2.4.3 Bias Testing of Mechanical Sampling Systems for Coal

Much work around bias testing of sampling systems has been done in the coal industry. Rose (2012), presents an examination and summary of results of 120 coal sampling system bias tests. This literature supports new methodology using multivariate statistics and further discusses the issues raised with the ISO 13909 standard (parts 1-8) for hard coal and coke mechanical sampling.

Samples used for the bias testing in the work by Rose (2012) were collected by the 'paired batch' method as per ISO standard. Material that was collected as a stopped-belt increment from the test batch was denoted as the 'reference sample' and the material collected from the sampling system was referred to as the 'system sample'. For each set of data (test batch), a difference in parameter value was determined. For instance, the % moisture value for the reference sample was subtracted from the % moisture value for the system sample. Almost all of the tests used four parameters, namely, moisture, dry ash, dry sulphur and the as-received calorific value. The different data was evaluated using a specific statistical methodology in order to conclude on system bias. All the systems tests included had either two or three sampling stages. 43 of the sampling stages included a falling stream primary cutter and 77 were equipped with a cross-belt cutter primary cutter.

Bias was detected in approximately 36 per cent of the tests reviewed, suggesting that much improvement is needed in designing, maintaining and monitoring the performance of sampling systems in order to avoid sampling bias (Rose, 2012). Only one test detected a bias of dry sulphur or as-received calorific value while no bias of

moisture and dry ash was detected. This was in line with the reviewed version of the ISO standard that in general, moisture and ash would be adequate. This paper further demonstrated that the existing ISO 13909 standard does not take into account the need to use a number of parameters to detect the causes of bias (inclusive of moisture loss and selective rejection of particles by size). Provisions for these exclusions can be made by making use of the simultaneous confidence intervals by means of multivariate statistical methods.

2.4.4 Discrete Element Modelling (DEM)

Many articles by Clearly & Robinson (2009 & 2011) on Discrete Element Modelling (DEM) have been published over the years. DEM has proved to be a useful tool for analysing sample bias for falling-stream cutters. It provides detailed information on bias and size dependent extraction ratios based on meticulously matched reference and actual samples taken from the same simulations. It has allowed the identification of additional operational and design parameters which influence sample cutter performance. To date, this has been performed on cohesionless bulk materials. Wet bulk materials typically become sticky and this strongly influences their flow behaviour and particularly the mobility of fine particles and the overall flowability of the material (Clearly et al., 2009).

DEM simulation is also a sensitive tool for investigating the possible increment extraction bias of sample cutters that it is able to show that increment extraction is not strictly correct for any of the three types of samples cutters which are most commonly used (falling-stream cutters, vezins, cross-belt cutters) (Clearly et al., 2009). Vezin samplers are used to take a small fraction of a stream of material which is intended to be representative of all the material. DEM suggests that this type of sampler performs very well giving a very good extraction ratio and negligible sample bias over a wide range of conditions (Clearly & Robinson, 2011; Clearly et al., 2009).

Pitard (2005) suggests that vezins sometimes need to be run at 0.3m/s or 0.45m/s rather that at the 0.6m/s specified by Gy's (1982) rules. DEM has been used to investigate the effects of several factors on extraction ratio and sample bias and to understand the mechanisms that can lead to sample bias on sampling using a vezin. The factors considered included:

- Top size of material
- Drop from end of feed to top of cutter
- Cutter speed
- Feed rate or bed depth on feeder
- Particle shape
- Material properties such as friction and restitution coefficients (Clearly et al., 2009).

In summary, the following conclusions were made by Clearly et al. (2009):

1. Vezin samplers that operate on particles with minimum size of 500µm appear to be quite consistent and robust devices as they produce extraction ratios close to 100% with negligible bias;

2. Vezin sampler performance is insensitive to material properties, especially the particle shape, friction coefficient and restitution coefficient;

3. As top size of the feed material increases, sample bias does not seem to increase on condition that the top size is smaller than the cutter aperture;

4. Through the investigations conducted, minimal evidence exists to suggest that high cutter speed produces problems;

5. Operational settings such as the fall height, bed depth and feed rate have little effect on the performance of the sampler;

6. Cutter design variations (example different face angles) for the cutter blades also have negligible effect on the performance of the sampler;

7. Four possible physical bias generating mechanisms were identified, one of which was air drag that mostly affects finer particles. With a minimum particle size of 500µm, this mechanism is expected to have little effect because the particle Reynolds number are large enough to point out that the fluid motions are insignificant.

2.5 Current Sampling Practice in the Mining Industry

Robinson & Clearly (2009) suggest that the designers of sample cutters should estimate the amount of sample bias which would occur for a variety of designs and make decisions considering the economic trade-off between the amount of bias and cost of sampling.

The importance of mechanically correct sampling cannot be stressed enough. When a sampler is mechanically correct, any lateral segregation in the process stream being sampled is of no consequence as material is sampled correctly from all points across the stream. This should be the industry Best Practice to be aspired for and is the prime motivation for correct sampling. If the material being sampled is segregated in a consistent manner in the process stream, mechanically incorrect sampling will lead to bias. With correct sampling, the issues of segregation are essentially eliminated (Kruger & Millar, 2002).

Various methods are currently used in industry to check samplers for bias. These include:

- A critical and physical inspection of a sampling system (adherence to good sampling practice);

- Comparison to a reference sampling procedure (for example, stop belt sampling vs. mechanical go-belt sampler);

- Relative method involving the comparison of samples taken by the sampler with the sampler rejects (comparison of a property such as particle size distribution) (Gy, 1982).

Sampling theory mentions that for a sample to be proportional, a minimum of 30 cuts should be taken (Kruger & Millar, 2002). According to the Central Limit Theorem of Mathematical Statistics, the distributional weight of active components in a sample tends to become normal as the number of increments increases.

Gy (1982) indicates that normality is practically achieved when the number of increments is larger than 30, which is somewhat arbitrary but acceptable from a strictly practical point of view, irrespective of the distribution law of the incremental weights. When the number is small (roughly smaller than 30), the distribution may deviate from normality and cannot be specified (Gy, 1982). As a rule of thumb, Gy and Allen recommend that at least 30 sample increments at regular intervals must be achieved to minimize grouping and segregation error and thus overcome distributional heterogeneity i.e. variability of PGM and base metal grade (Trottier & Dhodapkar, 2012). Current practice in industry is to apply this rule of thumb to all aspects of sampling, be it primary or secondary sampling. No test work has been conducted to validate if indeed a minimum of 30 cuts are necessary in secondary sampling on UG2 Concentrator plants.

The number of secondary cuts can be manipulated:

- By adjusting the secondary cutter speed (i.e. of rotations per minute);

- By installing a timer on the secondary cutter (i.e. only take a secondary sample at predetermined time intervals);

- By adjusting the number of open secondary cutters on the secondary sampler;
- By adjusting the nozzle or insert diameter of the intermediate hopper discharge end (Kruger, & Millar, 2002).

The number of secondary cuts per primary increment (Kruger, & Millar, 2002) are generally calculated as follows:

$$No.of\ cuts = \left[\frac{Hopper\ retention\ time * cutter\ rpm}{60}\right] * no.of\ open\ cutters$$

....Equation 4

2.6 Metal Accounting Principles and Plant Performance Parameters

Production operations are exposed to the financial risk linked with its metal accounting process to the degree that there is poor confidence in the evaluation of the metal content fed to that operation and subsequently produced by it. Furthermore, there is often risk associated with the reputation of a company and of negative market perceptions resulting from major metal accounting discrepancies (Gaylard, 2007). As stated in the AMIRA Code Guidelines (2007): “one of the prime objectives in the design of a metal accounting system is to enable an operation to quantify, manage, and minimize the level of risk to which it could become exposed, through failures or shortcomings in its metal accounting system”.

On any Concentrator plant, it is vital that an evaluation facility exists to account for the metals entering and leaving the Concentrator. Metal accounting provides an indication of the metal content entering the plant so that it can be reconciled with the metal content leaving the plant. Furthermore, every Concentrator plant employs a metal accounting system which determines the distribution of various constituents and the value in each of them. The information gathered from metal accounting enables metallurgists to calculate recovery and subsequently build-up grade and so

allows for decisions to be made concerning process efficiency. Metal accounting is thus a crucial aspect of all efficient metallurgical processes.

The information obtained from metal accounting is however very dependent on the collection of representative samples. The metal accounting system must be based on accurate measurements of mass and metal content (Gaylard, 2007). Samples are often taken by the evaluation personnel at various points in the process on a daily basis. Samples obtained from automatic samplers within a concentrator plant include process control and metal accounting samples. Process control samples are generally taken in order to assess various efficiencies/recoveries within the flotation circuits. An example of typical samples taken and subsequent analyses done on each sample is shown in Figure 2.10 below.

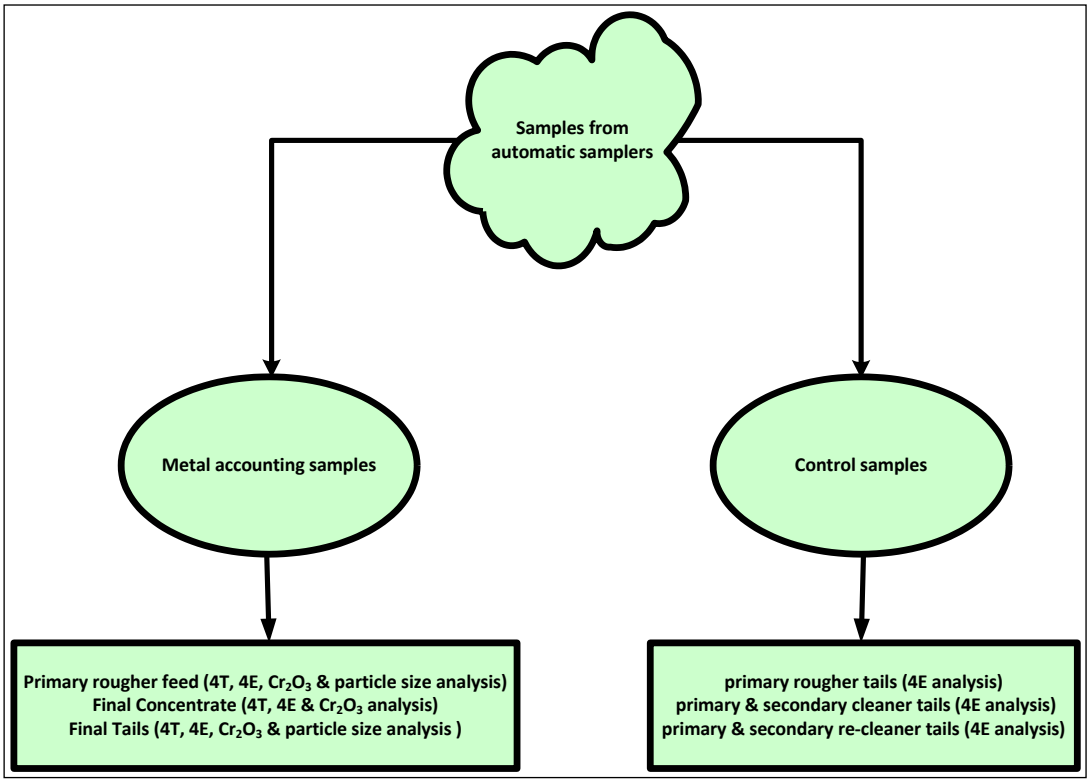


Figure 2.10: Summary of the Sampling and Analyses Done at a Typical UG2 Concentrator.

Both process control samples and metal accounting samples are taken however the metal accounting samples take precedence over the control samples for the obvious

reasons mentioned previously. These samples are then prepared in the sample preparation laboratory and are sent off for analyses to a reputable (usually ISO accredited) laboratory.

A plant performance report detailing actual and target values is generally circulated on a daily basis. These main values may include that of the head, concentrate and tails grade, mass pull, recovery, accountability, platinum ounces, concentrate tonnage and tonnage treated. A typical plant performance report is shown below. The variance value for each term is calculated by subtracting the target value from the actual value.

Progressive for the Month			
Safety Days			
	Actual	**Target**	**Variance**
Tons treated (BP)			
Head Grade			
Sample			
BUH			
Concentrate Grade			
Concentrate Tons			
Mass Pull			
Tails Grade			
Recovery			
Ounces			
Accountability			
Mill Stops			

Figure 2.11: Typical Performance Report Template.

The parameters in Figure 2.11 are defined as follows:

- Safety days – is the number of lost time injury (LTI) free days' year to date;
- Tons treated (BP) – refers to the amount of ore that is milled. BP is an abbreviation for Business Plan. The actual and target values are the cumulative values for a calendar month;
- Head grade – Head grade is divided into sample head grade and build-up head grade;

Sample head grade – a 4T (Platinum, palladium, rhodium and gold) analysis is done in order to get the grade (reported as grams per ton (g/t)) of the primary rougher feed. Typically, the primary rougher feed stream is sampled by an automatic sampler at regular intervals. The sample resulting is then prepared and is sent to a reputable (usually ISO accredited) laboratory for further analyses.

Build-up head (BUH) – Build-up head grade (g/t) is essentially the calculated head grade as opposed to the sample head grade of the primary rougher feed which is measured (Kruger, & Millar, 2002). BUH is calculated as follows:

$$BUH = \frac{(conc.mass \times conc.grade) + (tails\ mass \times tails\ grade)}{mass\ milled}$$

....Equation 5

- Concentrate grade – is the concentration of Platinum Group Metals (PGMs) in the final concentrate (concentrate 4T);

- Concentrate tons – is the weighed tonnage or mass of the final concentrate that is dispatched to the Smelter for further processing;

- Mass pull – mass pull is defined as the amount of dry concentrate tonnage produced relative to the tonnage treated (Kruger, & Millar, 2002):

$$Mass\ pull = \frac{concentrate\ mass}{tonnage\ treated} \times \frac{100}{1}$$

....Equation 6

- Tails grade – is the grade of the secondary rougher tails going to the tailings thickener (tails 4T);

Recovery and accountability are distinct but related parameters. The determination of both parameters is required for the efficient and effective monitoring (over defined boundaries) of the performance of metallurgical plants or unit processes, as well as for reliable forecasting and planning (Gaylard, 2007).

- Recovery – BUH recovery and 2-product recovery (Kruger, & Millar, 2002) are defined as follows:

$$BUH\ recovery = \frac{mass\ of\ conc. \times conc.grade}{(conc.mass \times conc.grade) + (tails\ mass \times tails\ grade)} \times \frac{100}{1}$$ ....Equation 7

$$2 - product\ recovery = \frac{conc.grade \times (feed\ grade - tails\ grade)}{feed\ grade\ (conc.grade - tails\ grade)} \times \frac{100}{1}$$ ...Equation 8

- Ounces – platinum ounces progressive value for the month is calculated as follows (Kruger, & Millar, 2002):

$$Ounces = \frac{mass\ of\ conc. \times platinum\ grade\ in\ conc. \times conversion\ factor}{1}$$ ....Equation 9

- Accountability – accountability is defined as the ratio of the total output of a plant or a section of a plant, for a particular element, to its total input (Kruger, & Millar, 2002):

$$Accountability = \frac{Build-up\ head\ grade}{Sample\ head\ grade} \times \frac{100}{1}$$ ...Equation 10

  A value over 100% indicates over-accountability and a value below 100% indicated under-accountability.

- Mill stops – the number of times either the primary or secondary mill stops is recorded since a great deal of power is needed to start up these mills again. In addition, mill stops decreases the lifespan of the milling components.

2.7 Variography

A variogram is the calibration of variance between samples a given distance apart. The study of the variability of process streams is known as variography. Variography can be applied to chronological process samples, where distance is replaced with time

(e.g. days). For process data, a one directional variogram is applied. Pitard (2006) recommends the use of the variogram in interpreting sampling issues.

A variogram represents the sources of variability and provides insight into the temporal continuity or correlation between related samples. The variances at increasing sample intervals (lags) are plotted to produce a semi-variogram with specific parameters unique to the material stream. The components of variance contributed by various sources can be separately estimated from a variogram (Minnitt, & Pitard, 2008).

The variogram is a graphical representation (usually a line chart) in which a sequence of mean variances at different lags as depicted in Figure 2.12 below is plotted against the corresponding lag.

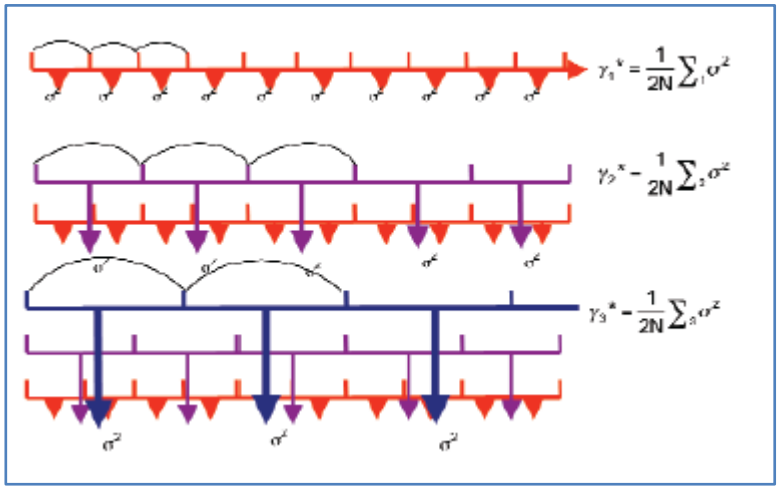


Figure 2.12: A Series of Sample Points Separated by Distance. (Minnitt, & Pitard, 2008)

It therefore measures how comparable values are a given distance apart (the lag) (Napier-Munn, T.J., 2015).

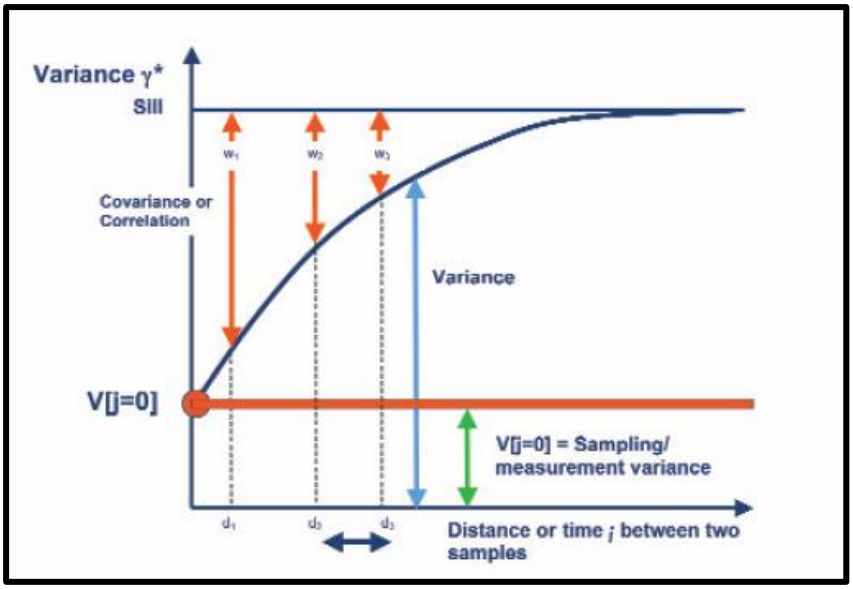


Figure 2.13: Components of a Typical Variogram. (Minnitt, & Pitard, 2008)

The following parameters can be calculated from a variogram:

1. **V0** is random variability (short range) and is a function of:

    a. Inherent distributional heterogeneity of the material. (FE being the fundamental error, GSE being the grouping and segregation error), related to particle size and sample size;

    b. Sampling system (design of the equipment). Uncontrolled sampling variability arising from the sampling protocol. This variability cannot be changed unless the sampling protocol is changed;

    c. Analytical variance (can be quantified from replicate assay data).

    V0 variability is not related to the process of taking a sample or the plant process itself. If V0 is large, other errors are also likely to be large. Theory suggests that the V0 is expected to be about 32% of the total sill (which is a measure of the overall variability) (Minnitt, & Pitard, 2008). The V0 can be reduced if attention is given to the sampling protocol.

2. **V (Sill)** is a measure of the total variability in the stream beyond the point where samples are correlated with one another i.e. when the variance does not increase if the time (lag) is increased.

3. **V1** is the total process variability which consists of the sum of V0 and V1.

4. **V (process)** is the process variability (i.e. difference between V1-V0). This variability cannot be controlled unless the routine sampling interval is reduced. It is the non-random component of variability that occur in the plant between 2 consecutive samples. This non-random component of variability is due to bias in the sampling process related to one or more of the factors such as:

    - Delimitation Error (DE);
    - Extraction Error (EE);
    - Preparation Error (PE);
    - Analytical error (AE).

    This non-random component can be eliminated through implementing an optimized sampling protocol.

5. **Range** is the point beyond which there is no correlation between data points. It is the time (i.e. days) at which point the sill is reached. The larger the range the more correlation between the data indicating a good sampling frequency.

The parameters determined from a variogram cannot be applied directly as a bias. These parameters only represent uncertainty (thus such parameters will have a positive or negative effect). The parameters can however assist in identifying possible areas of concern when measured against target values or when the magnitude of uncertainty is compared between different streams (Minnitt, & Pitard, 2008).

2.8 Summary of Literature Review

The main outcomes of the review are summarized as follows:

- ISO standards for gold and platinum does not exist unlike in the coal industry. Nevertheless, sampling for PGMs should follow the accepted rules (Best Sampling Practice and Theory of Sampling) for unbiased samples to result;
- Representative sampling for PGMs is complex because of the mineral heterogeneity aspects and often sampling protocols and sampling equipment designs need to reviewed over time;
- The mechanical design of an automatic sampler is as important as the operation of the sampler. The literature review details examples of key design flaws and correctly designed samplers in industry as well as the recommended design criteria (cutter gaps, cutter speeds, cutter widths etc.);
- Evaluation of a sampler performance can be done via bias testing. Bias testing of a sampling system with respect to particle size is a more powerful method than testing for bias with respect to a chemical constituent, especially when the chosen analyte(s), in this case, PGMs, are present in small concentration (trace elements in the UG2 reef ore body);
- DEM is a useful tool for analysing sample bias for falling-stream cutters. DEM suggests that a vezin sampler performs very well giving a very good extraction ratio and negligible sample bias over a wide range of conditions;
- The parameters determined from a variogram cannot be applied directly as a bias however they can be used to identify possible areas of concern when measured against target values or when the magnitude of uncertainty is compared between different streams;
- Bias generation due to settling of coarser particles in the intermediate hopper of a vezin-vezin sampling system has yet been explored in the UG2 reef environment. Chromite grains dominate the size fractions near 350µm and these fractions are relatively low in PGMs. The heterogeneity with

respect to PGMs of the fractions above 350µm is low, but for sizes below 100µm, there is a radical increase in the heterogeneity;

- Segregation is not entirely understood and is complex. The settling velocity of particles in a liquid can be described by Stokes Law or Newton's Law depending on the type of flow present. Gravity plays an important role at particle diameters greater than approximately 50µm;
- There are many mechanisms of segregation that have been identified, with the six main mechanisms being highlighted as sifting segregation, repose angle segregation, air entrainment segregation, impact fluidization segregation, trajectory segregation and vibration segregation;
- Much work has been performed in identifying segregation mechanisms and kinetics of segregation processes however the focus has now shifted towards controlling and minimizing the extent of segregation in industry;
- Segregation of particles in hopper filling and discharge was examined by Bauer & Denburg (1962). To the author's knowledge, a similar study of particles suspended in slurry in an intermediate hopper of a vezin-vezin sampling system has not been conducted.

3 Methodology

3.1 Overview

Crushed run-of-mine UG2 ore is fed into a semi-autogenous (SAG) mill and the mill product is then pumped to a classification screen to produce undersize and oversize material streams respectively. The oversize classification screen material is sent back to the SAG mill for further grinding. The undersize material is gravity fed to a surge tank and this material is then pumped to the primary rougher flotation circuit. Prior to being fed to the primary rougher flotation circuit, the material is sampled by the automatic vezin-vezin sampler. The position of the automatic feed vezin-vezin sampler in the production process is noted in Figure 3.1 below:

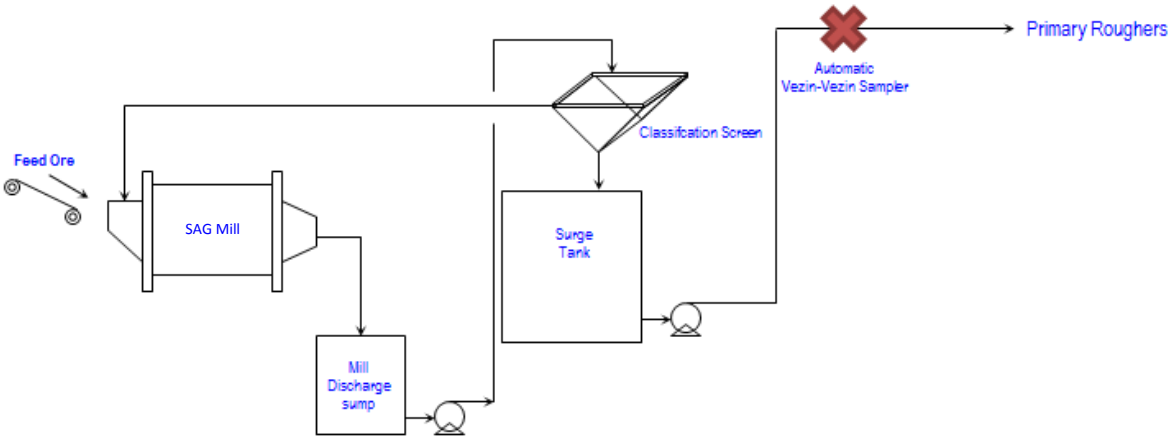


Figure 3.1: Basic Process Flow Sheet.

The automatic vezin-vezin feed sampler as illustrated in Figure 3.2 overleaf was used to perform all experimental work relating to this research project. The quantification of particle segregation was evaluated primarily by measuring the bias in particle size distribution for all stages of test work.

Dual primary vezin samplers as depicted in Figure 3.2 overleaf were available on site. Under normal operating conditions, only one primary vezin sampler is meant to operate at a time. The primary sampler included a single vezin cutter arrangement and the secondary sampler included a four cutter vezin arrangement.

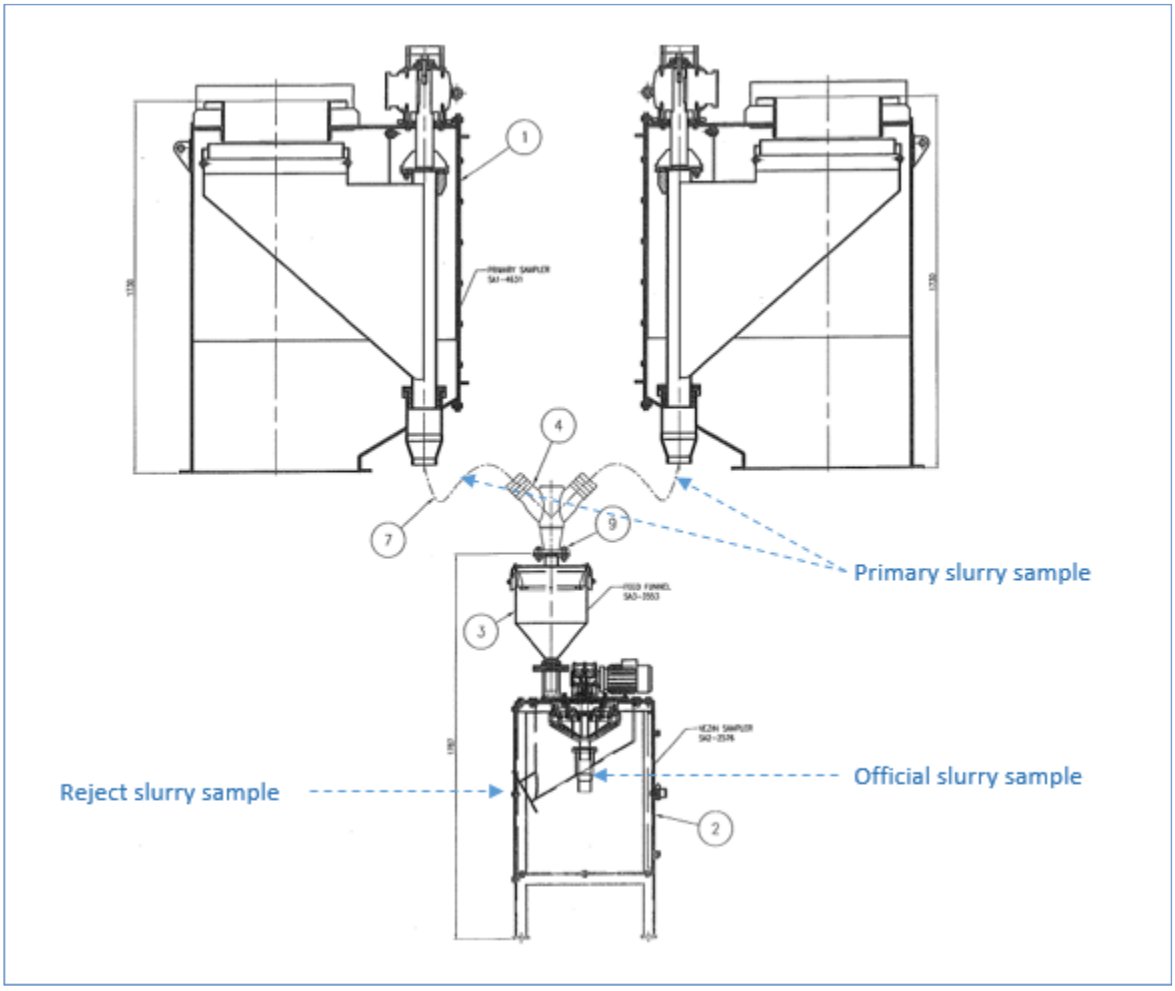


Figure 3.2: Vezin-Vezin Sampler Combination.

The primary sampler typically produces a primary sample which is then discharged from the primary cutter outlet through a flexible pipe ("7" in Figure 3.2) into a Y-feed pipe arrangement ("4" in Figure 3.2) and then into the intermediate hopper (also referred to as a feed funnel shown by "3" in Figure 3.2) of volume capacity (20L). The primary sample is then discharged from the intermediate hopper through a nozzle or insert via gravity, at which point, sub-sampling begins. The intermediate hopper is fitted with a regulated compressed air supply (minimum of 4 bar pressure). The above-mentioned steps happen automatically as well as sequentially. The individual equipment specifications are tabulated in Table 3.1 overleaf.

Table 3.1: Equipment Specifications

Specification	Primary Vezin Sampler	Intermediate Hopper	Secondary Vezin Sampler
Critical Cutter Width (mm)	20	-	13
Critical Cutter Speed (m/s)	0.60	-	0.60
Cutting Interval (minutes)	Every 15 minutes	-	Rotates continuously
Capacity (litres)	~ 5.4	20	~ 0.54
Trash Screen Mesh (mm)	-	5	-
Nozzle/insert size (mm)	-	10	-
Gearbox/Motor	525V, 0.55kW, 50Hz, 6.1rpm	-	525V, 0.37kW, 50Hz, 28rpm

Principal bias testing relating to segregation of particles in the intermediate hopper was conducted using the Vezin Credibility technique (Kruger & Millar, 2002). The primary and secondary sampling stages as depicted in Figure 3.2 previously were used to collect samples in order to further determine and investigate particle segregation in the intermediate hopper. Further details relating to the experimental approach are described in the sub-sections that follow.

Prior to any test work taking place, process parameters such as feed flow rates, feed densities and mill stability were assessed and noted. However, conducting test work in a production environment was viewed as a limitation since random variation due to the process could not be disregarded.

All sample preparation was done according to current Standards and Best Practice for the mining company in question. Downstream errors which were out of the control of the author included sample reduction errors (sample preparation errors) and errors in determining the assays (analytical variance).

Twin stream analyses were requested for all samples sent to the analytical laboratory in order to determine the analytical variance. The analytical laboratory that conducted

the assaying is ISO 17025 accredited. A Certified Reference Material (CRM) matching the samples was used for quality control purposes. These were randomly placed in each batch of samples that were analysed. All samples were analysed in triplicates and the relative standard deviation were used to eliminate outliers. If there were no outliers, the average value of the three results was then reported. Back-up samples were reserved (where possible) for repeat analysis.

3.2 Stage 1: Baseline Test Work on Existing Sampling Equipment

The first objective of this research project was to investigate if particle segregation is indeed present in the intermediate hopper of a UG2 feed sampling system. In order to test the hypothesis that particle segregation is present in the intermediate hopper, two different tests were performed, namely, a vezin credibility test and a chronological sub-sampling test. Figure 3.2 previously shows the vezin-vezin sampling equipment that was used for both tests. These two tests form the crux of the test work conducted in this study and feature throughout the various stages of test work. Further details relating to the different stages of test work can be found in Appendix A.

3.2.1 Stage 1, Test 1 Vezin Credibility Test Work

Prior to commencing this test, dummy runs were conducted to determine how much official and reject slurry sample (in particular the % solids and corresponding dry mass of solids) can be obtained from one primary cut. It was determined that one primary cut results in roughly 5.4litres of primary slurry sample with a % solids of approximately 50%. In addition, the primary slurry sample, once sub-sampled, was reduced to about 10% by volume. It was then decided that a minimum of three primary cuts were needed in order for adequate sample mass to be generated for the reject and official sample portions to meet analytical requirements. For a feed sample to be analysed in twin stream, the analytical laboratory required a minimum of 250g (dry mass) per sample submitted.

A total of five test runs were performed for repeatability purposes. For each test run, five individual samples were generated. The experimental methodology entailed the Vezin Credibility Technique (Kruger & Millar, 2002).

The vezin credibility testing involved the following steps:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (See Appendix C). The equipment was inspected for leaks and physical damage. Any concerns were noted. The secondary vezin speed was also determined (See Appendix B);

c. The main feed stream was sampled by the mechanically designed primary vezin on a pre-determined time interval basis. The primary vezin sampler was placed on manual operation mode for the purposes of the test;

d. A clean and empty 20L plastic bucket was placed at the secondary vezin reject sample pipe discharge end and a clean and empty 5L container was placed at the official sample pipe discharge end;

e. With the primary vezin sampler in manual mode, the manual cut button was pressed once. This resulted in a single cut of the main stream. After approximately 30 seconds and another manual cut was taken. In total, three manual cuts were taken using this approach;

f. Each primary sample increment resulting from the primary vezin operation was then sub-sampled by the secondary vezin sampler to produce an official sample and reject slurry portion. The hopper retention time was measured in order to calculate the number of secondary cuts per primary increment. The official sample and reject

slurry portions were collected in the separate containers as described in step d above. A picture of a secondary vezin sampler is shown in Figure 3.3:

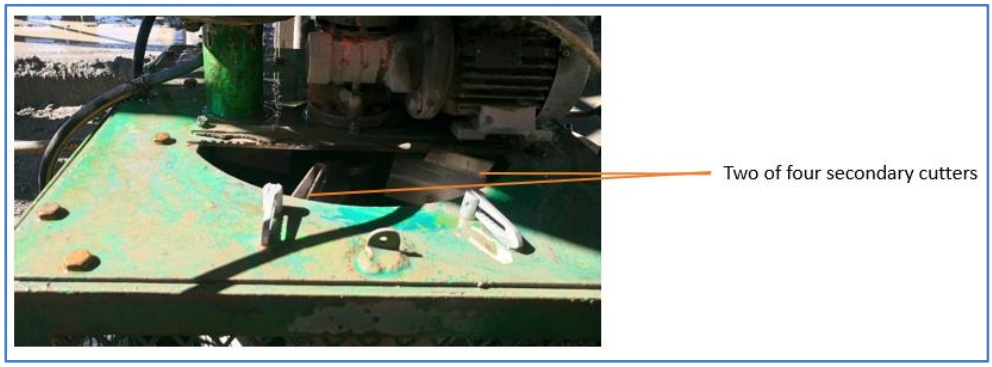


Figure 3.3: Secondary Vezin Sampler with Four Cutter Arrangement.

g. The two sample containers having the official and reject samples were then removed from the sampling points. The containers were closed securely with the provided lids to ensure that no moisture evaporated and no sample was spilled. Each resulting sample was accompanied by a sample identification tag;

h. The flexible hose from the discharge point of the primary vezin cutter connected to the Y-bend feed inlet of the intermediate hopper was then detached.

i. A single manual primary cut was then taken. An empty and clean 20L bucket was used to collect this primary sample increment. The sample container with the collected primary slurry sample was then removed from the sampling point. The container was closed securely with the provided lid to ensure that no moisture evaporated and no sample was spilled. The resulting sample was accompanied by a sample identification tag;

j. The flexible hose was then reattached to the inlet of the intermediate hopper;

k. Steps d to g were repeated to generate another official and reject slurry sample combination;

l. Steps c to j were done five times for repeatability purposes. The time between each test run was minimized (less than 15minutes) to reduce the risk of introducing unpredicted process variability into the test work;

m. Once all the required number of samples had been collected i.e. five primary slurry sample increments and 10 pairs of official samples and reject slurry samples respectively, the sampler was immediately switched back to automatic operation mode;

n. The collected samples were then taken to a central storage area for further preparation and data recording.

The vezin credibility test thus generated the following samples:

Table 3.2: Stage 1, Test 1 Sample Generation

Test Run	Sample Identification	Sample Description
1	Sample 1A	Reject Slurry Sample
	Sample 1B	Official Slurry Sample
	Sample 1C	Primary Slurry Sample
	Sample 1D	Reject Slurry Sample
	Sample 1E	Official Slurry Sample
2	Sample 2A	Reject Slurry Sample
	Sample 2B	Official Slurry Sample
	Sample 2C	Primary Slurry Sample
	Sample 2D	Reject Slurry Sample
	Sample 2E	Official Slurry Sample
3	Sample 3A	Reject Slurry Sample

	Sample 3B	Official Slurry Sample
	Sample 3C	Primary Slurry Sample
	Sample 3D	Reject Slurry Sample
	Sample 3E	Official Slurry Sample
4	Sample 4A	Reject Slurry Sample
	Sample 4B	Official Slurry Sample
	Sample 4C	Primary Slurry Sample
	Sample 4D	Reject Slurry Sample
	Sample 4E	Official Slurry Sample
5	Sample 5A	Reject Slurry Sample
	Sample 5B	Official Slurry Sample
	Sample 5C	Primary Slurry Sample
	Sample 5D	Reject Slurry Sample
	Sample 5E	Official Slurry Sample

The samples generated from Test 1 as shown in Table 3.2 were then subjected to the following procedure:

- Each sample was weighed wet. The bucket and lid tare masses were noted and as a result the net wet mass was determined per sample. This information was recorded on a raw data log sheet;

- The wet slurry sample was then filtered in a filter press to produce a wet filter cake. The wet filter cake mass was recorded on a raw data log sheet (See Appendix D);

- The wet filter cake was then placed in an oven to dry until constant mass was obtained (roughly 8 to 10 hours per sample);

- The dry sample was then allowed to cool to room temperature at which point the sample was weighed. The dry sample mass was recorded on a raw data log sheet (See Appendix D);

- The % solids was then calculated (See Appendix D);

- The dry sample was then lump broken in a lump breaker to get rid of large lumps of material;

- The broken material was then divided into sub-samples using a 10-way rotary splitter;

- One cup of sample was used to determine the particle size distribution (PSD) via a wet screening approach. The screen sizes used for generation of the PSD were 425µm, 300µm, 212µm, 150µm, 106µm, 75µm, 53µm, 38µm and pan (-38µm) respectively;

- The remaining cups of sample were combined and sent for 6T, base metal and Cr_2O_3 twin stream analyses (only applicable to Test Run 4 samples);

- Only one sample i.e. Test Run 4 sample 4C was sent for size by size analysis to obtain an indication of grade association by particle size. In order to obtain enough sample mass, various size fractions were combined. Figure 3.4 overleaf gives further information;

- Quality assurance was attained by monitoring quality control aspects at various points during the sample preparation. Refer to Appendix E for further details relating to sample preparation and data logging.

Figure 3.4 below is a summary of the sampling and sample preparation methodology followed for Stage 1, Test 1.

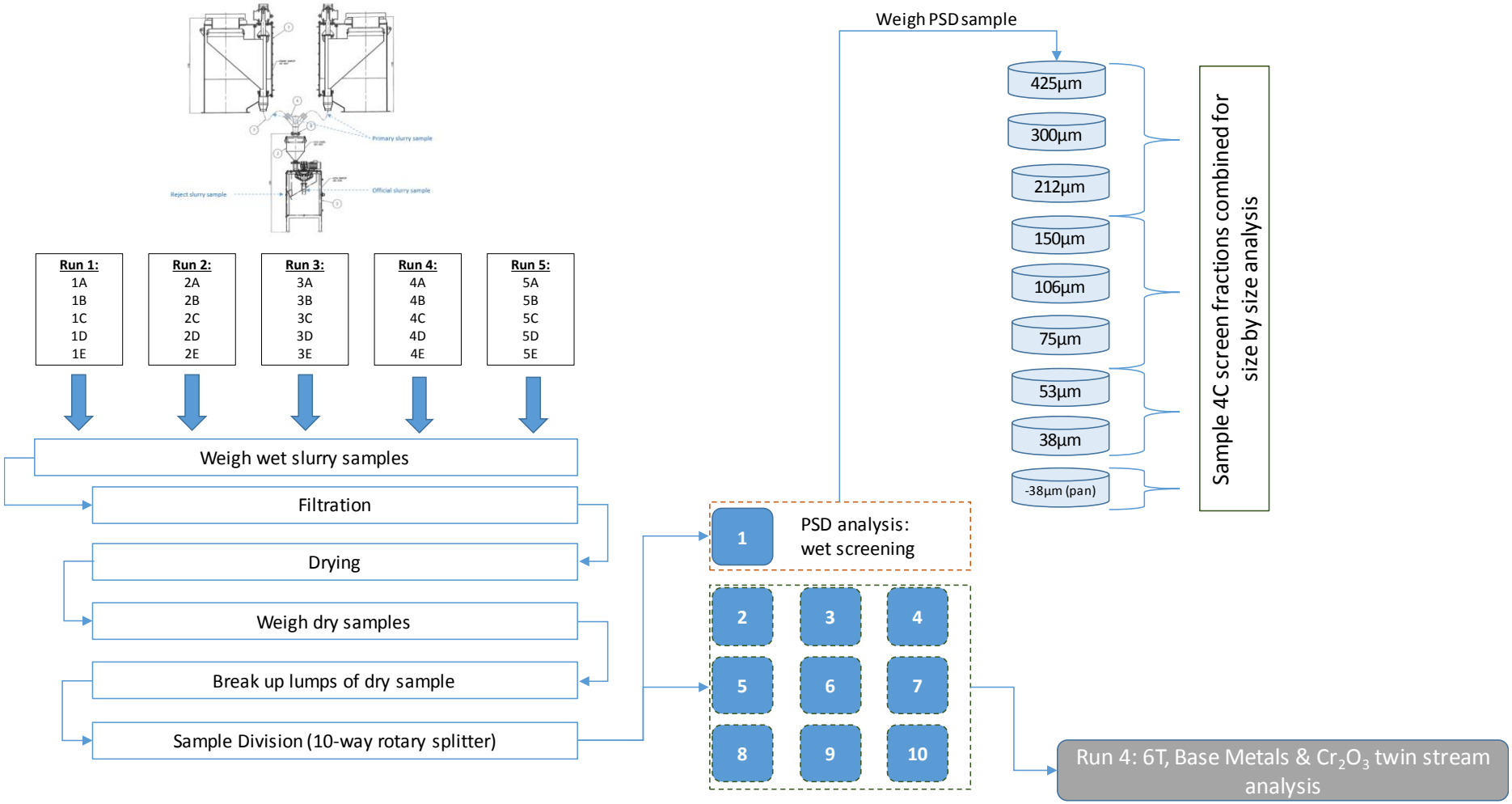


Figure 3.4: Sampling & Sample Preparation Methodology for Stage 1, Test 1.

The second test performed was a sub-sampling test. The details of this test are explained in Section 3.2.2 that follows.

3.2.2 Stage 1, Test 2 Sub-Sampling Test Work

The following experimental test work design was conducted in order to validate the occurrence of particle segregation over time and to prove that coarser particles settle faster in the intermediate hopper and as a result exit the hopper quickly (if not immediately) and are therefore not sub-sampled for the entire duration of the sampling campaign.

In summary:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (Refer to Appendix C);

c. For every primary increment sub-sampled by the secondary vezin, an official slurry sample portion was collected every 6 seconds in separate containers until the intermediate hopper emptied out i.e. at time = 0 seconds, container 1 was placed in the official sample collection point. At time t = 6 seconds, container 2 replaced container 1. At time = 12 seconds, container 3 replaced container 2 and so forth.

d. Seven primary increments were taken and step c above was repeated until enough sample mass was cumulatively collected in this chronologically sequence;

e. Each of the chronological sub-samples were accompanied by a sample identification tag:

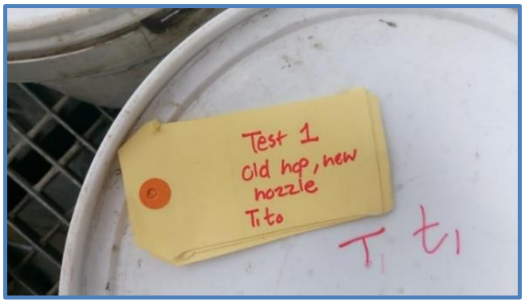


Figure 3.5: Example of Chronological Sub-Sample Identification.

f. The sub-samples were then wet screened independently over a 38µm screen to produce a +38µm fraction and -38µm fraction;

g. The -38µm fraction was then dried and weighed (data logged);

h. The +38µm fraction was filtered, dried and weighed (data logged);

i. The two fractions were then combined and weighed (data logged);

j. The % +38µm was then calculated;

k. The combined sample was then sent for 6T, base metals and Cr_2O_3 twin stream analysis.

The sub-sampling test was only conducted once and thus generated the following samples:

Table 3.3: Stage 1, Test 2 Sample Generation

Test Run	Sample Identification	Sample Description
1	T2t0	0 - 6 seconds sub-sample
	T2t1	6 - 12 seconds sub-sample
	T2t2	12 - 18 seconds sub-sample
	T2t3	18 - 24 seconds sub-sample
	T2t4	24 - 33 seconds sub-sample

Figure 3.6 below is a summary of the sampling and sample preparation methodology adopted for Stage 1, Test 2.

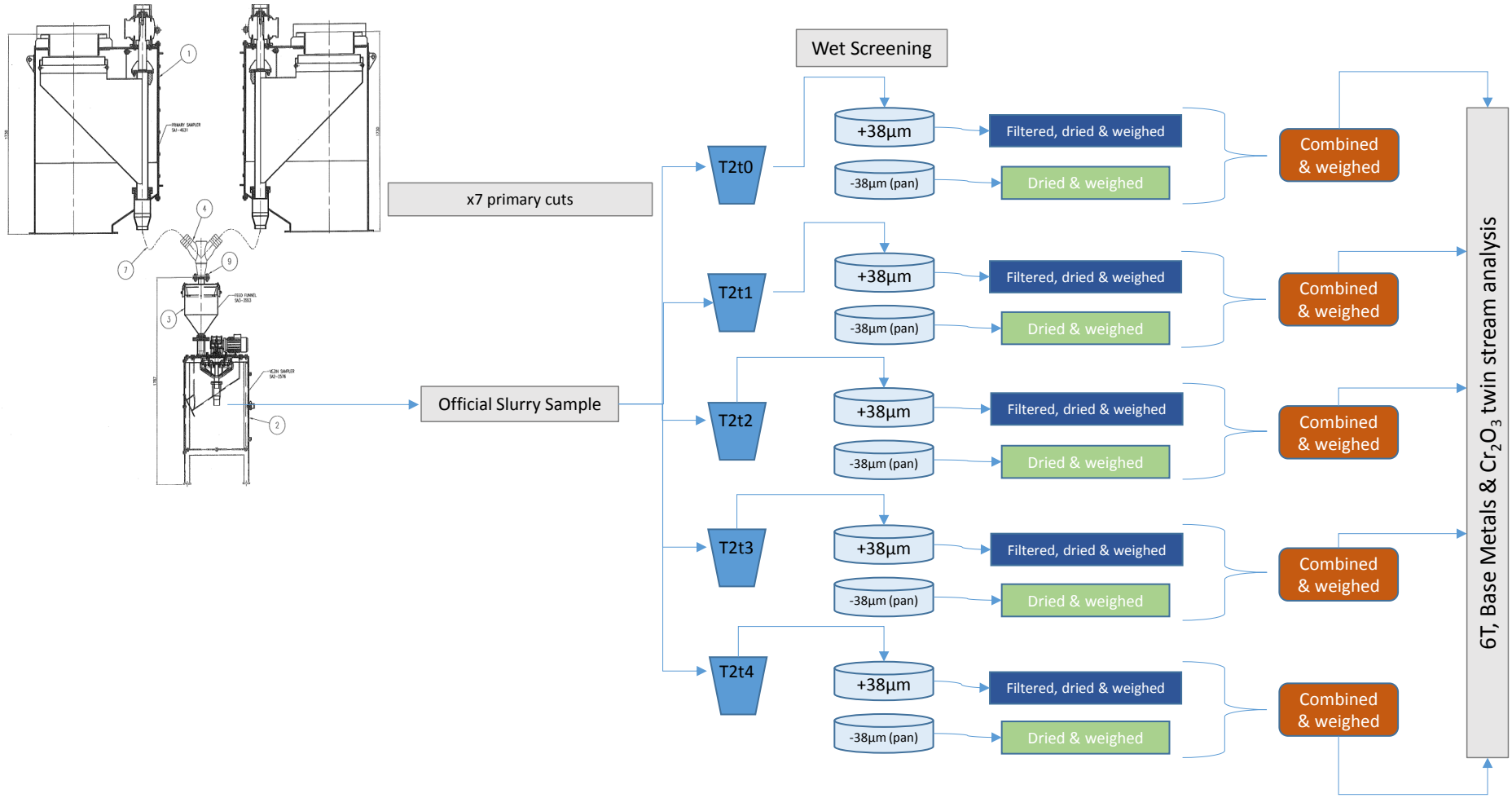


Figure 3.6: Sampling & Sample Preparation Methodology for Stage 1, Test 2.

4 Results and Discussion

4.1 Stage 1: Baseline Test Work on Existing Sampling Equipment

The test work described here were conducted under controlled and ideal conditions as indicated in Section 3 and Appendix A. This should be taken into consideration when interpreting the results that follow.

The main objective of the baseline test work was to investigate if particle segregation occurs in the intermediate hopper of the UG2 feed vezin-vezin sampling system.

4.1.1 Stage 1, Test 1 Vezin Credibility Test Work

The purpose of a vezin credibility test is to verify whether the vezin sampler produces sound, repeatable and unbiased results. If a vezin sampler is credible then the characteristics under consideration should be almost identical for both the official sample and reject sample.

4.1.1.1 Comparison of % Solids between Different Samples

Figure 4.1 overleaf indicates the % solids for the reject, official and primary slurry samples.

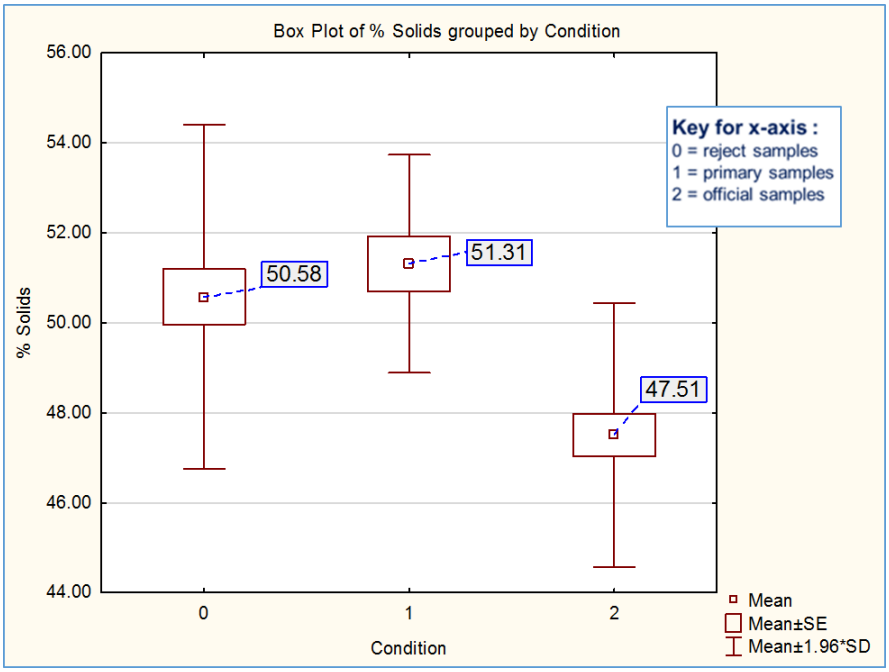


Figure 4.1: Stage 1 - % Solids for Reject, Official and Primary Slurry Samples.

When no bias exists the average % solids for the reject samples should be identical to that of the average % solids for the official samples but still closely related to the average % solids for the primary samples. The variances in the % solids for the reject and official samples are similar whereas the variation in the % solids for the primary samples are smaller.

In terms of average % solids, it is clear that the primary sample and the reject sample are almost the same (~51%) and that the official sample has a significantly lower % solids of ~48% in comparison to the primary and the reject sample. For the official sample % solids to be significantly lower, implies that either a lower dry mass of solids or a higher mass of water was sampled.

The sample split in the secondary vezin sampler is 90:10 meaning that 90% of the mass of the primary sample when sub-sampled would report to the reject sample and 10% would report to the official sample. For mass balancing principles to be obeyed, one would expect that as the official sample has less solids than the primary sample then the reject sample must have more solids than the primary sample for solids mass to balance. In an ideal situation, the secondary vezin should be mass proportional and volumetrically proportional in sampling the primary increment.

However, if there is particle size segregation within the primary increment collected in the intermediate hopper, then the secondary sampler may still be volumetrically proportional but can be biased in terms of mass proportionality. The primary samples ('C' samples) in this instance cannot be directly related to the official and reject samples produced because of the manner it was collected as explained in detail in Section 3.2.1. The official and reject samples are directly comparable and forms the basis of the data analysis.

4.1.1.2 Particle Size Analyses: Cumulative % Passing

Figures 4.2 indicates the particle size distributions for all 25 samples that were originally generated.

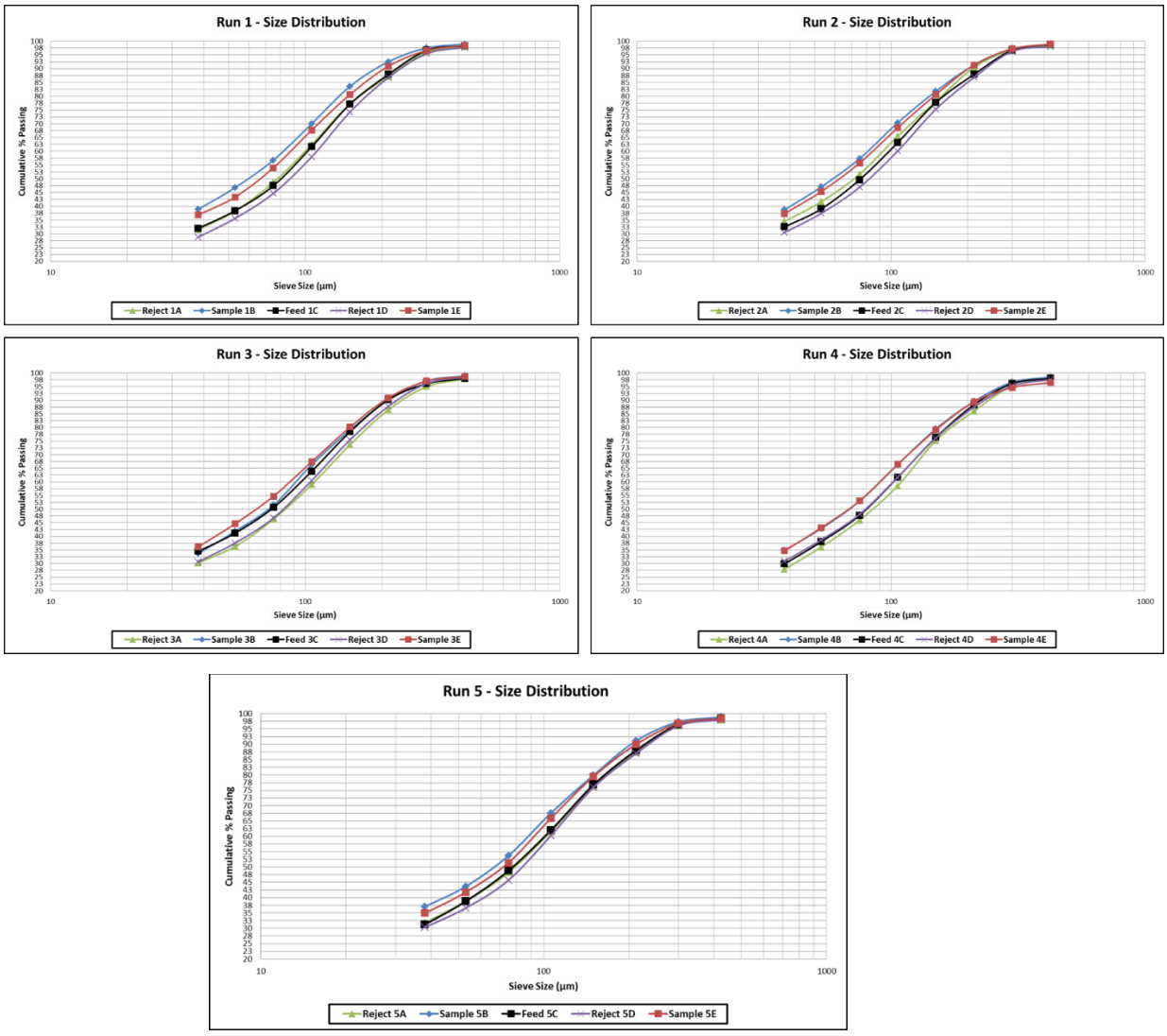


Figure 4.2: Stage 1- Particle Size Distribution for Run 1 to Run 5.

Figures 4.2 show that, in all 5 test runs performed, the reject sample is coarser than the official sample and that the primary ('feed') sample PSD's lies between the official sample and reject sample PSD's. This means that the sampler has a tendency to sample more of the finer particles as opposed to the coarser fraction. This could be as a result of the higher terminal or settling velocity of the larger, coarser particles which is a function of d_p^2, meaning that the coarser particles once they enter the intermediate hopper and subsequently the secondary vezin sampler accelerate faster and escape the cut while the smaller, finer particles are sampled for the larger part of the sampling campaign. In essence, the PSD's generally indicate a bias low towards coarser particles in the official samples but adequate and not over sub-sampling of the fines.

Figure 4.3 and Figure 4.4 indicates the comparison of the cumulative % passing the particular sieve sizes for the official and reject samples for all five runs as well as the average cumulative % passing for the combination of all five runs.

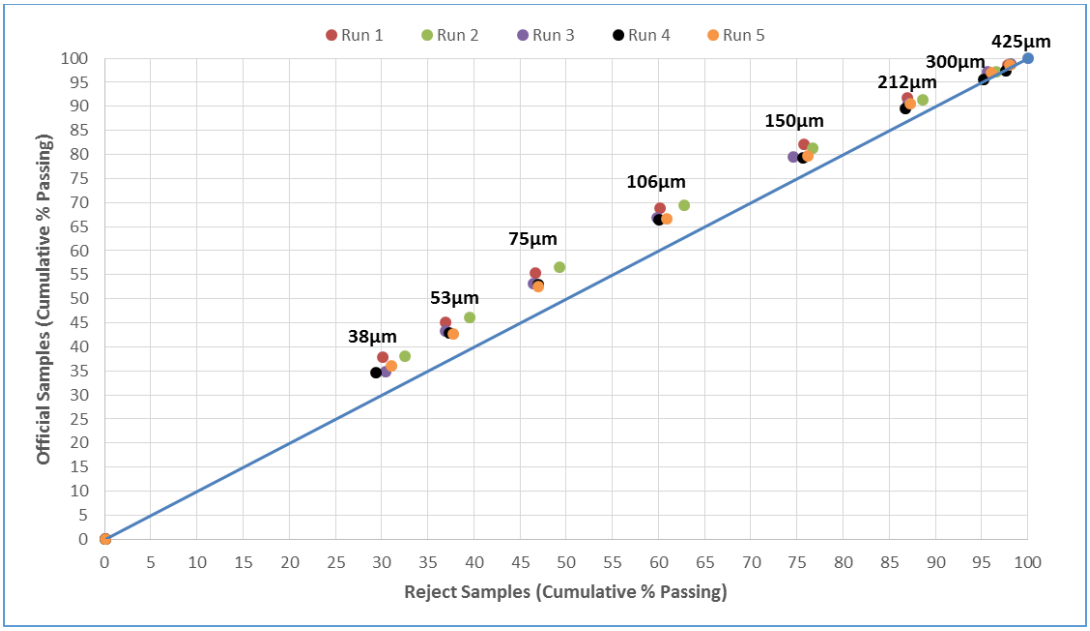


Figure 4.3: Stage 1 – Cumulative % Passing Comparison (Official & Reject Samples).

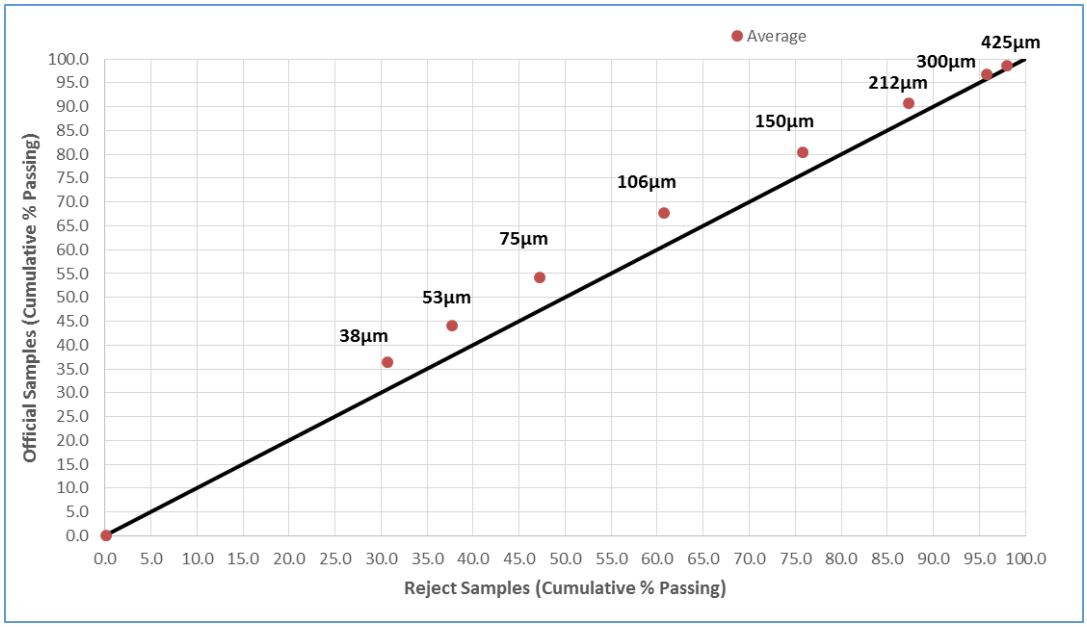


Figure 4.4: Stage 1 – Average Cumulative % Passing (Official & Reject Samples).

It is clear from Figure 4.3 and Figure 4.4 that bias exists towards fine particle size for the official samples. The official samples consistently have a higher cumulative % passing than that of the reject samples across all screen sizes. This is further supported by Figure 4.5 where the official, reject and primary sample PSD's for all five runs have been plotted.

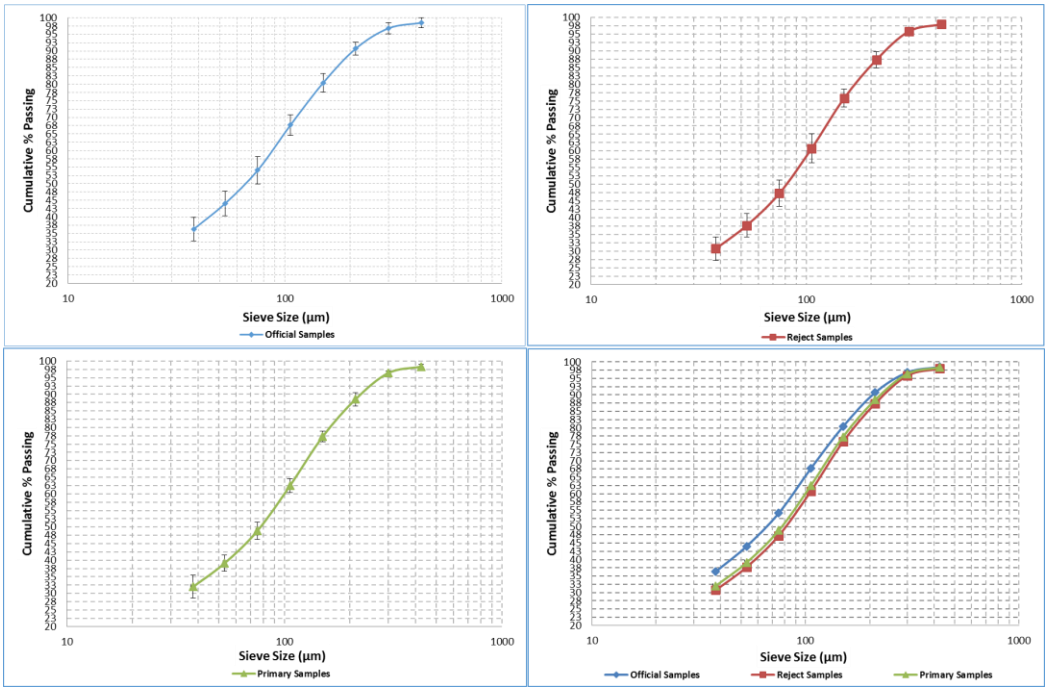


Figure 4.5: Stage 1 - Cumulative % Passing Comparison.

Figure 4.5 also shows the standard deviation at 95% confidence intervals for the official, reject and primary samples by means of error bars. No obvious outliers are observed indicating that the test work and sample preparation were repeatable.

The % bias between the reject and official samples were calculated per size fraction and is shown in Figure 4.6.

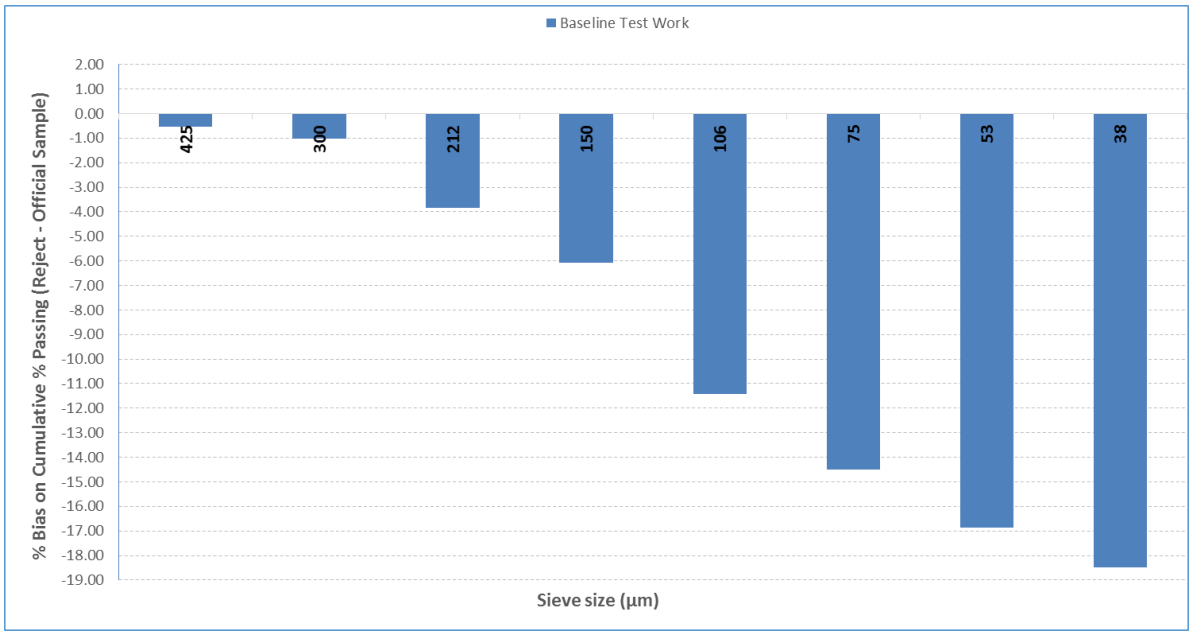


Figure 4.6: Stage 1- % Bias between Reject and Official Samples passing each Sieve Size.

It is clear from Figure 4.6 that, on average for all five runs, a consistent bias is present for all the sieve sizes. The official samples are consistently finer than the reject samples. The largest % bias of 18.5% is observed for the -38µm fraction. Considering the previous suggestion that sub 75µm size range particles normally have higher grades, such biases would therefore have an effect on the overall grade of the primary, reject and official sample resulting in the declaration of an incorrect feed grade.

4.1.1.3 % Mass Retained on Respective Screens

Figures 4.7 and Figure 4.8 indicate the % mass retained on each screen for the reject, primary and official samples respectively.

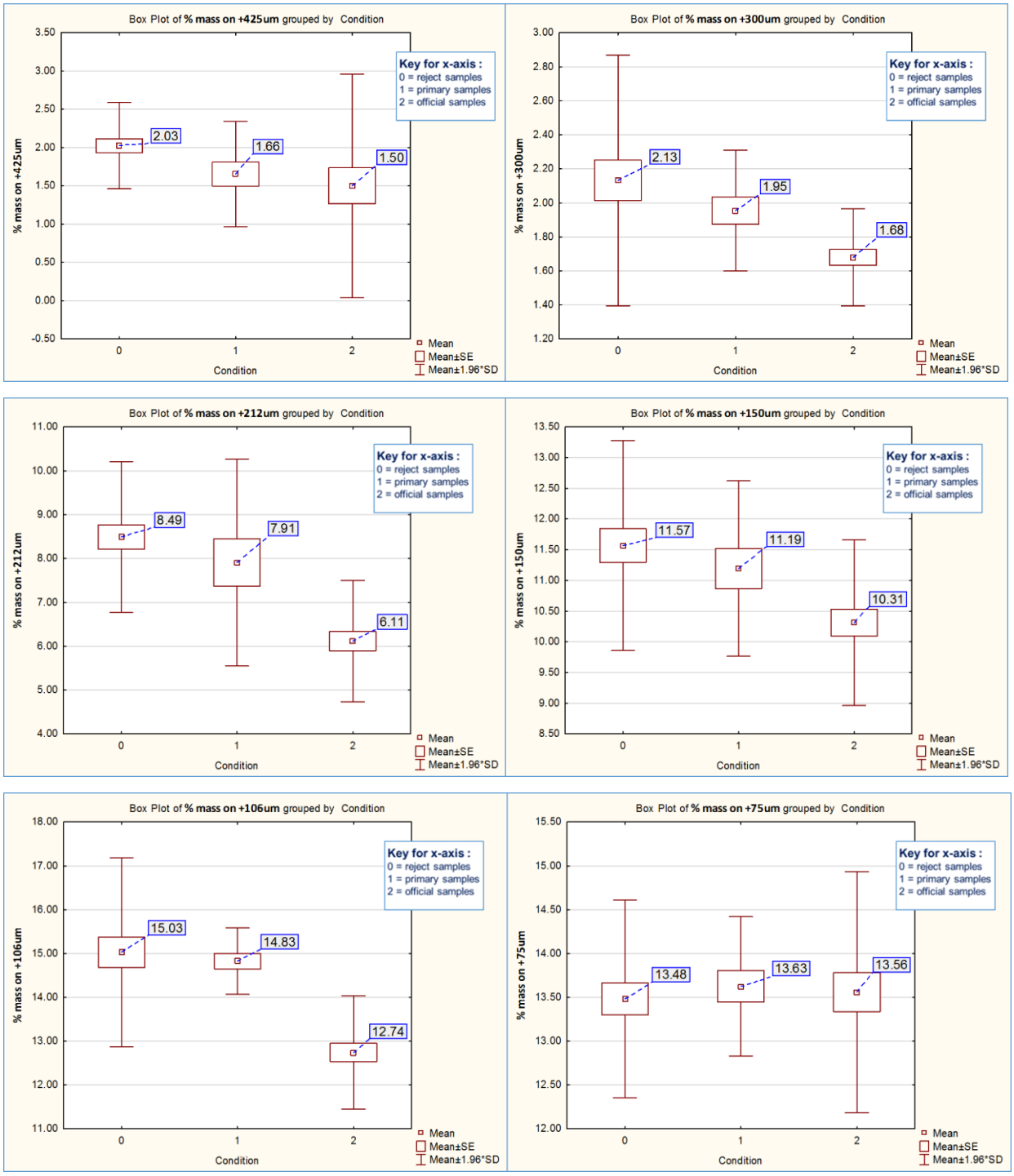


Figure 4.7: Stage 1 - % Mass Retained on Various Sieve Sizes 1 of 2.

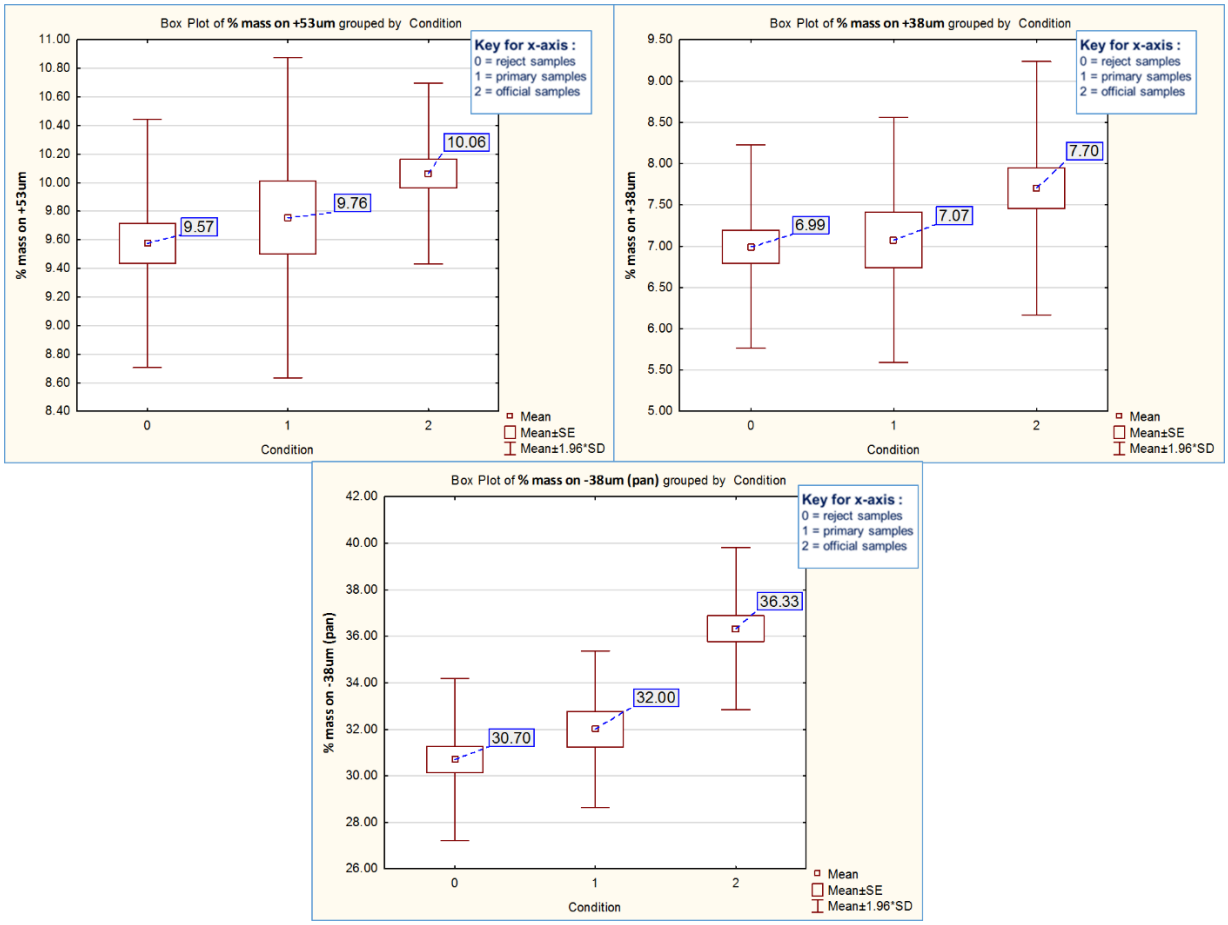


Figure 4.8: Stage 1 - % Mass Retained on Various Sieve Sizes 2 of 2.

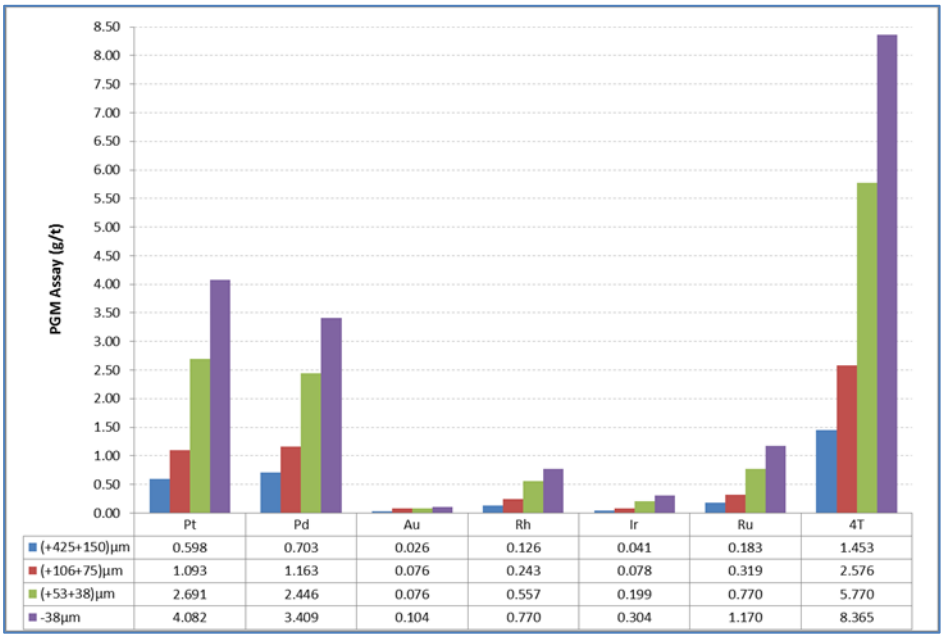
Figures 4.7 and 4.8 further support the cumulative % passing trends previously observed. The % mass retained on screens 425µm, 300µm, 212µm, 150µm and 106µm for the official samples are consistently lower than that of the primary and reject samples. Conversely the % mass retained on screens 53µm and 38µm, and the pan (-38µm) for the official samples are generally higher than that of the primary and reject samples.

4.1.1.4 Size by Assay Analysis

A size by assay analysis was performed on primary sample 4C. In order to generate enough sample mass for such an analysis, various size fractions were combined. The +425µm to +150µm were combined to produce size fraction range 1. The +106µm to +75µm were combined to produce size fraction range 2. The +53µm to +38µm were

combined to produce size fraction range 3. And lastly, the -38µm (pan) fraction made up size fraction range 4.

Figure 4.9 to 4.11 indicates the grade associated with particle size for PGM's, base metals and Cr_2O_3 respectively.

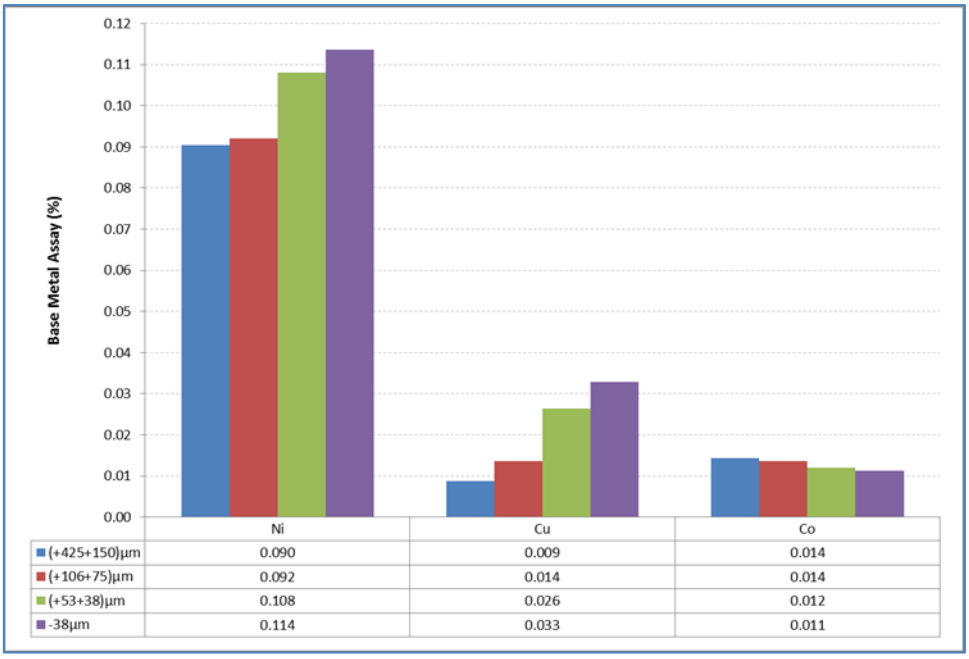


	Pt	Pd	Au	Rh	Ir	Ru	4T
(+425+150)µm	0.598	0.703	0.026	0.126	0.041	0.183	1.453
(+106+75)µm	1.093	1.163	0.076	0.243	0.078	0.319	2.576
(+53+38)µm	2.691	2.446	0.076	0.557	0.199	0.770	5.770
-38µm	4.082	3.409	0.104	0.770	0.304	1.170	8.365

*Assay data contained in Figure 4.9 has been factorized for confidentiality purposes.

Figure 4.9: Stage 1 - PGM Grade Association with Particle Size.

It is clear from Figure 4.9 that there is almost an exponential increase of the PGM grade with the decrease in particle size. This means that if sampling has a bias towards the finer fraction (below 75microns) which is much higher in PGM grade than the coarser fraction which has a lower PGM grade then the overall grade of the official sample will be much higher than that of the primary or reject samples.

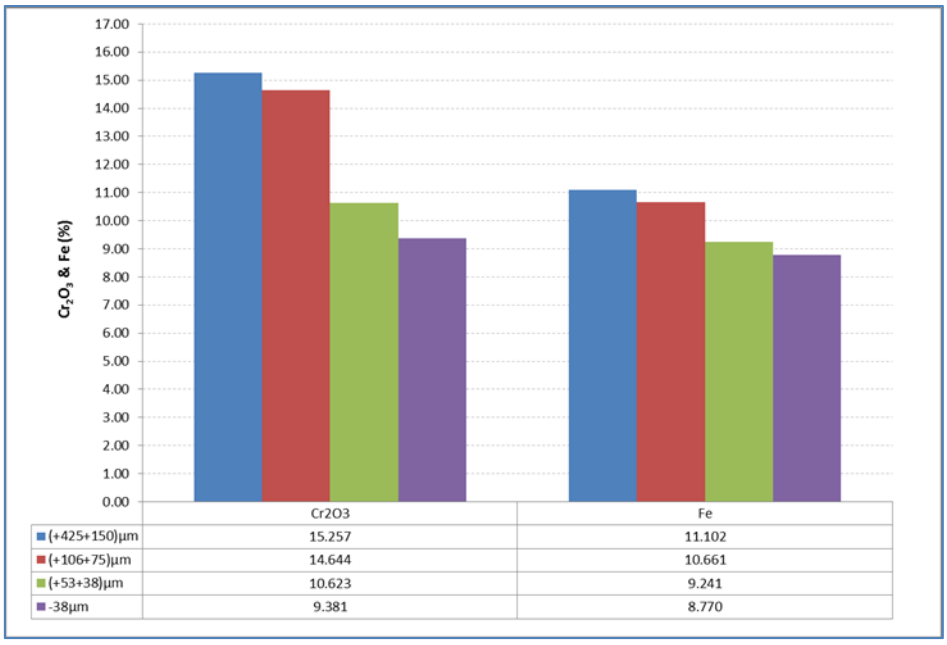


	Ni	Cu	Co
(+425+150)µm	0.090	0.009	0.014
(+106+75)µm	0.092	0.014	0.014
(+53+38)µm	0.108	0.026	0.012
-38µm	0.114	0.033	0.011

*Assay data contained in Figure 4.10 has been factorized for confidentiality purposes.

Figure 4.10: Stage 1 - Base Metal Grade Association with Particle Size.

A similar trend is seen with Nickel and Copper analysis however the grade variation is to a lesser degree in comparison to the PGM grade variation resulting in the base metal assay being less dependent on particle size as shown in Figure 4.10.



	Cr2O3	Fe
(+425+150)µm	15.257	11.102
(+106+75)µm	14.644	10.661
(+53+38)µm	10.623	9.241
-38µm	9.381	8.770

*Assay data contained in Figure 4.11 has been factorized for confidentiality purposes.

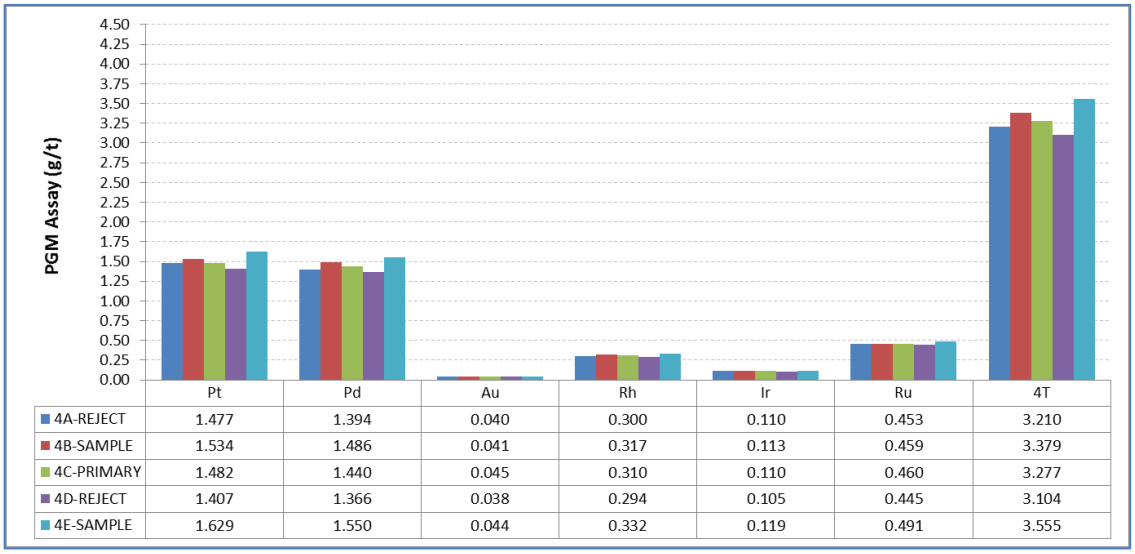
Figure 4.11: Stage 1 - Cr_2O_3 and Fe Grade Association with Particle Size.

It is interesting to note that the grade of Cr_2O_3 & Fe is lower in the finer fractions suggesting that Cr_2O_3 & Fe are better represented at a coarser size fraction. This effect, though to a lesser extent compared to the PGMs, is observed in Figure 4.11 where the official sample shows a marginally lower Cr_2O_3 & Fe content compared to the primary and reject samples. Should the coarse particles not have the similar probability of being sub-sampled (included in the official sample), it may bias the Cr_2O_3 towards lower concentrations and exacerbate the PGM grade even further leading to an under-accounting scenario utilizing BUH and SHG values.

The size by assay information was in line with historical mineralogy report data and typical UG2 feed size by assay analyses.

4.1.1.5 Analytical Results

It was not viable to assay all 25 samples and therefore only 5 samples were assayed for PGMs, base metals and Cr_2O_3, namely: reject sample 4A, official sample 4B, primary sample 4C, reject sample 4D and official sample 4E. Figures 4.12 to 4.14 below indicate the assay results obtained for these 5 samples.

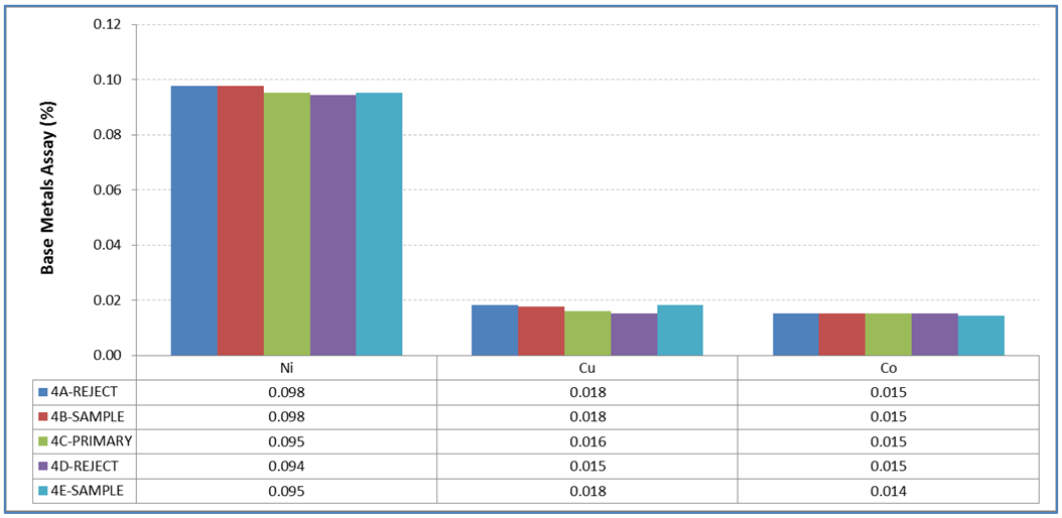


	Pt	Pd	Au	Rh	Ir	Ru	4T
4A-REJECT	1.477	1.394	0.040	0.300	0.110	0.453	3.210
4B-SAMPLE	1.534	1.486	0.041	0.317	0.113	0.459	3.379
4C-PRIMARY	1.482	1.440	0.045	0.310	0.110	0.460	3.277
4D-REJECT	1.407	1.366	0.038	0.294	0.105	0.445	3.104
4E-SAMPLE	1.629	1.550	0.044	0.332	0.119	0.491	3.555

*Assay data contained in Figure 4.12 has been factorized for confidentiality purposes.

Figure 4.12: Stage 1- PGM Assays for Run 4.

The official samples (4B and 4E) clearly have the highest 4T and other PGM grade values followed by the primary sample (4C) and reject samples (4A and 4D). This observation confirms that the official sample has finer and richer particles whereas the reject sample has more coarse leaner particles resulting in the official samples having a higher grade than the primary sample.

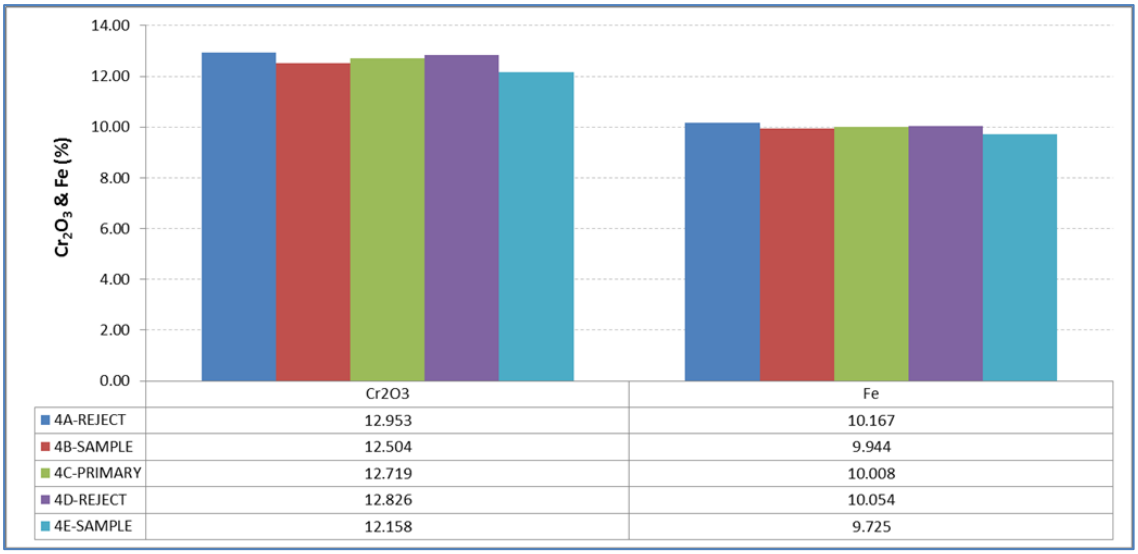


	Ni	Cu	Co
4A-REJECT	0.098	0.018	0.015
4B-SAMPLE	0.098	0.018	0.015
4C-PRIMARY	0.095	0.016	0.015
4D-REJECT	0.094	0.015	0.015
4E-SAMPLE	0.095	0.018	0.014

*Assay data contained in Figure 4.13 has been factorized for confidentiality purposes.

Figure 4.13: Stage 1 - Base Metal Assays for Run 4.

The assay results in Figure 4.13 show that the official, reject and primary samples base metal assays are comparable suggesting that the deportment of base metals does not change much across the particle sizes as does the deportment of PGMs, and historical mineralogy investigations have proved that.



	Cr2O3	Fe
4A-REJECT	12.953	10.167
4B-SAMPLE	12.504	9.944
4C-PRIMARY	12.719	10.008
4D-REJECT	12.826	10.054
4E-SAMPLE	12.158	9.725

*Assay data contained in Figure 4.14 has been factorized for confidentiality purposes.

Figure 4.14: Stage 1 - Cr_2O_3 and Fe Assays for Run 4.

The content of Cr_2O_3 and Fe in the official, reject and primary samples assays are also comparable suggesting that Cr_2O_3 and Fe are equitably distributed across the size ranges of the samples.

Twin stream analyses of each of the assayed samples was omitted however a precision check was done on official sample 4E and was found to be within the laboratory's limits.

The reject samples (4A and 4D) were consistently lower in PGM grade than the official samples (4B and 4E) and the opposite trend was observed for Cr_2O_3 content.

The % bias in terms of 4T grade in this instance was calculated to be between 7.92% and 11.97% relative to the primary sample grade and content (highly reliant on mass). The % bias in terms of 4T grade between pairs of sample 4B and 4A assays, and sample 4E and 4D assays was comparable to the indicative % bias mentioned above and was in the range of 5.00% and 12.69%.

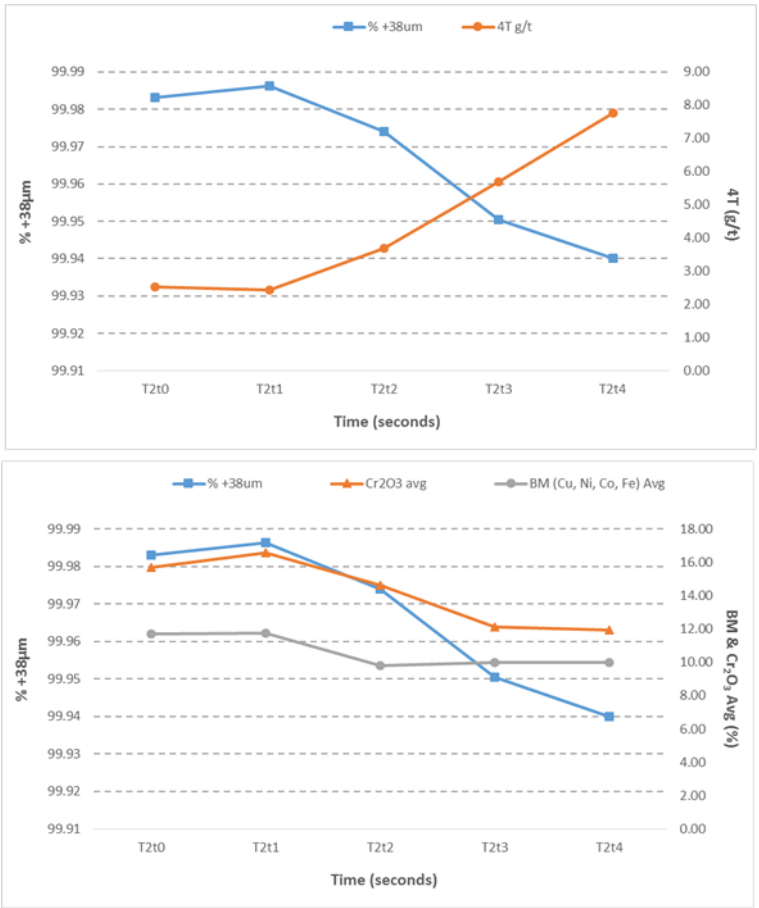
Similarly, the % bias in Cr_2O_3 composition was calculated to be between 2.29% and 3.35% relative to the primary sample. The % bias in terms of Cr_2O_3 composition between pairs of sample 4B and 4A assays, and sample 4E and 4D assays was

comparable to the indicative % bias mentioned above and was in the range of 3.59% and 5.50% with the reject samples having more Cr_2O_3 than the official samples.

4.1.2 Stage 1, Test 2 Sub-Sampling Test Work

The hypothesis that coarser particles exit the intermediate hopper during the initial stages of sub-sampling was tested by obtaining chronological sub-samples over time.

Figure 4.15 below indicates the 4T grade variation and BM & Cr_2O_3 composition variation as a function of +38µm fraction variation over time.



*Assay data contained in Figure 4.15 has been factorized for confidentiality purposes.

Figure 4.15: Stage 1 - Variation of Grade/Composition and % +38µm Retained Over Time.

The chronological sub-samples of the official sample indicated that for the initial 12 seconds of secondary sampling (T2t0 to T2t1) the 4T grade remains fairly constant.

The 4T grade thereafter increases as the % +38µm fraction decreases. This proves the point that coarser particles exit the intermediate hopper faster than finer particles. The BM composition remains fairly constant as time progresses with the Cr_2O_3 composition following the %+38µm trend. The % Relative Standard Deviation (RSD) for the +38µm was calculated to be 0.021%. The change in this % RSD value will either indicate improvement or no improvement in terms of the amount of +38µm material present at each time interval. From Figure 4.15, the BM's trend are relatively flat and are not influenced by the segregation hypothesis. The Cr_2O_3 grade decreases as time elapses indicating that the sample is effectively depleted in the coarser Cr_2O_3 fraction.

Table 4.1 indicates the number of secondary cuts per sub-sample obtained during Stage 1, Test 2.

Table 4.1: Stage 1 - Number of Secondary Cuts per Sub-Sample.

Test Run	Sample Identification	Sample Description	Number of Secondary Cuts
1	T2t0	0 - 6 seconds sub-sample	84
	T2t1	6 - 12 seconds sub-sample	84
	T2t2	12 - 18 seconds sub-sample	84
	T2t3	18 - 24 seconds sub-sample	84
	T2t4	24 - 33 seconds sub-sample	126

It is clear that the rule of thumb according to literature is obeyed (a minimum of 30 cuts per sampling campaign is achieved). One could still argue though that the differences in grade and % +38µm is attributed to distributional heterogeneity. A decrease in PSD and 4T grade bias is an indirect measure of reduction in particle segregation in the intermediate hopper. The mechanism of particle segregation mostly observed in the intermediate hopper is impact fluidization segregation. Clearly et al. (2009) investigated particle segregation of particles greater than 500µm and concluded that vezin sampler performance is insensitive to material properties. This is not the case for this study where the particles are below 500µm. This statement has bearing on the method adapted in evaluating particle segregation in

this study as well as in the interpretation of the study's findings. Particle size or particle diameter plays an important role in the settling velocity of individual particles and this is clearly demonstrated by the chronological sub-sampling test. Clearly et al. (2011) also noted that testing a sampling system for bias with respect to particle size is generally a more powerful method that testing for bias with respect to a chemical constituent, especially when the chosen analyte is present in small concentration. Hence a decrease in PSD bias was used primarily for improvement measurement.

4.2 Stage 2: Optimization of Existing Sampling Equipment

Stage 2 test work was conducted using the same sampling equipment arrangement with a different nozzle design which is described in Section 3 and Appendix A.

The main objective of the following test work was to determine if the particle segregation evident in Stage 1 test work can be overcome by optimization of the existing sampling equipment with an alternate nozzle design.

4.2.1 Stage 2, Test 1 Vezin Credibility Test Work

4.2.1.1 Comparison of % Solids between Different Samples

Figure 4.16 overleaf indicates the % solids for the reject, official and primary slurry samples.

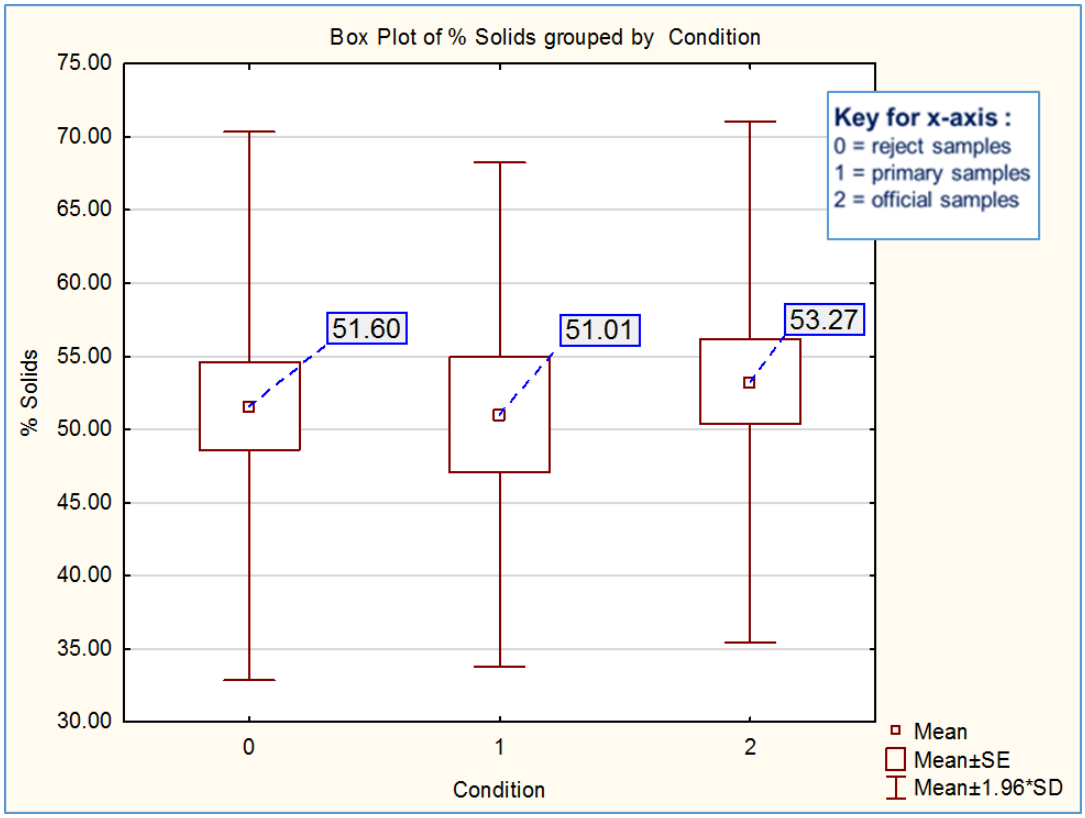


Figure 4.16: Stage 2 - % Solids for Reject, Official and Primary Slurry Samples.

The % solids for the reject, primary and official samples are much closer together compared to the results obtained with the old nozzle. The official samples in this test however recorded the highest % solids compared to the reject and primary sample. The variances in the % solids for the all three sample types were found to be similar.

4.2.1.2 Particle Size Analyses: Cumulative % Passing

Figures 4.17 indicates the particle size distributions for all 25 samples that were originally generated.

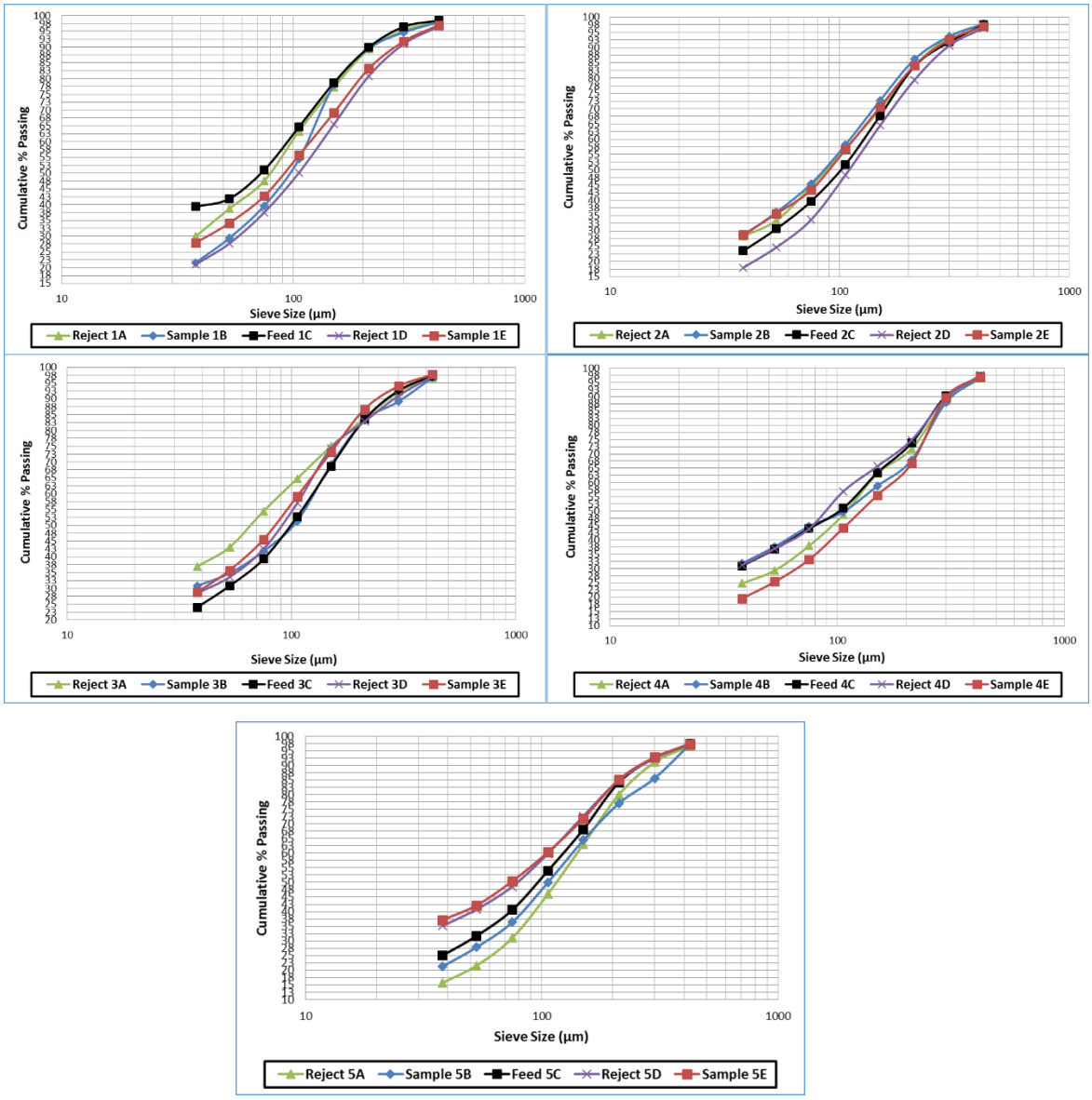


Figure 4.17: Stage 2 - Particle Size Distribution for Run 1 to 5.

There is generally a close agreement between reject, official and primary samples on the cumulative % passing 425µm. For each pair of sub-samples generated (reject sample and official sample), a minimum of 30 secondary cuts per sampling campaign was achieved.

With respect to Figures 4.17, a consistent trend is not seen as with Stage 1, Test 1.

Figure 4.18 indicates the comparison of the cumulative % passing the particular sieve sizes for the official and reject samples for all five runs as well as the average cumulative % passing for the combination of all five runs.

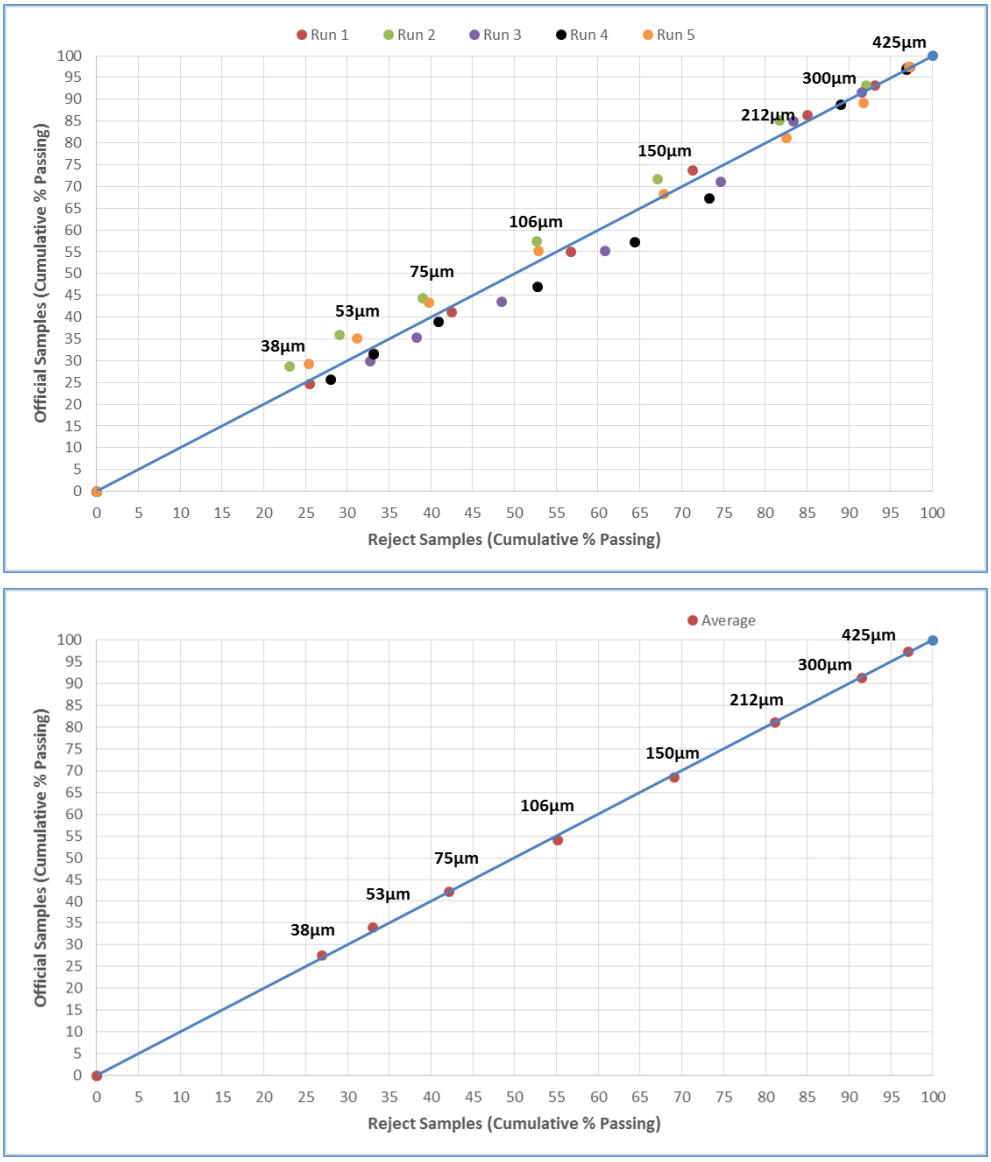


Figure 4.18: Stage 2 - Cumulative % Passing Comparison (Official and Reject Samples).

It is clear from Figure 4.18 that the reject and official samples are not identical at each respective size fraction as the data is generally scattered around the 45° line. The averaged cumulative % passing comparison graph shows no net segregation. This indicates that over an entire sampling campaign, the random bias observed for individual increments would mostly likely average out and not result in a consistent bias in terms of particle size and hence overall grade of the reject and official samples.

The observation from Figure 4.18 is further supported by Figure 4.19 where the official, reject and primary sample PSD's with errors bars and the combined particle size distribution per sample type (primary, reject and official) for all five runs have been plotted.

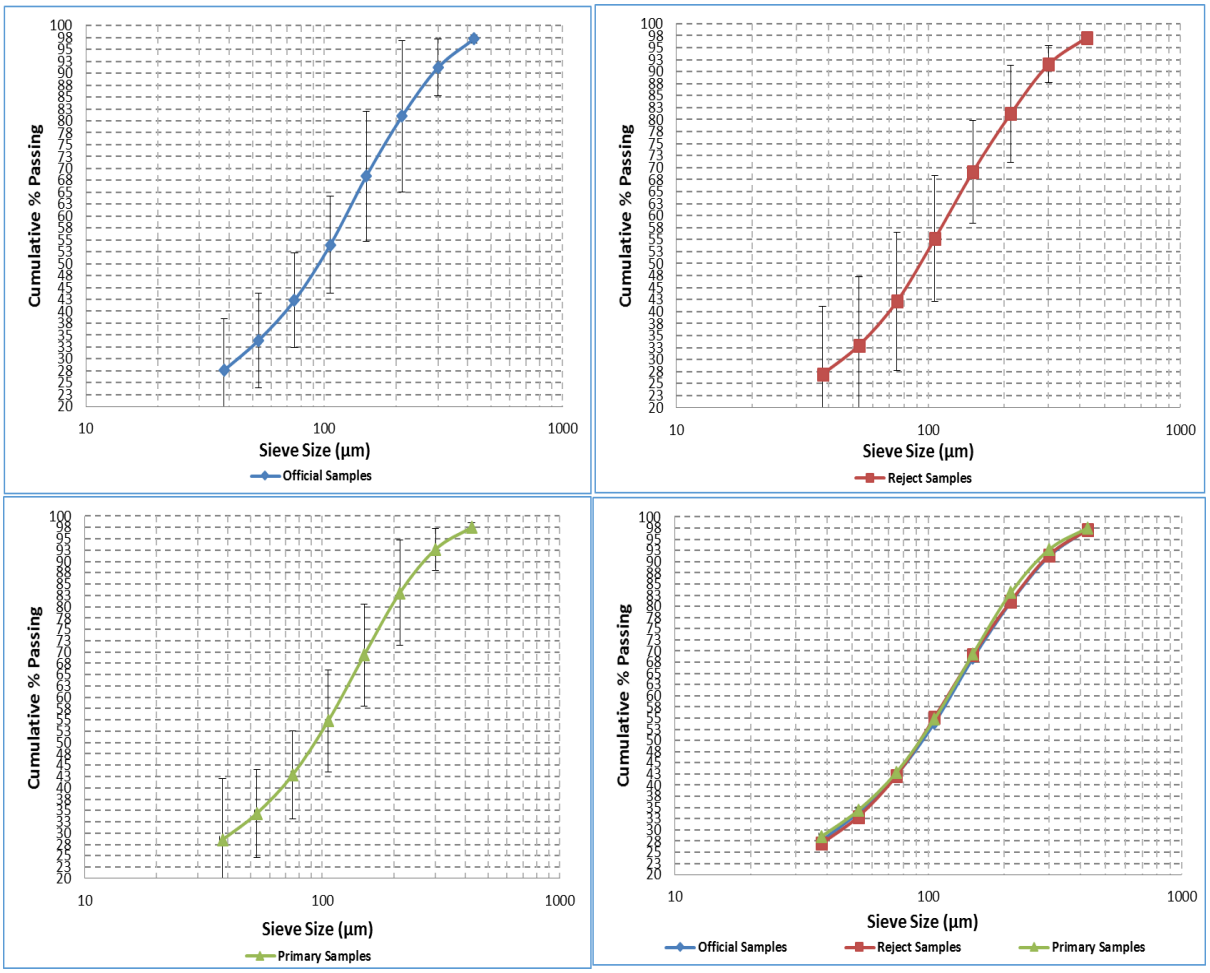


Figure 4.19: Stage 2 - Cumulative % Passing Comparison.

The standard deviation at 95% confidence levels for cumulative % passing the various screen sizes are shown in Figures 4.19 for the official, reject and primary samples respectively. The primary, reject and official sample combined PSD's are comparable (lines lie on top of each other).

The % bias between the reject and official samples were calculated per size fraction and is plotted in Figure 4.20 which also compares the new bias values with those obtained from the baseline test work.

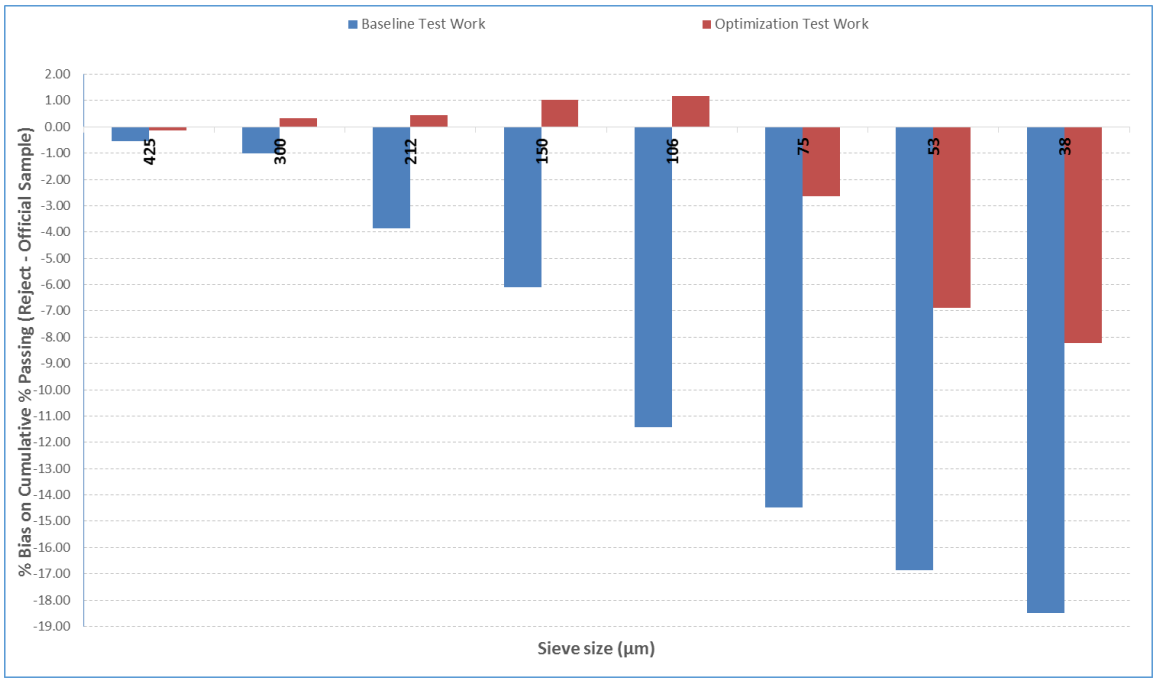


Figure 4.20: % Bias between Reject and Official Samples passing each Sieve Size.

From Figure 4.20 above, a consistent bias is not seen in any particular direction as compared with Stage 1, Test 1 previously.

4.2.1.3 % Mass Retained on Respective Screens

Figures 4.21 to 4.22 indicate the % mass retained on each screen for the reject, primary and official samples respectively.

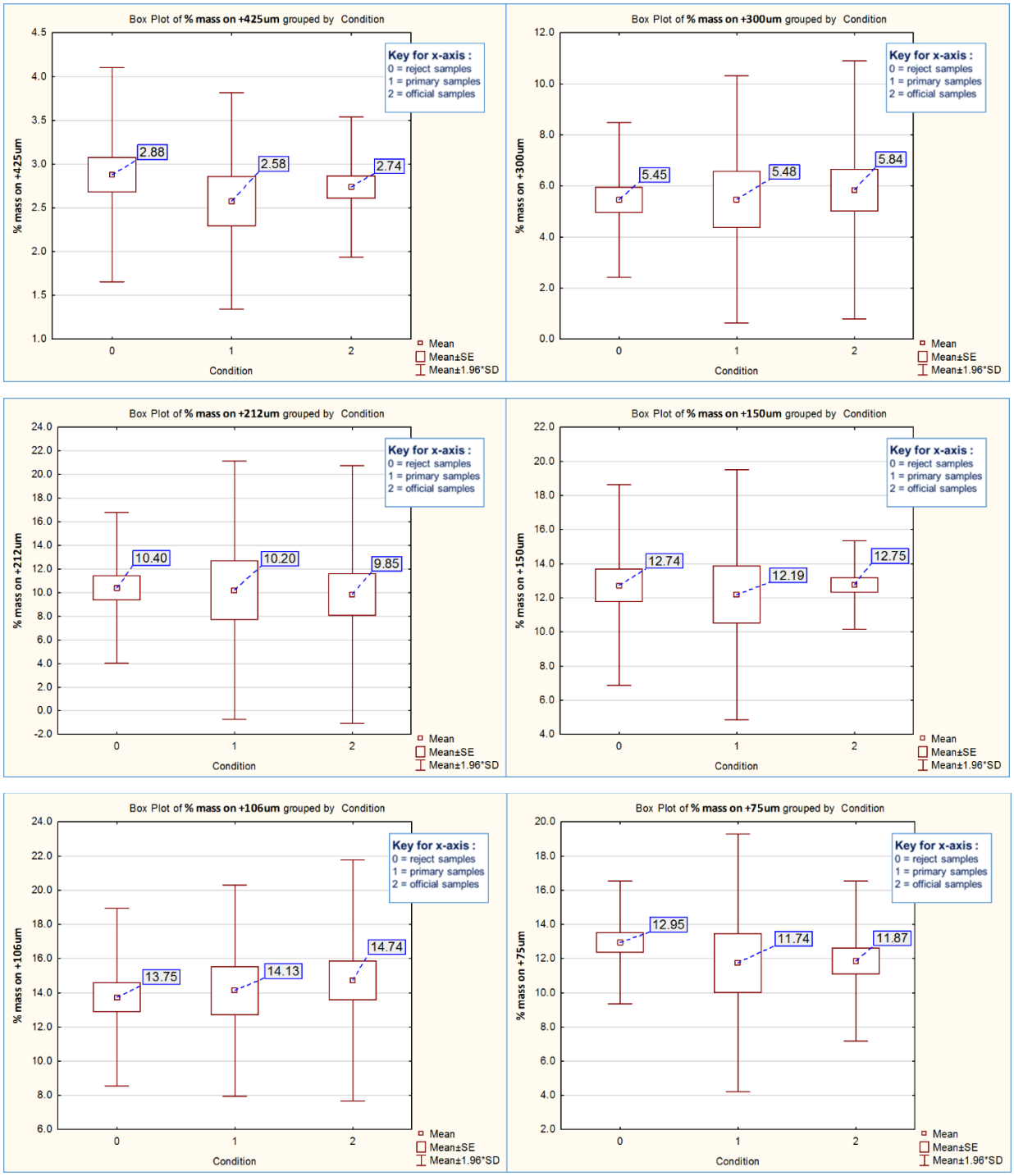


Figure 4.21: Stage 2 - % Mass Retained on Various Sieve Sizes 1 of 2.

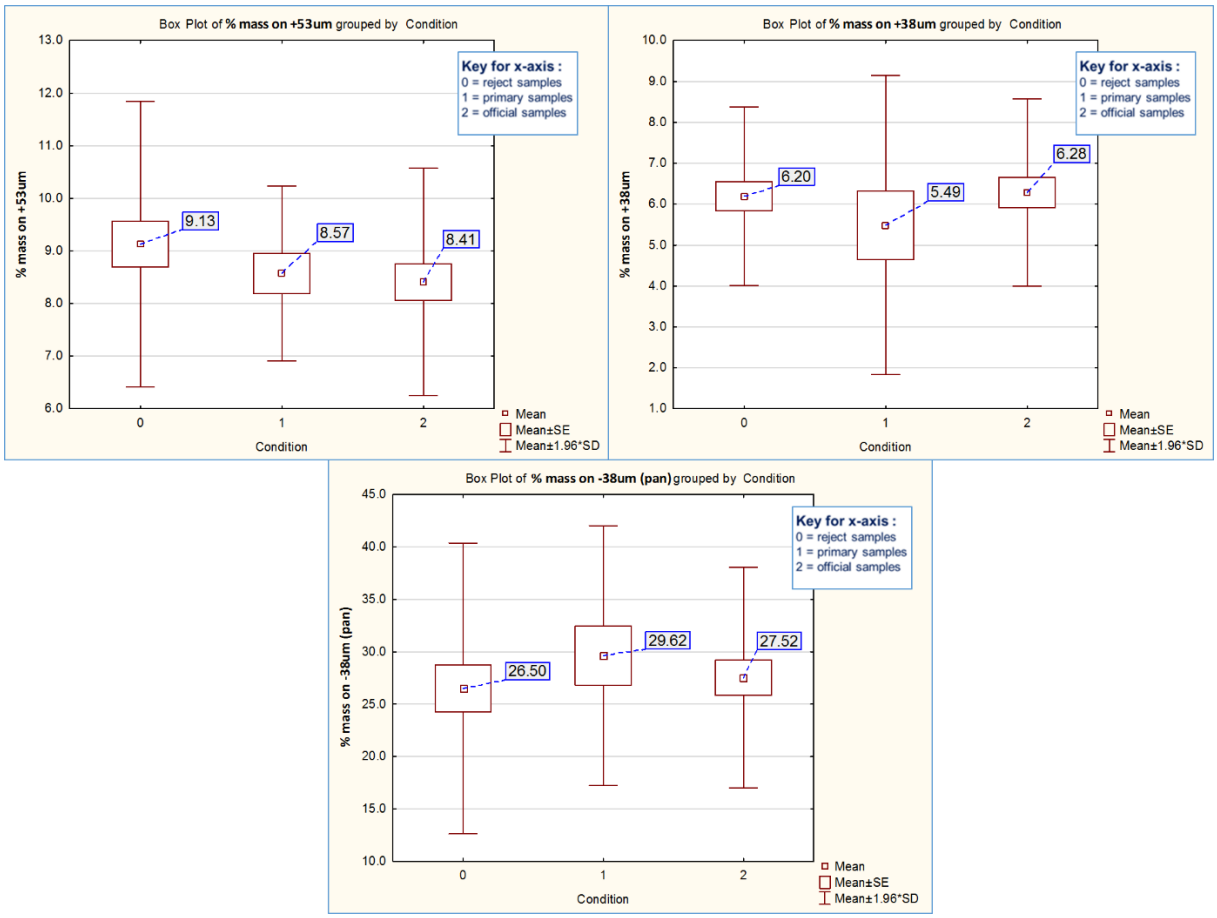
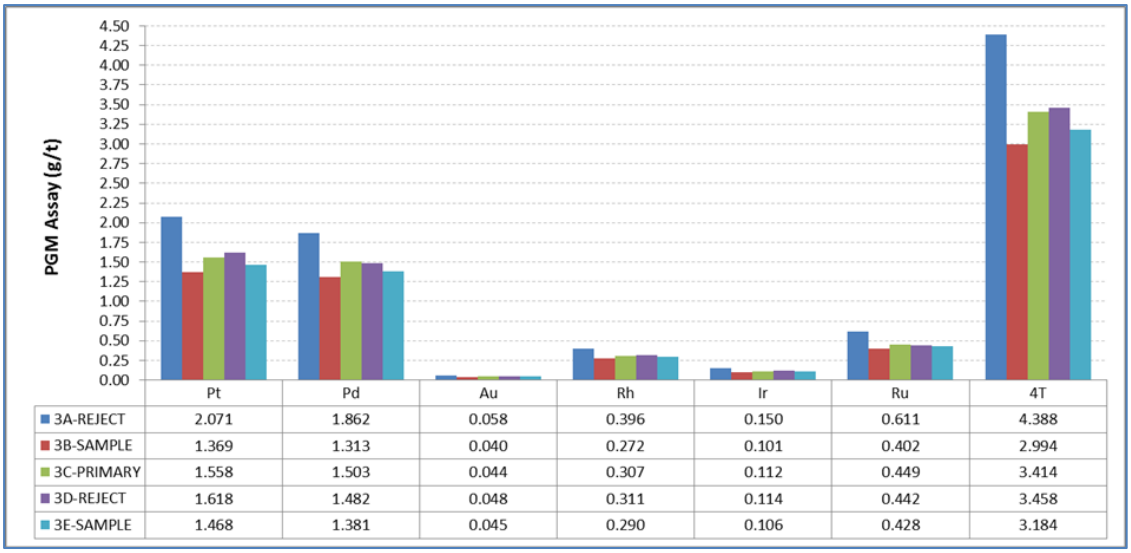


Figure 4.22: Stage 2 - % Mass Retained on Various Sieve Sizes 2 of 2.

The % mass retained on each of the respective screens are very similar for the reject, primary and official samples demonstrating that the nozzle 2 design possibly minimizes segregation and almost eliminates the bias which was so evident with nozzle 1 design.

4.2.1.4 Analytical Results

5 samples were assayed for PGMs, base metals and Cr_2O_3, namely: reject sample 3A, official sample 3B, primary sample 3C, reject sample 3D and official sample 3E. Figures 4.23 to 4.25 indicate the assay results obtained for these 5 samples. Twin stream analyses was performed for all samples and the % RSD between the two legs were within the accepted laboratory limits for all elements.



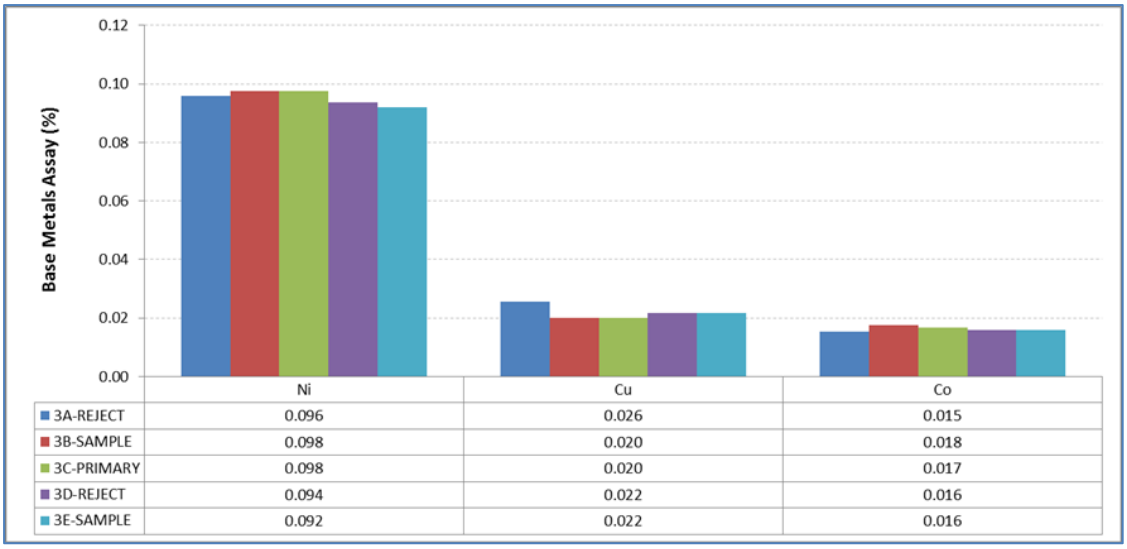
	Pt	Pd	Au	Rh	Ir	Ru	4T
3A-REJECT	2.071	1.862	0.058	0.396	0.150	0.611	4.388
3B-SAMPLE	1.369	1.313	0.040	0.272	0.101	0.402	2.994
3C-PRIMARY	1.558	1.503	0.044	0.307	0.112	0.449	3.414
3D-REJECT	1.618	1.482	0.048	0.311	0.114	0.442	3.458
3E-SAMPLE	1.468	1.381	0.045	0.290	0.106	0.428	3.184

*Assay data contained in Figure 4.23 has been factorized for confidentiality purposes.

Figure 4.23: Stage 2 - PGM Assays for Run 3.

Figure 4.23 shows the reject samples (3A and 3D) having the highest 4T values followed by the primary sample (3C). The official samples (3B and 3E) have the lowest 4T values. This trend is opposite to the trend observed in Stage 1, Test 1. The new nozzle does not seem to have eliminated the bias between pair of reject and official samples with respect to the PGM assay as expected from the unbiased PSD and unbiased mass distribution across the samples. This may be due to the fact that only Run 3 samples were assayed and from Figure 4.18, if any of the other samples from Run 1-2 or 4-5 were to have been assayed, it is highly probable that the grade trend would have been different too. Ultimately, over time and as more increments are taken, the random variation would be such that the grade would possibly be unbiased.

As per paper written by Clearly & Robinson (2009 & 2011), DEM suggests that vezin-vezin samplers perform well giving a very good extraction ratio and negligible sample bias. Given that the bias in PSD is basically eliminated, it can be implied that particle segregation in the intermediate hopper is essentially reduced through optimization of the hopper discharge nozzle design.

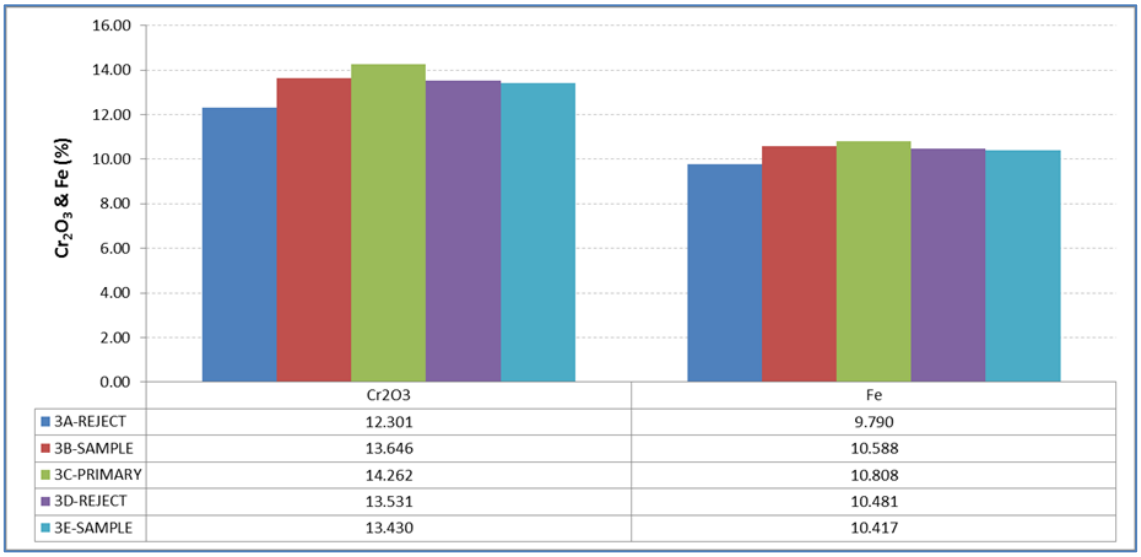


	Ni	Cu	Co
3A-REJECT	0.096	0.026	0.015
3B-SAMPLE	0.098	0.020	0.018
3C-PRIMARY	0.098	0.020	0.017
3D-REJECT	0.094	0.022	0.016
3E-SAMPLE	0.092	0.022	0.016

*Assay data contained in Figure 4.24 has been factorized for confidentiality purposes.

Figure 4.24: Stage 2 - Base Metals Assays for Run 3.

The official, reject and primary samples base metal assays are comparable and this is expected (in line with historical mineralogy investigations/data).



	Cr2O3	Fe
3A-REJECT	12.301	9.790
3B-SAMPLE	13.646	10.588
3C-PRIMARY	14.262	10.808
3D-REJECT	13.531	10.481
3E-SAMPLE	13.430	10.417

*Assay data contained in Figure 4.25 has been factorized for confidentiality purposes.

Figure 4.25: Stage 2 - Cr_2O_3 and Fe Assays for Run 3.

The official, reject and primary samples Cr_2O_3 and Fe assays are also comparable in this case.

The reject samples (3A and 3D) were consistently higher in PGM grade than the official samples (3B and 3E). This statement is opposite to the trend observed for Stage 1, Test 1. Given that the number of observations are again only 2, one cannot confidently confirm the % bias in terms of grade. It is also possible that particle characteristics such as particle density is responsible for the 4T grade bias observed and such characteristics should not be overlooked.

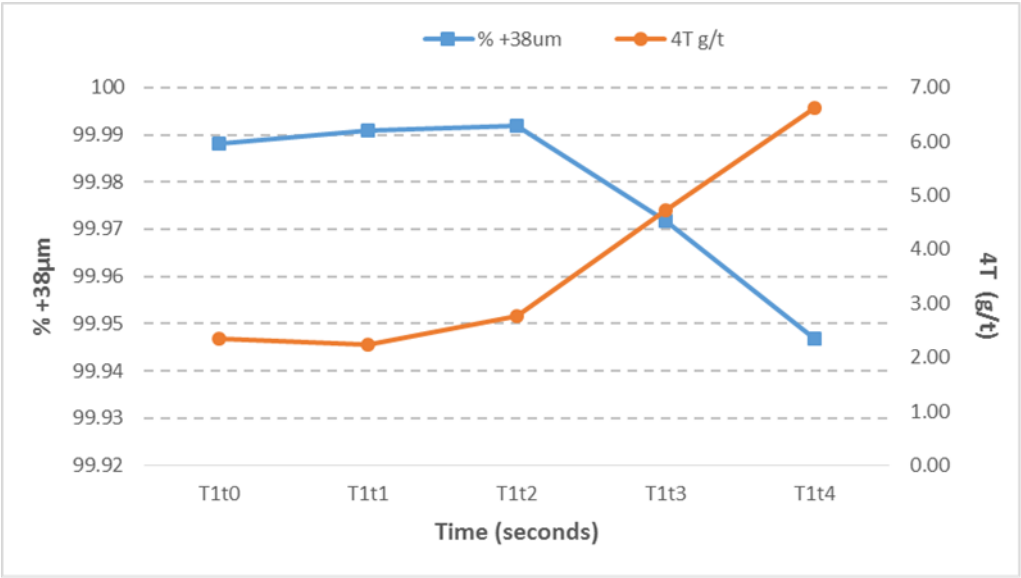
The % bias in terms of 4T grade was however calculated to be between 1.95% and -26.63% relative to the primary sample grade and content (highly dependent on mass). The % bias in terms of 4T grade between pairs of sample 3B and 3A assays, and sample 3E and 3D assays was unmatched to the indicative % bias mentioned above and was in the range of 8.62% and 46.6% respectively.

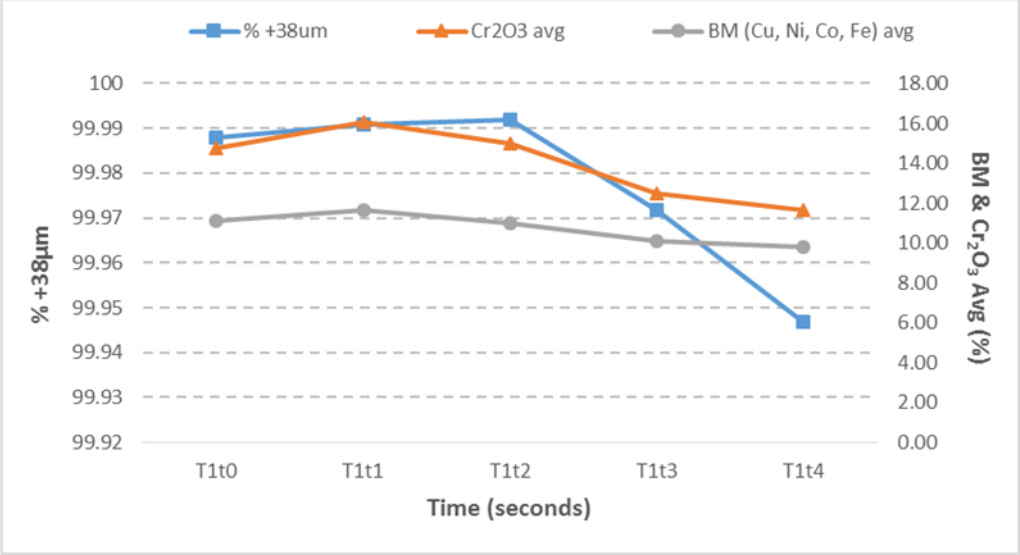
Similarly, the % bias in Cr_2O_3 composition was calculated to be between -0.51% and 5.44% relative to the primary sample. The % bias in terms of Cr_2O_3 composition between pairs of sample 3B and 3A assays, and sample 3E and 3D assays was comparable to the indicative % bias mentioned above and was in the range of -0.76% and 9.86% with the reject samples having less Cr_2O_3 present than the official samples (3B compared to 3A).

A size by assay analysis was not repeated and the results from Stage 1 test work was used as a basis.

4.2.2 Stage 2, Test 2 Sub-Sampling Test Work

Figure 4.26 indicates the 4T grade variation and BM & Cr_2O_3 composition variation as a function of +38µm fraction variation over time.





*Assay data contained in Figure 4.26 has been factorized for confidentiality purposes.

Figure 4.26: Stage 2 - Variation of Grade/Composition and %+38µm Retained Over Time.

The chronological sub-samples of the official sample indicated that for the initial 18 seconds of secondary sampling (T1t0 to T1t2) the 4T grade remains fairly constant. The 4T grade thereafter increases as the %+38µm fraction decreases to a lesser degree though. In the case of nozzle 2, the mixing appears to reduce the segregation causing the coarser particles to exit the intermediate hopper at a constant rate for a longer period of time i.e. 18 seconds, compared to what was observed with the tests done with nozzle 1 i.e. < 12 seconds. The BM composition remains fairly constant as time progresses with the Cr_2O_3 composition following the %+38µm trend.

Figure 4.27 shows a comparison of the % +38µm fraction for the old hopper old nozzle and old hopper new nozzle configuration.

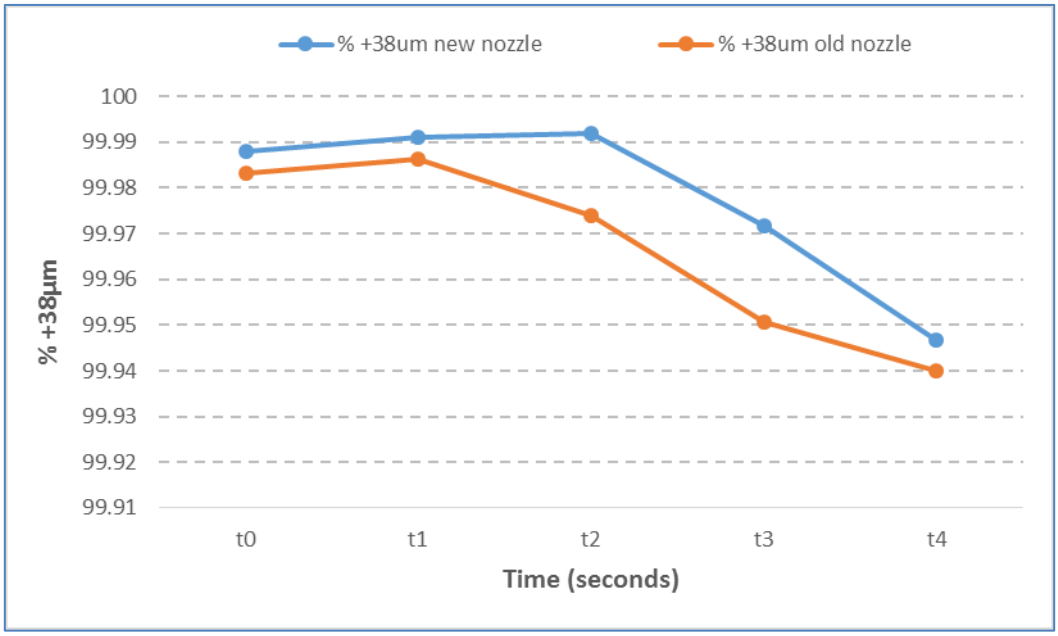


Figure 4.27: Variation of % +38µm Retained over Time for Stage 1 & Stage 2 Test 2.

RSD for the +38µm was calculated to be 0.019%. This is a slight improvement from Stage 1 Test 2 with the old nozzle design in place. The analytical variance for the samples in question were within the laboratory limits (available on special request from Author).

Table 4.2 below indicates the number of secondary cuts per sub-sample obtained during Stage 2, Test 2.

Table 4.2: Stage 2 - Number of Secondary Cuts per Sub-Sample.

Test Run	Sample Identification	Sample Description	Number of Secondary Cuts
1	T1t0	0 - 6 seconds sub-sample	84
	T1t1	6 - 12 seconds sub-sample	84
	T1t2	12 - 18 seconds sub-sample	84
	T1t3	18 - 24 seconds sub-sample	84
	T1t4	24 - 33 seconds sub-sample	126

It is clear that the rule of thumb according to literature is obeyed (a minimum of 30 cuts per sampling campaign is achieved).

4.3 Stage 3A: Re-designed Mechanical Hopper with Old Nozzle Design

Stage 3 test work was conducted using a re-designed mechanical hopper which is described in Appendix A. Stage 3A test work included the new mechanical hopper fitted with the old nozzle design. The main objective of the following test work was to determine if the particle segregation still evident in Stage 2 test work can be overcome introduction of an alternate hopper design and sampling protocol with the old nozzle design in place.

4.3.1 Stage 3A, Test 1 Vezin Credibility Test Work

4.3.1.1 Comparison of % Solids between Different Samples

Figure 4.28 indicates the % solids for the reject, official and primary slurry samples.

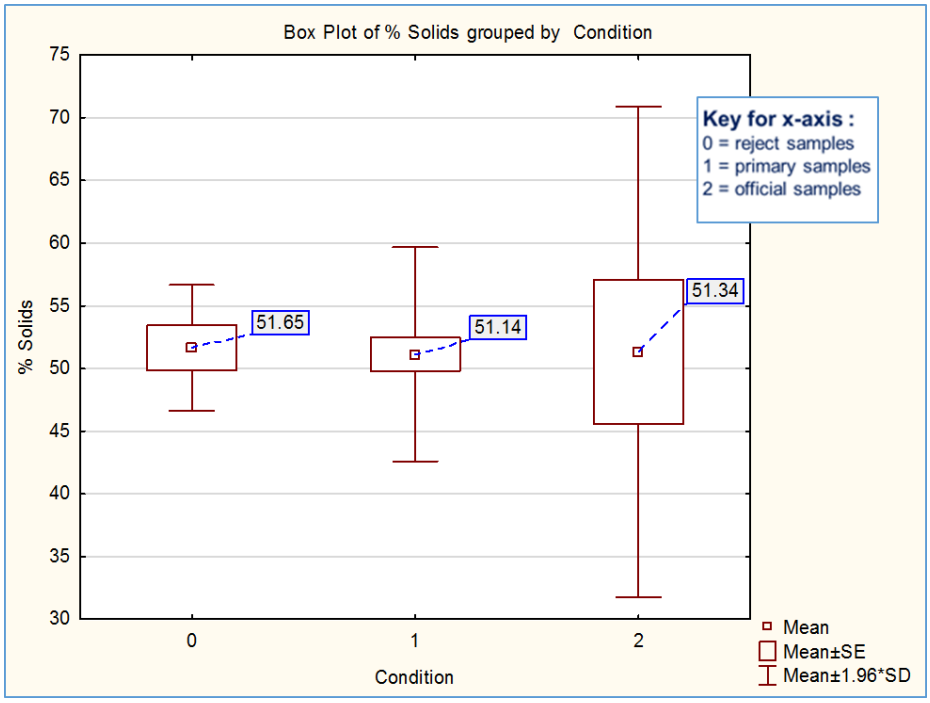


Figure 4.28: Stage 3A - % Solids for Reject, Official and Primary Slurry Samples.

The average % solids for the reject, official and primary slurry samples are comparable but the variation in the % solids per sample type are quite different.

4.3.1.2 Particle Size Analyses: Cumulative % Passing

Figure 4.29 indicates the particle size distribution for all the samples that were originally generated from the three runs namely, run 7, 9 and 11 respectively.

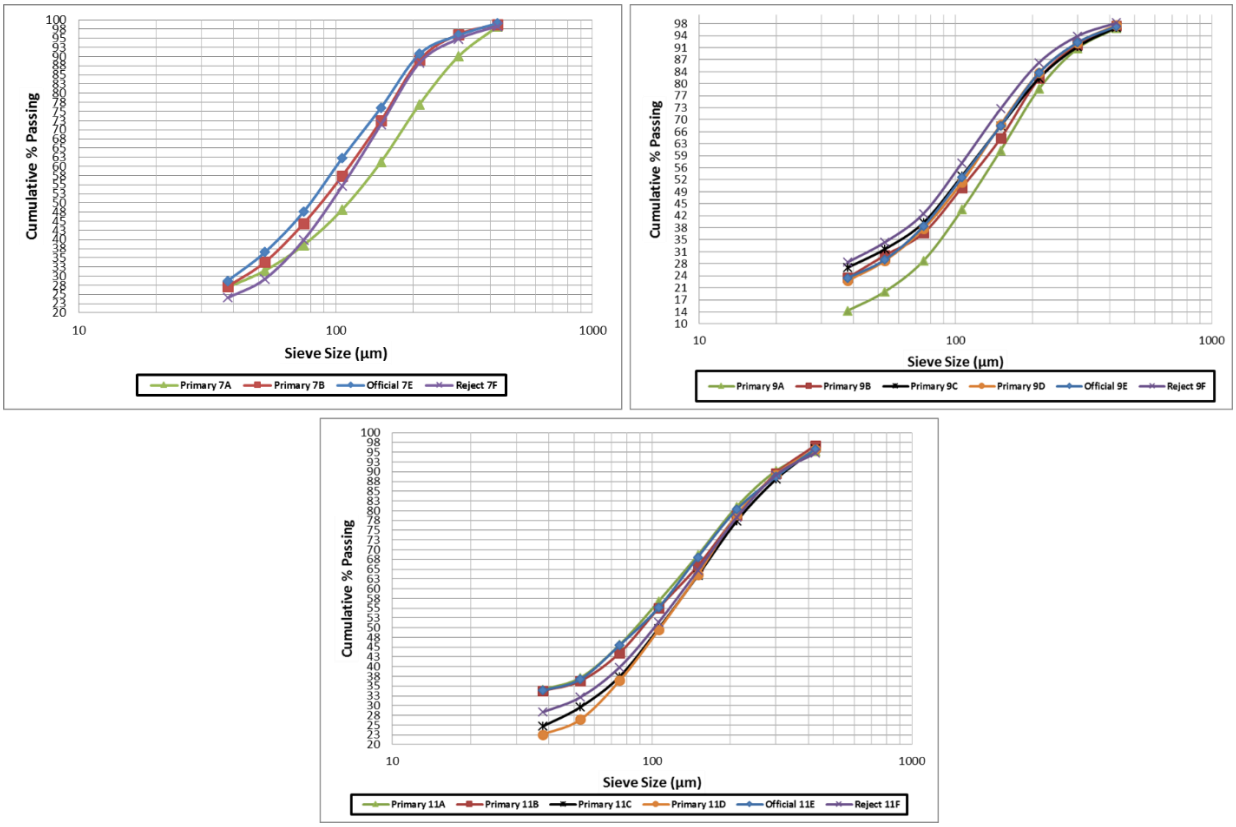


Figure 4.29: Stage 3A - Particle Size Distribution for Run 7, 9 and 11.

From Figure 4.29, it is clear that when comparing the primary samples to one another and across the three runs, the primary increment stream characteristics varies over even a short period of time. This may be as a result of process stability or random variation. For two of the three runs, the official sample PSD's are finer than the reject sample PSD's. A consistent trend is not seen as with Stage 1, Test 1.

Figure 4.30 indicates the comparison of the cumulative % passing the particular sieve sizes for the official and reject samples for all three runs as well as the average cumulative % passing for the combination of the three runs.

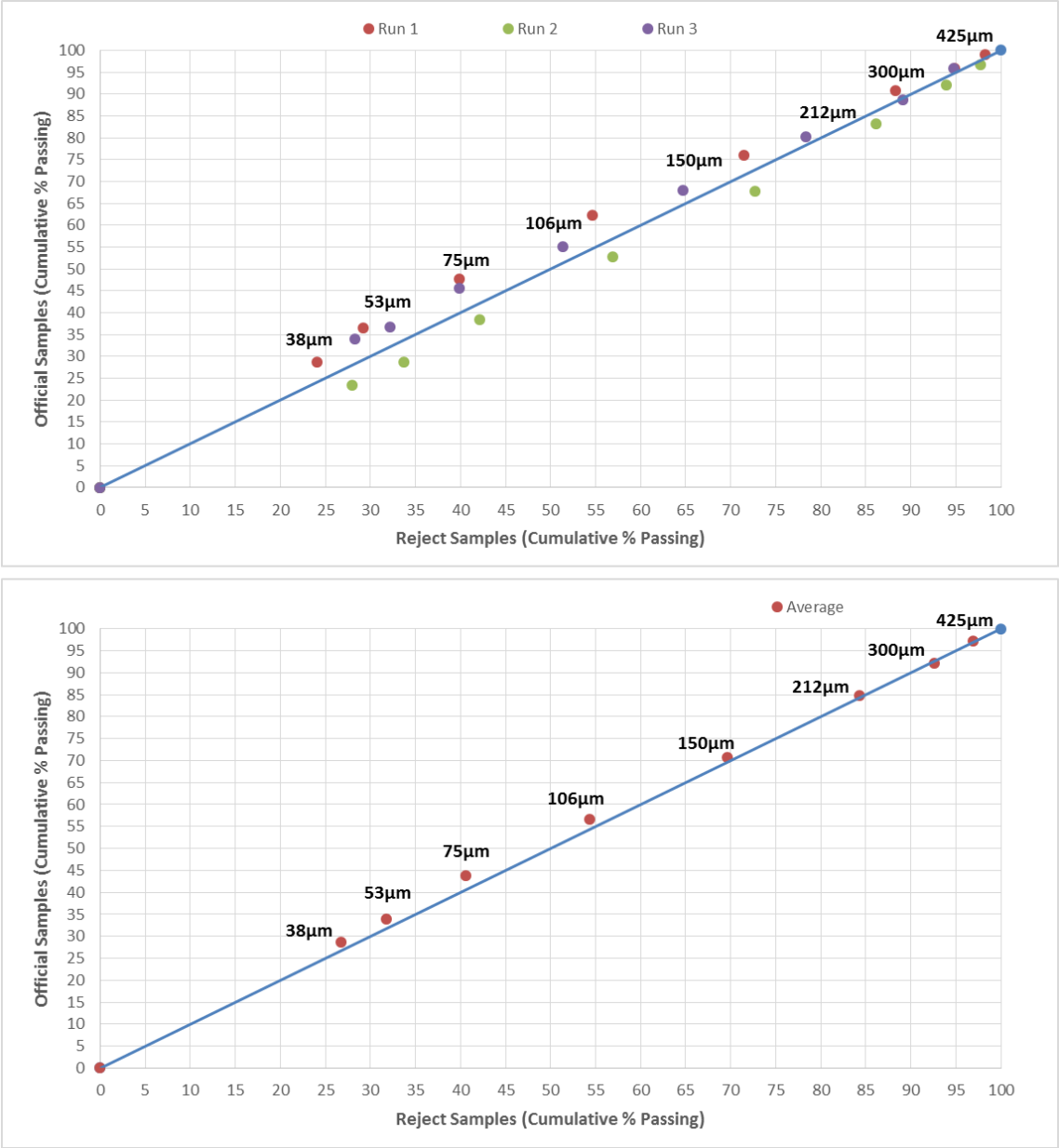


Figure 4.30: Stage 3A - Cumulative % Passing Comparison (Official and Reject Samples).

From Figure 4.30, it is clear that the reject and official samples are not identical at each of the respective size fractions. Two of the three test runs, runs 1 and 3, conducted however indicate a consistent bias with the official samples being finer than the reject samples. The combined graph indicates a very subtle bias with the

official samples being bias low towards the coarse fraction (i.e. finer). The significance of this bias would need to be further investigated with more test runs being done to obtain enough data points to perform sound statistical analysis.

The observation from Figure 4.30 is supported by Figure 4.31 where the official, reject and primary sample PSD's are plotted.

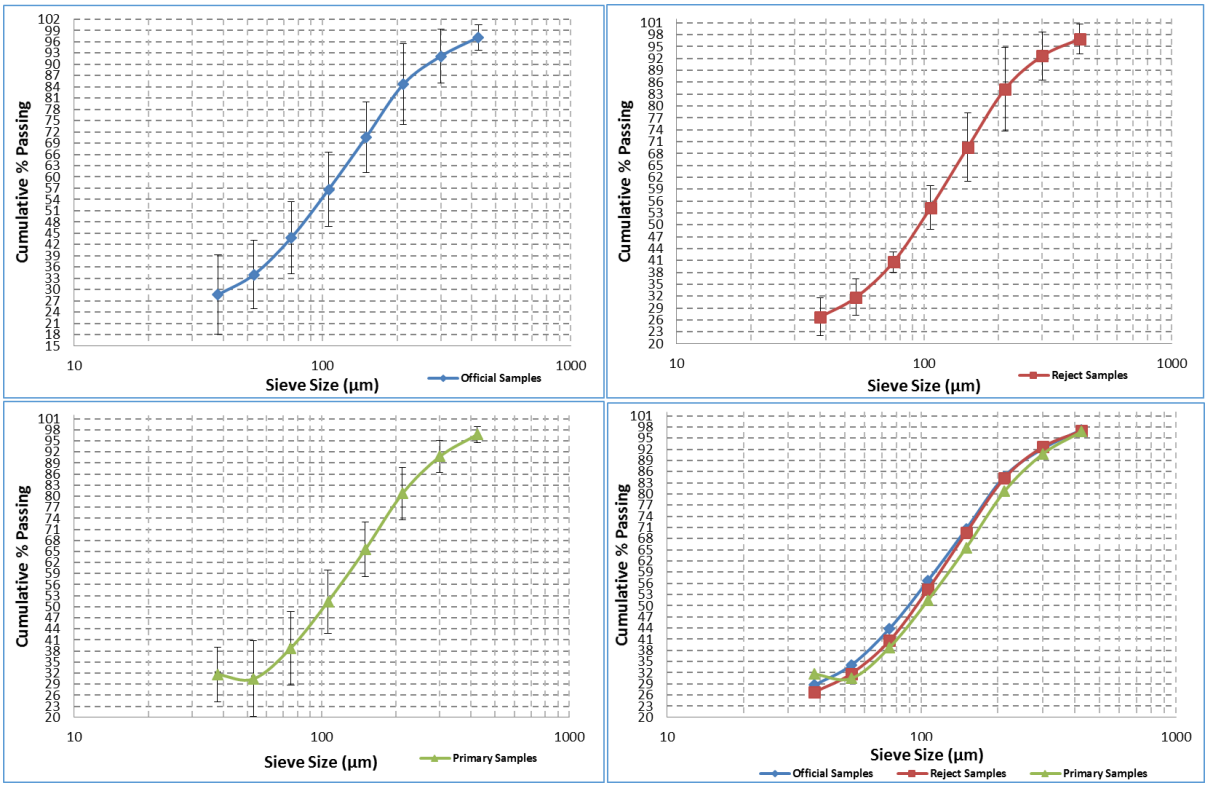


Figure 4.31: Stage 3A - Cumulative % Passing Comparison.

The reject and official samples are identical at sieve sizes 425µm, 300µm, 212µm and 150µm. The PSD's at <150µm deviate with the official sample PSD being finer than the reject sample PSD. The standard deviation at the 95% confidence levels for the cumulative % passing the various sieve sizes are also shown in Figure 4.31 by means of error bars.

The % bias between the reject and official samples for baseline test work, optimization test work and new hopper, old nozzle arrangement is shown in Figure 4.32.

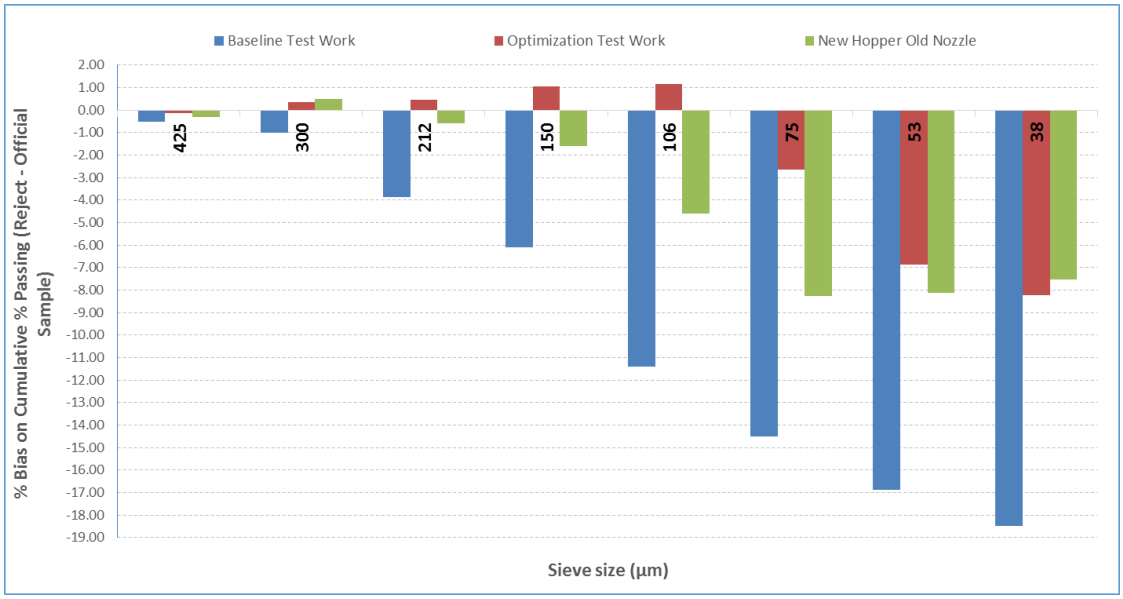


Figure 4.32: % Bias between Reject and Official Samples passing each Sieve Size.

From Figure 4.32, a consistent bias is observed particularly with the sub 150µm sieve sizes with the official samples being finer than the reject samples. The consistent bias is not as pronounced as with the baseline test work but follows a similar trend. The similarity between the baseline test work (Stage 1) and mechanical hopper test work (specifically Stage 3A) is that the nozzle of the old design was used for test work purposes. In Stage 3, the nozzle diameter was altered from 10mm to 20mm and a mechanical agitation introduced. It appears that the increase in nozzle diameter and mechanical agitation had a positive impact in terms of minimizing bias within the sampling system.

4.3.1.3 % Mass Retained on Respective Screens

Figures 4.33 to 4.34 indicate the % mass retained on each screen for the reject, primary and official samples respectively.

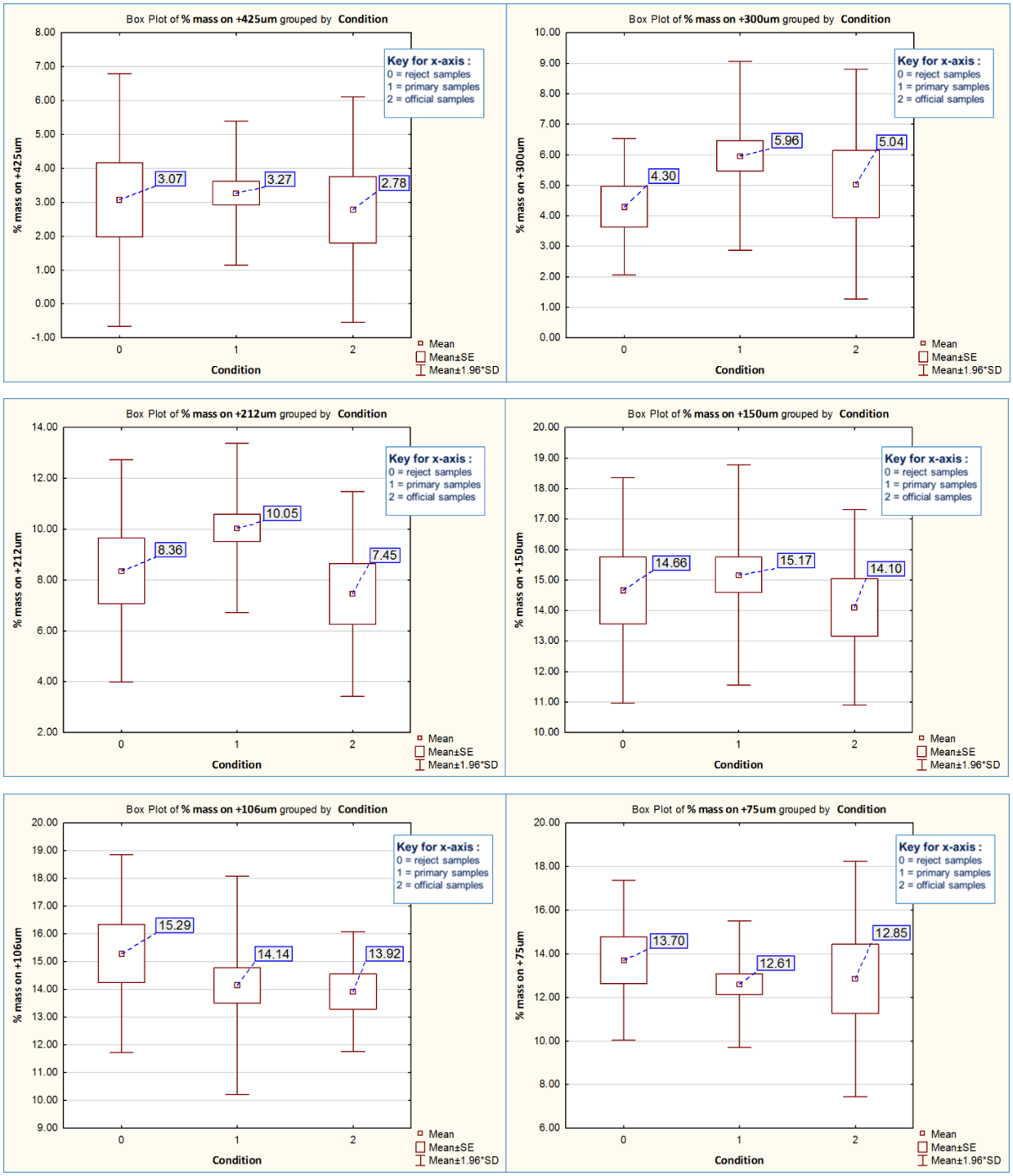


Figure 4.33: Stage 3A - % Mass Retained on Various Sieve Sizes 1 of 2.

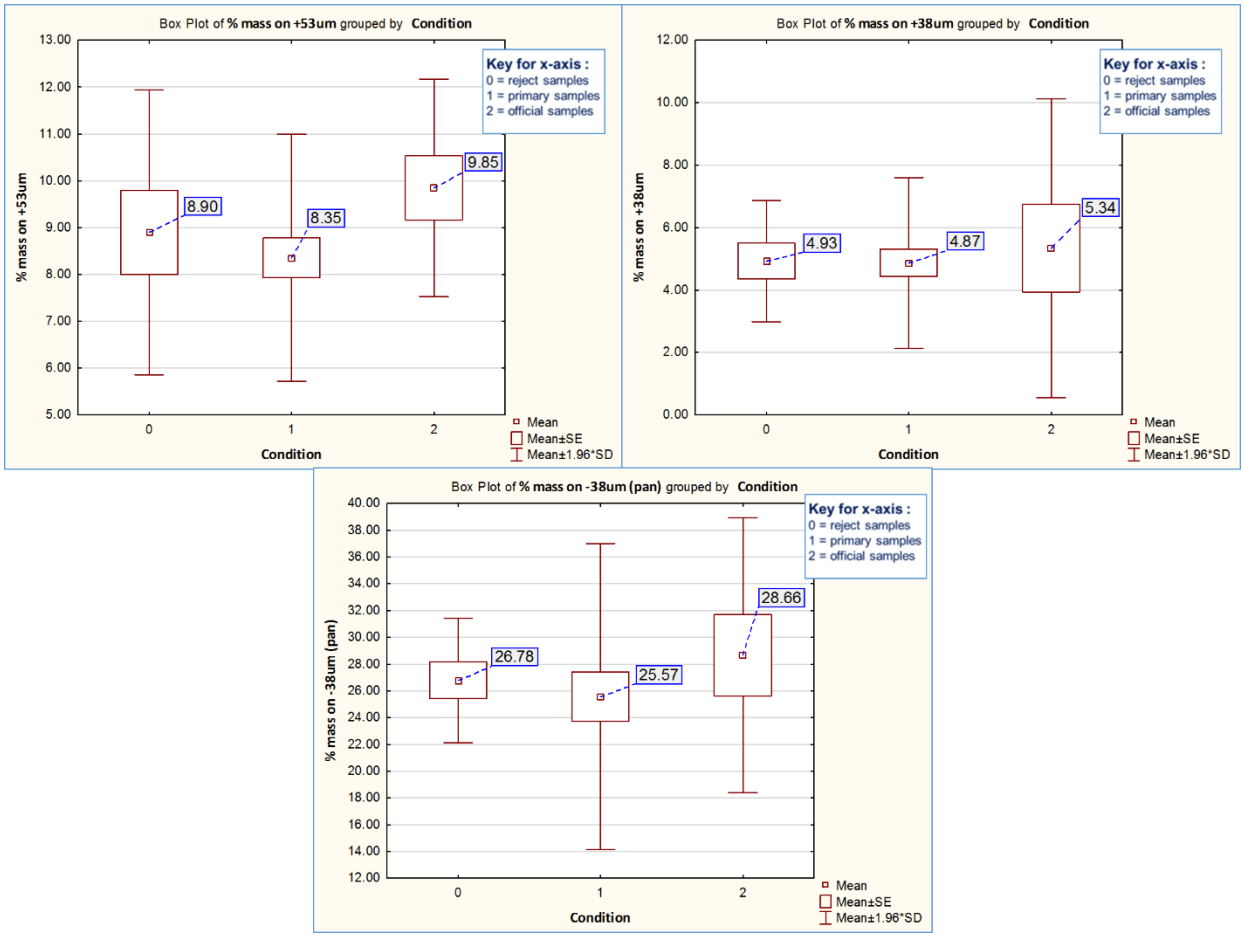
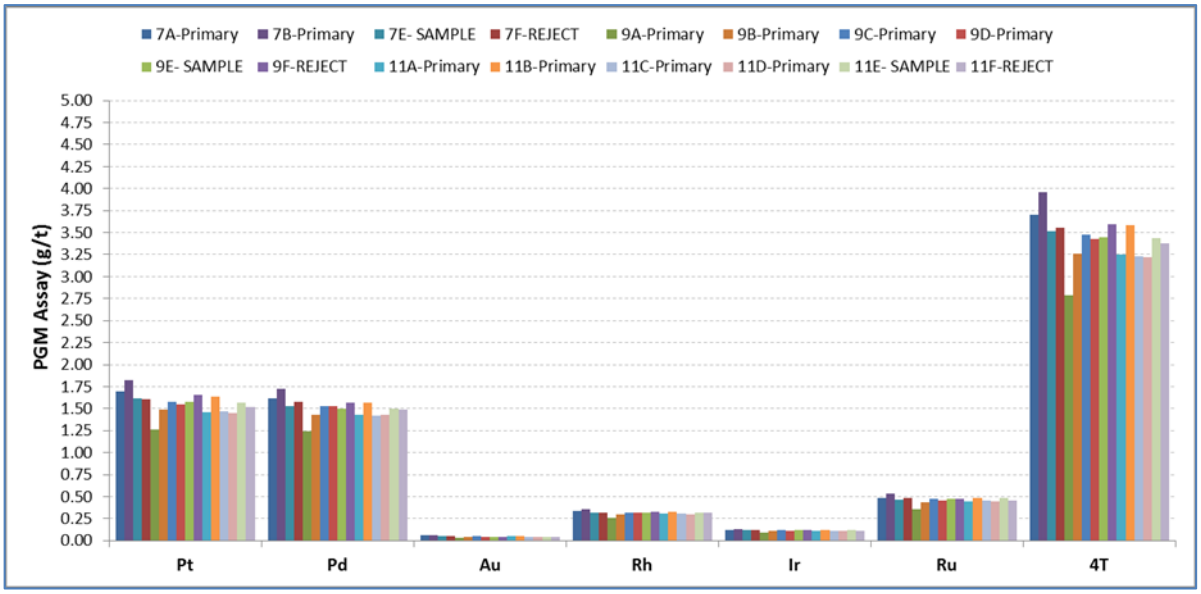


Figure 4.34: Stage 3A - % Mass Retained on Various Sieve Sizes 2 of 2.

The % mass retained on each of the respective screens are fairly similar for the reject, primary and official samples. A consistent trend for the % mass retained on specific screen sizes is not observed. Given that the -38µm size fraction is considered as part of the finer fraction of the total sample, one would expect the official samples to be higher in 4T grade compared to the reject samples.

4.3.1.4 Analytical Results

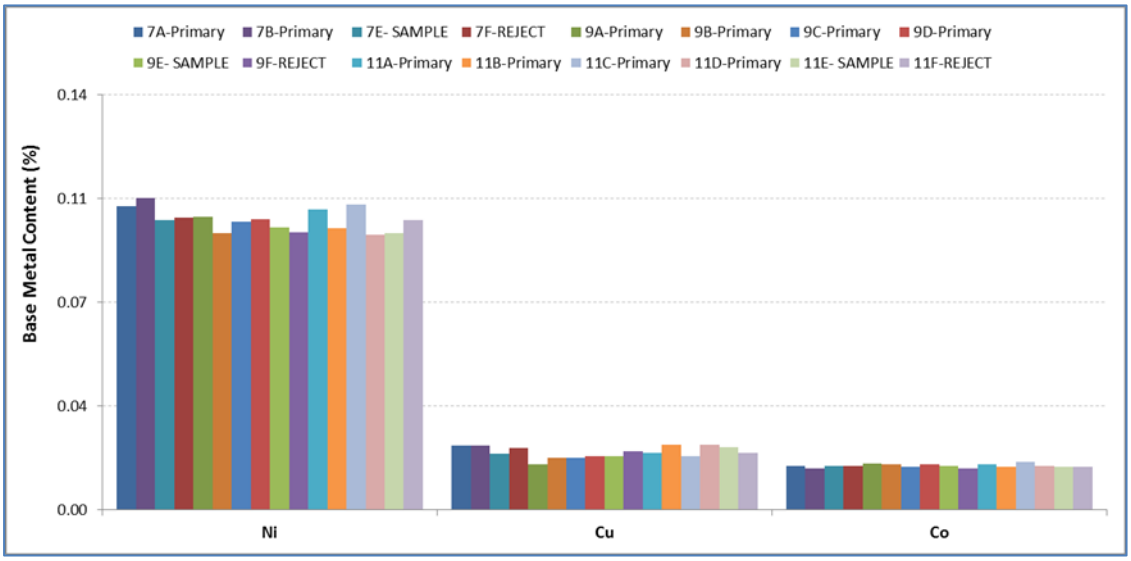
All 18 samples generated from the three test runs were assayed for PGM's, BM's and Cr_2O_3. Figures 4.35 to 4.37 indicate the assay results obtained for these 18 samples. Twin stream analyses was performed for all samples and the % RSD between the two legs were within the accepted laboratory limits for all elements.



*Assay data contained in Figure 4.35 has been factorized for confidentiality purposes.

Figure 4.35: Stage 3A - PGM Assays for Run 7 to 9.

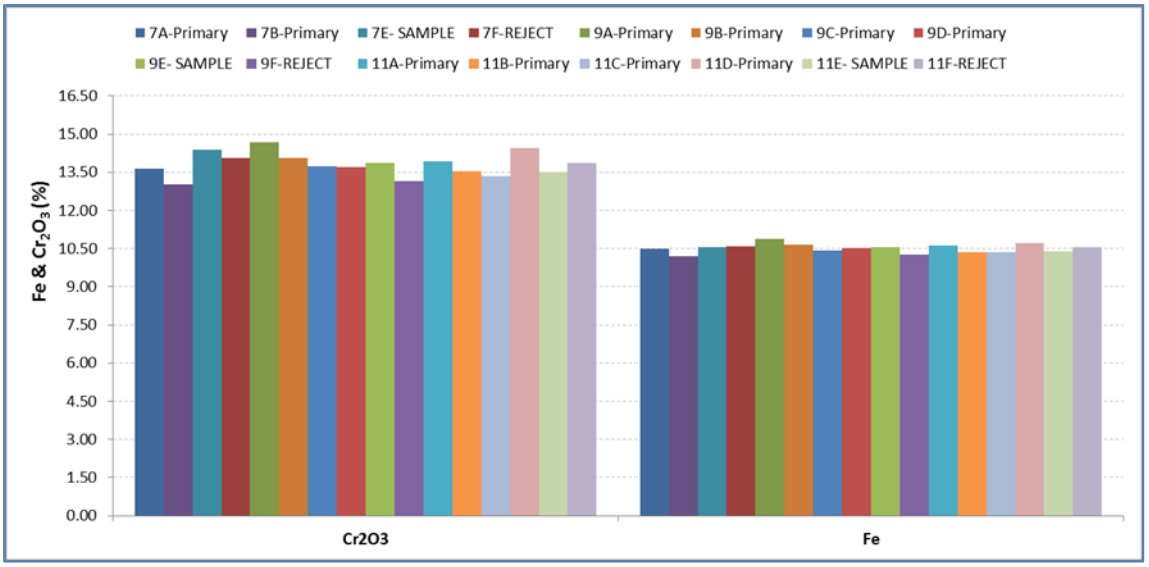
Figure 4.35 shows the reject and official samples assays for run 7, 9 and 11. For run 9, where the reject PSD was finer than the official PSD, the reject sample produced a higher 4T result compared to the official sample with less fines as expected.



*Assay data contained in Figure 4.36 has been factorized for confidentiality purposes.

Figure 4.36: Stage 3A - Base Metals Assays for Run 7 to 9.

The official, reject and primary samples base metal assays are comparable and this is expected as historical mineralogy data does not indicate a strong correlation between BM's grade and particle size.



*Assay data contained in Figure 4.37 has been factorized for confidentiality purposes.

Figure 4.37: Stage 3A - Cr_2O_3 and Fe Assays for Run 7 to 9.

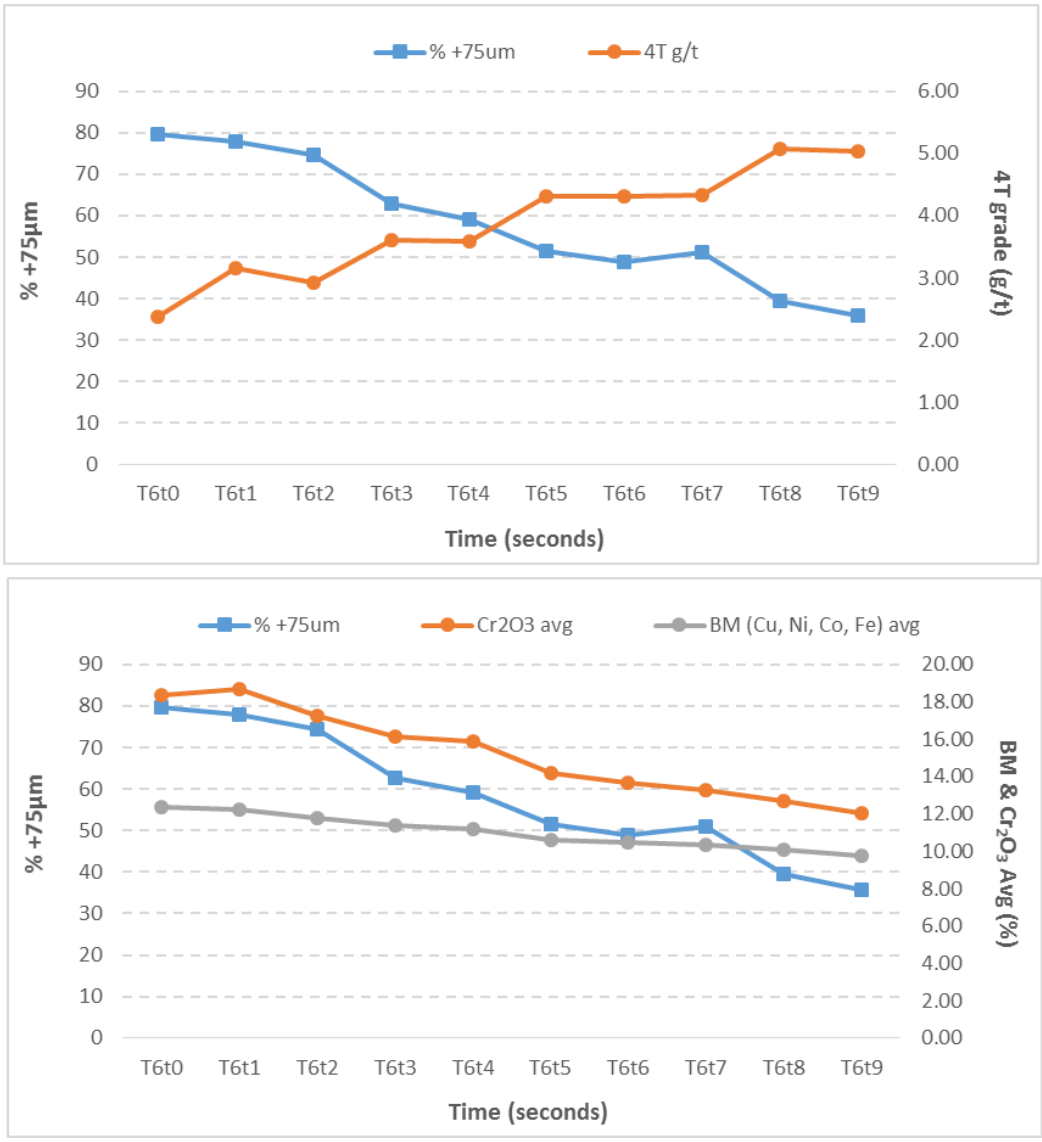
The official, reject and primary samples Cr_2O_3 and Fe assays are comparable in this case.

The % bias in terms of 4T grade was calculated to be between 2.12% and 5.91% relative to the primary sample grade and content (highly dependent on mass). The % bias in terms of 4T grade between pairs of sample 7E and 7F assays, sample 9E and 9F, and sample 11E and 11F assays was unmatched to the indicative % bias mentioned above and was in the range of -4.32% and 1.83% respectively.

Similarly, the % bias in Cr_2O_3 composition was calculated to be between 2.77% and 8.53% relative to the primary sample. The % bias in terms of Cr_2O_3 composition between pairs of sample 7E and 7F assays, sample 9E and 9F, and sample 11E and 11F assays was incomparable to the indicative % bias mentioned above and was in the range of -2.49% and 5.12%.

4.3.2 Stage 3A, Test 2 Sub-Sampling Test Work

Figure 4.38 indicates the 4T grade variation and BM & Cr_2O_3 composition variation as a function of +75µm fraction variation over time.



*Assay data contained in Figure 4.38 has been factorized for confidentiality purposes.

Figure 4.38: Stage 3A - Variation of Grade and % +75µm Retained Over Time.

The chronological sub-samples of the official sample indicated that the 4T grade increases as the % +75µm fraction decreases with time. For T6t5 to T6t7, the % +75µm fraction as well as the 4T grade remained fairly constant. Even though agitation was introduced as a means to keep all the particles (both fine and coarse) in suspension, it is clear that the % +75µm fraction still varies over time together with the corresponding 4T grade. The BM composition declined slightly as time progresses with the Cr_2O_3 composition following the % +75µm trend.

The mechanical agitation does not seem to have eliminated particle segregation that was originally evident. The agitation in the mechanical hopper may have caused

increased vortexing thereby introducing another form of segregation in the hopper. According to theory, vortexing increases at high agitator speeds. It is likely that the agitator speed of 258rpm used in the test work may be higher that what is required for such an application. In addition, the mechanical hopper was designed to exclude internal baffles which would have otherwise counteracted the vortexing to produce a much more homogenous mixture.

RSD for the % +75µm was calculated to be 26.7%. The analytical variance for the samples in question were within the laboratory limits.

Table 4.3 below indicates the number of secondary cuts per sub-sample obtained during Stage 3A, Test 2.

Table 4.3: Stage 3A – Number of Secondary Cuts per Sub-Sample

Test Run	Sample Identification	Sample Description	Number of Secondary Cuts
6	T6t0	0 - 6 seconds sub-sample	12
	T6t1	6 - 15 seconds sub-sample	18
	T6t2	15 - 30 seconds sub-sample	30
	T6t3	30 - 60 seconds sub-sample	60
	T6t4	60 - 90 seconds sub-sample	60
	T6t5	90 - 120 seconds sub-sample	60
	T6t6	120 - 150 seconds sub-sample	60
	T6t7	150 - 180 seconds sub-sample	60
	T6t8	180 - 210 seconds sub-sample	60
	T6t9	210 - 240 seconds (or until hopper empties) sub-sample	158

It is clear that the rule of thumb according to literature is not obeyed for T6t0 to T6t1 as a minimum of 30 cuts per sampling campaign if not achieved. One could argue though that the differences in the grade/composition and the % +75µm fraction for the above mentioned sub-samples are attributed to distributional heterogeneity.

4.4 Stage 3B: Re-designed Mechanical Hopper with New Nozzle Design

Stage 3 test work was conducted using the re-designed mechanical hopper which is described in detail in Appendix A. Stage 3B test work specifically included the new mechanical hopper fitted with the new nozzle design. The main objective of the following test work was to determine if the particle segregation still evident in Stage 3A test work can be overcome introduction of an alternate hopper design and sampling protocol with the new nozzle design in place.

4.4.1 Stage 3B, Test 1 Vezin Credibility Test Work

4.4.1.1 Comparison of % Solids between Different Samples

Figure 4.39 below indicates the % solids for the reject, official and primary slurry samples.

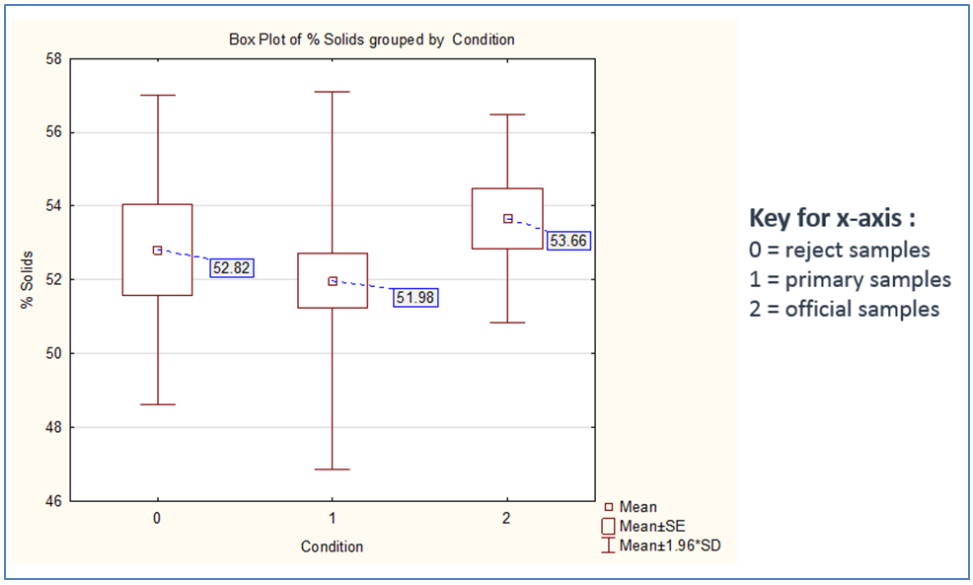


Figure 4.39: Stage 3B - % Solids for Reject, Official and Primary Slurry Samples.

The average % solids for the reject, official and primary slurry samples are comparable but the variation in the % solids for the reject and official samples are quite different.

4.4.1.2 Particle Size Analyses: Cumulative % Passing

Figure 4.40 indicates the particle size distribution for all the samples that were originally generated from the three runs namely, run 12, 14 and 16 respectively.

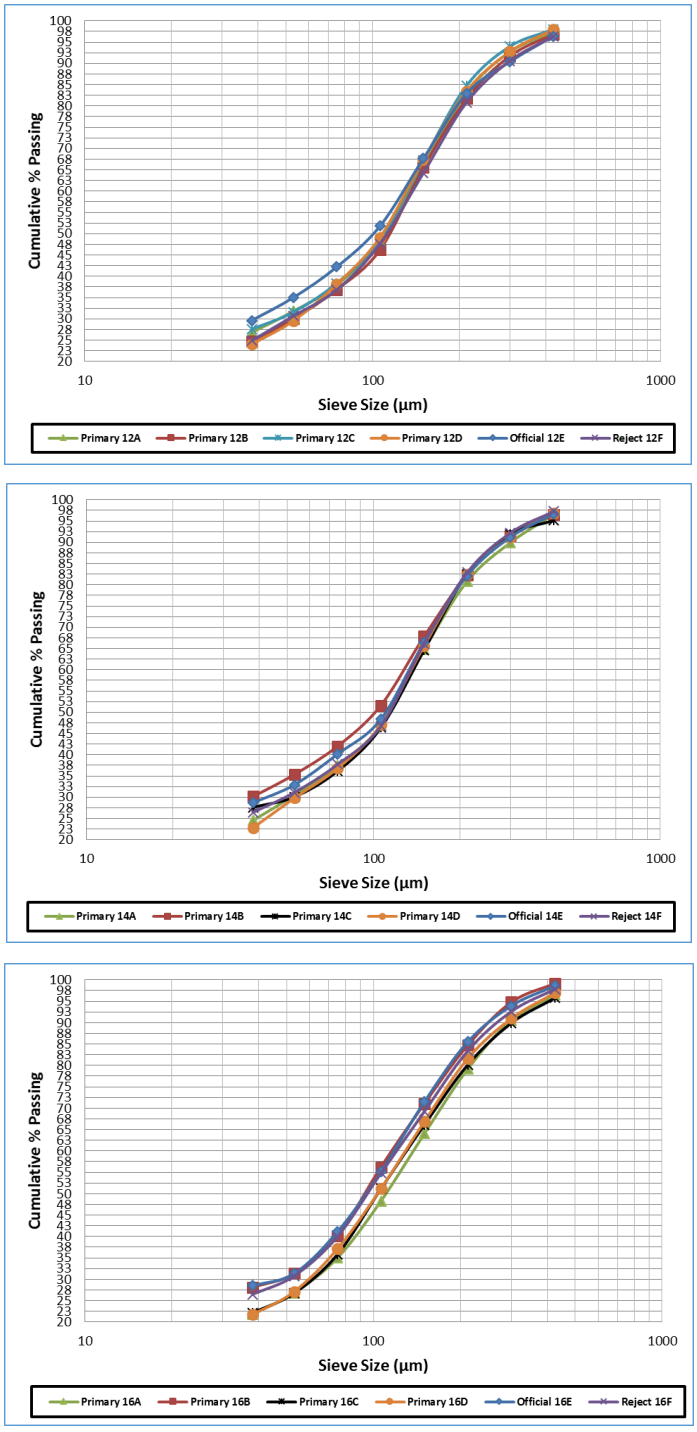


Figure 4.40: Stage 3B - Particle Size Distribution for Run 12, 14 and 16.

The PSD's do not indicate much bias when comparing the reject to the official samples and primary samples. For each pair of sub-samples generated (reject and

official sample), a minimum of 30 secondary cuts per sampling campaign was achieved.

Figure 4.41 indicates the comparison of the cumulative % passing the particular sieve sizes for the official and reject samples for all three runs as well as the average cumulative % passing for the combination of the three runs.

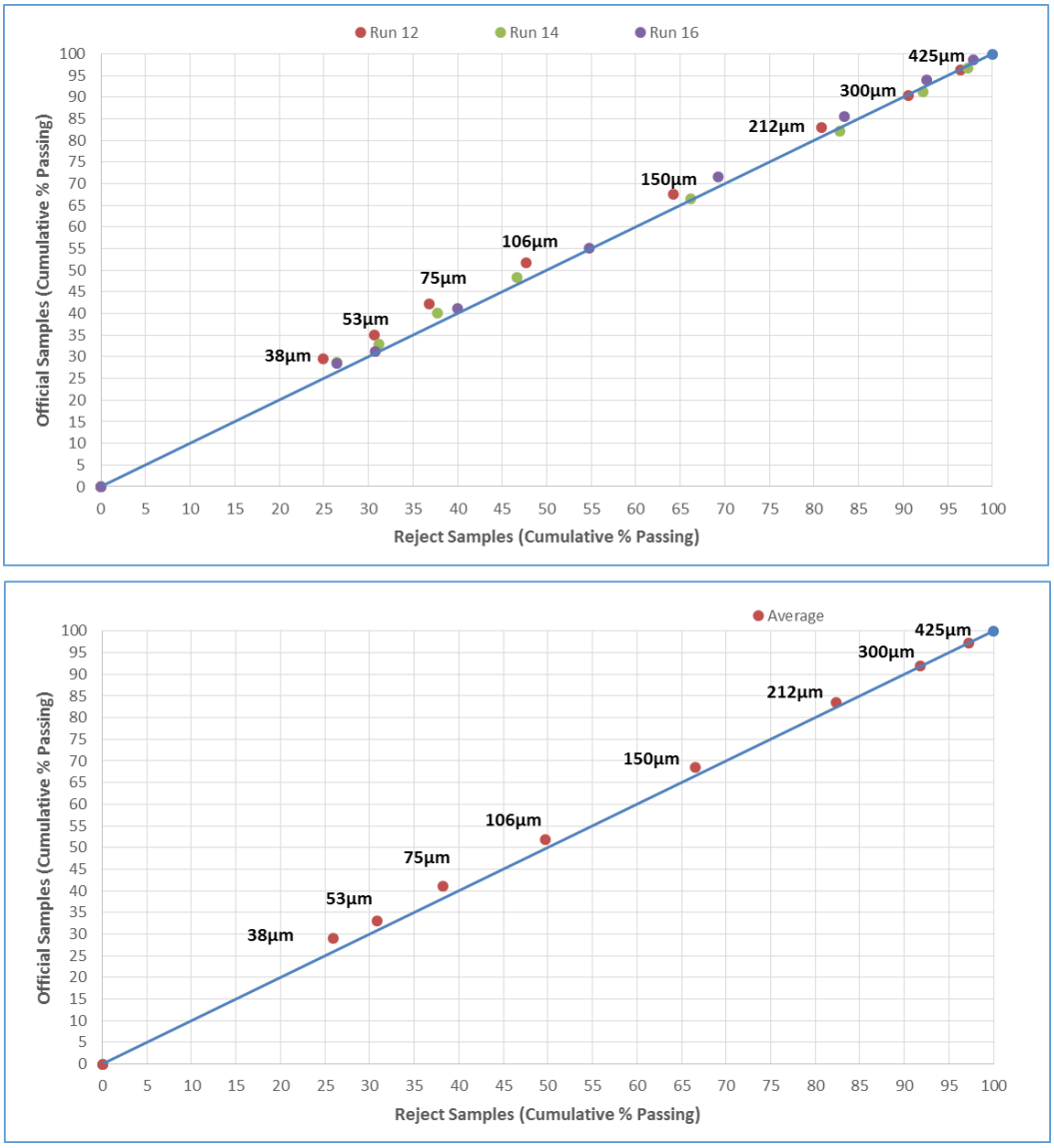


Figure 4.41: Stage 3B - Cumulative % Passing Comparison (Official and Reject Samples).

From Figure 4.41, it is clear that the reject and official samples are close to each other at the respective size fractions with the exception of run 12. Run 12 indicates a consistent bias with the official samples being finer than the reject samples. The

combined graph indicates a very slight bias with the official samples being slightly bias low towards the coarse fraction meaning that segregation may have been reduced with this configuration (new nozzle design and mechanical agitation). In general, minimal bias is observed.

The observation from Figure 4.41 is supported by Figure 4.42 where the official, reject and primary sample PSD's for all three runs are plotted.

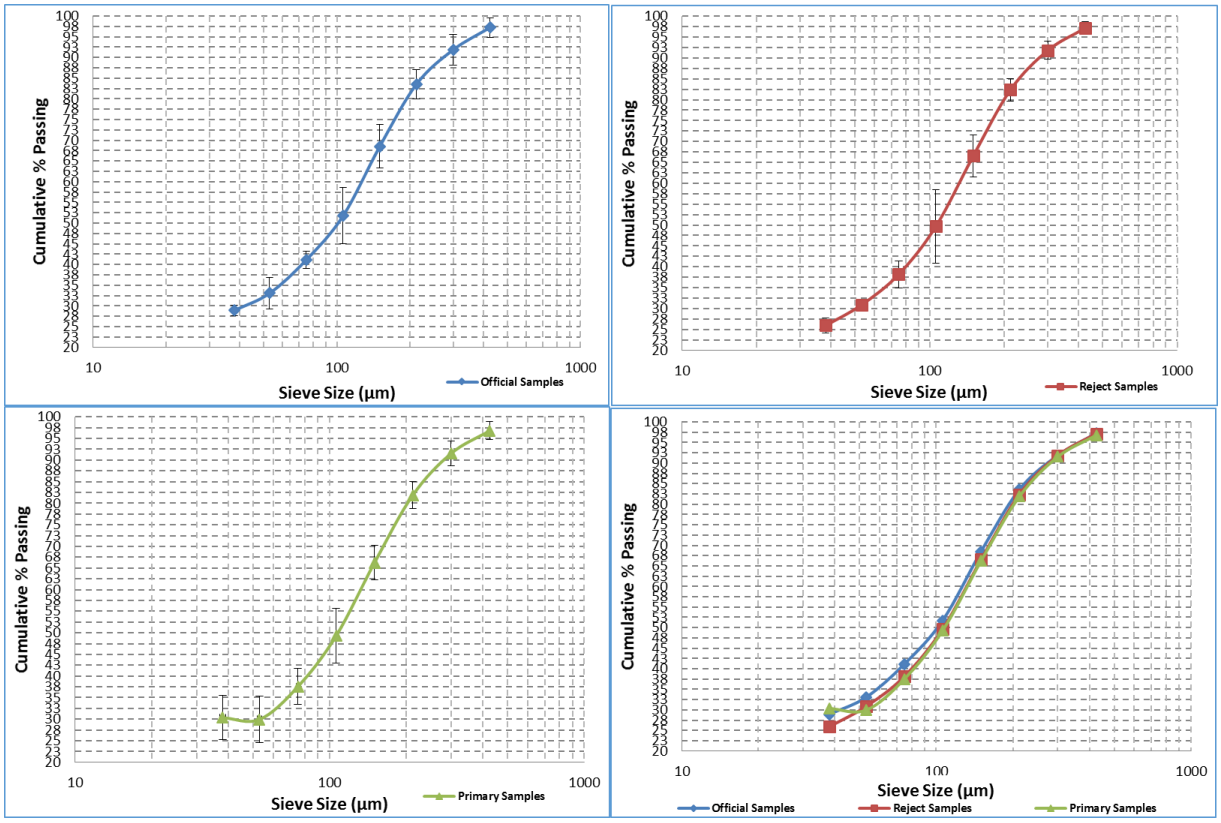


Figure 4.42: Stage 3B - Cumulative % Passing Comparison.

The reject, primary and official samples are identical at sieve sizes 425µm, 300µm, 212µm, 150µm and 106µm. The PSD's at <106µm deviates with the official sample PSD being finer than the reject and primary sample PSD's. The standard deviation at the 95% confidence levels for the cumulative % passing the various sieve sizes are also shown in Figure 4.42 by means of error bars.

The % bias between the reject and official samples for all the test configurations are plotted in Figure 4.43.

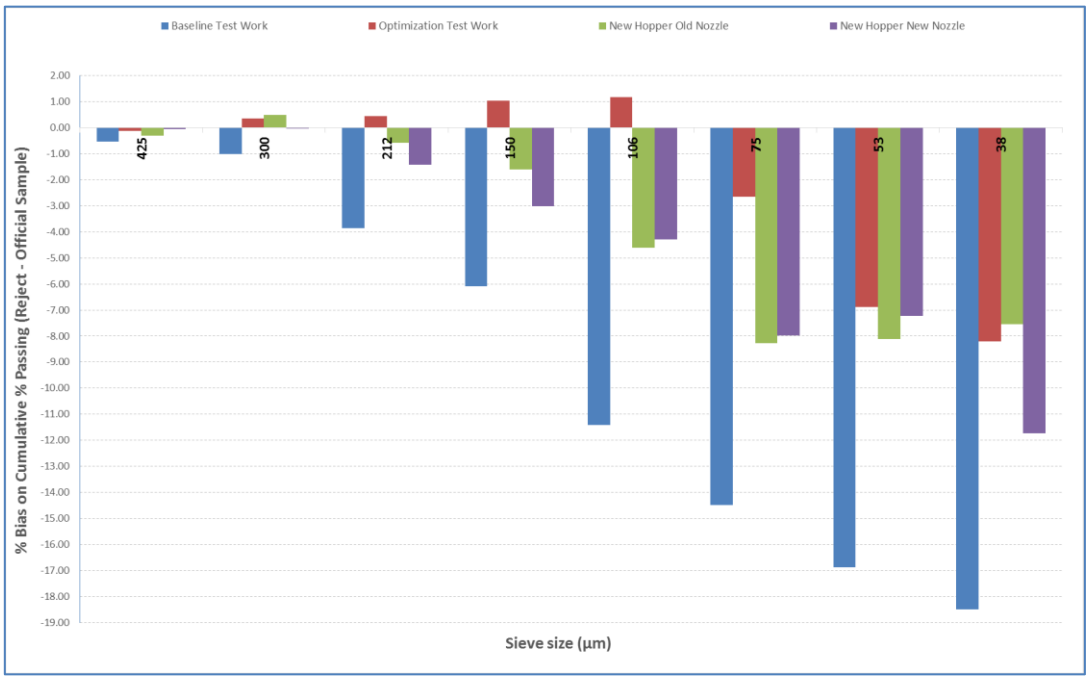


Figure 4.43: % Bias between Reject and Official Samples passing each Sieve Size.

From Figure 4.43, a consistent bias is observed with the official samples being finer than the reject samples. The bias with the new hopper, new nozzle is not as pronounced as for the baseline test work but follows a similar trend. The bias halved with the Stage 3B configuration compared to Stage 1 configuration.

4.4.1.3 % Mass Retained on Respective Screens

Figures 4.44 to 4.45 indicate the % mass retained on each screen for the reject, primary and official samples respectively.

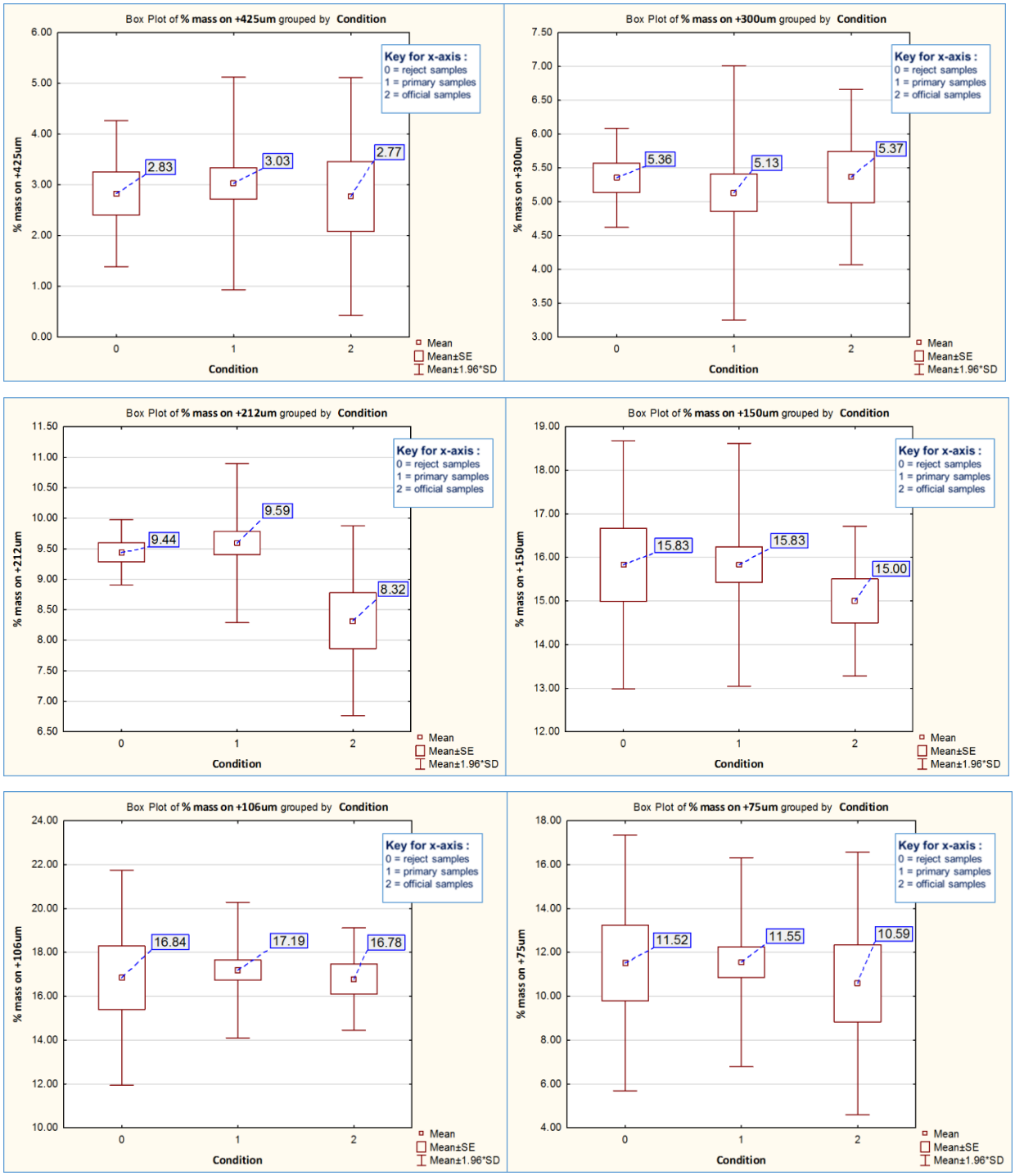


Figure 4.44: Stage 3B - % Mass Retained on Various Sieve Sizes 1 of 2.

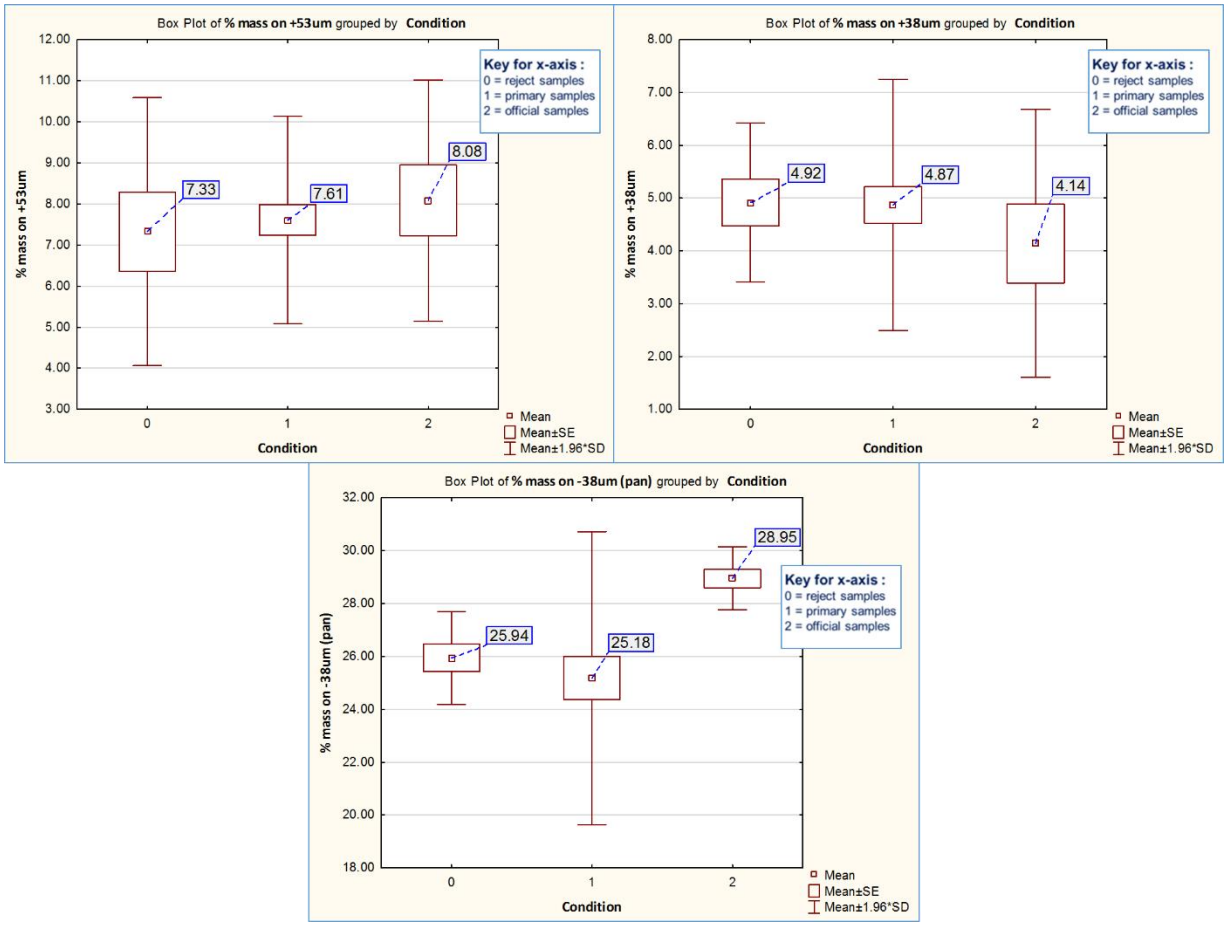
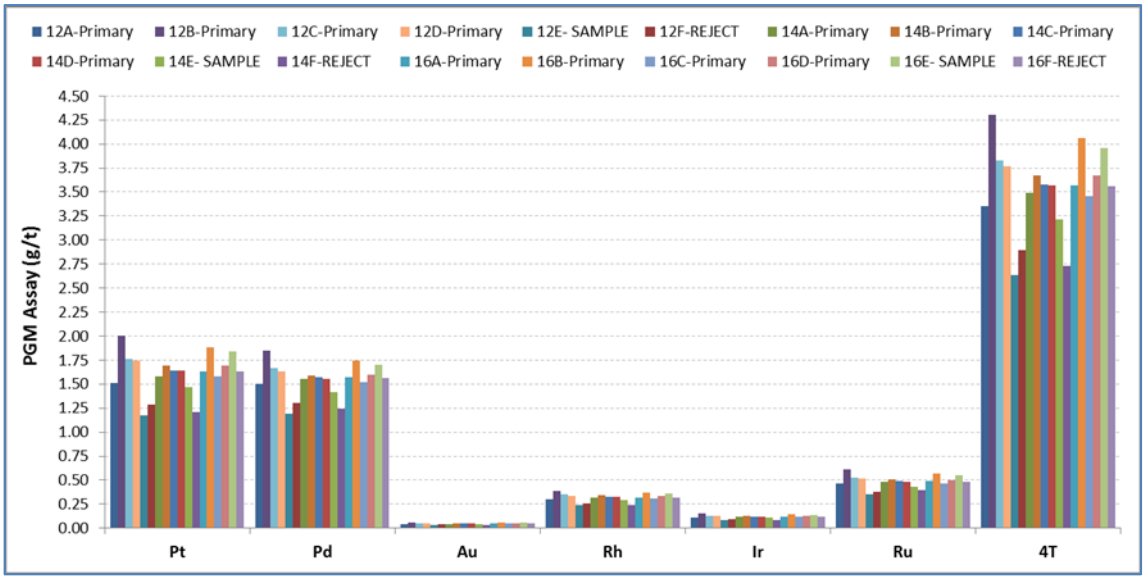


Figure 4.45: Stage 3B - % Mass Retained on Various Sieve Sizes 2 of 2.

The % mass retained on each of the respective screens are fairly similar for the reject, primary and official samples with the exception of the -38µm and +212µm sieve sizes. Given that the -38µm size fraction is considered as part of the finer fraction of the total sample and the official samples reported the lowest +212µm on average, one would expect the official samples to be higher in 4T grade compared to the reject samples.

4.4.1.4 Analytical Results

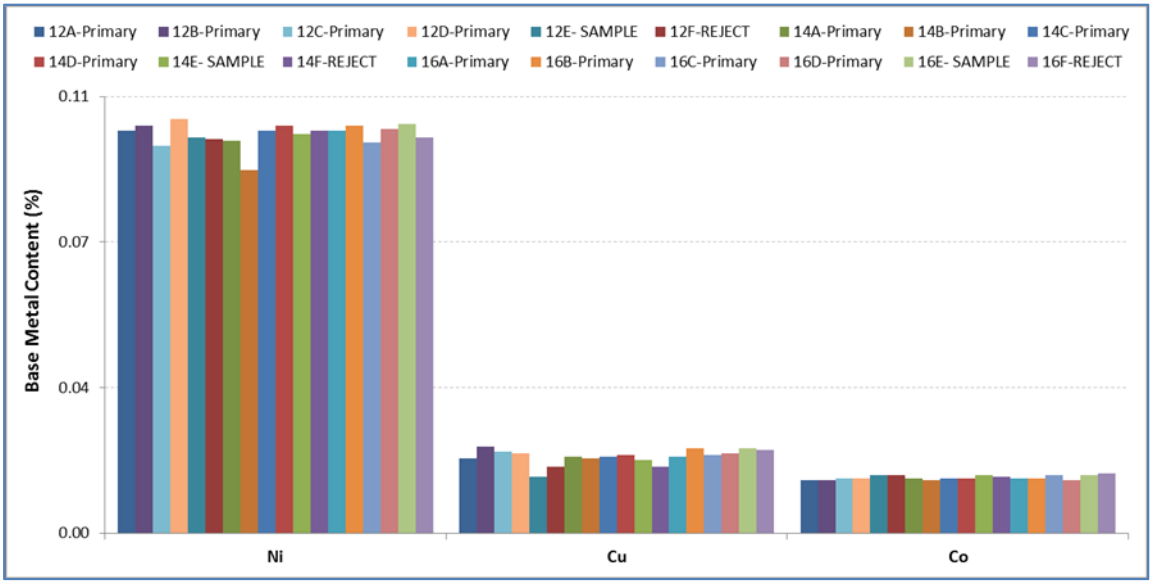
All 18 samples generated from the three test runs were assayed for PGM's, BM's and Cr_2O_3. Figures 4.46 to 4.48 indicate the assay results obtained for these 18 samples.



*Assay data contained in Figure 4.46 has been factorized for confidentiality purposes.

Figure 4.46: Stage 3B - PGM Assays for Run 12, 14 and 16.

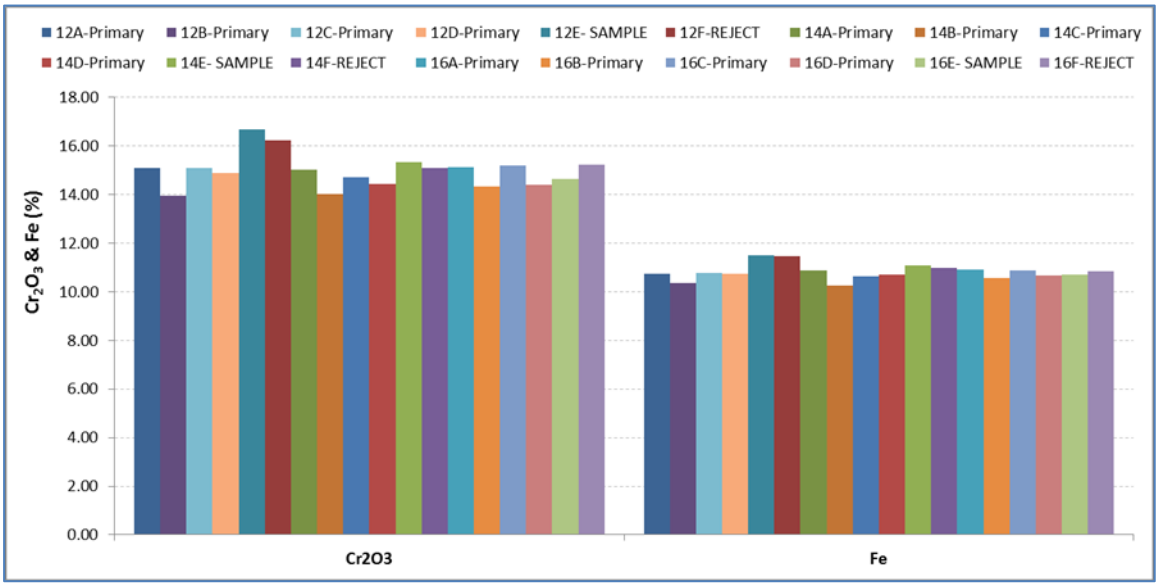
Figure 4.46 shows the reject and official samples assays differ for all elements. Even though the PSD's previously indicated a slight bias with the official samples being finer than the reject samples, the bias in terms of 4T grade is significant. In fact, the official samples reported a higher 4T grade than the reject samples for 2 of the 3 test runs.



*Assay data contained in Figure 4.47 has been factorized for confidentiality purposes.

Figure 4.47: Stage 3B - Base Metals Assays for Run 12, 14 and 16.

The official, reject and primary samples base metal assays are comparable and this is expected as historical mineralogy data does not indicate a strong correlation between BM's grade and particle size.



*Assay data contained in Figure 4.48 has been factorized for confidentiality purposes.

Figure 4.48: Stage 3B - Cr_2O_3 and Fe Assays for Run 12, 14 and 16.

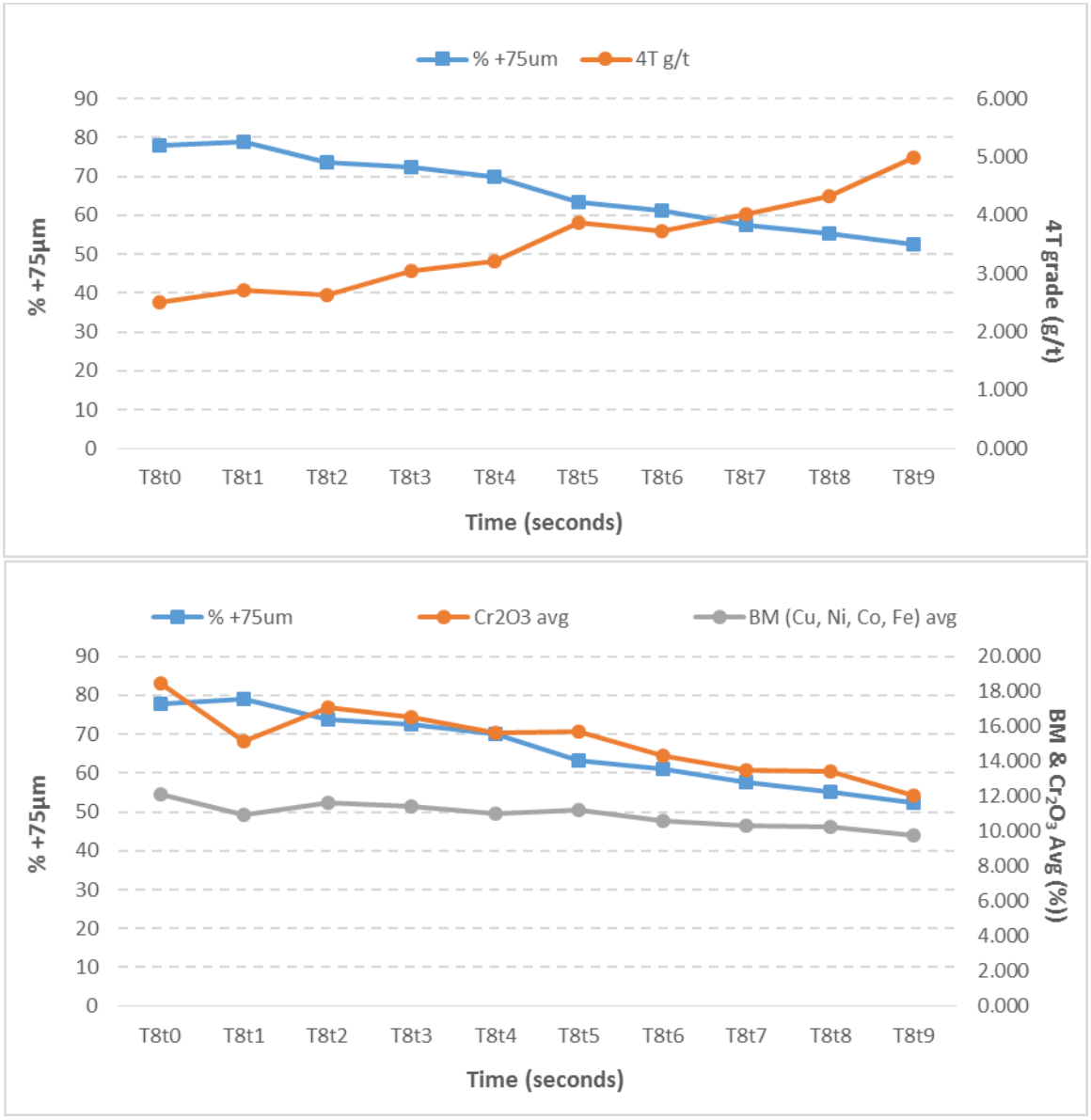
The official, reject and primary samples Cr_2O_3 and Fe assays are comparable in this case.

The % bias in terms of 4T grade was calculated to be between -15.63% and 17.15% relative to the primary sample grade and content (highly dependent on mass). The % bias in terms of 4T grade between pairs of sample 12E and 12F assays, sample 14E and 14F, and sample 16E and 16F assays was fairly comparable to the indicative % bias mentioned above and was in the range of -9.86% and 15.20% respectively.

Similarly, the % bias in Cr_2O_3 composition was calculated to be between -22.81% and 14.09% relative to the primary sample. The % bias in terms of Cr_2O_3 composition between pairs of sample 12E and 12F assays, sample 14E and 14F, and sample 16E and 16F assays was incomparable to the indicative % bias mentioned above and was in the range of -3.99% and 2.68%.

4.4.2 Stage 3B, Test 2 Sub-Sampling Test Work

Figure 4.49 indicates the 4T grade variation and BM & Cr_2O_3 composition variation as a function of +75µm fraction variation over time.



*Assay data contained in Figure 4.49 has been factorized for confidentiality purposes.

Figure 4.49: Stage 3B - Variation of Grade and % +75µm Retained Over Time.

The chronological sub-samples of the official sample indicated that the 4T grade increases as the % +75µm fraction decreases with time. For T8t5 to T8t6, the % +75µm fraction as well as the 4T grade remained fairly constant. Even though agitation was introduced as a means to keep all the particles (both fine and coarse)

in suspension, it is again clear that the % +75µm fraction still varies over time together with the corresponding 4T grade. The % +75µm however decreased to a lesser extent over time compared to Stage 3A, Test 2 and this observation may be subject to the nozzle design as opposed to the mechanical hopper change. The BM composition remains fairly constant as time progresses with the Cr_2O_3 composition following the % +75µm trend.

Figure 4.50 shows a comparison of the % +75µm fraction for the new hopper old nozzle and new hopper new nozzle configuration.

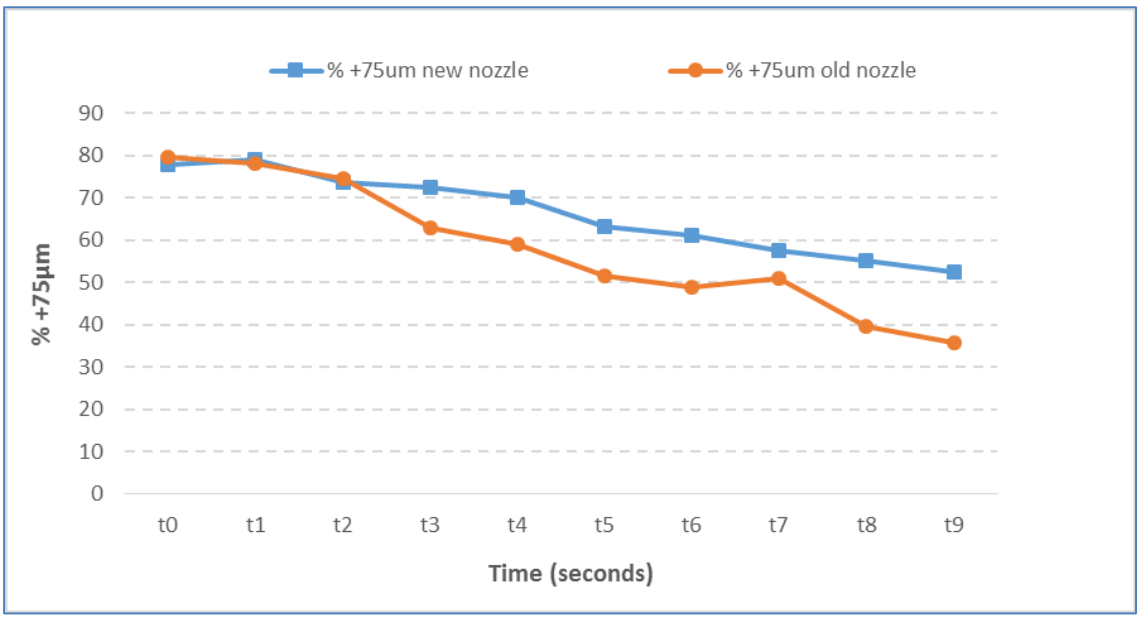


Figure 4.50: Variation of % +75µm Retained over Time for Stage 3A & 3B Test 2.

RSD for the % +75µm was calculated to be 14.5% for Stage 3B, Test 2 compared to the 26.7% calculated for Stage 3A, Test 2. The analytical variance for the samples in question were within the laboratory limits.

Table 4.4 overleaf indicates the number of secondary cuts per sub-sample obtained during Stage 3B, Test 2.

Table 4.4: Stage 3B – Number of Secondary Cuts per Sub-Sample

Test Run	Sample Identification	Sample Description	Number of Secondary Cuts
8	T8t0	0 - 6 seconds sub-sample	12
	T8t1	6 - 15 seconds sub-sample	18
	T8t2	15 - 30 seconds sub-sample	30
	T8t3	30 - 60 seconds sub-sample	60
	T8t4	60 - 90 seconds sub-sample	60
	T8t5	90 - 120 seconds sub-sample	60
	T8t6	120 - 150 seconds sub-sample	60
	T8t7	150 - 180 seconds sub-sample	60
	T8t8	180 - 210 seconds sub-sample	60
	T8t9	210 - 240 seconds (or until hopper empties) sub-sample	240

It is clear that the rule of thumb according to literature is not obeyed for T8t0 to T8t1 as a minimum of 30 cuts per sampling campaign if not achieved. One could argue though that the differences in the grade/composition and the % +75µm fraction for the above mentioned sub-samples are attributed to distributional heterogeneity.

4.5 Statistical Analyses: t-tests

The paired t-test method was applied in order to confirm whether there is a consistence difference (bias) between the reject and official samples that are correlated (i.e. it is expected that these measures would change with the change in the feed conditions) and are significantly different from 0. The differences in % mass retained for each pair of reject and official sample arising from an independent feed condition was compared in the statistical analysis.

Table 4.5 indicates the confidence levels for the significance in difference or bias between reject and official samples. Red, yellow and green highlighted cells indicate greater than 95% confidence, between 90% and 94.9% confidence and less than 89.9% confidence respectively.

Table 4.5: Paired t-tests between Reject and Official Samples

	Summary of Statistical Confidence in the Differences of % Retained between Reject and Official Samples					
	Stage 1		Stage 2		Stage 3A	Stage 3B
	(Reject Sample A - Official Sample B)	(Reject Sample D - Official Sample E)	(Reject Sample A - Official Sample B)	(Reject Sample D - Official Sample E)	(Reject Sample F - Official Sample E)	(Reject Sample F - Official Sample E)
+425µm	99.8	42.7	58.9	32.8	30.02	10.19
+300µm	96.3	95.7	85.0	97.1	73.95	2.75
+212µm	98.0	100.0	51.6	24.5	51.39	80.03
+150µm	93.3	98.7	1.8	57.5	30.22	85.29
+106µm	99.1	99.9	51.8	69.3	75.18	4.11
+75µm	53.7	67.7	82.6	94.5	75.50	97.18
+53µm	29.4	99.2	80.0	12.1	92.06	96.41
+38µm	80.1	90.2	26.2	36.0	24.97	83.37
-38µm	99.8	99.8	8.4	31.4	37.84	92.62

For Stage 1 test work, there is generally a greater than 95% confidence that a bias exists and that the bias is significant between the reject and official sample. The confidence for Stage 2 test work indicates that bias is not significant. In addition, Stage 2 configuration is the only configuration out of all four configurations that appears to produce the least bias and highlights that modifying the hopper discharge nozzle design was sufficient in overcoming particle segregation in the intermediate hopper of the sampling system. Stage 3A confidence in the difference is comparable to Stage 2 with only 3 test runs being conducted. Stage 3A and Stage 3B configurations still produced results that was deemed not as statistically biased as Stage 1 configuration. This inherently means that the addition of the agitator does assist in producing positive results (comparing specifically Stage 1 to Stage 3A where the only change is the hopper design with the nozzle design being constant).

In addition, given that the different stages of test work were conducted in a production environment where random variation due to the process cannot be isolated, it is possible that there were other potential sources that could have contributed to the observed biases.

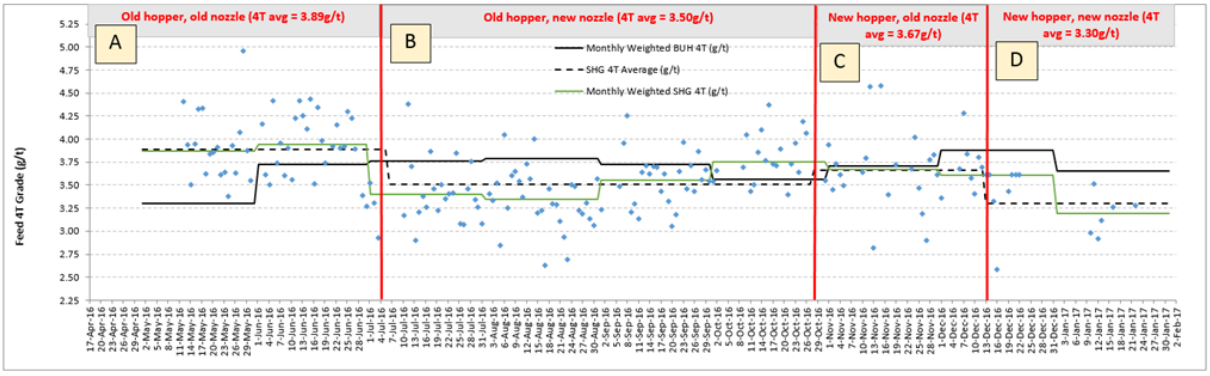
4.6 Plant Performance

To evaluate the secondary objective of this study, the historical and present data relating to key performance indicators such as 4T accountability and sample head grades over an adequate period of time (inclusive of analytical and metal accounting

data) was analysed to assess the effects of changes implemented as per main objectives stated previously.

4.6.1 BUH vs. SHG and 4T Accountability

Figure 4.51 indicates the monthly weighted build-up 4T head grade and sample head grade as well as the average sample 4T head grade plotted over each period (A to D) of time.



*Assay data contained in Figure 4.51 has been factorized for confidentiality purposes.

Figure 4.51: Sample Head Grade vs. Build-Up Head Grade.

4T accountability is one of the performance indicators used for governance purposes and to evaluate site performance as it incorporates both mass measurement and analytical data sources (assays reported are directly related to quality of metal accounting samples taken).

From Figure 4.51, it is evident that the month to month performance were not within an acceptable range of 98-102% for 4T accountability (accepted range accounts for analytical variance only) as the 4T BUH grade and 4T SH grade do not compare well from month to month. In fact, for the months of May and June, an under-accounting trend is observed with accountabilities ranging between 85% and 95%. This is followed by an over-accounting for months July, August and September. October is an anomaly as the under-accounting trend is again apparent. November presented with an ideal 4T accountability of 100±1%. In December and January, an

over-accounting trend resurfaced with accountabilities ranging between 107% and 114%.

As mentioned previously, the sample head grade depends greatly on the sample taken by the automatic feed sampler. If a consistent bias is present with the official samples being higher or lower in 4T grade, this would impact directly on the 4T accountability that is reported. On the other hand, factors such as concentrate lock-up or concentrate release would impact the build-up head grade and also impact on the 4T accountability. The changes in the sampler (nozzle design and mechanical hopper installation in Periods B, C and D) does not correspond with the change in SHG or BUH grade trend and may indicate that the % bias indicated in the test work on PSD, 4T grade and Cr_2O_3 composition is in fact insignificant.

4.6.2 Semi-Variograms for Stage 1, 2 and 3

An attempt was made to produce variograms for this feed material in question. Figure 4.52 indicates the corresponding variograms produced from the daily 4T grade for the period:

- 1 January 2016 to 30 June 2016 (old hopper, old nozzle) *(Top left)*;
- 01 July 2016 to 07 November 2016 (old hopper, new nozzle) *(Top right)* and;
- 07 November 2016 to 28 February 2017 *(Bottom centre)*.

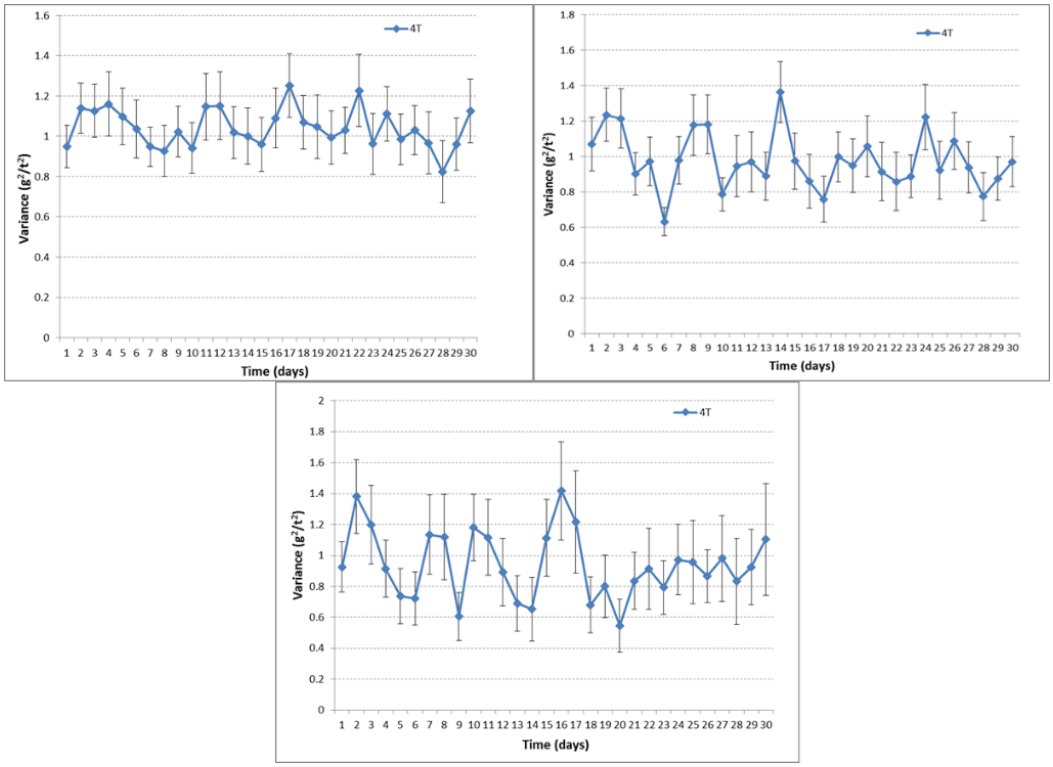


Figure 4.52: Semi-Variograms for Stage 1, Stage 2 and Stage 3 (New and Old Nozzle).

In all three attempts, the variograms produced are not true variograms: the sill is reached after just one point i.e. the range is short and a negative gradient should not appear once the sill has formed. The variograms indicates that there is no correlation from day to day i.e. 4T assays from day to day are not related. The V_0 value was however extrapolated for indicative purposes for Stage 1, 2 and 3 to be 0.759, 0.901 and 0.470 respectively.

For Stage 1, a six-month period worth of data points was used to produce a variogram. For Stage 2 and 3, a four-month period worth of data points was used to produce a variogram. In addition, a change took place in Stage 3 within the sampling system with reference to the installation of the new nozzle design. Even though there was a change, the V_0 value improved from Stage 1 to Stage 3 and this indicates that sample representativeness improved (debatable since proper variograms were not producible). The V_0 for Stage 3 is very close to what is expected from theory as it accounts for ~33% of the total sill (as opposed to 32% according to theory).

To recall, V_0 is the random variability and is a function the inherent distributional heterogeneity of the material (fundamental error, and grouping and segregation error), the sampling system (design of the equipment) and the analytical variance. Assuming analytical variance remained fairly constant between Stage 1, 2 and 3, incidentally any improvement seen in V_0 can only be attributed to a decrease in the fundamental error and/or segregation error or having better control on the sampling protocol (collection of multiple primary increments and agitation incorporated to allow for all particles to remain in suspension until secondary sampling could take place). Stage 2 V_0 value was the largest for all three stages and one may argue that this is due to the inconsistency in the total number of data points used. The minimum number of data points required to produce a variogram is generally 60.

5 Conclusions

The hypothesis that particle segregation is present in the intermediate hopper of a typical UG2 feed sampling system was confirmed in Stage 1, Test 1. A consistent bias was observed between the reject and official samples with the official samples being depleted of coarse particles and higher in 4T grade than the reject samples. By means of a paired t-test, the calculated bias for % mass retained was deemed significant at the 95% confidence level. This outcome together with the size by assay analysis performed indicated that an under-accounting scenario would result.

Stage 2 test work indicated that optimization of the existing sampling system by installation of a nozzle with a different design at the base of the intermediate hopper changed the dynamics at the base of the hopper and resulted in a random distribution of fine and coarse particles in both the reject and official samples. The PSD's for reject and official samples were identical across all test runs however the respective sample 4T grades were the opposite to that of Stage 1, Test 1. The calculated bias for % mass retained was not significant at the 95% confidence level. Stage 2 test work also highlighted that the need for a redesigned hopper was possibly unnecessary.

Stage 3 test work indicated that the introduction of an alternative sampling protocol by means of collecting the primary increments, agitating the material and then sub-sampling to produce an official and reject sample created the platform for better suspension of all particles. The calculated bias for % mass retained was not significant at most measurements at the 90% and 95% confidence level. By altering the nozzle design and essentially doubling the nozzle diameter for both Stage 3A and Stage 3B, the particle segregation in the intermediate hopper was reduced.

Test 2 for Stage 1, 2, 3A and 3B is summarized in Table 5.1 overleaf.

Table 5.1: % COV Summary

	Stage 1	Stage 2	Stage 3A	Stage 3B
4T grade	51.6	50.9	23.1	23.4
Cr_2O_3	14.7	13.2	15.6	12.6
BM (Cu, Ni, Co, Fe)	9.3	7.1	8.2	6.5
% +38µm	0.021	0.019	-	-
% +75µm	-	-	26.7	14.5

The 4T grade variation over time remained essentially constant when comparing Stage 1 to Stage 2 and Stage 3A to Stage 3B. The change in nozzle and hopper design seemed to not have an impact on the overall 4T grade of the official sub-samples generated over the sampling campaign. The % COV with respect to the Cr_2O_3 composition decreased from Stage 1 to Stage 2 and from Stage 3A to Stage 3B respectively. The implication is that the larger Cr_2O_3 particles were better suspended in the hopper due to a combination of the alternative nozzle design and additional agitation by means of the agitator. A similar trend was observed for the BM's but to a lesser degree.

There was a slight improvement in the % COV for the % +38µm from Stage 1 to Stage 2. A considerable improvement in the % COV for the % +75µm was observed from Stage 3A to Stage 3B. With the inclusion of the new nozzle design to the mechanical hopper, the % COV for the % +75µm improved from 26.7% to 14.5%.

It is important to emphasize that the results presented for each stage of test work were limited to time, cost and scope constraints. Although many other material characteristics or parameters could have been investigated and tested, particle size was deemed the highest contributing factor to the noted particle segregation on this Concentrator plant. Furthermore, the results contained in this study were limited to a minimal number of repeatability test runs and should be acknowledged.

The research objectives were all met even though particle segregation in the intermediate hopper was not eliminated. In general, it is believed that the particle segregation which was so evident in the baseline test was significantly reduced with the incorporation of the alternative nozzle design and mechanical agitation. Compressed air agitation alone does not seem to keep all particles of varying size and density in

suspension in the intermediate hopper. The average % solids was also more comparable as the various stages of test work and this indicates that particle segregation in the hopper was reduced i.e. the reject and official samples were identical in terms of solids density.

The mechanical stirred hopper with additional capacity allows for flexibility in manipulating the sampling protocol as per individual requirement. The sampling interval of a primary stream can be reduced significantly and this can only reduce the distributional heterogeneity as the stream will be sampled more frequently to account for the variability in the stream being attempted to evaluate.

Given that a proper variogram could not be produced, it is suggested that as assay data becomes available, another attempt be made to produce a true variogram. A true variogram will essentially highlight, in a relative manner, if the grouping and segregation error decreases or increases over time.

6 Recommendations

Preliminary test work conducted on the mechanical hopper configuration has prompted the need to re-examine the initial design of the mechanical hopper. A future mechanical hopper prototype should be re-designed and fabricated from a cheaper yet robust material and should also be ergonomically improved. This should result in a piece of equipment that can withstand the severe production environment and can still be easily manoeuvred for maintenance, inspection and cleaning purposes. It is recommended that further advice be obtained regarding the agitator motor-gearbox ratio for the application at hand. The incorporation of internal baffles inside the mechanical hopper should also be considered to reduce the impact of vortexing. An inspection port should also be integrated into the design to be able to view the agitator in operation and observe for vortexing of the slurry material or retention of residual solids in the hopper after sub-sampling takes place. Multiple air agitation points may also be considered in future designs of the mechanical hopper (for instance, an air agitation point above and below the pneumatic valve).

In cases where continuous ingress of slurry into the primary cutter is observed, effort should be made to counteract this, as the mechanical hopper is designed to hold multiple primary increments and any ingress would automatically bias the entire sample.

The experimental conditions created for the test work are not realistic and served to provide a snapshot of the dynamics that result in particle segregation in the intermediate hopper of a typical UG2 feed sampling system. It is well known that feed stream characteristics such as grind and density in a typical Concentrator Plant change over time. In order to exclude these changes over time, more elaborate test work needs be conducted in a testing environment as opposed to a production environment. As this did not form part of the scope of this project, it is recommended that any future investigation or test work around particle segregation in the intermediate hopper be conducted in a controlled testing environment. In this way, any random variation due to the process can be disregarded and the true bias (if any) can be determined and

confirmed. The number of test runs must also be reconsidered as 3 test runs was statistically inadequate in this project. At least 6 to 10 test runs must be done.

Further research work may include:

- Extension of conceptual ideas to entail simulations around DEM prior to testing occurring in the testing or production environment;

- Expansion of this project to investigate the change in physical shape of the intermediate hopper and the impact on particle segregation;

- Determination of the minimum number of secondary cuts per sampling campaign. Currently, theory states as a rule of thumb that 30 cuts should be sufficient to overcome distributional heterogeneity. To the author's knowledge, no test work has yet been done to validate this reference. Such an investigation or test work should be conducted only once particle segregation in the intermediate hopper has been completely confirmed and eliminated.

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Appendices

Appendix A: Methodology – Details

The experimental work in this research project was conducted in various stages as outlined in Table A.1 below.

Table A.1: Experimental Work Stages

Stage	Details
1	Baseline Test Work on Existing Sampling Equipment
2	Optimization of Existing Sampling Equipment
3	Ratification and Testing of Re-Designed Mechanical Hopper

Stage 1 involved experimental baseline test work on the existing sampling equipment as per Section 3, Figure 3.2 and Table 3.1 previously. Stage 2 involved test work using an alternative intermediate hopper nozzle design. Stage 3 included test work using a new designed mechanical intermediate hopper. Furthermore, Stage 3 test work covered tests with the old and new nozzle designs fitted to the new mechanical hopper.

A1. Stage 1: Baseline Test Work on Existing Sampling Equipment

The first objective of this research project was to investigate if particle segregation is indeed present in the intermediate hopper of a UG2 feed sampling system. In order to test the hypothesis that particle segregation is present in the intermediate hopper, two different tests were performed. Figure 3.2 previously shows the equipment that was used for both tests.

In particular, the following must be noted with respect to Figure 3.2 previously:

- As mentioned previously, the primary vezin sampler is duplicated in the plant process due to the presence of parallel delivery lines to the flotation circuit

i.e. one duty line and one standby line. For the purposes of the test work, only one line was operated at a time and the same line was used for the entire test work period (Stages 1 to 3) in order to eliminate possible variances arising from use of alternate lines. Figure A.1 below is a picture of the primary vezin sampler setup on site:



Figure A.1: Dual Primary Vezin Samplers.

- The regulated compressed air supply to the intermediate hopper was kept constant at 4 bar during the entire duration of the tests;

- Intermediate hopper volume capacity was fixed at 20litres however depending on the plant feed flow rate the hopper resulting retention times were different;

- The secondary vezin cutters critical width was determined to be ~13mm for all four cutters and the cutters were inspected prior to the test work to check for radialness. As per guideline given by Francois-Bongarcon & Gy (2002), the collection opening must be a minimum of 3d +10mm where d is the diameter of the largest fragment. The cutter critical width was therefore adequate as the largest fragment/particle diameter to be sampled was sub 1mm.

The general operation of this sampling system is as follows:

1. The primary vezin sampler is operated under automatic conditions and takes a cut of the incoming stream at a pre-determined interval. This

interval is generally determined during commissioning of the equipment to ensure enough sample results at the end of a particular shift;

2. The cut taken by the primary vezin sampler is referred to as a primary cut or primary slurry sample. Figure A.2 below shows the primary cutter parked outside the stream:

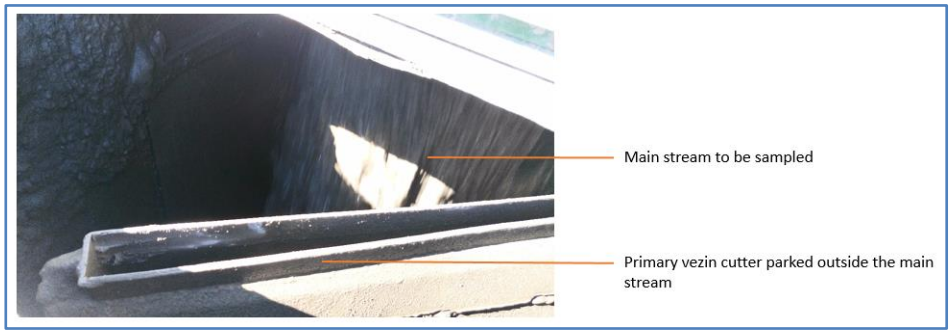


Figure A.2: Primary Vezin Cutter in Stationary Position.

3. The primary slurry sample then flows into the intermediate hopper of the sampling system via gravity as per Figure A.3:

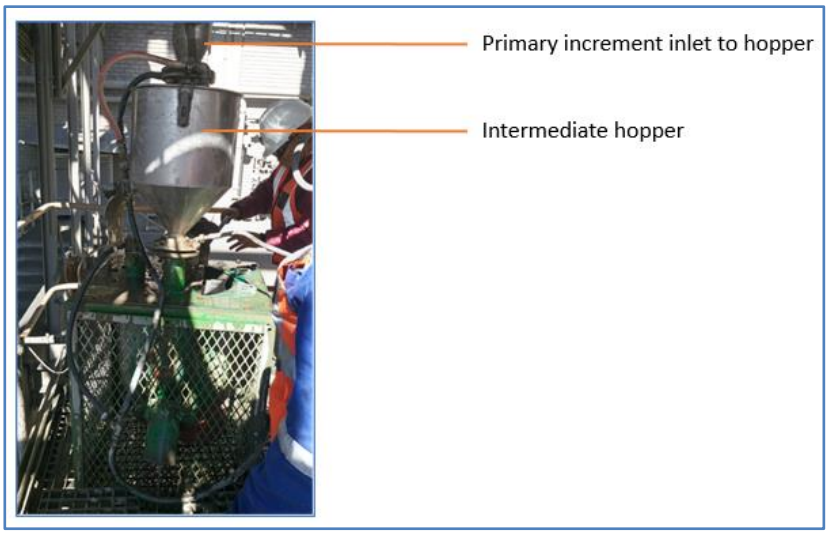


Figure A.3: Intermediate Hopper (Old Design).

4. The intermediate hopper is fitted with regulated, compressed air supply at the base:



Figure A.4: Intermediate Hopper with Compressed Air Supply Connection.

This air supply serves two purposes: to prevent the hopper discharge outlet from choking and to keep particles in suspension until the entire primary cut or increment has been sub-sampled;

5. The primary slurry sample exits the intermediate hopper via a nozzle and is then sub-sampled by the secondary vezin sampler with a four-cutter arrangement to produce an official slurry sample and a reject slurry sample. Figure A.5 below shows the position of the hopper nozzle relative to the hopper:

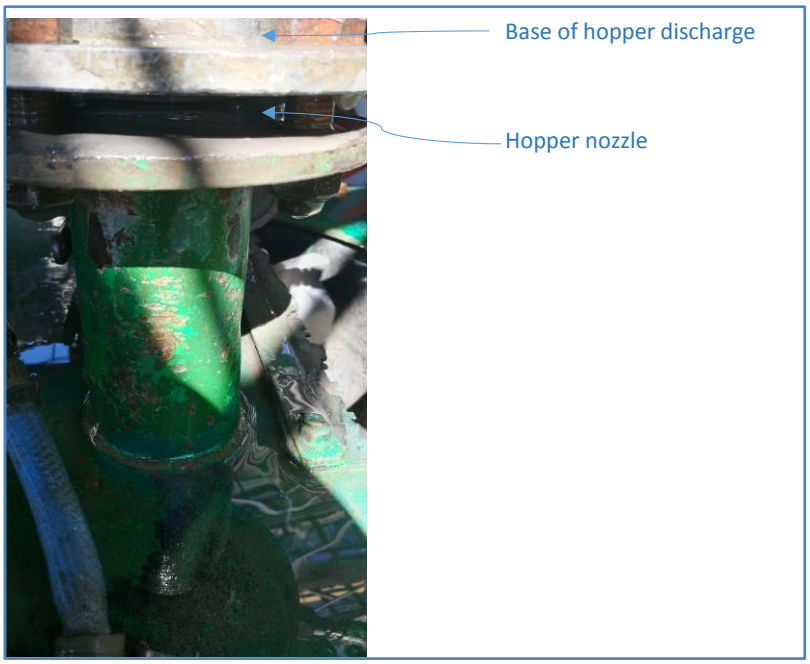


Figure A.5: Position of Hopper Nozzle.

6. The official slurry sample is collected in a sample bucket over a period of time and is then processed for metal accounting or process control purposes;

7. The reject slurry sample is commonly discarded to the spillage bund area.

A1.1. Stage 1, Test 1 Vezin Credibility Test Work

Prior to commencing this test, dummy runs were conducted to determine how much official and reject slurry sample (in particular the % solids and corresponding dry mass of solids) can be obtained from one primary cut. It was determined that one primary cut results in roughly 5.4litres of primary slurry sample with a % solids of approximately 50%. In addition, the primary slurry sample, once sub-sampled, was reduced to about 10% by volume. It was then decided that a minimum of three primary cuts were needed in order for adequate sample mass to be generated for the reject and official sample portions to meet analytical requirements. For a feed sample to be analysed in twin stream, the analytical laboratory required a minimum of 250g (dry mass) per sample submitted.

A total of five test runs were performed for repeatability purposes. For each test run, five individual samples were generated. The experimental methodology entailed the Vezin Credibility Technique (Kruger & Millar, 2002).

The vezin credibility testing involved the following steps:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (See Appendix C). The equipment was inspected for leaks and physical damage. Any concerns were noted. The secondary vezin speed was also determined (See Appendix B);

c. The main feed stream was sampled by the mechanically designed primary vezin on a pre-determined time interval basis. The primary vezin sampler was placed on manual operation mode for the purposes of the test;

d. A clean and empty 20L plastic bucket was placed at the secondary vezin reject sample pipe discharge end and a clean and empty 5L container was placed at the official sample pipe discharge end;

e. With the primary vezin sampler in manual mode, the manual cut button was pressed once. This resulted in a single cut of the main stream. After approximately 30 seconds and another manual cut was taken. In total, three manual cuts were taken using this approach;

f. Each primary sample increment resulting from the primary vezin operation was then sub-sampled by the secondary vezin sampler to produce an official sample and reject slurry portion. The hopper retention time was measured in order to calculate the number of secondary cuts per primary increment. The official sample and reject slurry portions were

collected in the separate containers as described in step d above. A picture of a secondary vezin sampler is shown in Figure A.6:

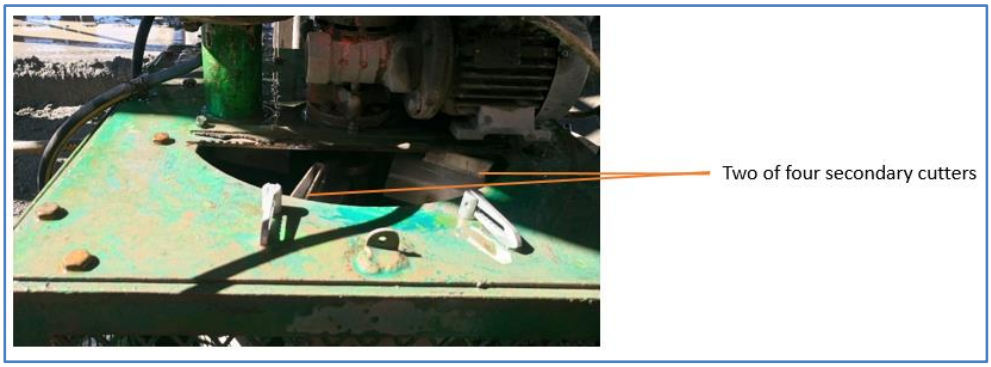


Figure A.6: Secondary Vezin Sampler with Four Cutter Arrangement.

g. The two sample containers having the official and reject samples were then removed from the sampling points. The containers were closed securely with the provided lids to ensure that no moisture evaporated and no sample was spilled. Each resulting sample was accompanied by a sample identification tag;

h. The flexible hose from the discharge point of the primary vezin cutter connected to the Y-bend feed inlet of the intermediate hopper was then detached.

i. A single manual primary cut was then taken. An empty and clean 20L bucket was used to collect this primary sample increment. The sample container with the collected primary slurry sample was then removed from the sampling point. The container was closed securely with the provided lid to ensure that no moisture evaporated and no sample was spilled. The resulting sample was accompanied by a sample identification tag;

j. The flexible hose was then reattached to the inlet of the intermediate hopper;

k. Steps d to g were repeated to generate another official and reject slurry sample combination;

l. Steps c to j were done five times for repeatability purposes. The time between each test run was minimized (less than 15minutes) to reduce the risk of introducing unpredicted process variability into the test work;

m. Once all the required number of samples had been collected i.e. five primary slurry sample increments and 10 pairs of official samples and reject slurry samples respectively, the sampler was immediately switched back to automatic operation mode;

n. The collected samples were then taken to a central storage area for further preparation and data recording.

The vezin credibility test thus generated the following samples:

Table A.2: Stage1, Test 1 Sample Generation

Test Run	Sample Identification	Sample Description
1	Sample 1A	Reject Slurry Sample
	Sample 1B	Official Slurry Sample
	Sample 1C	Primary Slurry Sample
	Sample 1D	Reject Slurry Sample
	Sample 1E	Official Slurry Sample
2	Sample 2A	Reject Slurry Sample
	Sample 2B	Official Slurry Sample
	Sample 2C	Primary Slurry Sample
	Sample 2D	Reject Slurry Sample
	Sample 2E	Official Slurry Sample
3	Sample 3A	Reject Slurry Sample
	Sample 3B	Official Slurry Sample

	Sample 3C	Primary Slurry Sample
	Sample 3D	Reject Slurry Sample
	Sample 3E	Official Slurry Sample
4	Sample 4A	Reject Slurry Sample
	Sample 4B	Official Slurry Sample
	Sample 4C	Primary Slurry Sample
	Sample 4D	Reject Slurry Sample
	Sample 4E	Official Slurry Sample
5	Sample 5A	Reject Slurry Sample
	Sample 5B	Official Slurry Sample
	Sample 5C	Primary Slurry Sample
	Sample 5D	Reject Slurry Sample
	Sample 5E	Official Slurry Sample

The samples generated from Test 1 as shown in Table A.2 were then subjected to the following procedure:

- Each sample was weighed wet. The bucket and lid tare masses were noted and as a result the net wet mass was determined per sample. This information was recorded on a raw data log sheet;

- The wet slurry sample was then filtered in a filter press to produce a wet filter cake. The wet filter cake mass was recorded on a raw data log sheet (See Appendix D);

- The wet filter cake was then placed in an oven to dry until constant mass was obtained (roughly 8 to 10 hours per sample);

- The dry sample was then allowed to cool to room temperature at which point the sample was weighed. The dry sample mass was recorded on a raw data log sheet (See Appendix D);

- The % solids was then calculated (See Appendix D);

- The dry sample was then lump broken in a lump breaker to get rid of large lumps of material;

- The broken material was then divided into sub-samples using a 10-way rotary splitter;

- One cup of sample was used to determine the particle size distribution (PSD) via a wet screening approach. The screen sizes used for generation of the PSD were 425µm, 300µm, 212µm, 150µm, 106µm, 75µm, 53µm, 38µm and pan (-38µm) respectively;

- The remaining cups of sample were combined and sent for 6T, base metal and Cr_2O_3 twin stream analyses (only applicable to Test Run 4 samples);

- Only one sample i.e. Test Run 4 sample 4C was sent for size by size analysis to obtain an indication of grade association by particle size. In order to obtain enough sample mass, various size fractions were combined. Figure A.7 gives further information;

- Quality assurance was attained by monitoring quality control aspects at various points during the sample preparation. Refer to Appendix E for further details relating to sample preparation and data logging.

Figure A.7 below is a summary of the sampling and sample preparation methodology followed for Stage 1, Test 1.

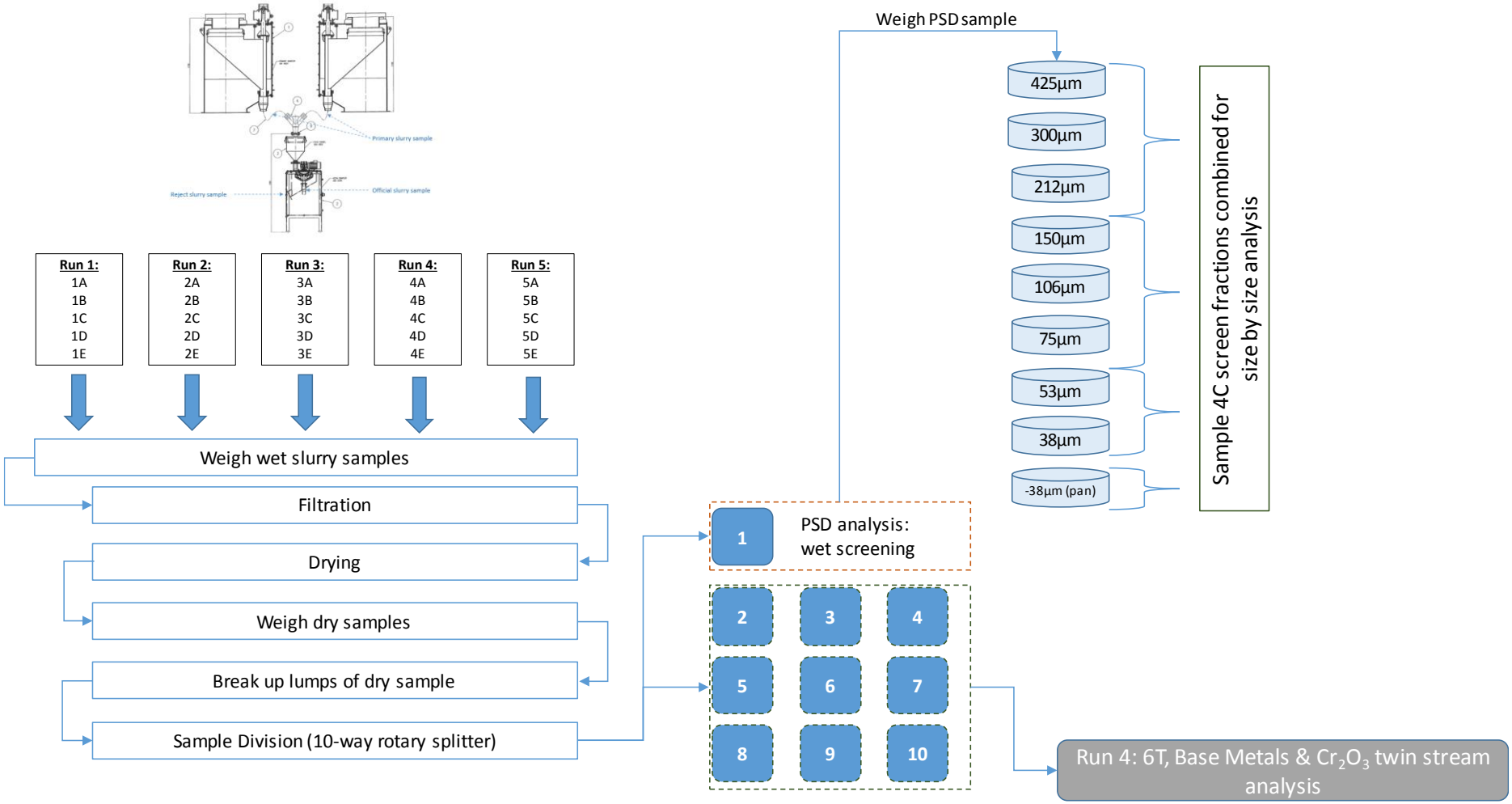


Figure A.7: Sampling & Sample Preparation Methodology for Stage 1, Test 1.

The second test performed was a sub-sampling test. The details of this test is explained in the section that follows.

A1.2. Stage 1, Test 2 Sub-Sampling Test Work

The following experimental test work design was conducted in order to validate the occurrence of particle segregation over time and to prove that coarser particles settle faster in the intermediate hopper and as a result exit the hopper quickly (if not immediately) and are therefore not sub-sampled for the entire duration of the sampling campaign.

In summary:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (Refer to Appendix C);

c. For every primary increment sub-sampled by the secondary vezin, an official slurry sample portion was collected every 6 seconds in separate containers until the intermediate hopper emptied out i.e. at time = 0 seconds, container 1 was placed in the official sample collection point. At time t = 6 seconds, container 2 replaced container 1. At time = 12 seconds, container 3 replaced container 2 and so forth.

d. Seven primary increments were taken and step c above was repeated until enough sample mass was cumulatively collected in this chronologically sequence;

e. Each of the chronological sub-samples were accompanied by a sample identification tag:

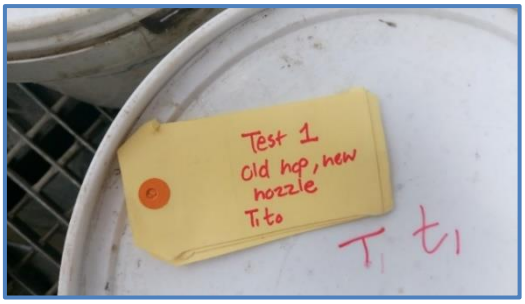


Figure A.8: Chronological Identification Example of Sub-Sample

f. The sub-samples were then wet screened independently over a 38µm screen to produce a +38µm fraction and -38µm fraction;

g. The -38µm fraction was then dried and weighed (data logged);

h. The +38µm fraction was filtered, dried and weighed (data logged);

i. The two fractions were then combined and weighed (data logged);

j. The % +38µm was then calculated;

k. The combined sample was then sent for 6T, base metals and Cr_2O_3 twin stream analysis.

The sub-sampling test was only conducted once and thus generated the following samples:

Table A.3: Stage 1, Test 2 Sample Generation

Test Run	Sample Identification	Sample Description
1	T2t0	0 - 6 seconds sub-sample
	T2t1	6 - 12 seconds sub-sample
	T2t2	12 - 18 seconds sub-sample
	T2t3	18 - 24 seconds sub-sample
	T2t4	24 - 33 seconds sub-sample

Figure A.9 below is a summary of the sampling and sample preparation methodology adopted for Stage 1, Test 2.

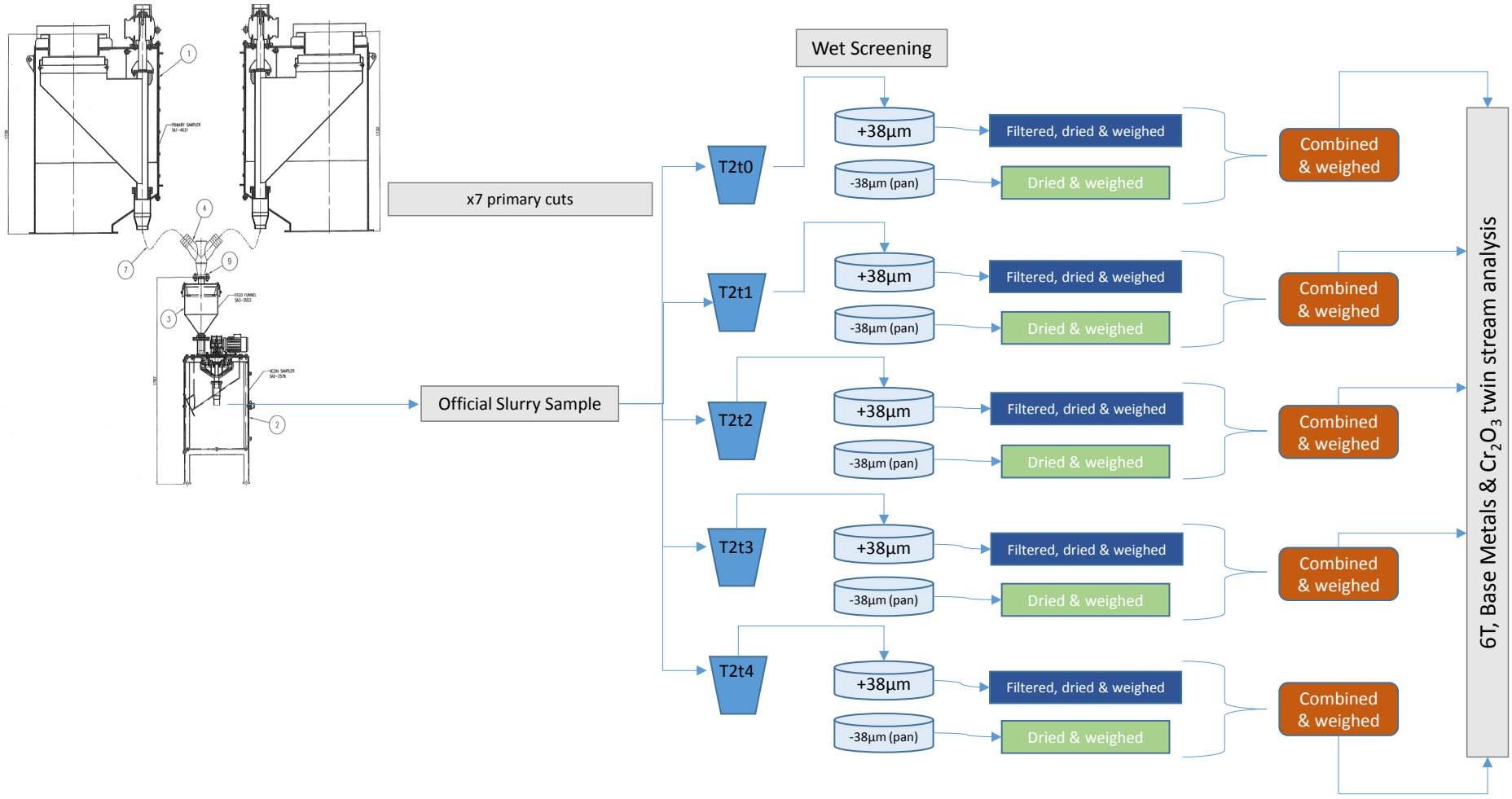


Figure A.9: Sampling & Sample Preparation Methodology for Stage 1, Test 2.

A2. Stage 2: Optimization of Existing Sampling Equipment

The second objective of this research project was to determine how particle segregation, if present, could be overcome by optimization of the existing sampling equipment.

Two optimization approaches to the existing sampling equipment were considered:

1. Re-design of the intermediate hopper nozzle;
2. Re-design of the intermediate hopper to incorporate mechanical stirring.

A2.1. Re-design of Intermediate Hopper Nozzle

The original nozzle design was as follows:



Figure A.10: Old Nozzle Design.

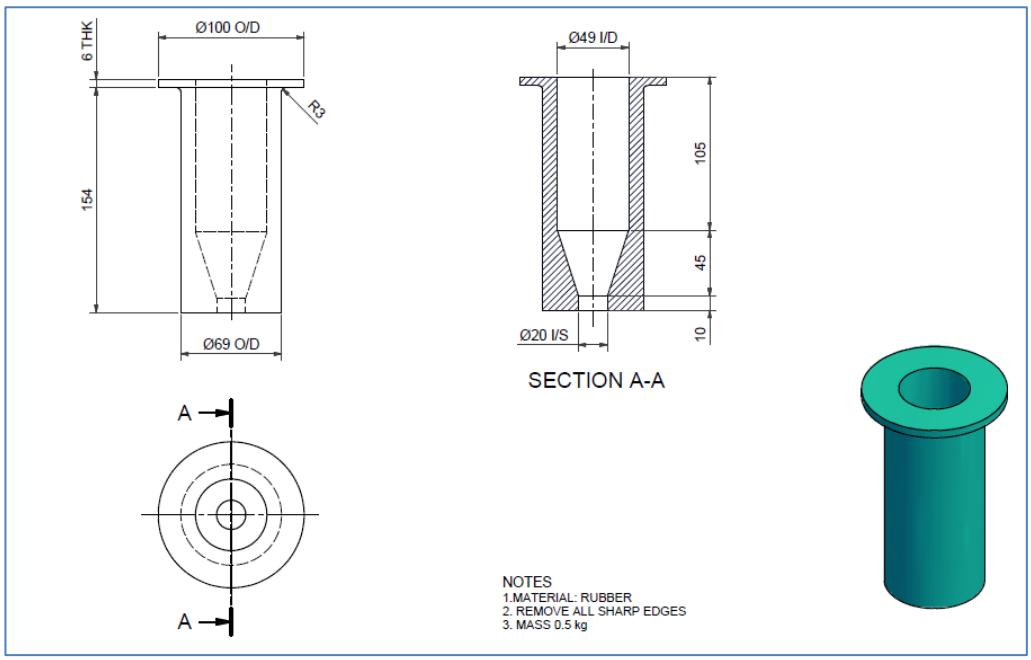


Figure A.11: Old Nozzle Design Engineering Schematic.

It was hypothesized that the geometry of the nozzle could be contributing to the possible particle segregation. The fact that the nozzle only tapers off to the nozzle diameter after 105mm of straight length promoted the argument that segregation would occur in this straight wide section. Under normal operation, the primary slurry sample would enter the intermediate hopper and be air agitated at the base of the hopper before entering the nozzle. The particles in the slurry material would then have an opportunity to settle out in the length of the nozzle (Figure A.11, total length of nozzle of 154mm) whose inside diameter is reduced gradually from 49mm to 20mm. The nozzle discharges into the secondary vezin sampler which is used for sub-sampling until the intermediate hopper is emptied out.

The idea of a new nozzle design was then suggested and discussed with a reputable supplier of sampling solutions and the following design was manufactured as a prototype nozzle[1]:



Figure A.12: New Nozzle Design.

[1] Author was only responsible for commissioning, ratification and analysis of test work results. Design credit to be given to Supplier of Sampling Solutions & Anglo American Platinum, Principal Sampling and Evaluation.

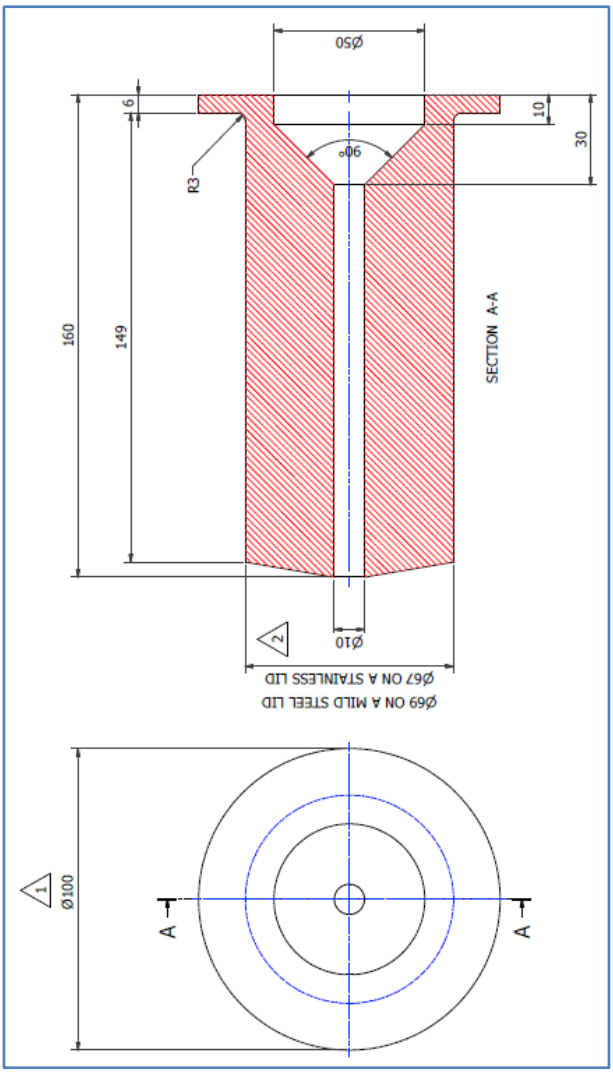


Figure A.13: New Nozzle Design Engineering Schematic.

The material of construction was changed from rubber to Nylatron (nylon plastic). The length of the nozzle was essentially the same as the old nozzle design. The tapering off of the nozzle internal diameter however was included immediately at the top of the nozzle opening. It was hypothesized that with a longer thinner straight section after tapering off, segregation can be mitigated against or minimised.

Test work was then conducted with the new nozzle design to compare both nozzle designs in terms of their effect on particle segregation in the intermediate hopper of the UG2 feed sampling system.

A2.2. Stage 2: Intermediate Hopper Nozzle Test Work

The baseline test work (Stage 1) was conducted using the old nozzle design with nozzle diameter of 10mm. A 10mm nozzle of the new design was then fabricated and replica of the experiments were conducted in order to make comparisons possible.

A2.2.1. Stage 2, Test 1 Vezin Credibility Test Work

As explained previously, two identical tests were conducted. The vezin credibility test being the first test for Stage 2 of the experimental work thus generated the following samples:

Table A.4: Stage 2, Test 1 Sample Generation

Test Run	Sample Identification	Sample Description
1	Sample 6A	Reject Slurry Sample
	Sample 6B	Official Slurry Sample
	Sample 6C	Primary Slurry Sample
	Sample 6D	Reject Slurry Sample
	Sample 6E	Official Slurry Sample
2	Sample 7A	Reject Slurry Sample
	Sample 7B	Official Slurry Sample
	Sample 7C	Primary Slurry Sample
	Sample 7D	Reject Slurry Sample
	Sample 7E	Official Slurry Sample
3	Sample 8A	Reject Slurry Sample
	Sample 8B	Official Slurry Sample
	Sample 8C	Primary Slurry Sample
	Sample 8D	Reject Slurry Sample
	Sample 8E	Official Slurry Sample
4	Sample 9A	Reject Slurry Sample
	Sample 9B	Official Slurry Sample
	Sample 9C	Primary Slurry Sample
	Sample 9D	Reject Slurry Sample

	Sample 9E	Official Slurry Sample
5	Sample 10A	Reject Slurry Sample
	Sample 10B	Official Slurry Sample
	Sample 10C	Primary Slurry Sample
	Sample 10D	Reject Slurry Sample
	Sample 10E	Official Slurry Sample

PSD's and assaying on all the samples from Stage 2, Test 1 were performed. A size by size analysis was not repeated as the previous size by size analysis was in line with historical mineralogical data. Figure A.14 overleaf indicates a summary of the sampling and sample preparation methodology followed for Stage 2, Test 1.

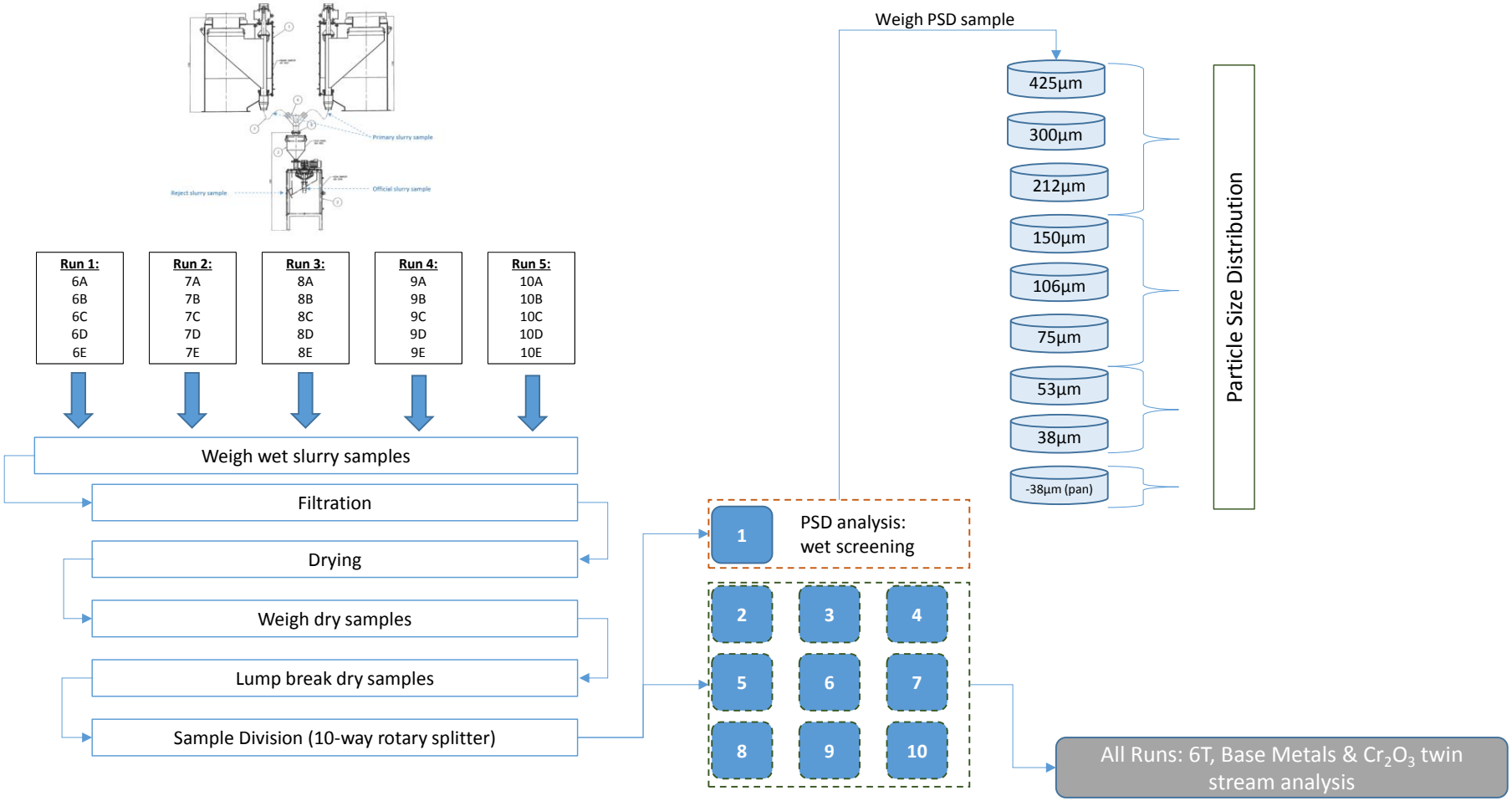


Figure A.14: Sampling & Sample Preparation Methodology for Stage 2, Test 1.

A2.2.2. Stage 2, Test 2 Sub-sampling Test Work

The exact procedure as explained previously was then repeated using the new nozzle. The sub-sampling test being the second test for Stage 2 of the experimental work was again only conducted once and thus generated the following samples:

Table A.5: Stage 2, Test 2 Sample Generation

Test Run	Sample Identification	Sample Description
1	T1t0	0 - 6 seconds sub-sample
	T1t1	6 - 12 seconds sub-sample
	T1t2	12 - 18 seconds sub-sample
	T1t3	18 - 24 seconds sub-sample
	T1t4	24 - 35 seconds sub-sample

Figure A.15 overleaf is a summary of the sampling and sample preparation methodology adopted for Stage 2, Test 2.

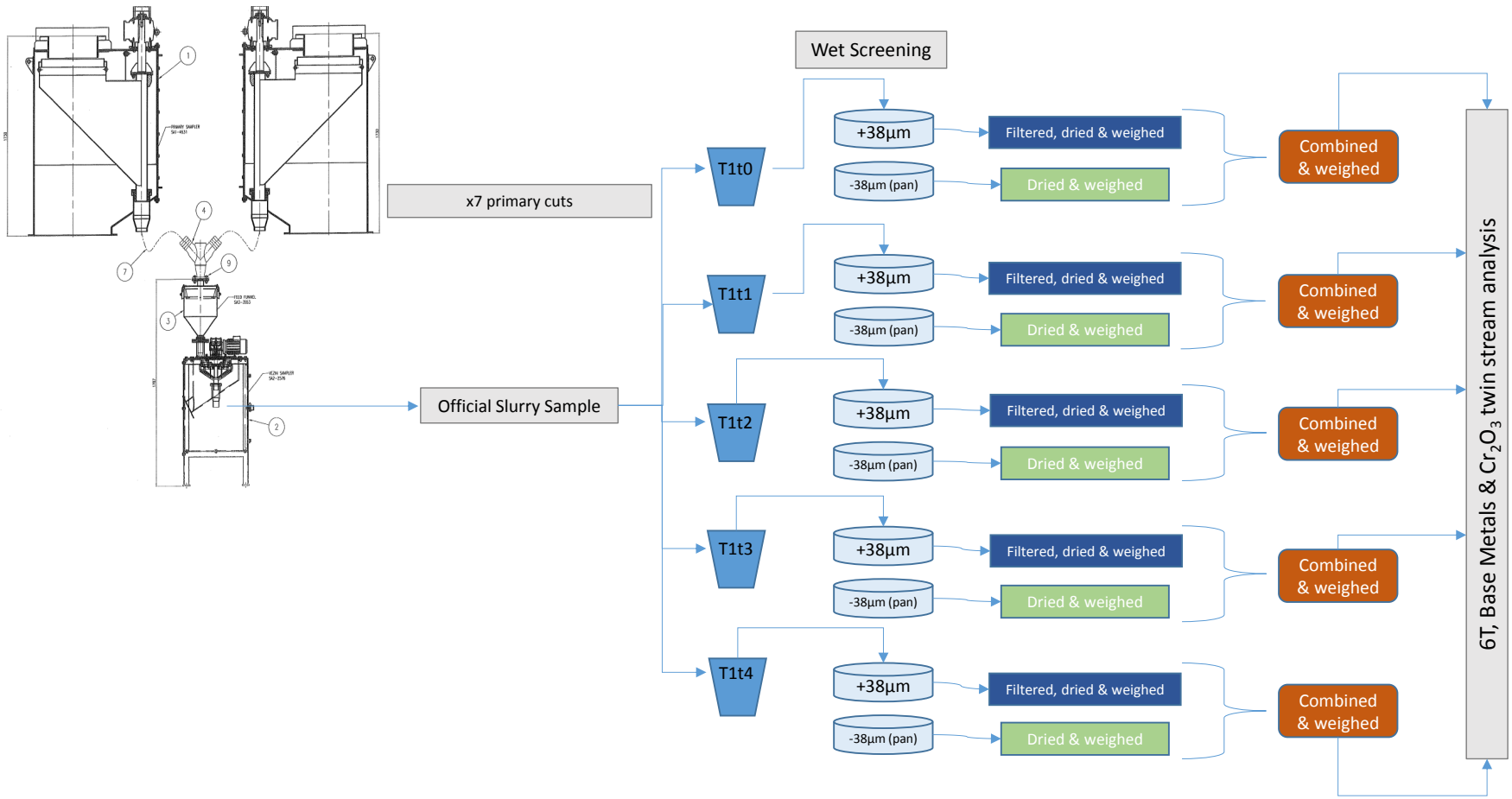


Figure A.15: Sampling & Sample Preparation Methodology for Stage 2, Test 2.

A2.3. Re-design of the Intermediate Hopper

After proving that particle segregation occurs in the intermediate hopper of the feed sampling system via the baseline vezin credibility test, optimization of the existing sample equipment and a re-design of the intermediate hopper were considered respectively.

Taking literature on mixing and particle segregation into account, it was decided that an improved new hopper design should incorporate an agitator. The agitator was supplied by an external supplier specializing in mixing. Typical UG2 feed material was provided to the supplier in order to specify an agitator suitable for the application in question. The agitator was designed[2] with two up thrust impellers and one down thrust impeller:

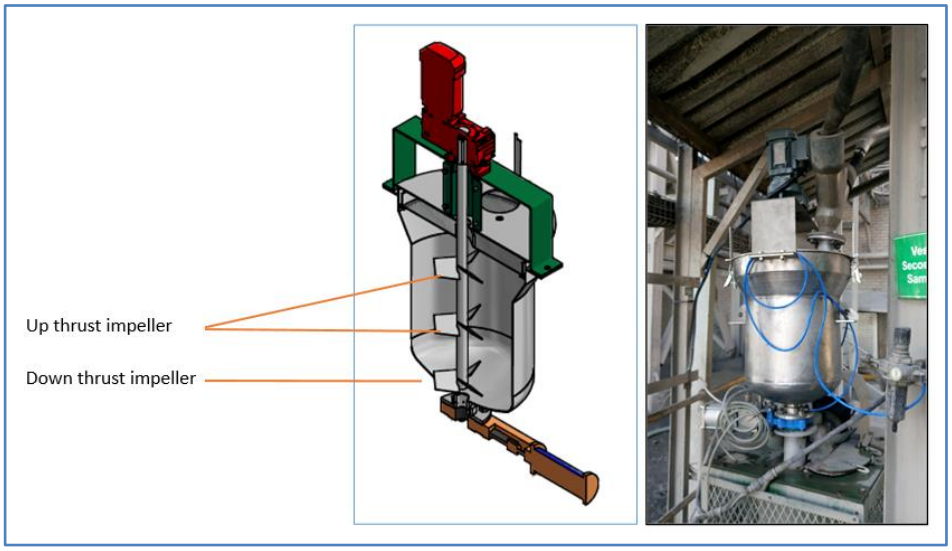


Figure A.16: Mechanical Hopper with Agitator.

A down thrust impeller functions to lift the material upwards in the hopper whereas the up thrust propellers function to keep the material in suspension.

[2] Author was only responsible for commissioning, ratification and analysis of test work results. Design credit to be given to Supplier of Sampling Solutions & Anglo American Platinum, Principal Sampling and Evaluation.

The shape of the hopper was also reconsidered and was changed from a conical base to a hemispherical base. In addition, it was decided that the sampling protocol be adjusted to include multiple primary slurry sample increments into the new hopper design prior to any sub-sampling taking place to overcome or minimize distributional heterogeneity. It was for this reason that the hopper capacity was tripled from 20L to 60L (effective volume).

The new hopper specifications are tabulated in Table A.6 below.

Table A.6: Equipment Specifications with Mechanical Hopper

Specification	Primary Vezin Sampler	Intermediate Hopper	Secondary Vezin Sampler
Critical Cutter Width (mm)	20	-	13
Critical Cutter Speed (m/s)	0.60	-	0.60
Cutting Interval (minutes)	Every 15 minutes	-	Rotates continuously
Capacity (litres)	~ 5.4	60	~ 0.54
Trash Screen Mesh (mm)	-	5	-
Nozzle/insert size (mm)	-	20	-
Gearbox/Motor	525V, 0.55kW, 50Hz, 6.1rpm	-	525V, 0.37kW, 50Hz, 28rpm
Agitator Speed	-	258rpm	-

A pneumatic valve was included in the new design to allow for multiple primary increments to be collected and retained in the hopper before sub-sampling could commence:



Figure A.17: Pneumatic Valve at Hopper Discharge End.

A3. Stage 3: Ratification & Testing of Re-Designed Mechanical Hopper

A3.1. Ratification of the Re-Designed Mechanical Hopper

The third objective of this research project was to explore a re-design of the sampling system. Given that the optimization of the nozzle design on the old hopper did not eliminate particle segregation, a mechanical hopper equipped with an agitator was designed and used with a view that it would further reduce the segregation observed in the old hopper. A prototype of the new hopper was fabricated by a reputable supplier of sampling solutions.

Prior to commissioning the new hopper on site, pre-work including a full risk assessment for the installation, operation and maintenance of the mechanical hopper was done (Refer to Appendix F for further details). An operating procedure and maintenance manual was also drafted and supplied to the site in question (Refer to Appendix G and H for a summary of the procedure and manual respectively). Change management was formally addressed and details can be found in Appendix I.

The original equipment manufacturer (OEM) was tasked to liaise with onsite engineering personnel in order to confirm the electrical and instrumentation requirements for the new installation.

The following items needed to be done on the new hopper arrangement:

- An additional control panel needed to be mounted in the field and this control panel needed to be integrated with the existing control panel in the field;

- The air supply for the pneumatic valve to release the primary samples for secondary sampling needed to be confirmed. A minimum of 4 bar air pressure was required. In addition, an air trap needed to be installed on the air supply line to filter the plant air (was likely to not be clean enough);

- Interconnecting cabling between the hopper agitator and the control panel was required.

The new hopper was commissioned on site on 28th October 2016. Cold commissioning involved switching on the agitator and feeding water into the hopper. Furthermore, it was vital to test that the lockable emergency stop button for the agitator functions properly.

Hot commissioning of the new hopper included:

- Establishment of the number of primary slurry increments that would adequately fit into the 60L hopper capacity. It was concluded that a maximum of ten primary increments would fit into the new hopper. The counter was thus set to 10:



Figure A.18: Primary Sample Counter.

- Determination of the hopper retention time. The time for the hopper to empty out completely was measured a number of times and averaged at approximately 6.5 minutes. A buffer was factored in (process flow variations or surges) and the timer for the valve to stay open was set at 8 minutes:



Figure A.19: Valve Open/Close Operation Timer.

- Installation of a safety guard for the rotating agitator shaft. This installation was not a preliminary requirement. During the commissioning of the new hopper, the onsite safety officer outlined that the exposed agitator shaft was a real concern. A guard was then designed, fabricated and installed by the OEM of the new hopper:



Figure A.20: Agitator Shaft Guard.

In summary, the control philosophy for the new hopper is:

1. A primary cut is taken automatically at a 15 minute time interval;
2. The hopper discharge valve must remain in the closed position;
3. Steps 1-2 is repeated until ten primary cuts are taken;
4. On the 10th primary cut, the discharge valve must open automatically and secondary sub-sampling must commence;
5. After 8 minutes, the discharge valve must close automatically;
6. The primary sample counter then resets to “0” and steps 1-5 begins again.

Once stable operation of the new hopper was confirmed, testing resumed.

A3.2. Testing of the Re-Designed Mechanical Hopper

As explained previously, two identical tests were conducted. The tests were conducted firstly with the new hopper, old nozzle design combination and then with the new hopper, new nozzle design combination. The nozzle diameter (old and new design) used for the following tests was kept constant at 20mm. The nozzle diameter

was doubled from previous tests to prevent the new hopper from choking. It was also clear that the new hopper was not ergonomically friendly as unchoking of the hopper required three times the manpower needed for the old hopper design (future versions would need to take this into consideration). The minimum number of secondary cuts were calculated to exceed 30 and thus this change was not deemed negative for test work purposes.

The experimental procedure however was slightly different due to the collection of primary increments in the mechanical hopper. The details are discussed below.

A3.2.1 New Hopper, Old Nozzle Design Combination

A3.2.1.1 Stage 3A, Test 1 Vezin Credibility Test

The standard vezin credibility technique had to be modified to incorporate the operation of the mechanical hopper.

The vezin credibility testing involved the following steps:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (Refer to Appendix C for further details). The equipment was inspected for leaks and physical damage. Any concerns were noted. The secondary vezin speed was rechecked (Refer to Appendix B for further details);

c. The main feed stream was sampled by the mechanically designed primary vezin on a pre-determined time interval of two minutes. For the purposes of the test, this parameter was kept constant;
d. The flexible hose from the discharge point of the primary vezin cutter connected to the Y-bend feed inlet of the intermediate hopper was

then detached. The first primary cut once automatically initiated was then collected in an empty and clean 20L bucket. The sample container with the collected primary slurry sample was then removed from the sampling point. The container was closed securely with the provided lid to ensure that no sample leaked out and no sample was spilled. The resulting sample was accompanied by a sample identification tag;

e. The flexible hose was then reattached to the inlet of the intermediate hopper;

f. The next two primary cuts were collected in the new hopper and the discharge valve was checked and found to be in the closed position. At this point, the counter display showed "3" primary cuts had been taken;

g. Steps d, e and f then followed with the exceptions of step d where the fourth primary cut was collected and step f where the counter display showed "6" primary cuts had been taken;

h. Again, steps d, e and f then followed with the exceptions of step d where the seventh primary cut was collected and step f where the counter display showed "9" primary cuts had been taken;

i. A clean and empty 20L plastic bucket was then placed at the secondary vezin reject sample pipe discharge end and a clean and empty 5L container was placed at the official sample pipe discharge end;

j. Upon initiation of the 10^{th} primary cut, the hopper discharge valve opened automatically and the material in the hopper was then sub-sampled by the secondary vezin sampler to produce an official sample

and reject slurry portion. The hopper retention time was measured (for the six primary increments collected in the hopper) in order to calculate the number of secondary cuts per six primary increments. The official sample and reject slurry portions were collected in the separate containers as described in step i above;

k. The two sample containers with the collected official and reject slurry samples were then removed from the sampling points. The containers were closed securely with the provided lids to ensure that no sample leaked out and no sample was spilled. Each resulting sample was accompanied by a sample identification tag;

l. This approach (steps c to k) continued three times for repeatability purposes (i.e. three test runs were done). The time between each test run was minimized (less than 30minutes) to reduce the risk of introducing unpredicted process variability into the test work;

m. Once all the required number of samples had been collected i.e. four primary slurry sample increments and 1 pair of official sample and reject slurry samples respectively, the sampler was immediately switched back to normal operation mode;

n. The collected samples were then taken to a central storage area for further preparation and data recording.

The vezin credibility test generated the following samples:

Table A.7: Stage 3A, Test 1 Sample Generation

Test Run	Sample Identification	Sample Description
1	Sample 7A	Primary Slurry Sample
	Sample 7B	Primary Slurry Sample
	Sample 7C	Primary Slurry Sample

	Sample 7D	Primary Slurry Sample
	Sample 7E	Official Slurry Sample
	Sample 7F	Reject Slurry Sample
2	Sample 9A	Primary Slurry Sample
	Sample 9B	Primary Slurry Sample
	Sample 9C	Primary Slurry Sample
	Sample 9D	Primary Slurry Sample
	Sample 9E	Official Slurry Sample
	Sample 9F	Reject Slurry Sample
3	Sample 11A	Primary Slurry Sample
	Sample 11B	Primary Slurry Sample
	Sample 11C	Primary Slurry Sample
	Sample 11D	Primary Slurry Sample
	Sample 11E	Official Slurry Sample
	Sample 11F	Reject Slurry Sample

The sample generated from Stage 3, Test 1 as per Table A.7 above were then subjected to the following process:

- Each sample was weighed wet. The bucket and lid tare masses were noted and as a result the net wet mass was determined per sample. This information was recorded on a raw data log sheet;

- The wet slurry sample was then filtered in a filter press to produce a wet filter cake. The wet filter cake mass was recorded on a raw data log sheet;

- The wet filter cake was then placed in an oven to dry until constant mass was obtained (roughly 8 to 10 hours per sample);

- The dry sample was then allowed to cool to room temperature at which point the sample was weighed. The dry sample mass was recorded on a raw data log sheet;

- The % solids was then calculated;

- The dry sample was then broken up in a lump breaker to get rid of large lumps of material;
- The lump broken material was then divided into sub-samples using a 10-way rotary splitter;

- One cup of sample was used to determine the particle size distribution (PSD) via a wet screening approach. The screen sizes used for generation of the PSD were 425µm, 300µm, 212µm, 150µm, 106µm, 75µm, 53µm, 38µm and pan (-38µm) respectively;

- The remaining cups of sample were combined and sent for 6T, base metal and Cr_2O_3 twin stream analyses;

- Quality assurance was attained by monitoring quality control aspects at various points during sample preparation. Refer to Appendix D and E for further details relating to sample preparation and data logging.

Figure A.21 is a summary of the sampling and sample preparation methodology followed for Stage 3, Test 1.

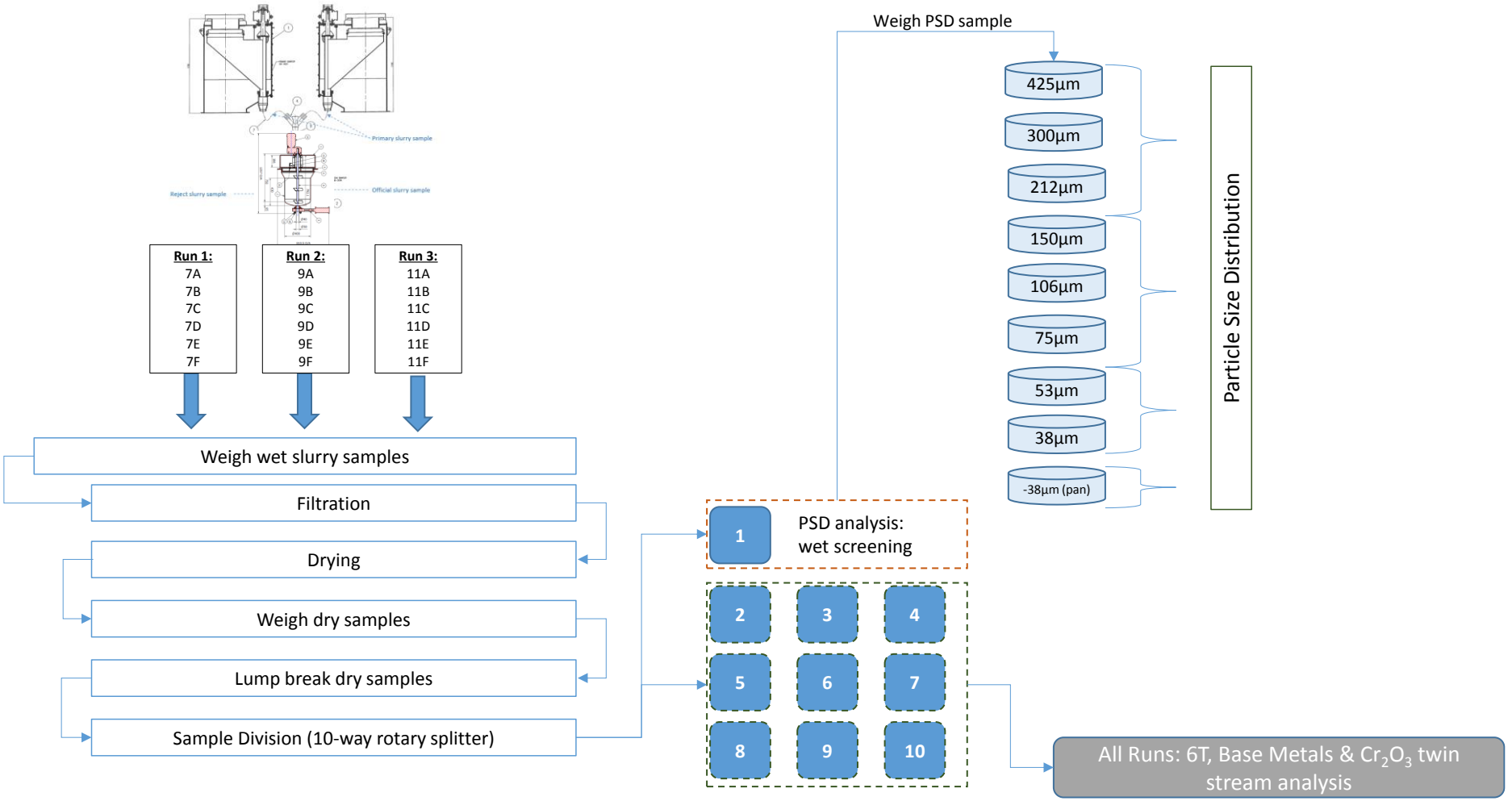


Figure A.21: Sampling & Sample Preparation Methodology for Stage 3A, Test 1.

A3.2.1.2. Stage 3A, Test 2 Sub-sampling Test Work

The previous sub-sampling experimental design had to be modified to incorporate the operation of the mechanical hopper.

In summary:

a. The plant control room personnel were notified of the test work plan;

b. A pre-work risk assessment was performed by all personnel involved in the test work (Refer to Appendix C for further details);

c. For every ten primary increments collectively sub-sampled by the secondary vezin, an official slurry sample portion was collected at the following times until the intermediate hopper emptied out and the discharge valve automatically closed:

- At time = 0 seconds, container 1 was placed in the official sample collection point;
- At time t = 6 seconds, container 2 replaced container 1;
- At time = 15 seconds, container 3 replaced container 2;
- At time = 30 seconds, container 4 replaced container 3;
- At time = 60 seconds, container 5 replaced container 4;
- At time = 90 seconds, container 6 replaced container 5;
- At time = 120 seconds, container 7 replaced container 6;

- At time = 150 seconds, container 8 replaced container 7;

- At time = 180 seconds, container 9 replaced container 8;

- At time = 210 seconds, container 10 replaced container 9. This container remained in position until the intermediate hopper emptied out.

d. Step c was repeated three times until enough sample mass was cumulatively collected in this chronologically sequence. Each of the chronological sub-samples were accompanied by a sample identification tag;

e. The sub-samples were then wet screened independently over a 75µm screen to produce a +75µm fraction and -75µm fraction;

f. The -75µm fraction was filtered, dried and weighed (data logged);

g. The +75µm fraction was filtered, dried and weighed (data logged);

h. The two fractions were then combined and weighed (data logged);

i. The % +75µm was then calculated;

j. The combined sample was then sent for 6T, base metals and Cr_2O_3 twin stream analysis.

The sub-sampling test being the second test for Stage 3A of the experimental work was only conducted once and generated the following samples overleaf:

Table A.8: Stage 3A, Test 2 Sample Generation

Test Run	Sample Identification	Sample Description
1	T6t0	0 - 6 seconds sub-sample
	T6t1	6 - 15 seconds sub-sample
	T6t2	15 - 30 seconds sub-sample
	T6t3	30 - 60 seconds sub-sample
	T6t4	60 - 90 seconds sub-sample
	T6t5	90 - 120 seconds sub-sample
	T6t6	120 - 150 seconds sub-sample
	T6t7	150 - 180 seconds sub-sample
	T6t8	180 - 210 seconds sub-sample
	T6t9	210 seconds till hopper emptied out sub-sample

Figure A.22 is a summary of the sampling and sample preparation methodology adopted for Stage 3A, Test 2.

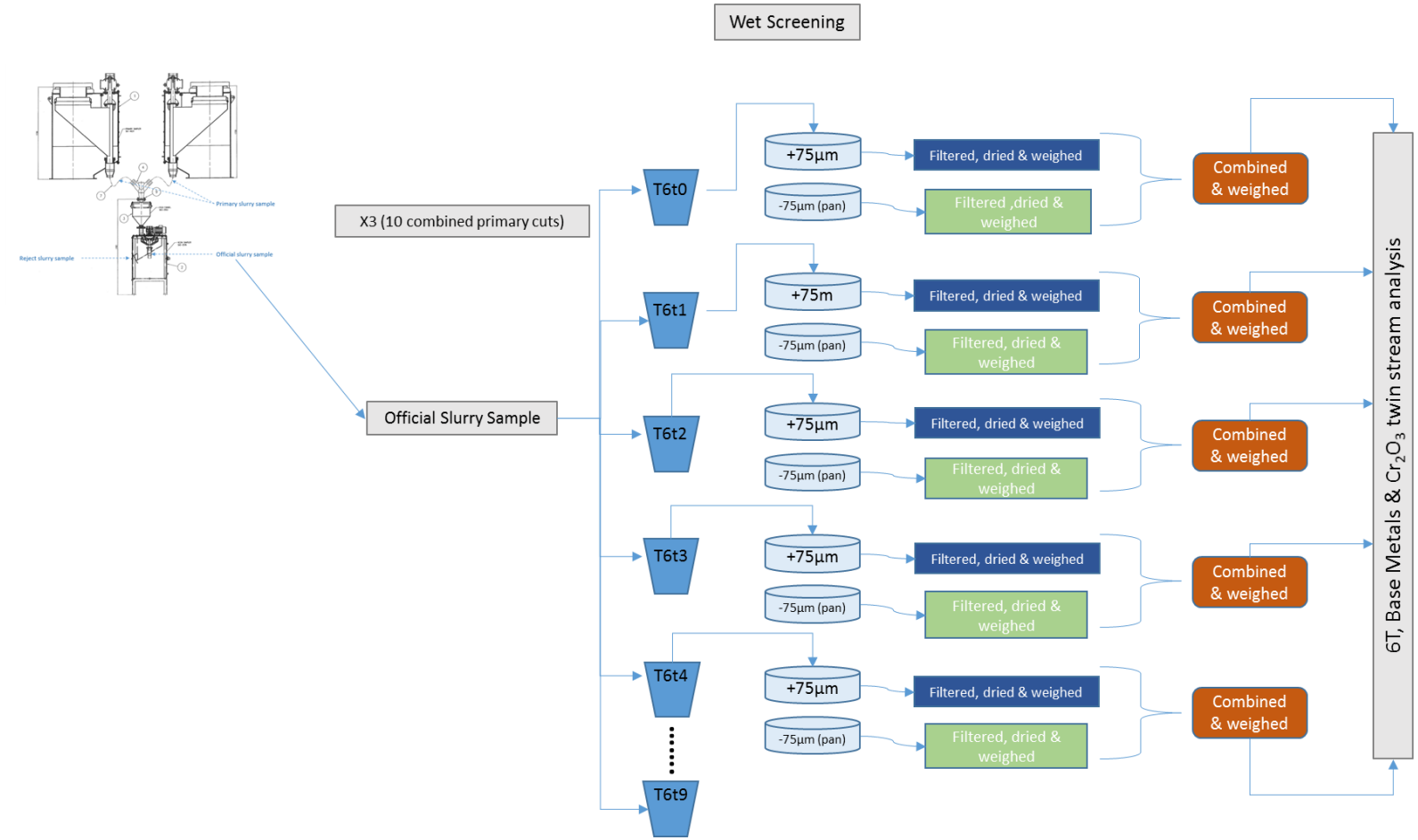


Figure A.22: Sampling & Sample Preparation Methodology for Stage 3A, Test 2.

A3.2.2. New Hopper, New Nozzle Design Combination

A3.2.2.1 Stage 3B, Test 1 Vezin Credibility Test

The same procedure described previously was followed using the new hopper with new nozzle design. The vezin credibility test being the third test for Stage 3 of the experimental work generated the following samples:

Table A.9: Stage 3B, Test 1 Sample Generation

Test Run	Sample Identification	Sample Description
1	Sample 12A	Primary Slurry Sample
	Sample 12B	Primary Slurry Sample
	Sample 12C	Primary Slurry Sample
	Sample 12D	Primary Slurry Sample
	Sample 12E	Official Slurry Sample
	Sample 12F	Reject Slurry Sample
2	Sample 14A	Primary Slurry Sample
	Sample 14B	Primary Slurry Sample
	Sample 14C	Primary Slurry Sample
	Sample 14D	Primary Slurry Sample
	Sample 14E	Official Slurry Sample
	Sample 14F	Reject Slurry Sample
3	Sample 16A	Primary Slurry Sample
	Sample 16B	Primary Slurry Sample
	Sample 16C	Primary Slurry Sample
	Sample 16D	Primary Slurry Sample
	Sample 16E	Official Slurry Sample
	Sample 16F	Reject Slurry Sample

Figure A.23 is a summary of the sampling and sample preparation methodology followed for Stage 3B, Test 1.

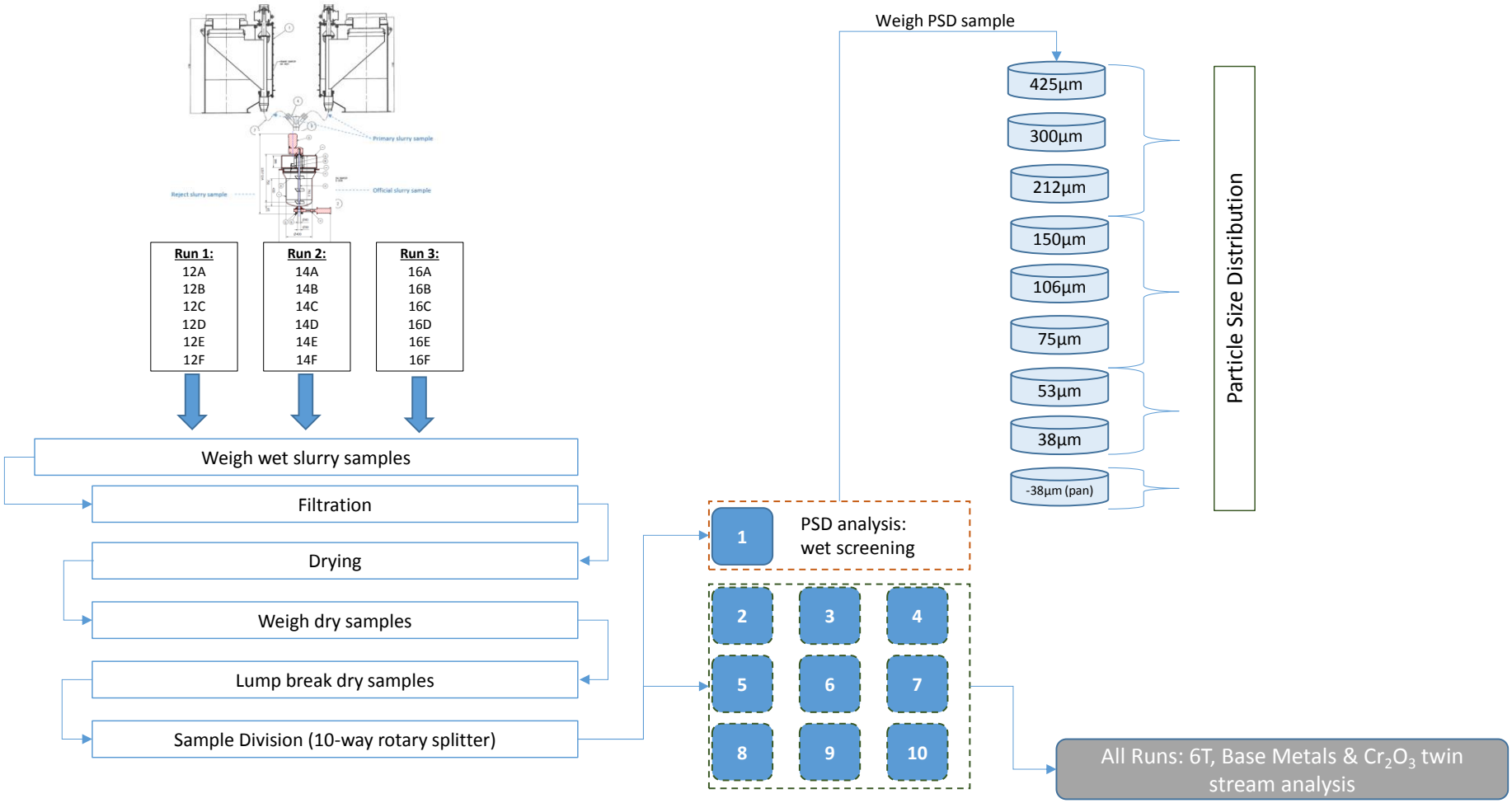


Figure A.23: Sampling & Sample Preparation Methodology for Stage 3B, Test 1.

A3.2.2.2. Stage 3B, Test 2 Sub-sampling Test Work

The same procedure described previously was followed using the new hopper with the new nozzle design.

The sub-sampling test being the fourth test for Stage 3 of the experimental work thus generated the following samples:

Table A.10: Stage 3B, Test 2 Sample Generation

Test Run	Sample Identification	Sample Description
1	T8t0	0 - 6 seconds sub-sample
	T8t1	6 - 15 seconds sub-sample
	T8t2	15 - 30 seconds sub-sample
	T8t3	30 - 60 seconds sub-sample
	T8t4	60 - 90 seconds sub-sample
	T8t5	90 - 120 seconds sub-sample
	T8t6	120 - 150 seconds sub-sample
	T8t7	150 - 180 seconds sub-sample
	T8t8	180 - 210 seconds sub-sample
	T8t9	210 seconds till hopper emptied out sub-sample

Figure A.24 is a summary of the sampling and sample preparation methodology adopted for Stage 3B, Test 2.

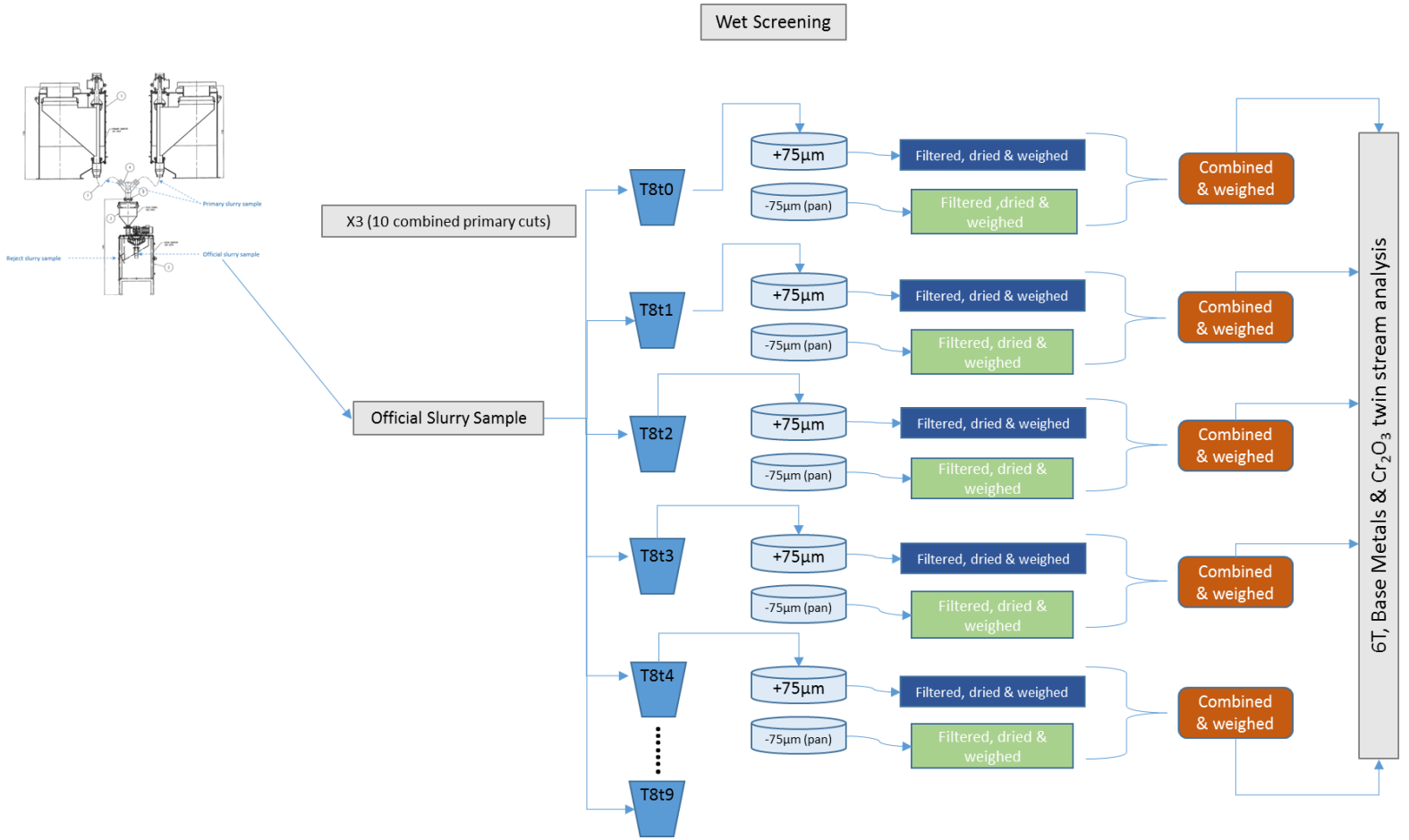
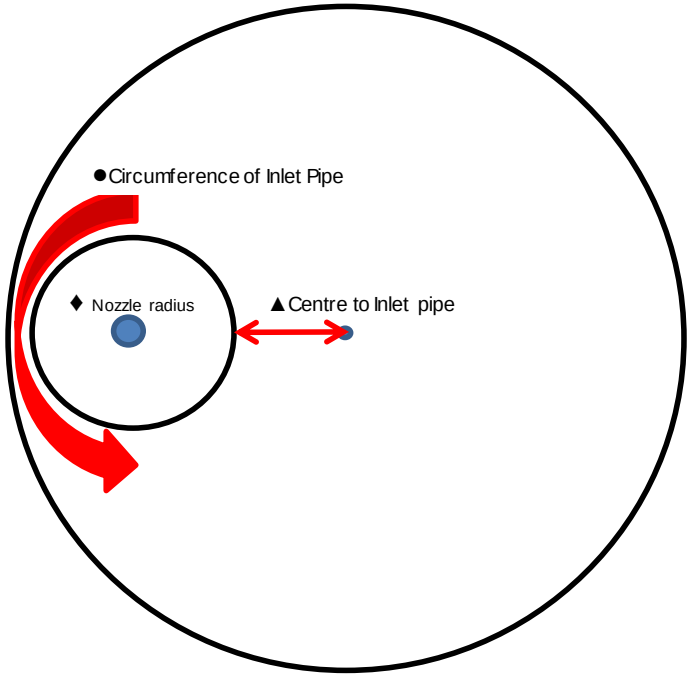


Figure A.24: Sampling & Sample Preparation Methodology for Stage 3B, Test 2.

Appendix B: Secondary Vezin Equipment Setup Calculations

An illustration of measurements required and the calculations of the secondary vezin speed and number of secondary cuts are shown below.

Top view of secondary vezin:



Measurements	
♦ **Visually determine Nozzle size**	10 mm
■ Nozzle Radius = Size of Nozzle / 2	5 mm
Radius of Vezin = ▲Centre to Inlet pipe + Radius of Inlet Pipe + Nozzle Radius	15.6 cm
Radius of Vezin in meters = Radius in cm / 100	0.156 m
Circumference of Vezin: Circumference = $2\pi R$ = 2 x 3.14 x Radius of Vezin = 6.28 x 0.156m = 0.980 m	
Revolutions per minute	30 rpm
Time for one revolution = 60 seconds in a minute / rpm	2 sec
Speed of Secondary Cutter = Circumference of Vezin / Time for one revolution = 0.980 m /2 sec = 0.49m/s	
Retention Time in Hopper	0 min 45 sec
Retention Time in Hopper (seconds only) = Minutes x 60 + seconds	45 sec
Number of Secondary cuts = (Retention time in seconds / Time for one revolution) x Number of secondary cutters =(45sec /2sec) x 4 cutters = 90 cuts	

Figure B.1: Illustration of Secondary Vezin Equipment Setup Calculations.

Appendix C: Pre-Work Risk Assessments

A pre-work risk assessment was performed prior to each stage of test work taking place and are shown in the figures that follow.

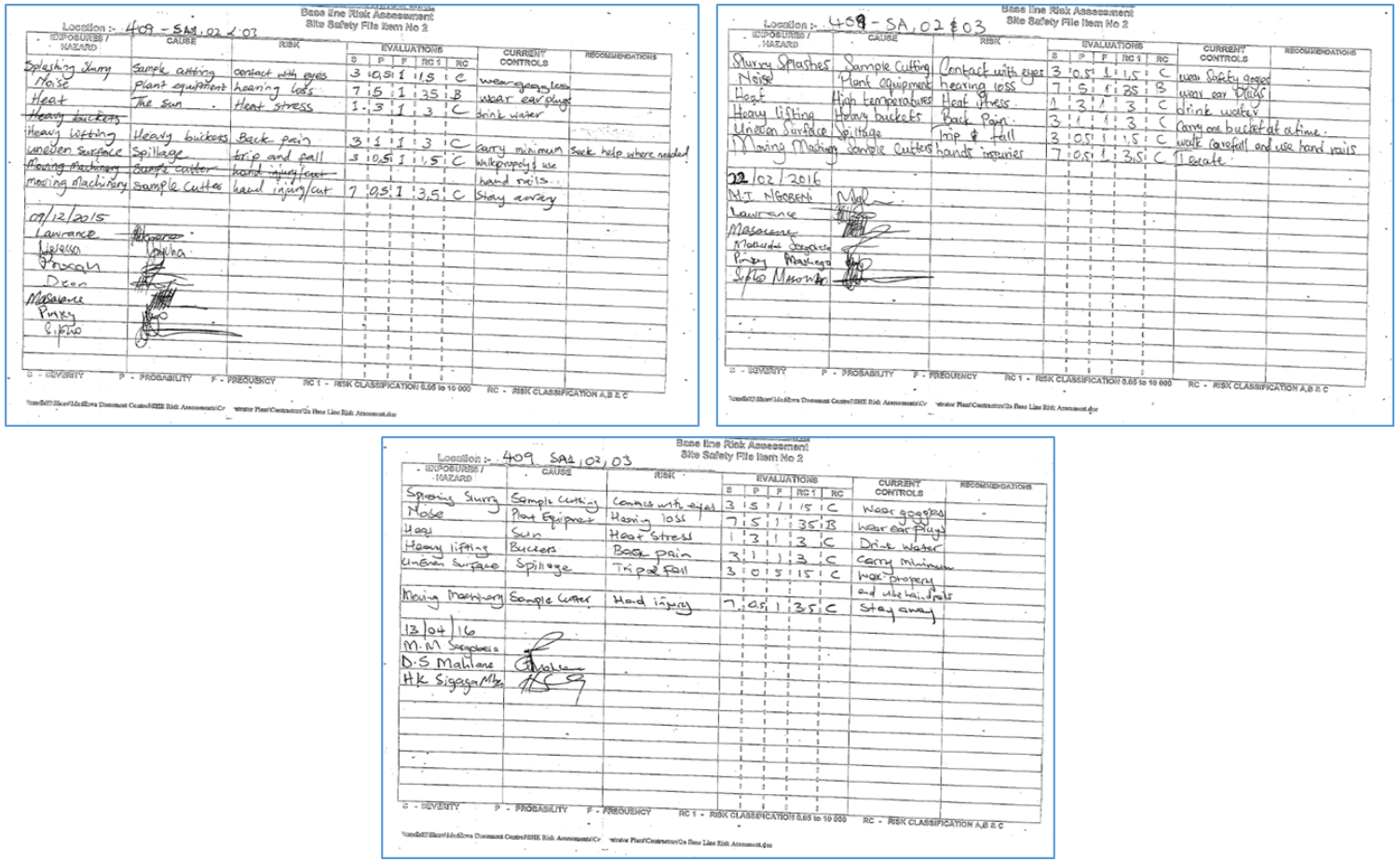
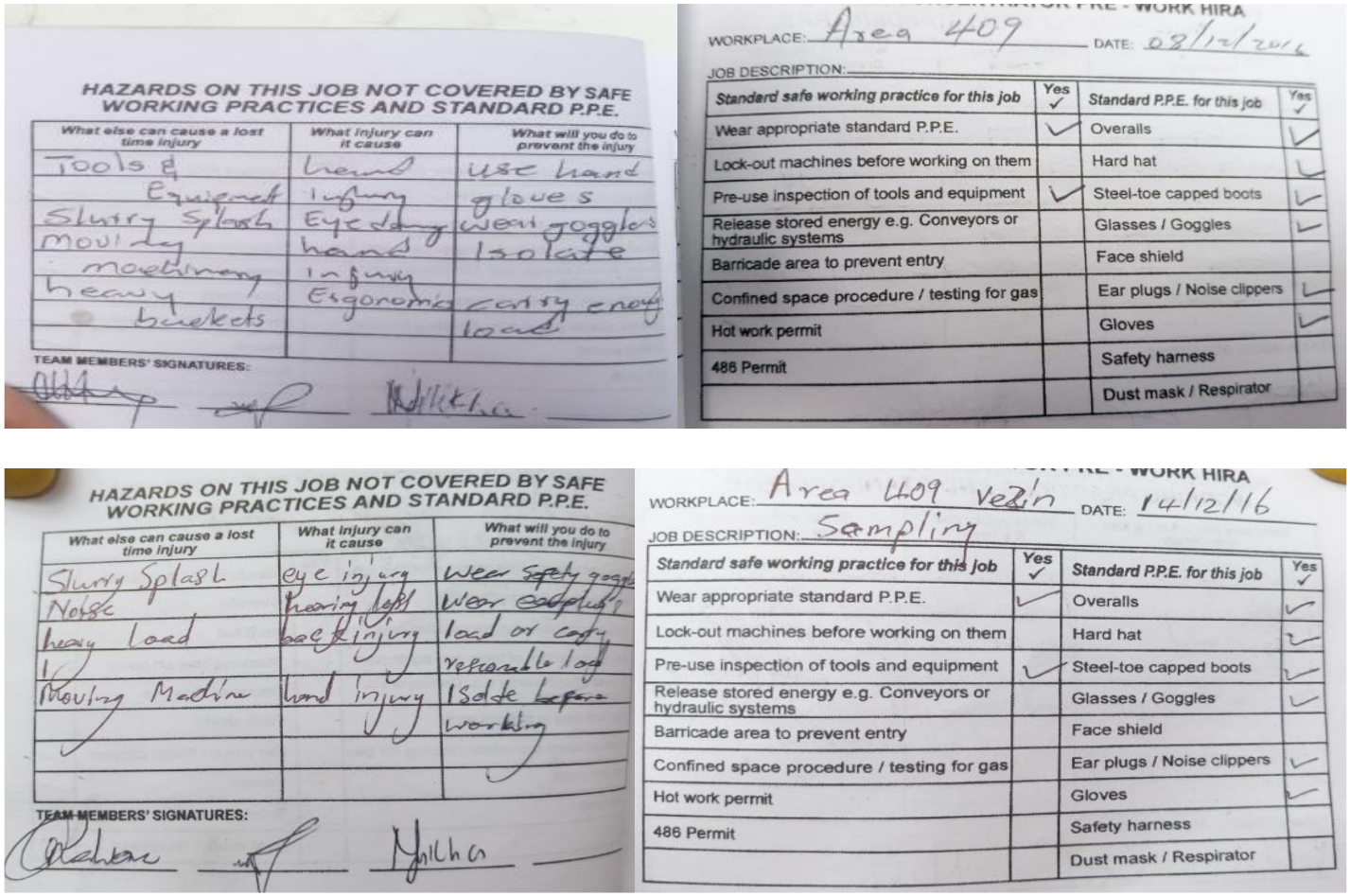


Figure C.1: Stage 1 and 2 Test Work Pre-Work Risk Assessments.



HAZARDS ON THIS JOB NOT COVERED BY SAFE WORKING PRACTICES AND STANDARD P.P.E.

What else can cause a lost time injury	What injury can it cause	What will you do to prevent the injury
Tools & Equipment	head injury	use hand gloves
Slurry Splash	Eye damage	wear goggles
mouldy	hand injury	Isolate
machinery		
heavy buckets	Ergonomic	carry energy load

TEAM MEMBERS' SIGNATURES:

WORKPLACE: Area 409 DATE: 08/12/2016

JOB DESCRIPTION:

Standard safe working practice for this job	Yes ✓	Standard P.P.E. for this job	Yes ✓
Wear appropriate standard P.P.E.	✓	Overalls	✓
Lock-out machines before working on them		Hard hat	✓
Pre-use inspection of tools and equipment	✓	Steel-toe capped boots	✓
Release stored energy e.g. Conveyors or hydraulic systems		Glasses / Goggles	✓
Barricade area to prevent entry		Face shield	
Confined space procedure / testing for gas		Ear plugs / Noise clippers	✓
Hot work permit		Gloves	✓
486 Permit		Safety harness	
		Dust mask / Respirator	

HAZARDS ON THIS JOB NOT COVERED BY SAFE WORKING PRACTICES AND STANDARD P.P.E.

What else can cause a lost time injury	What injury can it cause	What will you do to prevent the injury
Slurry Splash	eye injury	Wear Safety goggle
Noise	hearing loss	Wear earplug
heavy load	back injury	load or carry reasonable load
Moving Machine	hand injury	Isolate before working

TEAM MEMBERS' SIGNATURES:

WORKPLACE: Area 409 Vezin DATE: 14/12/16

JOB DESCRIPTION: Sampling

Standard safe working practice for this job	Yes ✓	Standard P.P.E. for this job	Yes ✓
Wear appropriate standard P.P.E.	✓	Overalls	✓
Lock-out machines before working on them		Hard hat	✓
Pre-use inspection of tools and equipment	✓	Steel-toe capped boots	✓
Release stored energy e.g. Conveyors or hydraulic systems		Glasses / Goggles	✓
Barricade area to prevent entry		Face shield	
Confined space procedure / testing for gas		Ear plugs / Noise clippers	✓
Hot work permit		Gloves	✓
486 Permit		Safety harness	
		Dust mask / Respirator	

Figure C.2: Stage 3A and 3B Test Work Pre-Work Risk Assessments.

Appendix D: Raw Data for all Test Work

The raw data for each stage of test work is included below.

Table D.1: Stage 1, Test 1 Wet and Dry Process Raw Data

VEZIN CREDIBILITY TEST										
TEST 1										
	SLURRY MASS (kg)			WET PROCESS			DRY PROCESS			
SAMPLE ID	GROSS MASS	BUCKET MASS	NETT SLURRY MASS	GROSS MASS	TRAY TARE MASS	NETT WET MASS	GROSS MASS	TRAY TARE MASS	NETT DRY MASS	% SOLIDS
Sample 1A - Reject	17.320	0.640	16.680	11.408	1.770	9.638	10.080	1.770	8.310	49.820
Sample 1B - Sample	1.950	0.154	1.796	2.178	1.129	1.049	1.986	1.129	0.857	47.717
Sample 1C - Primary	21.090	0.650	20.440	15.615	1.762	13.853	14.141	1.762	12.379	60.563
Sample 1D - Reject	16.570	0.650	15.920	10.915	1.487	9.428	9.571	1.487	8.084	50.779
Sample 1E - Sample	1.890	0.153	1.737	2.117	1.121	0.996	1.938	1.121	0.817	47.035
TEST 2										
	SLURRY MASS (kg)			WET PROCESS			DRY PROCESS			
SAMPLE ID	GROSS MASS	BUCKET MASS	NETT SLURRY MASS	GROSS MASS	TRAY TARE MASS	NETT WET MASS	GROSS MASS	TRAY TARE MASS	NETT DRY MASS	% SOLIDS
Sample 2A - Reject	15.890	0.640	15.250	9.717	1.130	8.587	8.238	1.130	7.108	46.610
Sample 2B - Sample	1.820	0.154	1.666	2.045	1.124	0.921	1.898	1.124	0.774	46.459
Sample 2C - Primary	23.340	0.640	22.700	14.953	1.755	13.198	13.341	1.755	11.586	51.040
Sample 2D - Reject	18.070	0.640	17.430	11.630	1.489	10.141	10.213	1.489	8.724	50.052
Sample 2E - Sample	2.060	0.154	1.906	2.205	1.127	1.078	2.022	1.127	0.895	46.957
TEST 3										
	SLURRY MASS (kg)			WET PROCESS			DRY PROCESS			
SAMPLE ID	GROSS MASS	BUCKET MASS	NETT SLURRY MASS	GROSS MASS	TRAY TARE MASS	NETT WET MASS	GROSS MASS	TRAY TARE MASS	NETT DRY MASS	% SOLIDS
Sample 3A - Reject	17.850	0.640	17.210	11.787	1.763	10.024	10.471	1.763	8.708	50.598
Sample 3B - Sample	2.100	0.310	1.790	2.179	1.126	1.053	1.983	1.126	0.857	47.877
Sample 3C - Primary	18.100	0.650	17.450	12.108	1.762	10.346	10.990	1.762	9.228	52.883
Sample 3D - Reject	18.380	0.640	17.740	12.399	1.307	11.092	10.863	1.307	9.556	53.867
Sample 3E - Sample	2.160	0.300	1.860	2.300	1.124	1.176	2.067	1.124	0.943	50.699
TEST 4										
	SLURRY MASS (kg)			WET PROCESS			DRY PROCESS			
SAMPLE ID	GROSS MASS	BUCKET MASS	NETT SLURRY MASS	GROSS MASS	TRAY TARE MASS	NETT WET MASS	GROSS MASS	TRAY TARE MASS	NETT DRY MASS	% SOLIDS
Sample 4A - Reject	20.810	0.640	20.170	13.392	1.293	12.099	11.929	1.293	10.636	52.732
Sample 4B - Sample	2.360	0.300	2.060	2.349	1.129	1.220	2.136	1.129	1.007	48.883
Sample 4C - Primary	18.410	0.640	17.770	12.001	1.490	10.511	10.629	1.490	9.139	51.429
Sample 4D - Reject	18.580	0.640	17.940	11.872	1.302	10.570	10.249	1.302	8.947	49.872
Sample 4E - Sample	2.200	0.302	1.898	2.187	1.127	1.060	2.009	1.127	0.882	46.470
TEST 5										
	SLURRY MASS (kg)			WET PROCESS			DRY PROCESS			
SAMPLE ID	GROSS MASS	BUCKET MASS	NETT SLURRY MASS	GROSS MASS	TRAY TARE MASS	NETT WET MASS	GROSS MASS	TRAY TARE MASS	NETT DRY MASS	% SOLIDS
Sample 5A - Reject	16.890	0.640	16.250	10.744	1.488	9.256	9.583	1.488	8.095	49.815
Sample 5B - Sample	2.070	0.311	1.759	2.111	1.129	0.982	1.925	1.129	0.796	45.253
Sample 5C - Primary	20.020	0.640	19.380	12.899	1.772	11.127	11.440	1.772	9.668	49.886
Sample 5D - Reject	18.060	0.640	17.420	12.278	1.780	10.498	10.771	1.773	8.998	51.653
Sample 5E - Sample	2.170	0.312	1.858	2.176	1.123	1.053	2.010	1.123	0.887	47.740

Table D.2: Stage 1, Test 1 PSD Raw Data

PARTICLE SIZE DISTRIBUTION - VEZIN CREDIBILITY TEST																										
TEST 1																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 1A - Reject	298	293	287	6	296	290	6	321	295	26	223	193	30	352	308	44	350	309	41	325	294	31	196	176	20	94
Sample 1B - Sample	280	179	176	3	299	295	4	299	285	14	312	287	25	715	677	38	249	212	37	326	298	28	215	193	22	109
Sample 1C - Primary	297	181	176	5	313	308	5	320	294	26	225	193	32	336	290	46	337	295	42	340	313	27	231	212	19	95
Sample 1D - Reject	264	315	309	6	199	193	6	317	294	23	328	295	33	145	102	43	343	308	35	200	176	24	230	212	18	76
Sample 1E - Sample	263	301	297	4	303	298	5	329	314	15	335	308	27	246	212	34	138	102	36	221	193	28	125	108	17	97
TEST 2																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 2A - Reject	252	318	314	4	180	176	4	209	193	16	325	294	31	340	308	32	333	298	35	310	285	25	305	287	18	87
Sample 2B - Sample	253	300	297	3	302	298	4	324	309	15	314	290	24	337	308	29	226	193	33	320	294	26	335	314	21	98
Sample 2C - Primary	274	311	308	3	315	309	6	200	176	24	240	212	28	325	285	40	335	298	37	326	297	29	332	314	18	89
Sample 2D - Reject	243	181	176	5	312	308	4	313	290	23	240	212	28	334	297	37	319	287	32	308	285	23	315	298	17	74
Sample 2E - Sample	289	311	308	3	319	314	5	311	294	17	224	193	31	211	176	35	324	287	37	325	295	30	321	298	23	108
TEST 3																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 3A - Reject	281	315	309	6	220	212	8	322	298	24	321	285	36	217	176	41	344	308	36	315	287	28	314	297	17	85
Sample 3B - Sample	282	317	314	3	300	295	5	329	309	20	318	287	31	321	285	36	332	290	42	203	176	27	321	298	23	95
Sample 3C - Primary	255	217	212	5	181	176	5	310	295	15	328	298	30	324	287	37	319	285	34	332	308	24	314	297	17	88
Sample 3D - Reject	261	289	285	4	218	212	6	312	290	22	330	298	32	326	287	39	331	295	36	332	308	24	312	294	18	80
Sample 3E - Sample	307	197	193	4	290	285	5	313	294	19	342	309	33	326	287	39	329	290	39	207	176	31	321	295	26	111
TEST 4																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 4A - Reject	294	200	193	7	321	314	7	336	309	27	208	176	32	346	297	49	187	150	37	141	112	29	322	298	24	82
Sample 4B - Sample	327	366	361	5	218	212	6	125	102	23	142	109	33	340	297	43	334	290	44	328	295	33	335	309	26	114
Sample 4C - Primary	258	300	295	5	217	212	5	310	290	20	328	297	31	325	287	38	334	298	36	310	285	25	330	309	21	77
Sample 4D - Reject	256	108	102	6	319	313	6	213	193	20	323	294	29	345	308	37	211	176	35	321	297	24	232	212	20	79
Sample 4E - Sample	283	295	285	10	217	212	5	305	290	15	338	309	29	333	297	36	332	294	38	336	308	28	338	314	24	98
TEST 5																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 5A - Reject	255	314	309	5	300	295	5	307	285	22	326	298	28	346	308	38	227	193	34	318	294	24	315	297	18	81
Sample 5B - Sample	259	179	176	3	313	309	4	301	285	16	324	295	29	330	298	32	229	193	36	334	308	26	311	294	17	96
Sample 5C - Primary	250	289	285	4	198	193	5	319	298	21	204	176	28	249	212	37	328	295	33	334	309	25	316	297	19	78
Sample 5D - Reject	254	181	176	5	217	212	5	332	309	23	323	295	28	353	313	40	323	286	37	313	290	23	324	308	16	77
Sample 5E - Sample	249	365	361	4	294	290	4	119	102	17	340	314	26	329	295	34	229	193	36	318	294	24	302	285	17	87

Table D.3: Stage 1, Test 2 Raw Data and Calculations

Sample #	Dry mass of +38µm (g)	Dry mass of -38µm (g)	Total dry sample mass (g)	% +38µm	Mass for analysis (g)
T2t0	403	0.068	403.068	99.98313	403.068
T2t1	833	0.114	833.114	99.98632	833.114
T2t2	478	0.124	478.124	99.97407	478.124
T2t3	291	0.144	291.144	99.95054	291.144
T2t4	120	0.072	120.072	99.94004	120.072

Table D.4: Stage 2, Test 2 Raw Data and Calculations

Sample #	Dry mass of +38µm (g)	Dry mass of -38µm (g)	Total dry sample mass (g)	% +38µm	Mass for analysis (g)
T1t0	359	0.043	359.043	99.98802	359.043
T1t1	872	0.079	872.079	99.99094	872.079
T1t2	537	0.043	537.043	99.99199	537.043
T1t3	329	0.093	329.093	99.97174	329.093
T1t4	289	0.154	289.154	99.94674	289.154

Table D.5: Stage 2, Test 1 Wet and Dry Process Raw Data

VEZIN CREDIBILITY TEST										
TEST 1										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 1A - Reject	22.000	0.650	21.350	10.812	1.755	9.057	8.710	1.755	6.955	32.576
Sample 1B - Sample	1.430	0.150	1.280	2.405	1.490	0.915	1.896	1.490	0.406	31.719
Sample 1C - Primary	23.540	0.640	22.900	12.543	1.490	11.053	9.777	1.490	8.287	36.188
Sample 1D - Reject	24.620	0.640	23.980	13.892	1.488	12.404	12.220	1.488	10.732	44.754
Sample 1E - Sample	1.570	0.150	1.420	1.995	1.126	0.869	0.748	0.014	0.734	51.690
TEST 2										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 2A - Reject	22.180	0.640	21.540	15.151	1.295	13.856	13.513	1.295	12.218	56.722
Sample 2B - Sample	1.440	0.150	1.290	3.191	1.491	1.700	2.228	1.491	0.737	57.132
Sample 2C - Primary	25.110	0.640	24.470	15.988	1.293	14.695	14.273	1.293	12.980	53.045
Sample 2D - Reject	23.600	0.640	22.960	12.800	1.488	11.312	11.441	1.488	9.953	43.349
Sample 2E - Sample	1.540	0.150	1.390	2.823	1.126	1.697	1.795	1.126	0.669	48.129
TEST 3										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 3A - Reject	23.020	0.640	22.380	14.543	1.490	13.053	13.213	1.490	11.723	52.382
Sample 3B - Sample	1.670	0.312	1.358	2.020	1.125	0.895	0.777	0.054	0.723	53.240
Sample 3C - Primary	27.650	0.650	27.000	17.114	1.489	15.625	15.542	1.489	14.053	52.048
Sample 3D - Reject	25.190	0.640	24.550	16.605	1.760	14.845	15.001	1.760	13.241	53.935
Sample 3E - Sample	1.820	0.312	1.508	2.100	1.120	0.980	0.843	0.014	0.829	54.973
TEST 4										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 4A - Reject	22.510	0.640	21.870	16.940	1.297	15.643	16.090	1.297	14.793	67.641
Sample 4B - Sample	1.480	0.310	1.170	3.151	1.755	1.396	2.545	1.755	0.790	67.521
Sample 4C - Primary	25.830	0.630	25.200	16.568	1.489	15.079	16.520	1.489	15.031	59.647
Sample 4D - Reject	27.160	0.640	26.520	17.510	1.297	16.213	16.699	1.297	15.402	58.077
Sample 4E - Sample	1.950	0.311	1.639	2.270	1.130	1.140	0.999	0.054	0.945	57.657
TEST 5										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 5A - Reject	24.470	0.620	23.850	17.620	1.488	16.132	14.690	1.488	13.202	55.354
Sample 5B - Sample	1.730	0.300	1.430	2.100	1.130	0.970	1.925	1.130	0.795	55.594
Sample 5C - Primary	26.850	0.750	26.100	17.450	1.293	16.157	15.419	1.293	14.126	54.123
Sample 5D - Reject	22.140	0.680	21.460	14.780	1.295	13.485	12.279	1.295	10.984	51.184
Sample 5E - Sample	1.620	0.310	1.310	1.980	1.119	0.861	0.735	0.014	0.721	55.038

Table D.6: Stage 2, Test 1 PSD Raw Data

PARTICLE SIZE DISTRIBUTION																												
TEST 1																												
		425			300			212			150			106			75			53			38			-38	-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**	**Weighed**
Sample 1A - Reject	380	114.44	107.28	7.16	119.81	109.08	10.73	122.94	100.32	22.62	165.48	119.52	45.96	414	361.17	52.83	421.54	361.42	60.12	326.83	293.3	33.53	396.51	363.44	33.07	113.98	106.05
Sample 1B - Sample	201	310.81	306.61	4.20	315.67	309.16	6.51	159.64	149.31	10.33	384.6	361.4	23.2	388.53	341.18	47.35	326.26	296.53	29.73	304.27	283.63	20.64	97.06	81.42	15.64	43.40	40.77
Sample 1C - Primary	234	73.67	69.98	3.69	102.54	97.94	4.60	102.28	86.99	15.29	114.11	87.89	26.22	133.31	100.5	32.81	119.78	87.68	32.10	113.32	91.98	21.34	115.54	109.7	5.84	92.11	65.98
Sample 1D - Reject	294	371.51	361.42	10.09	123.67	107.28	16.39	139.04	109.08	29.96	338.3	293.3	45.00	145.41	100.32	45.09	343.87	306.66	37.21	392.5	363.49	29.01	211.59	192.17	19.42	61.83	53.87
Sample 1E - Sample	241	114.56	107.28	7.28	121.46	109.08	12.38	314.23	293.3	20.93	133.93	100.32	33.61	151.76	119.15	32.61	394.73	363.44	31.29	212.78	192.17	20.61	104.66	89.56	15.1	67.19	63.21
TEST 2																												
		425			300			212			150			106			75			53			38			-38	-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**	**Weighed**
Sample 2A - Reject	281	22.19	16.08	6.11	28.34	16.08	12.26	42.55	16.08	26.47	56.06	16.08	39.98	52.06	16.08	35.98	51.14	16.08	35.06	47.25	16.08	31.17	30.81	16.08	14.73	79.24	69.77
Sample 2B - Sample	246	93.16	87.68	5.48	110.59	100.5	10.09	106.32	87.89	18.43	120.22	86.99	33.23	133.52	97.94	35.58	391.44	359.99	31.45	123.22	100.32	22.9	380.93	362.12	18.81	70.03	64.78
Sample 2C - Primary	297	23.43	16.08	7.35	33.08	16.08	17.00	39.41	16.08	23.33	64.26	16.08	48.18	63.46	16.08	47.38	51.99	16.08	35.91	42.78	16.08	26.70	37.61	16.08	21.53	69.62	63.61
Sample 2D - Reject	271	302.82	293.2	9.62	122.87	107.12	15.75	111.72	81.42	30.30	401.6	361.09	40.51	405.2	361.33	43.87	403.23	363.41	39.82	133.44	109.08	24.36	314.55	296.47	18.08	48.69	44.95
Sample 2E - Sample	278	89.84	81.45	8.39	110.32	97.94	12.38	110.19	86.99	23.20	125.77	87.92	37.85	398.94	360.15	38.79	137.4	100.5	36.90	109.08	87.68	21.4	381.41	362.26	19.15	79.94	68.43
TEST 3																												
		425			300			212			150			106			75			53			38			-38	-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**	**Weighed**
Sample 3A - Reject	267	264.06	255.43	8.63	306.6	294.33	12.27	233.54	211.43	22.11	336.93	313.05	23.88	387.52	360.35	27.17	387.15	359.57	27.58	323.57	293.20	30.37	379.71	363.47	16.24	98.75	86.85
Sample 3B - Sample	238	95.47	87.68	7.79	118.54	100.5	18.04	112.07	97.94	14.13	340.01	306.66	33.35	106.35	63.77	42.58	329.28	306.56	22.72	108.45	91.955	16.495	119.25	109.7	9.55	73.35	47.85
Sample 3C - Primary	258	368.14	361.16	6.98	131.65	119.51	12.14	386.81	363.44	23.37	126.47	87.89	38.58	122.4	81.45	40.95	121.62	86.99	34.63	315.18	293.3	21.88	128.11	110.66	17.45	62.02	57.73
Sample 3D - Reject	245	112.86	105.7	7.16	97.88	82.98	14.90	120.09	100.08	20.01	382.15	361.42	20.73	120.98	78.32	42.66	111.12	75.56	35.56	122.93	101.28	21.65	374.72	362.26	12.46	69.87	44.63
Sample 3E - Sample	277	367.59	361.16	6.43	117.47	107.28	10.19	382.18	362.26	19.92	147.01	109.08	37.93	128.13	89.56	38.57	129.89	91.98	37.91	136.02	109.02	27.00	380.66	361.42	19.24	79.81	74.43
TEST 4																												
		425			300			212			150			106			75			53			38			-38	-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**	**Weighed**
Sample 4A - Reject	270	261.87	252.02	9.85	216.32	195.12	21.20	113.57	68.42	45.15	110.23	86.99	23.24	188.23	149.31	38.92	117.01	87.68	29.33	110.78	87.68	23.10	110.23	97.94	12.29	66.92	55.23
Sample 4B - Sample	279	96.05	86.99	9.06	125.06	100.45	24.61	143.95	87.89	56.06	91.51	66.38	25.13	121.58	96.25	25.33	308.37	294.29	14.08	128.8	109.08	19.72	127.02	110.66	16.36	88.65	69.63
Sample 4C - Primary	282	108.51	100.32	8.19	139.00	119.51	19.49	167.73	121.61	46.12	80.07	50.85	29.22	321.9	286.81	35.09	127.34	107.28	20.06	316.59	296.47	20.12	188.82	172.31	16.51	87.2	46.27
Sample 4D - Reject	285	106.65	99.51	7.14	114.57	91.94	22.63	273.08	231.17	41.91	211.43	185.3	26.13	280.45	255.33	25.12	330.39	293.3	37.09	317.59	297.94	19.65	377.5	361.16	16.34	88.99	43.20
Sample 4E - Sample	309	371.12	361.42	9.70	385.34	363.36	21.98	415.69	344.26	71.43	393.64	359.65	33.99	395.84	360.15	35.69	147.62	113.59	34.03	132.82	109.01	23.81	98.43	80.41	18.02	60.35	39.36
TEST 5																												
		425			300			212			150			106			75			53			38			-38	-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**	**Weighed**
Sample 5A - Reject	245	118.63	110.66	7.97	100.91	86.99	13.92	114.74	87.68	27.06	151.19	109.7	41.49	150.94	109.08	41.86	145.66	109.01	36.65	121.09	97.94	23.15	225.92	211.43	14.49	38.41	37.25
Sample 5B - Sample	270	94.84	87.68	7.16	98.14	66.36	31.78	132.77	109.7	23.07	123.77	89.87	33.9	401.49	362.26	39.23	248.04	211.43	36.61	383.11	360.15	22.96	311.18	293.3	17.88	57.41	48.80
Sample 5C - Primary	258	300.2	293.3	6.90	223.86	211.48	12.38	383.81	362.26	21.55	404.82	363.44	41.38	400.03	363.44	36.59	394.6	360.15	34.45	384.24	361.42	22.82	378.56	361.16	17.4	64.53	55.43
Sample 5D - Reject	250	115.08	109.08	6.00	123.6	110.6	13.00	118.9	100.32	18.58	392.06	361.42	30.64	398.65	366.44	32.21	389.23	361.16	28.07	315.88	296.47	19.41	123.26	109.01	14.25	87.84	77.99
Sample 5E - Sample	240	116.27	109.7	6.57	98.38	87.68	10.70	127.5	109.08	18.42	142.54	110.66	31.88	136.66	109.01	27.65	131.06	107.28	23.78	127.06	107.28	19.78	112.27	100.32	11.95	89.27	69.14

Table D.7: Stage 3A, Test 1 Wet and Dry Process Raw Data

VEZIN CREDIBILITY TEST										
TEST 1										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 7A - Primary	4880.000	640.000	4240.000	4167.000	1765.000	2402.000	3759.000	1765.000	1994.000	47.028
Sample 7B - Primary	6660.000	630.000	6030.000	4150.000	1125.000	3025.000	3557.000	1125.000	2432.000	40.332
Sample 7C - Primary	4130.000	650.000	3480.000	0.801	0.679	0.122	0.764	0.679	0.085	0.00244
Sample 7D - Primary	4520.000	630.000	3890.000	0.798	0.678	0.120	0.770	0.678	0.092	0.00237
Sample 7E - Sample	2250.000	620.000	1630.000	1076.000	0.760	1075.240	1012.000	0.760	1011.240	62.039
Sample 7F1 - Reject	5920.000	640.000	5280.000	2398.000	1130.000	1268.000	2371.000	1130.000	1241.000	23.504
Sample 7F2 - Reject	11750.000	630.000	11120.000	6789.000	1765.000	5024.000	5951.000	1765.000	4186.000	37.644
TEST 2										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 9A - Primary	7510.000	650.000	6860.000	4752.000	1130.000	3622.000	4650.000	1130.000	3520.000	51.312
Sample 9B - Primary	9070.000	620.000	8450.000	6396.000	1129.000	5267.000	5608.000	1129.000	4479.000	53.006
Sample 9C - Primary	8330.000	660.000	7670.000	53906.000	1124.000	52782.000	5207.000	1124.000	4083.000	53.233
Sample 9D - Primary	8070.000	680.000	7390.000	6330.000	1762.000	4568.000	5646.000	1762.000	3884.000	52.558
Sample 9E - Sample	3110.000	650.000	2460.000	2382.000	1125.000	1257.000	2165.000	1125.000	1040.000	42.276
Sample 9F1 - Reject	21230.000	670.000	20560.000	14782.000	1292.000	13490.000	12183.000	1292.000	10891.000	52.972
Sample 9F2 - Reject	12240.000	650.000	11590.000	76254.000	1129.000	75125.000	7424.000	1129.000	6295.000	54.314
TEST 3										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 11A - Primary	7590.000	640.000	6950.000	5577.000	1125.000	4452.000	4922.000	1125.000	3797.000	54.633
Sample 11B - Primary	7650.000	630.000	7020.000	5558.000	1120.000	4438.000	4875.000	1120.000	3755.000	53.490
Sample 11C - Primary	9280.000	640.000	8640.000	6402.000	1127.000	5275.000	5587.000	1127.000	4460.000	51.620
Sample 11D - Primary	6780.000	640.000	6140.000	5212.000	1117.000	4095.000	4442.000	1117.000	3325.000	54.153
Sample 11E - Sample	2670.000	640.000	2030.000	2329.000	1131.000	1198.000	2140.000	1131.000	1009.000	49.704
Sample 11F1 - Reject	20200.000	647.000	19553.000	13391.000	1765.000	11626.000	11716.000	1765.000	9951.000	50.892
Sample 11F2 - Reject	12820.000	660.000	12160.000	8548.000	1129.000	7419.000	6983.000	1129.000	5854.000	48.141

Table D.8: Stage 3A, Test 1 PSD Raw Data

PARTICLE SIZE DISTRIBUTION																										
TEST 1																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 7A - Primary	0.329	0.021	0.015	0.006	0.042	0.015	0.027	0.058	0.015	0.043	0.067	0.015	0.052	0.058	0.015	0.043	0.047	0.015	0.032	0.038	0.015	0.023	0.03	0.015	0.015	0.088
Sample 7B - Primary	0.335	0.019	0.015	0.004	0.024	0.015	0.009	0.038	0.015	0.023	0.070	0.015	0.055	0.065	0.015	0.05	0.058	0.015	0.043	0.050	0.015	0.035	0.037	0.015	0.022	0.094
Sample 7C - Primary				0			0			0			0			0			0			0			0	0
Sample 7D - Primary				0			0			0			0			0			0			0			0	0
Sample 7E - Sample	0.334	0.018	0.015	0.003	0.026	0.015	0.011	0.032	0.015	0.017	0.064	0.015	0.049	0.061	0.015	0.046	0.064	0.015	0.049	0.052	0.015	0.037	0.041	0.015	0.026	0.096
Sample 7F - Reject	0.295	0.02	0.015	0.005	0.025	0.015	0.01	0.034	0.015	0.019	0.064	0.015	0.049	0.064	0.015	0.049	0.058	0.015	0.043	0.046	0.015	0.031	0.03	0.015	0.015	0.074
TEST 2																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 9A - Primary	0.291	0.026	0.015	0.011	0.032	0.015	0.017	0.049	0.015	0.034	0.067	0.015	0.052	0.065	0.015	0.05	0.058	0.015	0.043	0.041	0.015	0.026	0.031	0.015	0.016	0.042
Sample 9B - Primary	0.372	0.027	0.015	0.012	0.036	0.015	0.021	0.053	0.015	0.038	0.082	0.015	0.067	0.07	0.015	0.055	0.066	0.015	0.051	0.040	0.015	0.025	0.040	0.015	0.025	0.078
Sample 9C - Primary	0.34	0.027	0.015	0.012	0.034	0.015	0.019	0.046	0.015	0.031	0.062	0.015	0.047	0.064	0.015	0.049	0.061	0.015	0.046	0.041	0.015	0.026	0.033	0.015	0.018	0.092
Sample 9D - Primary	0.318	0.024	0.015	0.009	0.031	0.015	0.016	0.042	0.015	0.027	0.062	0.015	0.047	0.067	0.015	0.052	0.057	0.015	0.042	0.044	0.015	0.029	0.033	0.015	0.018	0.078
Sample 9E - Sample	0.343	0.026	0.015	0.011	0.031	0.015	0.016	0.045	0.015	0.03	0.067	0.015	0.052	0.066	0.015	0.051	0.063	0.015	0.048	0.048	0.015	0.033	0.033	0.015	0.018	0.084
Sample 9F - Reject	0.315	0.022	0.015	0.007	0.027	0.015	0.012	0.039	0.015	0.024	0.057	0.015	0.042	0.064	0.015	0.049	0.061	0.015	0.046	0.041	0.015	0.026	0.033	0.015	0.018	0.091
TEST 3																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	**START MASS (g)**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**GROSS**	**TARE**	**NETT**	**Calc**
Sample 11A - Primary	0.312	0.029	0.015	0.014	0.030	0.015	0.015	0.042	0.015	0.027	0.052	0.015	0.037	0.050	0.015	0.035	0.048	0.015	0.033	0.040	0.015	0.025	0.024	0.015	0.009	0.117
Sample 11B - Primary	0.307	0.024	0.015	0.009	0.035	0.015	0.02	0.045	0.015	0.03	0.051	0.015	0.036	0.045	0.015	0.03	0.047	0.015	0.032	0.035	0.015	0.02	0.022	0.015	0.007	0.123
Sample 11C - Primary	0.248	0.025	0.015	0.01	0.034	0.015	0.019	0.041	0.015	0.026	0.049	0.015	0.034	0.048	0.015	0.033	0.045	0.015	0.03	0.034	0.015	0.019	0.027	0.015	0.012	0.065
Sample 11D - Primary	0.270	0.026	0.015	0.011	0.032	0.015	0.017	0.042	0.015	0.027	0.055	0.015	0.04	0.052	0.015	0.037	0.049	0.015	0.034	0.041	0.015	0.026	0.025	0.015	0.01	0.068
Sample 11E - Sample	0.332	0.028	0.015	0.013	0.037	0.015	0.022	0.041	0.015	0.026	0.053	0.015	0.038	0.055	0.015	0.04	0.045	0.015	0.03	0.042	0.015	0.027	0.024	0.015	0.009	0.127
Sample 11F - Reject	0.29	0.03	0.015	0.015	0.031	0.015	0.016	0.046	0.015	0.031	0.054	0.015	0.039	0.053	0.015	0.038	0.048	0.015	0.033	0.037	0.015	0.022	0.026	0.015	0.011	0.085

Table D.9: Stage 3A, Test 2 Raw Data and Calculations

Sample #	Dry mass of +75µm (kg)	Dry mass of -75µm (kg)	Total dry sample mass (kg)	% +75µm	Mass for analysis (kg)
T6t0	0.177	0.045	0.222	79.73	0.222
T6t1	0.301	0.085	0.386	77.98	0.386
T6t2	0.322	0.11	0.432	74.54	0.432
T6t3	0.233	0.138	0.371	62.80	0.371
T6t4	0.14	0.097	0.237	59.07	0.237
T6t5	0.115	0.108	0.223	51.57	0.223
T6t6	0.11	0.115	0.225	48.89	0.225
T6t7	0.074	0.071	0.145	51.03	0.145
T6t8	0.076	0.116	0.192	39.58	0.192
T6t9	0.18	0.322	0.502	35.86	0.502

Table D.10: Stage 3B, Test 1 Wet and Dry Process Raw Data

VEZIN CREDIBILITY TEST										
TEST 1										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 12A - Primary	9.500	0.640	8.860	6.923	1.307	5.616	6.125	1.307	4.818	54.379
Sample 12B - Primary	10.700	0.630	10.070	8.116	1.762	6.354	7.063	1.762	5.301	52.642
Sample 12C - Primary	9.150	0.640	8.510	6.414	1.130	5.284	5.631	1.130	4.501	52.891
Sample 12D - Primary	7.770	0.640	7.130	5.809	1.498	4.311	5.156	1.498	3.658	51.304
Sample 12E - Sample	1.880	0.640	1.240	1.899	1.131	0.768	1.811	1.131	0.680	54.839
Sample 12F - Reject	19.590	0.650	18.940	13.608	1.766	11.842	12.068	1.766	10.302	54.393
TEST 2										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 14A - Primary	8.060	0.640	7.420	5.671	1.124	4.547	5.025	1.124	3.901	52.574
Sample 14B - Primary	12.790	0.640	12.150	9.187	1.761	7.426	8.115	1.761	6.354	52.296
Sample 14C - Primary	9.220	0.650	8.570	6.990	1.766	5.224	6.227	1.766	4.461	52.054
Sample 14D - Primary	6.990	0.650	6.340	5.179	1.129	4.050	4.608	1.129	3.479	54.874
Sample 14E - Sample	2.530	0.640	1.890	2.285	1.123	1.162	2.145	1.123	1.022	54.074
Sample 14F - Reject	27.590	0.640	26.950	18.508	1.768	16.740	16.237	1.768	14.469	53.688
TEST 3										
	SLURRY MASS (kg)			**WET PROCESS**			**DRY PROCESS**			
SAMPLE ID	**GROSS MASS**	**BUCKET MASS**	**NETT SLURRY MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT WET MASS**	**GROSS MASS**	**TRAY TARE MASS**	**NETT DRY MASS**	**% SOLIDS**
Sample 16A - Primary	7.810	0.640	7.170	5.645	1.125	4.520	5.013	1.125	3.888	54.226
Sample 16B - Primary	9.390	0.640	8.750	6.526	1.490	5.036	6.007	1.490	4.517	51.623
Sample 16C - Primary	6.350	0.640	5.710	4.440	1.124	3.316	3.977	1.124	2.853	49.965
Sample 16D - Primary	8.870	0.650	8.220	5.451	1.130	4.321	4.824	1.130	3.694	44.939
Sample 16E - Sample	3.170	0.650	2.520	2.652	1.119	1.533	2.431	1.119	1.312	52.063
Sample 16F - Reject	24.740	0.630	24.110	15.920	1.755	14.165	13.904	1.755	12.149	50.390

Table D.11: Stage 3B, Test 1 PSD Raw Data

PARTICLE SIZE DISTRIBUTION																										
TEST 1																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	START MASS	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	Calc
Sample 12A - Primary	0.265	0.022	0.015	0.007	0.027	0.015	0.012	0.04	0.015	0.025	0.060	0.015	0.045	0.061	0.015	0.046	0.042	0.015	0.027	0.031	0.015	0.016	0.028	0.015	0.013	0.074
Sample 12B - Primary	0.293	0.024	0.015	0.009	0.030	0.015	0.015	0.044	0.015	0.029	0.062	0.015	0.047	0.071	0.015	0.056	0.042	0.015	0.027	0.035	0.015	0.02	0.030	0.015	0.015	0.075
Sample 12C - Primary	0.252	0.02	0.015	0.005	0.025	0.015	0.01	0.038	0.015	0.023	0.059	0.015	0.044	0.062	0.015	0.047	0.04	0.015	0.025	0.032	0.015	0.017	0.025	0.015	0.01	0.071
Sample 12D - Primary	0.297	0.021	0.015	0.006	0.03	0.015	0.015	0.042	0.015	0.027	0.062	0.015	0.047	0.068	0.015	0.053	0.047	0.015	0.032	0.040	0.015	0.025	0.031	0.015	0.016	0.076
Sample 12E - Sample	0.337	0.027	0.015	0.012	0.035	0.015	0.02	0.040	0.015	0.025	0.066	0.015	0.051	0.068	0.015	0.053	0.047	0.015	0.032	0.039	0.015	0.024	0.033	0.015	0.018	0.102
Sample 12F - Reject	0.280	0.025	0.015	0.01	0.031	0.015	0.016	0.042	0.015	0.027	0.061	0.015	0.046	0.061	0.015	0.046	0.045	0.015	0.03	0.032	0.015	0.017	0.031	0.015	0.016	0.072
TEST 2																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	START MASS	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	Calc
Sample 14A - Primary	0.320	0.022	0.015	0.011	0.036	0.015	0.021	0.044	0.015	0.029	0.066	0.015	0.051	0.072	0.015	0.057	0.045	0.015	0.03	0.037	0.015	0.022	0.034	0.015	0.019	0.080
Sample 14B - Primary	0.350	0.024	0.015	0.012	0.032	0.015	0.017	0.047	0.015	0.032	0.065	0.015	0.05	0.071	0.015	0.056	0.048	0.015	0.033	0.038	0.015	0.023	0.033	0.015	0.018	0.109
Sample 14C - Primary	0.250	0.018	0.015	0.012	0.023	0.015	0.008	0.038	0.015	0.023	0.059	0.015	0.044	0.060	0.015	0.045	0.040	0.015	0.025	0.030	0.015	0.015	0.021	0.015	0.006	0.072
Sample 14D - Primary	0.290	0.025	0.015	0.009	0.031	0.015	0.016	0.040	0.015	0.025	0.063	0.015	0.048	0.068	0.015	0.053	0.044	0.015	0.029	0.035	0.015	0.02	0.035	0.015	0.02	0.070
Sample 14E - Sample	0.337	0.023	0.015	0.011	0.033	0.015	0.018	0.045	0.015	0.03	0.067	0.015	0.052	0.075	0.015	0.060	0.042	0.015	0.027	0.039	0.015	0.024	0.029	0.015	0.014	0.101
Sample 14F - Reject	0.264	0.022	0.015	0.007	0.028	0.015	0.013	0.039	0.015	0.024	0.058	0.015	0.043	0.065	0.015	0.050	0.038	0.015	0.023	0.032	0.015	0.017	0.027	0.015	0.012	0.075
TEST 3																										
		425			300			212			150			106			75			53			38			-38
SAMPLE ID	START MASS	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	GROSS	TARE	NETT	Calc
Sample 16A - Primary	0.320	0.026	0.015	0.011	0.034	0.015	0.019	0.051	0.015	0.036	0.063	0.015	0.048	0.065	0.015	0.050	0.057	0.015	0.042	0.041	0.015	0.026	0.031	0.015	0.016	0.072
Sample 16B - Primary	0.250	0.017	0.015	0.002	0.026	0.015	0.011	0.040	0.015	0.025	0.049	0.015	0.034	0.052	0.015	0.037	0.055	0.015	0.04	0.037	0.015	0.022	0.023	0.015	0.008	0.071
Sample 16C - Primary	0.313	0.028	0.015	0.013	0.033	0.015	0.018	0.045	0.015	0.03	0.058	0.015	0.043	0.061	0.015	0.046	0.062	0.015	0.047	0.043	0.015	0.028	0.029	0.015	0.014	0.074
Sample 16D - Primary	0.306	0.024	0.015	0.009	0.033	0.015	0.018	0.043	0.015	0.028	0.059	0.015	0.044	0.062	0.015	0.047	0.057	0.015	0.042	0.045	0.015	0.03	0.031	0.015	0.016	0.072
Sample 16E - Sample	0.219	0.018	0.015	0.003	0.025	0.015	0.01	0.033	0.015	0.018	0.045	0.015	0.030	0.050	0.015	0.035	0.045	0.015	0.030	0.036	0.015	0.021	0.021	0.015	0.006	0.066
Sample 16F - Reject	0.334	0.022	0.015	0.007	0.032	0.015	0.017	0.045	0.015	0.03	0.061	0.015	0.046	0.062	0.015	0.047	0.063	0.015	0.048	0.045	0.015	0.03	0.029	0.015	0.014	0.095

Table D.12: Stage 3B, Test 2 Raw Data and Calculations

Sample #	Dry mass of +75µm (g)	Dry mass of -75µm (g)	Total dry sample mass (g)	% +75µm	Mass for analysis (g)
T8t0	0.240	0.068	0.308	77.92208	0.308
T8t1	0.240	0.064	0.304	78.94737	0.304
T8t2	0.246	0.088	0.334	73.65269	0.334
T8t3	0.389	0.148	0.537	72.43948	0.537
T8t4	0.372	0.160	0.532	69.92481	0.532
T8t5	0.200	0.116	0.316	63.29114	0.316
T8t6	0.203	0.129	0.332	61.14458	0.332
T8t7	0.150	0.111	0.261	57.47126	0.261
T8t8	0.149	0.121	0.27	55.18519	0.270
T8t9	0.597	0.542	1.139	52.4144	1.139

Appendix E: Quality Control (Example)

The sample preparation tasks were monitored by means of quality control systems. Dust losses/gains and relative difference on rotary splitting were calculated and recorded on templates as shown in the example below.

Table E.1: Quality Control on Sample Preparation Tasks

SAMPLE TYPE		**Example**		**SAMPLE DATE**			
OPERATOR NAME							
Wet / Dry Process							
Tray ID	Shift	Wet Mass (gross)	BUCKET MASS	Wet Nett Mas	Dry Mass (gross)	Tray Tare Mass	Dry nett Mass
n/a	n/a	7.810	0.640	7.170	5.013	1.125	3.888

	Screening / Lump breaking				
	Bucket (gross)	Bucket Tare Mass	Nett Mas	Mass Before Screening	Mass After Screening
	4.195	0.311	3.884	3.888	3.884
% Dust Loss	0.103				

First Splitting				
Mass Before splitting	3.884			
Morning Shift (M/S)	Cup ID	Gross Mass	Tare Mass	Net Mass
	Cup 1	2.401	1.754	0.647
	Cup 2	2.400	1.755	0.645
	Cup 3	2.411	1.760	0.651
	Cup 4	2.408	1.760	0.648
	Cup 5	2.405	1.763	0.642
	Cup 6	2.409	1.764	0.645
	Totals			3.878
% Relative Difference	1.4		Max	Min
Mass after Splitting	3.9		0.651	0.642
% Dust Loss	0.15			
%Average	***0.65***			
%STDEV	***0.00***			
%RSD	***0.48***			

Appendix F: Risk Assessment for Installation and Operation of Mechanical Hopper

Table F.1: Risk Assessment for Installation of Mechanical Hopper

No.	Task	Potential Hazard	Risk Rating				Controls
			Probability	Consequence	Total	Rating	
1	Inspect work area for potential hazards	Potential tripping and falling hazards	E	4	23	Low	Rid area of all loose equipment and materials Barricade off areas from which loose equipment or materials cannot be removed
2	Isolate all equipment	Inadvertent operation of equipment could resulting in injury due to automatic starting of equipment	D	4	21	Low	Get area familiar competent person to perform isolation Lockout to be performed by each person working on equipment
3	Take tools and equipment to work area	Slips and trips	E	5	25	Low	Ensure proper access to work site Remove obvious tripping hazards Barricade off tripping hazards that cannot be removed Carry such quantities and weights of equipment that will ensure ability of reaching work area without over taxing physical ability
4	Installation of hopper	Manual handling	C	4	18	Low	Ensure correct lifting and walking procedures followed when carrying loads. Carry such quantities and weights of equipment that will ensure ability of reaching work area without over taxing physical ability. Wear elastic corset/back support if prone to small of back weakness
5	Tighten bolts and nuts	Tool handling	C	4	18	Low	Always use correct tools
6	Connect pipes	Nip points	C	4	18	Low	Always wear correct hand protection Always use correct tools
7	Install and terminate all electrical cabling	Hand injurie	D	5	24	Low	Always wear correct hand protection Always use correct tools
8	De isolate all equipment for testing	Electric shock	C	3	13	Med	Insure that all terminations are complete before switching on the power and test for incorrect connections
9	Test equipment	Moving machinery	D	3	17	Low	Stand clear of all moving machinery



Table F.2: Risk Assessment for Operation of Mechanical Hopper

No (Task No)	Sub System(Task)	Hazard - "what if"	Cause	Risk	Controls in Place	C	L	R	Recommended Controls	C	L	R
1	Feed sampler Operation (Mechanical hopper)	Moving machinery: Agitator, primary vezin & secondary vezin	a.Parts need to move for operational purposes	Hand injuries	a. Isolation at primary control panel	3	3	13 (H)	a. Guard the agitator shaft and install a held E-stop b.Emergency stop c.Interlock with primary vezin	3	1	6 (M)
		Heavy equipment: Mechanical hopper & sample buckets	a. Construction of durable hopper b.Sample needs to be collected for metal accounting	a. Back injuries b. Pinching of fingers	a. Practice correct lifting techniques b. Ask for help	2	5	16 (H)	a. Install a beam with lifting mechanism	1	3	4 (L)
		Noise	a. Plant operation	a.Hearing loss	a. Use hearing protection devices	4	3	18 (H)	a. Minimize time in noisy area	1	2	2 (L)
		Compressed air	a. Used for agitation b. Vave opening/closing	a. Body injury	a. Inspect air lines regularly	3	1	6 (M)				
		Uneven floor/ Mentis grating	a. Spillage b. Poor installation	a. Trip, slip & fall	a. Observe were you walk carefully	3	3	13 (H)	a.Use three point contact	2	2	5 (L)
		Hopper lid clamps	a. To prevent contamination of sample	a. Pinch parts	a. use correct safety gloves	3	1	6 (M)				
		Slurry splashes	a. Samples stream being cut	a. Poor visibility b. Loss of sample	a. Wear safety glasses	3	4	17 (H)				
		Spillage	a. Leaking pipes b. Poor plant operation	a.Slip and fall	a.Clean up spillage immediately	2	4	12 (M)	a.Perform proper maintenance at regular intervals	1	3	4 (L)
		Feed pipes not fitted securely and T-piece (hopper inlet	a. Cleaning purposes	a. Loss of sample due to spillage	a. Physical inspection	2	2	5 (L)				

CONSEQUENCE

Standard Risk Matrix		Hazard Effect / Consequence				
Loss Type		1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
(S/H) Harm to People (Safety / Health)		Slight injury or health effects - first aid / minor medical treatment level	Minor injury or health effects - restricted work or minor lost workday case	Major injury or health effects - major lost workday case / permanent disability	Permanent total disabilities, single fatality	Multiple fatalities
(EI) Environmental Impact		Minimal environmental harm	Material environmental harm	Serious environmental harm	Major environmental harm	Extreme environmental harm
(AD) Business Disruption / Asset Damage & Other Consequential Losses		No disruption to operation / R220k to less than R600k	Brief disruption to operation / R600k to less than R6M	Partial shutdown / R6m to less than R60M	Partial loss of operation /R60M to less than R450M	Substantial or total loss of operation /R450m and higher
(L&R) Legal & Regulatory		Low level legal issue	Minor legal issue; non compliance and breaches of the law	Serious breech of law; investigation/report to authority, prosecution and/or moderate penalty possible	Major breech of the law; considerable prosecution and penalties	Very considerable penalties & prosecutions. Multiple law suits & jail terms
(R) Impact on Reputation/Social/Community		Slight impact - public awareness may exist but no public concern	Limited impact - local public concern	Considerable impact - regional public concern	National impact - national public concern	International impact - international public attention
Likelihood	Likelihood Examples (use as guide only)	Risk Rating				
5 Almost Certain	The unwanted event has occurred frequently; occurs in order of one or more times per year & is likely to reoccur within 1 year	11 (M)	16 (H)	20 (H)	23 (Ex)	25 (Ex)
4 Likely	The unwanted event has occurred infrequently; occurs in order of less than once per year & is likely to re-occur within 5 years	7 (M)	12 (M)	17 (H)	21 (Ex)	24 (Ex)
3 Possible	The unwanted event could well have occurred in the business at some point within 10 years	4 (L)	8 (M)	13 (H)	18 (H)	22 (Ex)
2 Unlikely	The unwanted event has happened in the business at some time; or could happen within 20 years	2 (L)	5 (L)	9 (M)	14 (H)	19 (H)
1 Rare	The unwanted event has never been known to occur in the business; or is highly unlikely that it could ever occur beyond 20 years	1 (L)	3 (L)	6 (M)	10 (M)	15 (H)

LIKELIHOOD

Risk Rating	Risk Level	Guidelines for Risk Matrix
21 to 25	(Ex) – Extreme (AA)	Eliminate, avoid, implement specific action plans / procedures to manage & monitor
13 to 20	(H) – High (A)	Proactively manage via appropriate management system
6 to 12	(M) – Medium (B)	Actively manage via appropriate management system
1 to 5	(L) – Low (C)	Monitor & manage as appropriate via management system

Appendix G: Operational Procedure for Mechanical Hopper

Summary of the steps that were followed in order to operate the feed sampler correctly or as per design:

1. Ensure all interconnecting pipes have been connected and secured to avoid spillage and to ensure that conditions for representative sampling is fulfilled;
2. Set primary sampler cutting frequency timer and counter as per requirements;
3. Ensure that the pneumatic valve is closed and that the agitator is rotating;
4. Check that primary sampling occurs at the correct frequency;
5. A single primary cut must be taken and be discharged into the hopper at each time interval as per step 2;
6. Hopper pneumatic/discharge valve must remain in the closed position until the required number of primary cuts are taken (will depend on the counter setting);
7. On the last primary cut (as per counter setting), the pneumatic valve must open and secondary sampling must commence;
8. After a pre-determined amount of time (as per timer setting), the pneumatic valve will close and the counter will reset to 0 again.
9. Remove the final sample in sample bucket at end of the sampling campaign;
10. Replace with an empty and clean sample bucket;
11. Take sample to laboratory for further preparation and analysis.

Appendix H: Maintenance & Control Philosophy - Mechanical Hopper

Planned Maintenance Summary:

Sampler planned maintenance should be conducted on a daily, weekly, monthly, 6-monthly and 3-yearly basis (as advised by reputable service providers/original equipment manufacturers (OEM's)). It is vital to maintain the sampler on an ongoing basis to avoid costly breakdowns. By following a proper maintenance schedule, effective and efficient operation of the sampler can be ensured.

Steps to follow to conduct daily planned maintenance:

- Operator must visually check that the hopper screen is free of material build-up. The entire unit must be isolated and the guard around the agitator shaft must be removed. The lid of the hopper must be lifted and rested on its stilts. The hopper screen can then be inspected thoroughly and if needed, can be removed to cleaned or washed and then replaced back into the original position. This is will prevent the hopper screen from becoming blocked or contaminated. If the screen is blocked, the entire hopper will eventually choke up and will result in no samples being taken. If the screen is contaminated with foreign material (plastic, wood chips, steel scats etc.) that may find their way into the sampling unit, the samples resulting may not be entirely representative of the bulk stream.

Steps to follow to conduct weekly planned maintenance:

- Supervisor or engineering personnel must visually check that the:
    - Hopper screen is free of obstructions;
    - Agitator blades are in place;
    - Agitator edges are sharp and are not worn excessively;
    - Sampler housing and motor/gearbox assembly are clean.

Steps to follow to conduct monthly planned maintenance:

- Engineering personnel must observe/check the:
    - Gear unit noise, oil temperature;

- Gear unit for leakage.

Steps to follow to conduct 6-monthly planned maintenance:

- Engineering personnel must check the geared motors. In particular:
  - Check the oil level;
  - Clean vent plug;
  - Clean drive according to the degree of contamination;
  - Check all fixing screws for tightness;
  - Carry out a complete inspection of the geared units.

Steps to follow to conduct 3 years planned maintenance:

- Engineering personnel must again check the geared motors. In particular, the oil of the geared units must be changed.

Control Philosophy of the Mechanical Hopper:

The agitated feed hopper consists of an agitator device that is powered by a geared drive unit. A pneumatic valve is located at the bottom of the hopper to ensure that the primary sample taken will not be released to the secondary sampler for sub-sampling purposes until such a time that the maximum number of primary increments has been collected in the hopper (over a pre-set time period) and has been thoroughly agitated to ensure that all particles are suspended and have an equal opportunity of being sub-sampled by the secondary sampler. The maximum number of primary increments is set by means of a counter which is adjusted and displayed in the lockable field control panel.

Once the pre-determined primary cuts or samples have been collected and thoroughly agitated in the hopper, the secondary unit will start up. The pneumatic valve will open and allow the sample to run through to the secondary sampler to ensure that sub-sampling of the combined primary increments can take place.

A timer will be set as per the commissioning phase to determine how long it takes to drain the hopper with the prescribed number of primary cuts/samples occupying a specific

volume of the total hopper volume capacity. Once this time has elapsed, the pneumatic valve will close and the cycle will repeat again (i.e. the counter will reset to “0” and count to the fixed number preferred).

In cases where the motor trips on overload, the sampler will stop and indicate a fault. An electrician will then be needed for further assistance.

Troubleshooting Decision Table:

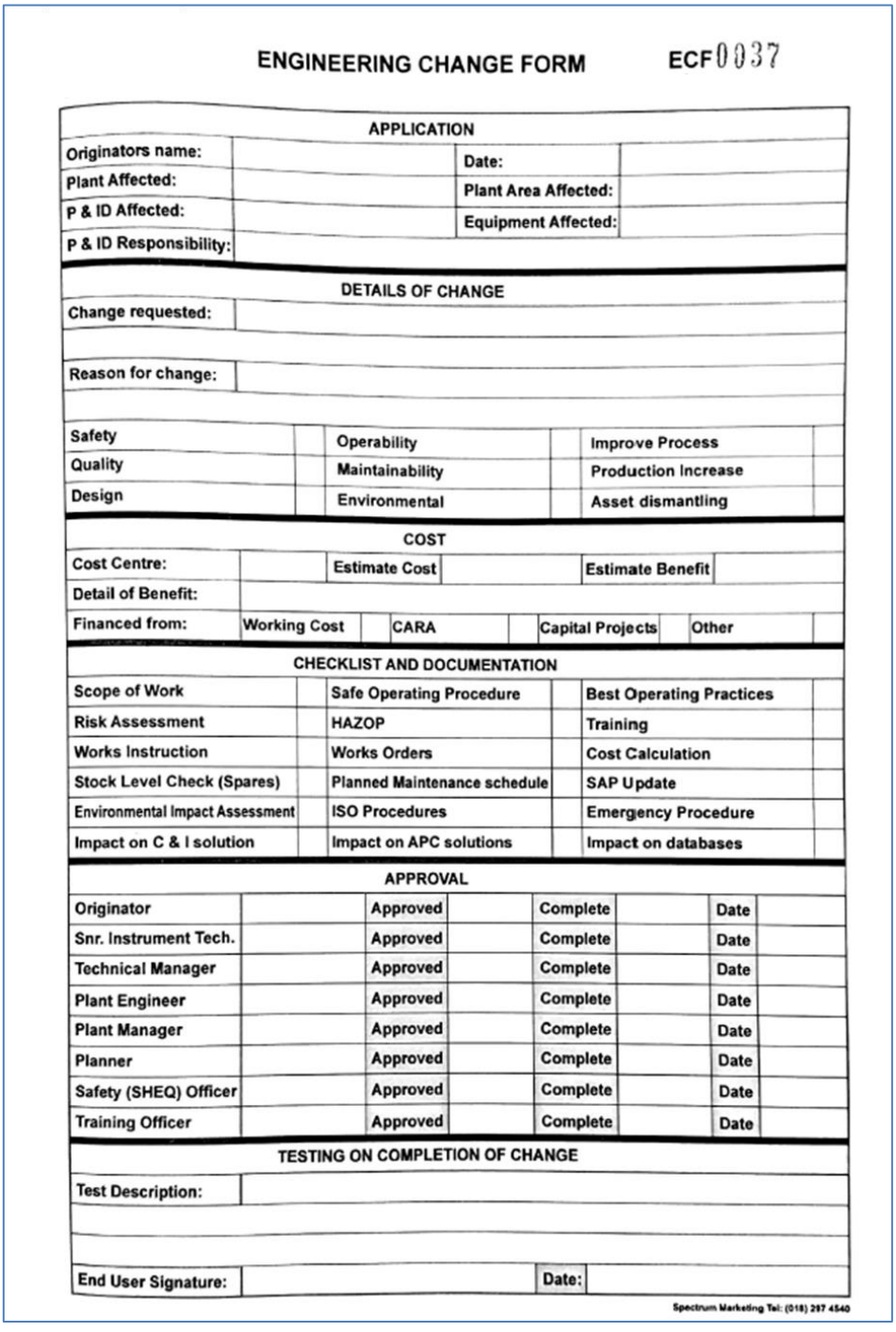
The following table provides a summary of issues which may result and possible thought process that should be followed together with the necessary action.

Table H.1: Sampler Decision Table

IF	THEN
Too much sample is being collected	Primary increment counter is set incorrectly or; Inspect primary sampler to determine if the unit is producing a correct sample or; Sampling frequency is set too high and must be adjusted down.
Too little sample is being collected	Screen is choked with foreign material or slurry material build-up or; Sampling frequency is set too low and must be adjusted up or; Primary increment counter is set incorrectly; Hopper is choked and needs to be un-choked as per procedure for unchoking.
Slurry is entering the secondary sampler between sampling intervals	Pneumatic valve is not closing fully, thus leaking or check for obstruction or; Check that the air supply is not restricted or.
No sample is collected when the plant is running	Pneumatic valve is defective or hopper is choked or; Controls are defective (unit tripped perhaps) or; There is no power to the unit or; Primary sampler is not running as per procedure.
Agitator does not rotate or move and the electrical connections appear secure	Check power is coming into the panel; Check that the isolator switch is on; Check that overload has not tripped. Ensure overload is at the correct setting; Check motor and gearbox are functioning.

Appendix I: Change Management for Mechanical Hopper

The site-specific change management procedure was followed and an identical engineering change management form was filled out in order to formalize the equipment change on site (original filled out form could not be included in this dissertation due to confidentiality purposes):



ENGINEERING CHANGE FORM ECF0037

APPLICATION			
Originators name:		Date:	
Plant Affected:		Plant Area Affected:	
P & ID Affected:		Equipment Affected:	
P & ID Responsibility:			

DETAILS OF CHANGE					
Change requested:					
Reason for change:					
Safety		Operability		Improve Process	
Quality		Maintainability		Production Increase	
Design		Environmental		Asset dismantling	

COST							
Cost Centre:		Estimate Cost		Estimate Benefit			
Detail of Benefit:							
Financed from:	Working Cost		CARA		Capital Projects	Other	

CHECKLIST AND DOCUMENTATION					
Scope of Work		Safe Operating Procedure		Best Operating Practices	
Risk Assessment		HAZOP		Training	
Works Instruction		Works Orders		Cost Calculation	
Stock Level Check (Spares)		Planned Maintenance schedule		SAP Update	
Environmental Impact Assessment		ISO Procedures		Emergency Procedure	
Impact on C & I solution		Impact on APC solutions		Impact on databases	

APPROVAL							
Originator		Approved		Complete		Date	
Snr. Instrument Tech.		Approved		Complete		Date	
Technical Manager		Approved		Complete		Date	
Plant Engineer		Approved		Complete		Date	
Plant Manager		Approved		Complete		Date	
Planner		Approved		Complete		Date	
Safety (SHEQ) Officer		Approved		Complete		Date	
Training Officer		Approved		Complete		Date	

TESTING ON COMPLETION OF CHANGE			
Test Description:			
End User Signature:		Date:	

Spectrum Marketing Tel: (018) 297 4540

Figure I.1: Change Management Template.