The case for using five-times particle nominal top size cutter width for dry material primary increment sampling at 0.6 m/s cutter speed

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The Theory of Sampling (TOS) empirically recommends that the width of a primary dry sampler's cutter must be a minimum of 30 mm or three times the nominal top size of the particle, nugget or cluster, whichever is larger. This recommendation has been tested and to a large degree verified but can result in non-random errors. Research has shown that >4-times-particle-size primary cutters result in minimum errors. Furthermore, if consecutive primary sample increments require downstream processing, which may include crushing or sub-sampling, then the increment sampled by a three-times-top-size cutter is too small to be drawn out in a controlled fashion to allow enough sub cuts. From this work, the recommendation for a larger primary cutter measuring five times nominal top size at 0.6 m/s cutter speed is proven to result in precision sampling preparation steps – over and above eliminating non-random sampling errors.

The cost impact of a larger primary sample increment is also considered; the crusher is a major part of the chemical sampling leg's capital and operational costs. When the sampling plant requires crushing, collecting a larger increment won't affect the crusher selection because the crusher is normally governed by particle size and not throughput (or the size of the increment). Similarly, downstream-of-the-crusher sample preparation equipment cost is also not increased.

Keywords: Cutter width, cutter speed, non-random error elimination, controlling the number of sub-cuts for precision sampling

INTRODUCTION

It is well proven by various contributions from the International Pierre Gy Sampling Association that incorrect sampling can results in financial losses. Correct sampling in accordance with the published Theory of Sampling (TOS), will not only result in direct financial gains from accurate sampling that allows successful arguments and proof against commercial trade penalties around quality assurances, but also intangible costs of market perception and competitor differentiation from superior QAQC product supply. Despite these proven works, cost is usually the driving force, which results in major flaws in sampling equipment, systems and procedures. However it is false economy, because there is no point in investing in the latest analytical equipment and spending considerable time and effort attempting to reconcile production figures if the samples presented for analysis are not representative in the first place (Holmes, 2004). Representativeness in-plant sampling is therefore the first essential step in the analytical result. TOS-compliant samplers including cross-stream cutters are essentially rectangular enclosures which are moved at constant speed through a falling stream of material to redirect a controlled portion of the particle stream into a collection container (Cleary and Robinson, 2008). The cutter is the heart of the machine and must be designed to minimise error generating mechanisms as set out by (Pitard, 2005).

A bigger cutter results in a bigger primary increment mass collected which may require a downstream sampling system that adds to capital and operational costs. However, extracting the representative, primary sample increment with minimum extraction error is not the only consideration; sample increment segregation and automated sub-sampling (sample division) considerations also play an important role. Larger sample increments, extracted by cutter apertures larger than three-times particle nominal top size (TOS rule) will not only minimise/eliminate extraction errors, but also produce larger increments for successful downstream increment preparation.

LITERATURE REVIEW

Theory of Sampling

The basic rule for correct sampling is that all parts of the ore being sampled must have an equal probability of being collected and becoming part of the final sample for analysis (Holmes, 2004). (Slabbert, 2022) indicated that the comprehensive application of the TOS into minerals sampling applications is still limited globally despite ongoing, active and dedicated contributions and learnings from free publications by (amongst others) the International Pierre Gy Sampling Association.

Accuracy of Sample Increments

Sample bias

A sampling bias is always introduced by incorrect sampling; however, sampling and analytical biases can be eliminated by taking preventive actions (Pitard, 2019). Cleary and Robinson (2008) emphasised that it is particularly important that samples be unbiased when they are part of the determination of the economic value of particulate material being bought and sold.

Extraction error

Increment extraction error occurs when an increment is not fully extracted, therefore an increment must be completely extracted without any material rebounding or being lost from the cutter (Holmes, 2004). Using five times instead of three times nominal top size cutter width reduces possibilities of missing particles (which are supposed to be sampled) which will result in reduction of extraction errors. Robinson *et al.*, (2008) used discrete element modelling (DEM) to prove that cross belt sampler extraction error was minimised using 3.5 times cutter aperture (on coal with a nominal top size of 50 mm). The best correlating sampling results were achieved by >3 times particle nominal top size cutter. Cleary and Robinson (2008) used DEM to show that extraction errors were minimised for a belt end cross stream sampler when a cutter aperture of 3.3 particle nominal top size was used at 0.6m/s cutter speed. In the final iteration of their work, a 4.8D cutter aperture resulted in even lower extraction errors, despite using a 1.2 m/s cutter speed. It can be reasonably assumed that a 4.8D (or 5 times D) cutter opening would yield even better results at 0.6m/s cutter speed – although beyond the scope of their work.

Bias Prevention: The Effect of Cutter Width and Speed on Primary Increment Extraction Error

The cutter is the heart of the machine and must be designed to minimise error generating mechanisms as set out by Pitard (2005). The importance of cutter aperture (width) has been explained with the mechanism that congestion near the mouth of the cutter has a major effect on sample extraction ratio (Cleary and Robinson, 2008). Also from their work, cutter speed does not have a major influence on sample extraction ratio or sample bias. However, the combination of a large cutter opening with low cutter speed will result in large primary increment (refer Equation 1) and a large final sample size at the end of the shift for a single stage sampling system.

The relationship between cutter width and cutter speed

It is well known from various TOS sources that the cutter width and cutter speed play an important role in eliminating increment sample extraction error. The speed of the cutter must be constant throughout the stream as well as the width of the cutter because if there is any change (either from cutter width or cutter speed), it can result in over- or under-sampling and bias.

Segregation error (short range quality variation error)
From the moment a sample increment is extracted by the primary sampler, segregation of different (or grouping of like) minerals occurs. The extent of segregation could be severe for even similar minerals, much like the principle of segregation explained by the Brazil nut effect. Segregation is an adverse enemy in sample preparation steps between one sampling stage and the next (Kruger, 2014). It is cumbersome and expensive to combat segregation between sample preparation steps (Sukha *et al.*, 2014). Probably the only effective way to account for segregation is to take enough sub-sample increments to measure all parts of the segregated stream, with equal probability and ratio, in other words instead of counteracting the segregation, rather measure the degree of segregated particles' representivity. The number of sub-sample increments are therefore vital to the precision level and accuracy of a well performing sampling system. This important operational parameter of the sampling plant should therefore not be left to chance, but the designer must ensure mechanical equipment design and particularly sample transport devices (like conveyors, feeders, chutes) are designed to prevent segregation where possible, but also draw out the sample increment under controlled and adjustable conditions to <u>ensure</u> that enough sub-sample increments are taken downstream – even if process conditions change.

The Number of Sample Increment Sub-Samples Required to Combat Segregation
ISO standards provide a guideline on the number of increments to be used as a starting point. However, the number of cuts for division of increments, partial samples and gross samples should be determined experimentally from the quality variation of the stream to be divided and the required sampling precision for the particular sampling stage. A good example of this calculation is in ISO 3082 (2009), Section 10.3.1.3 *Number of increments (cuts)*. However, the variability input parameter and segregation effects are not always available at the design onset of a sampling project or could be variable during sampling plant operation and the designer must rely on a heuristic for the plant design. Some ISO standards list an umbrella number of sub-cuts at 4-6, although in our experience across minerals and applications, a minimum number of 12 sub-cuts (for dry materials) guarantees good precision for most cases.

Benefit of Five Times Nominal Top Size Cutter Width for a Primary Sample Increment
4.8 times nominal top size cutter provides the lowest percentage of missed particles and a highest extraction ratio with no sign of bias (Cleary and Robinson, 2008). If consecutive primary sample increments require downstream processing, which may include crushing or sub-sampling, then the increment sampled by a five times nominal top size is large and may allow for enough sub-cuts.

Single versus Multiple Stage Sampling System
Single stage sampling systems are cheaper than multiple stage sampling systems and can be utilised effectively when low tonnages are being treated. However, if high tonnages are being treated, the final size becomes too large to handle and therefore a multistage sampling system is required to reduce the final sample size to the manageable size required. When secondary (or subsequent) sampling stages are required, the samplers used are again governed by the same cutter speed rules as set out by TOS. The slow travelling cutter may then not have time in its subsequent application to traverse across the stream, park, discharge the sample, close the latch, ramp up, traverse the stream in reverse, ramp down and repeat the cycle. The time available for successful cycle completion will be determined by the size of the increment presented for sub-sampling and the draw out rate of this increment towards the cutter.

The number of sub-sample increments possible by a rotary sampler is higher than that of a linear sampler because the former does not require stop, discharge, latch open/closing and ramp up/down times. The rotary sampler can typically accommodate four off cutters, rotating at 18-27 rpm while still complying with sampling rules of tip speed on outer radius and cutter opening on inner radius (Pitard, 2005). To take a minimum of six sub-cuts (from the four cutters rotating at 18 rpm), the increment must be fed to the equipment over a duration of 0.8s. If only one cutter is used on the flexible equipment, then the increment must be fed over a duration of 3.3s.

METHOD, EQUATIONS AND ASSUMPTIONS USED IN THE INVESTIGATION

The investigation starts by calculating primary sample increment mass for two minerals (iron ore and coal), over a range of throughput production capacities, at different respective particle sizes typical of each commodity, and two associated cutter widths namely, 3- and 5 times particle nominal top size. Primary sample increment mass, reported in Table I-IV (the tables), column 3 is given by Equation 1:

$$M_{increment} = \frac{W_{cutter} \times \dot{M}}{v_{conveyor} \times 3600} \quad [1]$$

Where
$M_{increment}$ is the increment mass in kg
W_{cutter} is the cutter width in mm
$\dot{M}$ is the production throughput in ton/h
$v_{conveyor}$ is the conveyor belt speed in m/s

The calculated increment masses have indicated that if the required number of primary sample increments (typical to ISO 3082 for iron ore and ISO 13909 for coal) are taken – the composite sample would not be ergonomic. Therefore, all iterations of the investigation include a secondary sampling stage. The selected secondary sampler is chosen as a rotating plate divider (RPD).

The second step calculates the increment volume. Coal and iron ore bulk densities of 1100 kg/L and 2600 kg/L are respectively used. The limits of bulk densities cater for a range of typical mineral properties where a low mass of coal will allow a large volume of increment to be sub-sampled (over an extended time) while iron ore bulk density is likely a governing constant. Increment volume (column 4 in Table I) is calculated using Equation 2 below:

$$V_{increment} = \frac{M_{increment}}{\rho_{bulk}} \quad [2]$$

Where
$V_{increment}$ is the increment volume in L
$M_{increment}$ is the increment mass in kg
ρ_{bulk} is the bulk density in kg/L

Given that downstream processing is required, the sample increment must be drawn out in a controlled fashion and be presented to the subsequent sampler to determine if the increment presentation time is enough to allow a minimum of six sub-cuts. The increment is drawn out via an adjustable feeder, profile gate. The minimum height and width of the profile gate cannot be smaller than three times particle nominal top size; otherwise it would result in frequent blockages in practice. The feeder conveyor drawing the increment out through the profile gate, typically must run at slow, controlled (and optionally variable speed drive adjustable) speed; we use a constant speed of 0.1 m/s for all iterations of this work. The profile gate cross sectional area is the square of the dimension of 3- or 5-times particle top size (column 5 in Table I) and calculated with Equation 3 below:

$$P = P_{height} \times P_{width} \quad [3]$$

Where
P is the profile gate area in m^2
P_{height} is the profile gate height in m
P_{width} is the profile gate width in m

The volumetric draw out rate achieved by the profile gate mounted on top of the conveyor is given by Equation 4 below (column 6 in the Tables).

$$V_{draw\ rate} = P\ X\ S_{feeder} \quad [4]$$

Where
$V_{draw\ rate}$ is the volumetric draw out rate in m^3/s
S_{feeder} is the sample feeder speed in m/s
P is the profile gate area in m^2

The volumetric draw out rate is then used to calculate the time it takes to draw out the primary increment into a secondary rotary sampler using Equation 5 (column 7 in the tables).

$$D_{time} = \frac{V_{increment}}{V_{draw\ rate} \times 1000} \quad [5]$$

Where
D_{time} is the draw out time in s
$V_{draw\ rate}$ is the volumetric draw out rate in m^3/s
$M_{increment}$ is the increment mass in kg
$B_{density}$ is the bulk in kg/m^3

The secondary sampler throughput (column 8, in the tables) is calculated by Equation 6:

$$F_{rate} = \frac{(M_{increment}\ /1000)}{(D_{time}\ \text{x}\ 3600)} \quad [6]$$

Where
F_{rate} is the feed rate to a secondary rotary sampler in tph
D_{time} is the draw out time in s
$M_{increment}$ is the increment mass in kg

Given RPD rotational speeds of 17.7 and 27 rpm, the number of sub-cuts taken by the sampler can be calculated and is listed in column 9 of the tables. Where less than the targeted six sub-cuts are taken, the cells are highlighted in red (for major non-conformance) or orange (for minor non-conformance).

Column 10 then lists the number of cutters required in the flexible equipment to achieve the required minimum of six sub-cuts.

The last column lists the number of sub-cuts achieved with the optimised sampling equipment. The optimisation of the RPD is superior to linear cross stream samplers where the number of cutters cannot be adjusted and are limited in their speed and adaptability which would have guaranteed less sub-cuts and more major non-compliances without possible rectification.

RESULTS: THE COMPARISON OF CUTTER WIDTH ON RESULTING SAMPLE INCREMENT MASS AND DOWNSTREAM SUITABILITY FOR SUB-SAMPLING CONTROL

Based on the results in Table I with a three times nominal top size cutter, insufficient sub-cuts are collected while sampling 50 mm particle size at 200 tph and 450 tph throughput. The same result is also observed while sampling 20 mm particle size at 200 tph throughput. However, after optimising the equipment configuration with regards to the number of installed cutters, the desired sub-cut integer can be achieved for all coal sampling scenarios.

Table II lists the outcomes when using a five times cutter nominal top size. The table indicates that only one scenario (of large particle size and low tonnages) poses an original non-conformance and that the system can be made compliant with the addition of cutters to the RPD.

But the low bulk density of coal allows for sample increments of high volume and therefore an easily achievable number of sub-cuts. Table III and IV list the results from the same investigation for iron ore where more non-compliances are expected.

The results show that 50 mm iron ore sample increments cannot successfully be sampled by a single cutter secondary sample and that even after increasing the number of cutters to four – the desired number of sub-cuts can still not always be achieved. It is then recommended that crushing (before sample division) be installed in practice to reduce particle size, which will allow reduction of the cross-sectional gate open area and increase the draw out time to allow sufficient sub-cuts of the increment. Using three times particle top size cutter widths in this instance will result in high capital and operational cost additions for small throughput production systems.

At 31.5 mm there are again non-conformances, but most could be addressed by using four cutters and in one case at lowest throughput, interstage crushing would be required.
At 6.3 mm particle size, all iterations were complaint with only one cutter installed in the RPD.

Increasing the primary cutter width to five times particle nominal top size sees a drastic change in the compliance of the systems for all particle sizes, where only 50 mm particles at low flow rates would require interstage crushing.

When comparing RPD throughput value (which represents downstream sampling plant throughput rates for each mineral at each particle size) between Table I and II and Table III and IV, respectively, throughput does not change as regulated by the profile gate. Only the draw out time, at that throughput rate, changes. Therefore, downstream size reduction, subsampling and interconnecting equipment selection is not affected. Given that throughput rates are a major cost driver for equipment selection, it can be concluded that an increase in primary sampler top size from 3-to-5 times nominal particle top size does not adversely affect sampling system costs – but will improve overall sampling plant results precision.

CONCLUSIONS

Empirically recommended three-times particle nominal top size cutters have been proven but remains challenged with DEM verification work (Cleary and Robinson, 2008) where larger cutter openings result in lower systematic extraction errors.

This work builds on those verifications of improved accuracy, by also considering the segregation of primary sample increments and that the segregation is best <u>measured</u> by a minimum number of sub-cuts.

Sampling of large particles, with high bulk density, at low production rates poses a significant risk that sample increments are too small to allow controlled preparation through a practically-reliable profile gate and that enough sub-cuts can be taken of the increment stream – compromising sampling precision and in severe cases can compromise sample accuracy.

Increasing primary sampler cutter widths to five times nominal top size improves the sampling precision through the number of sub-cuts taken and in most iterations of our work had practical implications. The increase in cutter size does not affect downstream sampling plant throughput rates and does not add to capital and operational cost of downstream plant.

Table I. Coal using three times nominal top size cutter width

Coal using three times nominal top size cutter width, 2/63-RPD, 17.7 RPM									
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	50	13.889	0.013	0.0225	0.00225	5.61	8.91	1.66	4	6.62
450	50	31.250	0.028	0.0225	0.00225	12.63	8.91	3.72	2	7.45
1000	50	69.444	0.063	0.0225	0.00225	28.06	8.91	8.28	1	8.28
1750	50	121.528	0.110	0.0225	0.00225	49.10	8.91	14.49	1	14.49
3000	50	208.333	0.189	0.0225	0.00225	84.18	8.91	24.83	1	24.83

Coal using three times nominal top size cutter width, 2/63-RPD, 17.7 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	20	5.556	0.005	0.0036	0.00036	14.03	1.43	4.14	2	8.28
450	20	12.500	0.011	0.0036	0.00036	31.57	1.43	9.31	1	9.31
1000	20	27.778	0.025	0.0036	0.00036	70.15	1.43	20.69	1	20.69
1750	20	48.611	0.044	0.0036	0.00036	122.76	1.43	36.21	1	36.21
3000	20	83.333	0.076	0.0036	0.00036	210.44	1.43	62.08	1	62.08

Coal using three times nominal top size cutter width, 2/40-RPD, 27 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	6.0	1.667	0.002	0.0003	0.0000324	46.76	0.13	21.04	1	21.04
450	6.0	3.750	0.003	0.0003	0.0000324	105.22	0.13	47.35	1	47.35
1000	6.0	8.333	0.008	0.0003	0.0000324	233.82	0.13	105.22	1	105.22
1750	6.0	14.583	0.013	0.0003	0.0000324	409.18	0.13	184.13	1	184.13
3000	6.0	25.000	0.023	0.0003	0.0000324	701.46	0.13	315.66	1	315.66

Table II. Coal using five times nominal top size cutter width

Coal using five times nominal top size cutter width (250 mm), 2/63-RPD, 17.7 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	50	23.148	0.021	0.0225	0.00225	9.35	8.91	2.65	3	7.95
450	50	52.083	0.047	0.0225	0.00225	21.04	8.91	5.96	1	5.96
1000	50	115.741	0.105	0.0225	0.00225	46.76	8.91	13.25	1	13.25
1750	50	202.546	0.184	0.0225	0.00225	81.84	8.91	23.19	1	23.19
3000	50	347.222	0.316	0.0225	0.00225	140.29	8.91	39.75	1	39.75

Coal using five times nominal top size cutter width (60 mm), 2/63-RPD, 17.7 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	20	9.259	0.008	0.0036	0.00036	23.38	1.43	6.90	1	6.90
450	20	20.833	0.019	0.0036	0.00036	52.61	1.43	15.52	1	15.52
1000	20	46.296	0.042	0.0036	0.00036	116.91	1.43	34.49	1	34.49
1750	20	81.019	0.074	0.0036	0.00036	204.59	1.43	60.35	1	60.35
3000	20	138.889	0.126	0.0036	0.00036	350.73	1.43	103.47	1	103.47

Coal using five times nominal top size cutter width 31.5 mm), 2/40-RPD, 27 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	6	2.778	0.003	0.0003	0.0000324	77.94	0.13	35.07	1	35.07
450	6	6.250	0.006	0.0003	0.0000324	175.36	0.13	78.91	1	78.91
1000	6	13.889	0.013	0.0003	0.0000324	389.70	0.13	175.36	1	175.36
1750	6	24.306	0.022	0.0003	0.0000324	681.97	0.13	306.89	1	306.89
3000	6	41.667	0.038	0.0003	0.0000324	1169.10	0.13	526.09	1	526.09

Table III. Iron ore using three times nominal top size cutter width

Iron ore using three times nominal top size cutter width (150 mm), 2/90-RPD, 11.3 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	50	13.889	0.005	0.0225	0.00225	2.37	21.06	0.45	4	1.79
450	50	31.250	0.012	0.0225	0.00225	5.34	21.06	1.01	4	4.02
1000	50	69.444	0.027	0.0225	0.00225	11.87	21.06	2.24	3	6.71
1750	50	121.528	0.047	0.0225	0.00225	20.77	21.06	3.91	2	7.82
3000	50	208.333	0.080	0.0225	0.00225	35.61	21.06	6.71	1	6.71

Iron ore using three times nominal top size cutter width (94.5 mm), 2/63-RPD, 17.7 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	31.5	8.750	0.003	0.0089	0.000893025	3.77	8.36	1.11	4	4.45
450	31.5	19.688	0.008	0.0089	0.000893025	8.48	8.36	2.50	3	7.50
1000	31.5	43.750	0.017	0.0089	0.000893025	18.84	8.36	5.56	2	11.12
1750	31.5	76.563	0.029	0.0089	0.000893025	32.97	8.36	9.73	1	9.73
3000	31.5	131.250	0.050	0.0089	0.000893025	56.53	8.36	16.68	1	16.68

Iron ore using three times nominal top size cutter width (18.9 mm), 2/40-RPD, 27 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m^2)	Volumetric draw out rate (m^3/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	6.3	1.750	0.001	0.0004	0.000035721	18.84	0.33	8.48	1	8.48
450	6.3	3.938	0.002	0.0004	0.000035721	42.40	0.33	19.08	1	19.08
1000	6.3	8.750	0.003	0.0004	0.000035721	94.21	0.33	42.40	1	42.40
1750	6.3	15.313	0.006	0.0004	0.000035721	164.87	0.33	74.19	1	74.19
3000	6.3	26.250	0.010	0.0004	0.000035721	282.64	0.33	127.19	1	127.19

Table IV. Iron ore using five times nominal top size cutter width

Iron ore using five times nominal top size cutter width (250 mm), 2.90-RPD, 11.3 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m²)	Volumetric draw out rate (m³/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	50	23.148	0.009	0.0225	0.00225	3.96	21.06	0.75	4	2.98
450	50	52.083	0.020	0.0225	0.00225	8.90	21.06	1.68	4	6.71
1000	50	115.741	0.045	0.0225	0.00225	19.78	21.06	3.73	3	11.18
1750	50	202.546	0.078	0.0225	0.00225	34.62	21.06	6.52	2	13.04
3000	50	347.222	0.134	0.0225	0.00225	59.35	21.06	11.18	1	11.18

Iron ore using five times nominal top size cutter width (157.5 mm), 2/63-RPD, 17.7 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m²)	Volumetric draw out rate (m³/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	31.5	14.583	0.006	0.0089	0.000893025	6.28	8.36	1.85	4	7.41
450	31.5	32.813	0.013	0.0089	0.000893025	14.13	8.36	4.17	4	16.68
1000	31.5	72.917	0.028	0.0089	0.000893025	31.40	8.36	9.26	3	27.79
1750	31.5	127.604	0.049	0.0089	0.000893025	54.96	8.36	16.21	2	32.42
3000	31.5	218.750	0.084	0.0089	0.000893025	94.21	8.36	27.79	1	27.79

Iron ore using five times nominal top size cutter width (18.9 mm), 2/40-RPD, 27 RPM										
Flow rate (ton/h)	Top size (mm)	Increment mass (kg/cut)	Increment volume (l)	Profile gate area (m²)	Volumetric draw out rate (m³/s)	Draw out time (s)	RPD Throughput	# Sub-cuts	# cutters	#Sub-cuts
200	6.3	2.917	0.001	0.0004	0.000035721	31.40	0.33	14.13	1	14.13
450	6.3	6.563	0.003	0.0004	0.000035721	70.66	0.33	31.80	1	31.80
1000	6.3	14.583	0.006	0.0004	0.000035721	157.02	0.33	70.66	1	70.66
1750	6.3	25.521	0.010	0.0004	0.000035721	274.79	0.33	123.65	1	123.65
3000	6.3	43.750	0.017	0.0004	0.000035721	471.07	0.33	211.98	1	211.98

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