GRINDING CIRCUIT DESIGN FOR ADANAC MOLY CORP USING A GEOMETALLURGICAL APPROACH

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ABSTRACT

This paper describes the design of an SABC grinding circuit using CEET technology applied to grindability data produced from testing 100 samples and distributed across the blocks of a mine plan using a geostatistical approach. The data distribution required the identification of the location of the sample points and a geological plan of the 130 million ton Ruby Creek orebody together with a mine plan of about 11000 blocks to be mined during the proposed 18 year life of the mine. The mill design was then made with consideration for the estimated hardness of each block in terms of both SAG and Ball milling with allowance for annual periods when the ore is harder to grind. Operating specifications were selected to achieve an optimum of capital and operating costs through use of the CEET program. The geostatistics assigned the statistical error that arises from having a limited amount of sample testing data to the hardness estimate of each block of ore in the mine plan. The final design could then include a quantification of risk and determination of safety factors based on the accuracy of block hardness estimates and CEET model fitting.

INTRODUCTION

The traditional approach to plant design involves the extensive testing of a single large composite sample or a small number of composite samples that are reputed to represent the ore body. It is accepted that the tests used can accurately measure in the laboratory the grindability of the sample by a process representing that to be used in the plant. The size of equipment required to achieve a specified throughput and product size is then calculated from one of a variety of models that have been developed by metallurgists over years of trial and error. Since these tests and models are tried and tested, they are accepted as reasonably precise; however during the operation of the resulting plant the design is sometimes found to be inadequate. It is then suspected that the flaw in the design process lies in the samples not being sufficiently representative of the ore body, since using only a single or small number of composite samples does not recognize the variability of the hardness of the ore, nor does it allow for the lack of precision in the hardness value used in the design.

This paper outlines a design procedure suited to an orebody that is described by a geostatistical analysis of a reasonably large number of small samples of drill core. The analysis required the identification of the location of the sample points and a geological plan of the orebody, together with a mine plan of the blocks to be mined during the proposed life of the mine. The mill design was then made using the estimated hardness of each individual block with an allowance for annual fluctuations in the grindability of the ore. The geostatistical analysis assigned a statistical error to the hardness estimates of blocks and of each production year such that the final design included risk estimates and safety factors based on the possible errors that arise from having a limited amount of sample data (Kosick et al. 2002).

ORE BODY SPECIFICATION

SAMPLE DATA

100 samples of drill core from the Ruby Creek ore body were subjected to grindability testing required for the design of a plant for Adanac Moly Corp. to include SAG and Ball milling. The hardness of each sample was measured in terms of SAG power index, SPI (for SAG grinding) and Bond Ball mill work index, BWi (for ball mill grinding). A further measure, the Minnovex crusher index, Ci was also measured for use in the CEET program to determine SAG mill feed size (Kosick and Bennett, 2001). The SPI values varied from 13.5 to 107 minutes with an average of 53 minutes. This variability, although apparently very high, is less than normal compared with sample sets from other orebodies; COV (i.e. standard deviation divided by mean value) is about 30% compared with a typical 40%. The BWi varied from 10.0 to 15.3 kWh/t with an average of 12.5 kWh/t. The variability is a little less than usual with COV at 10%. The lack of correlation of BWi with SPI in this set of samples is very unusual, as shown in Figure 1. Normally BWi and SPI increase together with a correlation coefficient of about 0.5. However, in this case there is a small trend to higher BWi with lower SPI; the ore can be relatively soft at

coarser sizes while relatively hard at finer sizes. This can have a significant impact in a SAG and Ball mill circuit where there is no scope for storage capacity between milling stages and throughput is normally limited by a bottleneck at one stage or the other. In this case any ore with a high BWi value will have reduced throughput due to the ball mill despite the capability of the SAG mill to handle more, and vice versa when the SPI value is high.

GEOSTATISTICAL ANALYSIS OF THE DATA

A representation of the grindability across the whole ore body requires a geostatistical analysis of all the data that is available. Although this paper is principally concerned with the use of such an analysis for the design of the grinding circuit, a short description of the geostatistics is a prerequisite to the understanding of the whole geometallurgical approach (Amelunxen et al, 2001). The analysis requires the consideration of much more information about the mine than would traditionally be used in plant design, i.e.

- Location of each sample within the ore body in terms of co-ordinates and section of core used.
- Geological description of the sample, e.g. lithology, alteration, rock type, and perhaps metal grade.
- Mine block plan with similar geological information.
- Planned mining schedule for the mine blocks, e.g. by year.

The objective of the analysis is the distribution the grinding test data across the blocks in the mine plan, assigning each block (and each mining period) an estimated hardness value (SPI, Ci and BWi) and a precision of each estimate.

In this study there were 100 samples, each comprising a 12m bench intercept from a total of 27 vertical drill holes. Minimum hole spacing was 50m and minimum spacing within a hole was 12m. This data was distributed across 10,903 mine blocks, representing a total of about 130 million tons of ore to produce a dataset on which to base the plant design.

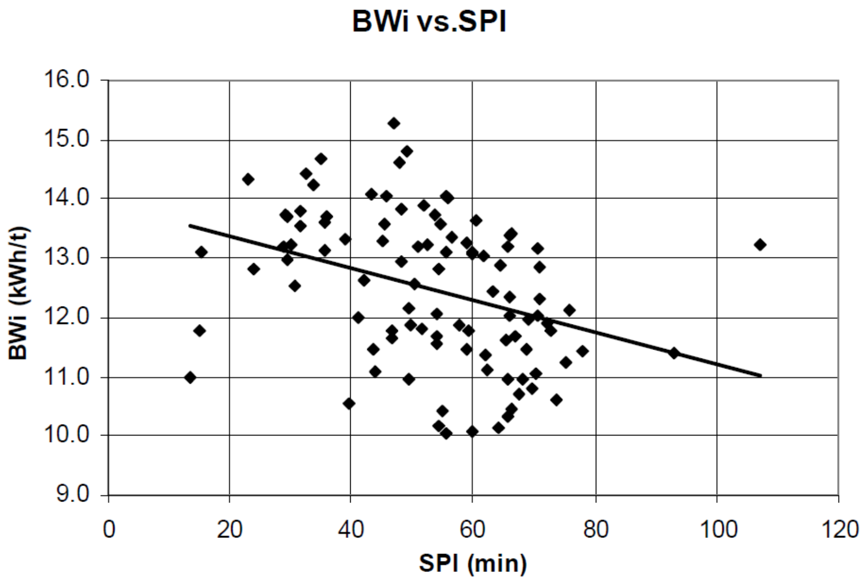

Figure 1: BWi variation with SPI value

The samples were identified as six main lithologies further split into a total of eleven sub-types. Statistical analysis indicated significant grindability differences between types but, with only 100 samples in total, there was insufficient data to do separate geostatistical analysis of each type. However, the samples and mine blocks were also identified as three different ore types and there were sufficient samples in two of these to conduct separate analysis for each, allowing block values to be estimated from samples of the same ore type treated as domains (Dagbert and Bennett, 2006). Blocks from the third ore type were estimated from a combination of all samples. Spacing of samples was adequate since, for each ore type, at least 75% of the mine blocks had a sample of the same type within 100m of the block.

Estimation of block values was made using the geostatistical Kriging technique (Preece, 2006). This involves the construction of geostatistical variograms for each measure of grindability (SPI, Ci and BWi) by plotting the semi-variance of differences in the value of pairs of samples of equal distance apart against that distance. The correlogram (i.e. 1 minus the correlation coefficient of pairs of samples) for SPI in ore type 2 is plotted as a variogram in Figure 2. The establishment of a model for the variogram allows for the estimation of the hardness and the precision of each estimate to be made for each block by combination of the values of samples that are within the range of influence. That range is determined by the shortest distance apart for pairs having attained the maximum variance. In this study the range for Ci values was 100m, SPI values was 200m and for BWi was 300m. The value where the curve cuts the y-axis is referred to as the nugget effect and is a measure of the inherent errors in sampling and measurement of individual data points.

Since blocks have been identified by year on the mining plan, the geostatistical analysis also allows the determination of annual average grindability values and their precision by the same Kriging technique, so it is possible to design the plant to deliver specified throughput in each production year. It is also possible to extend the analysis to calculate how many more samples need to be tested from within the range of the blocks mined in a production year in order to improve the precision to any desired level.

The profiles (i.e. cumulative frequency distribution) of the estimated SPI and BWi values for the complete ore body are shown in Figure 3. SPI values of blocks vary from 25 to 77 minutes and BWi values from 10.7 to 14.8 kWh/t. The Kriging technique has created some smoothing of the data by always using more than one sample to estimate the

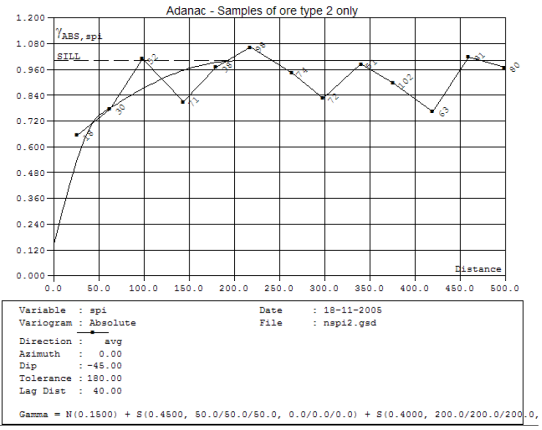

Figure 2: Correlogram (plotted as a Variogram) for SPI in ore type 2

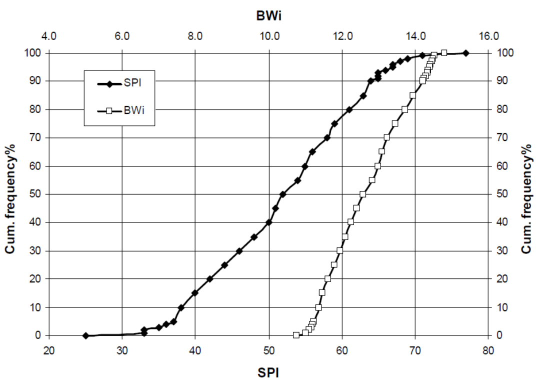

Figure 3: Profile of SPI and BWi values in the orebody

hardness of any block. This dataset of 10,903 mine blocks was used as the basis of the grinding plant design.

GRINDING PLANT DESIGN

The plant design was conducted using the CEET internet-based software developed by SGS Minnovex. This software can simultaneously handle the grindability values for enormous numbers of mine blocks (limited only by computer memory) to produce an optimum design to meet the specifications for throughput and product size for the complete ore body.

SPECIFICATIONS AND ASSUMPTIONS

Specifications for the capability of the grinding plant and assumptions about the operation are used as inputs to the CEET program. Critical parameters are shown in Table 1.

Table 1: Specifications and assumptions used as program inputs

CEET INPUT PARAMETERS		
	Assumptions	Values
Circuit Throughput		
	Tph Average	906
	Tph Maximum	1133
	Tph Minimum	725
	TPH min exceptions	2
Grinding Circuit Product		
	P_{80} required (micron)	210
	Maximum P_{80} allowed (micron)	225
	Minimum P_{80} allowed (micron)	180
Grinding Circuit Details		
	Primary crusher CSS (mm)	150
	Grate Size (mm)	50, 60 , 75
	Screen type	Trommel
	Screen aperture (mm)	13, 16, 19, 22 , 25
	SAG % ball load	12
	SAG load %	26
	Pebble crusher product P_{80} (mm)	16
	Pebble crusher product P_{50} (mm)	10
Operating Costs		
	Ball wer g/kWh (SAG, BM)	133
	Mill liner wear g/kWh (SAG, BM)	10.1
	Pebble crusher liner wear g/kWh	34
	Steel ball cost (US$/t)	660
	Liner sot (US$/t)	2110
	Electricity cost (US$/t)	0.12
	Water cost (US$/t)	0.05
	Labour cost (US$/t)	0.1

Since the ore body has variability in the hardness, the throughput of the grinding plant and product size must be allowed to vary about the specified average results. There will be times when the hard ore is restricting throughput to a minimum and others when the ore is soft and throughput is allowed to reach a maximum determined by limitations in material handling equipment or other parts of the plant. The larger the variability that is allowed, the less influence the hardest blocks of ore will have on the design and the smaller and lower cost the plant. In this case the throughput was allowed to range from 725 to 1133 tph whilst still achieving the specified average of 906 tph (20,000tpd at 92% availability). An exception limit of 2% was set for the minimum throughput value to avoid a small amount of very hard ore having excessive influence over the mill design. This means that potentially 2% of the tonnage will be treated at a rate of less than 725tph, however, in practice the ore will probably be blended to some extent by working simultaneous faces and the very hard ore will not be a sole source of feed.

Similarly the 80% passing product size P_{80} is permitted to vary over the range 180 to 225 microns (while achieving an average of 210 microns) to allow higher throughput to be achieved at coarser size during periods when the ore is softer. The extent of this range of size is dependent on downstream extraction plant requirements.

The CEET program can compute mill power requirements for circuits with three different SAG grate apertures and five different SAG screen apertures and compare results during any single run. Grates from 50 to 75mm and screens from 13 to 25mm were investigated during this study.

A pebble crusher is included in the SAG circuit with the crushed product size of 80% passing 16mm.

Since CEET is an economic evaluation tool and not just a mill sizing calculator, the various site specific operating costs were included as part of the input. Electrical energy cost was of particular concern in this project. Capital equipment costs are estimated using CEET default values and updated in the software as necessary.

DESIGN FOR COMPLETE ORE BODY

The results of CEET runs comparing the effects of changes to SAG mill grate and screen apertures are shown in Table 2. The CEET program maintains the average tph at the specified level of 906 and the average P_{80} at 210 microns at all apertures. The major effect of increasing the screen aperture is a change in the SAG to Ball mill transfer size, T_{80}, from about 2.5 to 5 mm, resulting in a move in maximum demand for power for SAG milling to that for Ball milling as T_{80} is increased as shown in Table 2. However, there is almost no change in overall energy requirement per ton milled as grinding energy use merely shifts from SAG to Ball milling. Increasing the grate aperture causes an increase in circulating load to the pebble crusher resulting in a reduction in maximum SAG power demand as the pebble crusher does more breakage. The potential for increased loss of balls from the SAG mill limits the grate aperture size. Power requirements here are quoted at the mill shell and should be increased by up to 7% to allow for losses in the drive train, depending on the system. The change in maximum power draw is reflected in the changing mill sizes shown in Table 2.

Table 2: Effect on energy requirements and equipment sizes of changes to SAG grate and screen apertures

Grate aperture	mm	50	50	50	50	50	60	60	60	60	60	75	75	75	75	75
Screen aperture	mm	13	16	19	22	25	13	16	19	22	25	13	16	19	22	25
T_{80}	microns	2389	2296	3609	4227	4859	2474	3094	3714	4335	4967	4578	3213	3844	4469	5100
P_{80}	microns	211	211	211	211	211	210	210	210	211	211	209	209	210	210	210
IW_{SAG}		4828	4594	4445	4341	4261	4682	4459	4321	4230	4160	4512	4300	4172	4092	4036
kW_{BM}		5074	5306	5474	5601	5701	5123	5350	5511	5632	5728	5186	5407	5562	5676	5765
$kW_{SAG}+kW_{BM}$		9902	9900	9919	9942	9962	9805	9809	9832	9862	9888	9698	9707	9734	9768	9801
t/h_{SAG}		1005	1006	1009	1012	1012	998	999	1003	1007	1011	989	990	994	998	1003
t/h_{BM}		976	975	974	972	972	978	977	975	973	972	981	981	979	977	974
$t/h_{Circuit}$		906	906	906	906	906	906	906	906	906	906	906	906	906	906	906
Ave $t/h_{CL/Crusher}$		100	85	72	61	52	110	94	81	69	60	123	106	92	79	69
CL/PCCL (%)		11	9	8	7	6	12	10	9	8	7	14	12	10	9	8
Max $t/h_{CL/Crusher}$		131	116	104	94	85	147	132	118	107	97	169	153	139	127	115
kWh/t_{SAG}		4.65	4.42	4.25	4.12	4.01	4.57	4.34	4.18	4.06	3.96	4.47	4.25	4.1	3.99	3.9
$kWh/t_{Crusher}$		0.09	0.07	0.05	0.04	0.02	0.1	0.08	0.06	0.04	0.03	0.12	0.1	0.07	0.05	0.04
kWh/t_{BM}		5.6	5.86	6.04	6.18	6.29	5.65	5.9	6.08	6.22	6.32	5.72	5.97	6.14	6.26	6.36
kWh/t Total		10.34	10.35	10.34	10.34	10.32	10.32	10.32	10.32	10.32	10.31	10.31	10.32	10.31	10.3	10.3

The selected configuration uses a 60mm grate and 19mm trommel screen aperture, but this is a matter of client preference. This selection allows the use of:

- One SAG mill drawing a maximum of 4321 kW at the shell followed by
- One Ball mill drawing a maximum of 5511 kW at the shell to achieve the required throughput and product size.
- A 5 ft diameter crusher is needed to handle the maximum pebble load generated at any time.

A detailed block-by-block analysis of the results from this configuration is produced as a standard output by the CEET program to generate a Geometallurgical model of the ore body (Dobby et al, 2004). The large amount of detail in the results for more than 10,000 blocks prevents the inclusion of a print out here. There are considerable changes in the operating results as the plant is fed by ore, first from one area of the mine then another, as would be expected due to the variability in the hardness. Variable hardness will cause the circuit throughput to vary over time within the specified range with the cumulative frequency distribution shown in Figure 4.

This selection of grate, screen and mill sizes means that the circuit is balanced between occasions when the SAG mill is limiting the throughput and those when the Ball mill is the limit as shown in Figure 5. Due to the unusual lack of correlation between SPI and Wi values, the throughput is severely limited by the ball mill size when the ore is soft for SAG milling (below SPI of about 57). When the feed has an SPI of greater than about 57, the circuit throughput is very limited by the SAG mill.

This graph is an excellent illustration of the value of mill sizing by the CEET program using all the available hardness data. Note that if only average SPI and Wi figures (as would be available from having only a composite sample) were applied to this combination of SAG and Ball mill we would get the impression that throughput would average somewhere in the region of 950 tph. However, it can clearly be seen from the graph that the operation will suffer SAG

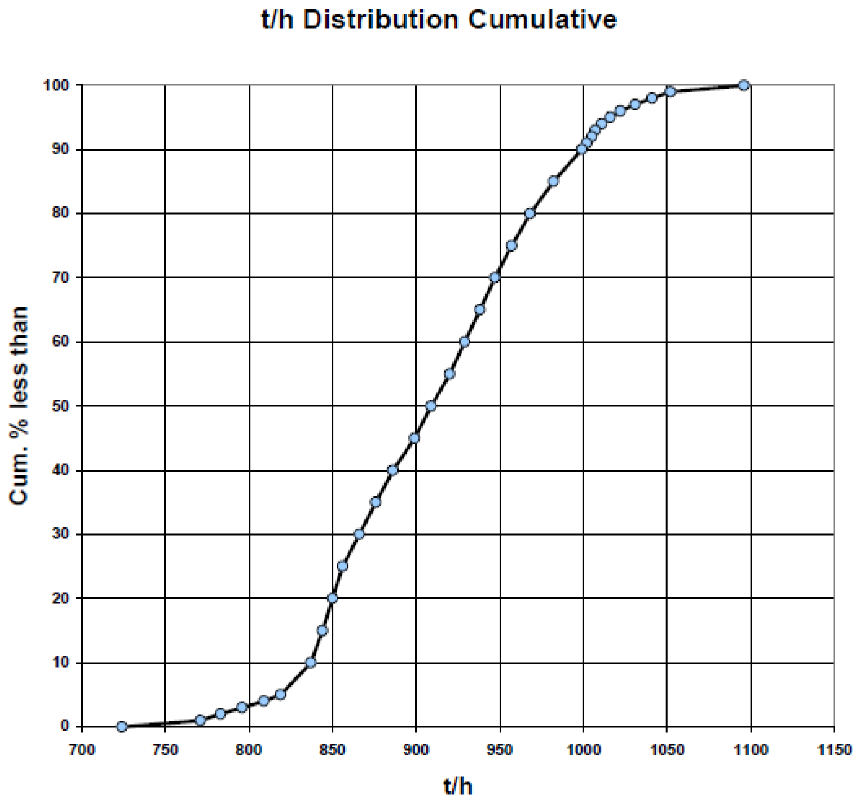

Figure 4: Variation in tph as a cumulative frequency distribution

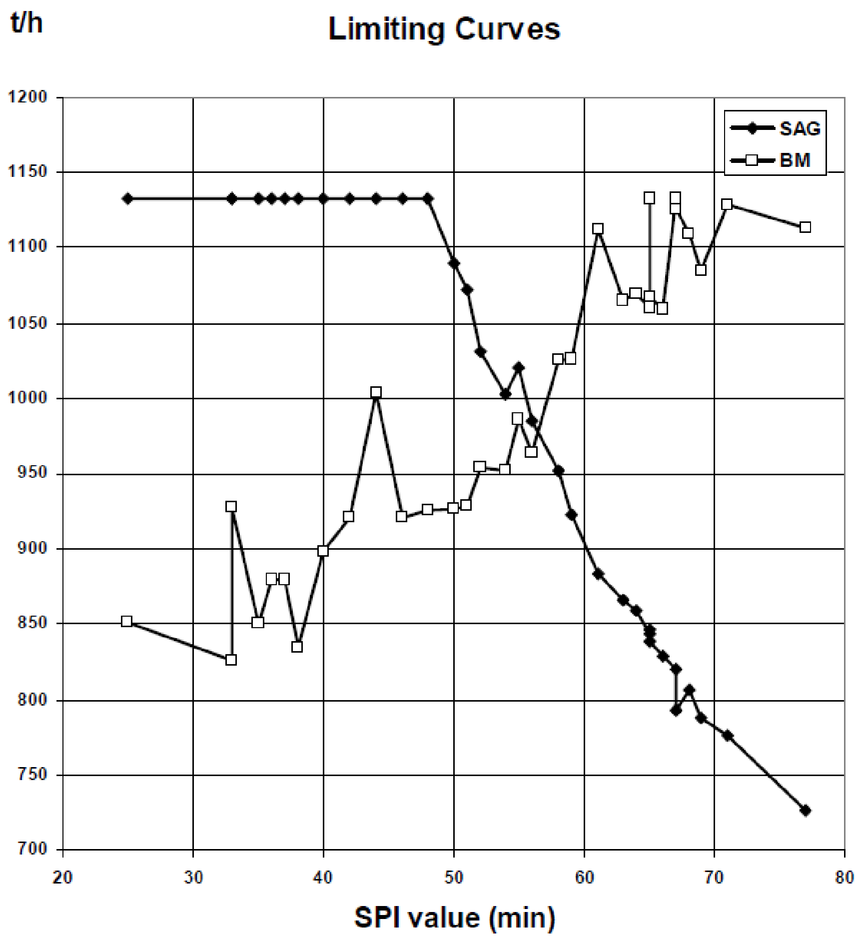

Figure 5: Limiting tph vs. SPI value

mill bottlenecks during periods when the ore has a high SPI value (SAG line lower than BM line) and Ball mill bottlenecks when the ore has a low SPI and the BWi has not fallen in proportion, but is in fact harder to ball mill (BM line lower than SAG line). The average throughput is consequently reduced to about 906 tph.

Examination of the detailed results (not presented here) shows that the changeover from SAG to ball mill limitation is also marked by a sudden change in product size P_{80}. The 65% of the ore that has SPI below 57 min and BWi above 12.5 kWh/t will suffer ball mill limitation and generate a product at the maximum allowable size of 225 microns. The 20% that has SPI above 61 min and BWi below 12.2 will be SAG mill limited and the product will be at the minimum allowable size of 180 microns. Suitable blending of hardest ores with softer material during mining operations will eliminate the extremes and reduce the bottleneck situations.

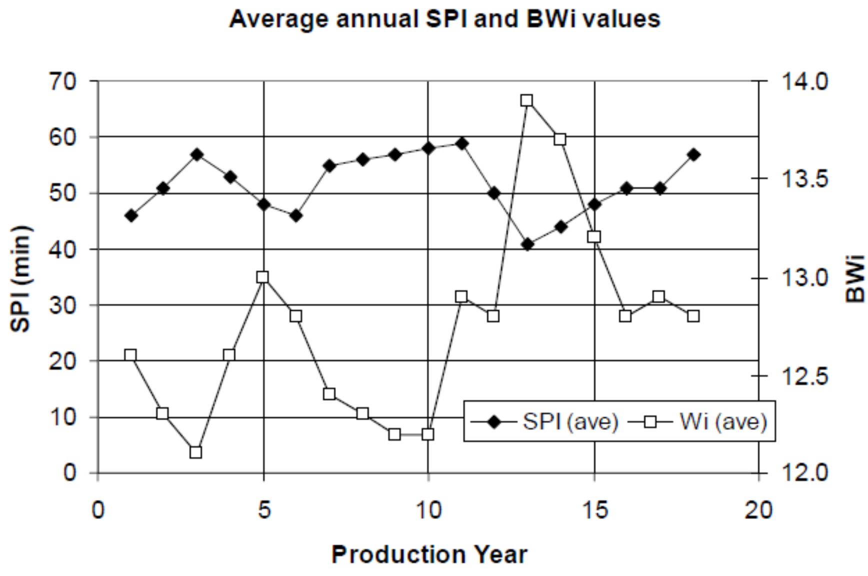

Figure 6: Annual average expected values for ore hardness

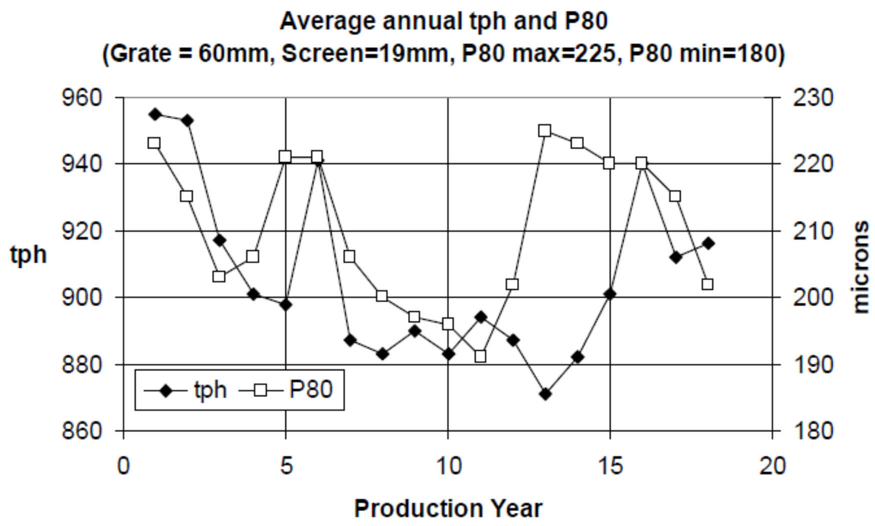

Figure 7: Forecast average throughput and product size

ANNUAL FLUCTUATIONS IN THROUGHPUT

Comparison of the hardness distribution across all of the mining blocks with the mining schedule allows a CEET forecast of throughput to be produced for each year in the life of the mine. Average values for SPI and BWi are plotted against time (production year) in Figure 6. They can be compared with forecast average tph and P_{80} produced for each year shown in Figure 7.

It appears that average tph will drop more than 15 tph below the required 906 in most of years 7 to 14. There will also be years when the average product size will be undesirably coarse (i.e. P_{80}>215 microns). However, adjustments to the operating conditions can correct for these situations as follows:

- When P_{80} is too high and tph is also more than required, reduce the maximum allowed P_{80} produced from the ball mill.
- When tph is too low and P_{80} is lower than required (this signifies a mostly SAG mill limited situation), increase the transfer size from SAG to Ball mill. Increasing the SAG screen aperture for that year of operation can do this or, more practically, allowing some crushed pebbles to by-pass the SAG directly to the SAG discharge screen. This requires the installation of a conveyor to transfer pebble crusher product to the screen for years 3 and 8 to 12 when the SPI is expected to be highest.
- When the tph is too low and P_{80} is too high (this signifies a mostly Ball mill limited situation), decrease the transfer size from SAG to Ball mill. This requires a reduction in the SAG screen aperture for those years of operation, i.e. years 13 to 15 when the BWi is expected to be highest.

After the application of these changes in the circuit, the forecast year by year results are plotted in Figure 8. The average P_{80} has now been maintained between 202 and 215 microns for every year, but the average tph is still expected to fall well below 906 in some years, with the lowest at 887 during Year 7.

Potentially, having crushed pebbles by-pass the SAG during short periods when blocks of high SPI value are mined in year 7 could increase the average tph. However, to introduce a factor of safety, it is suggested that the plant be enlarged to ensure that the required throughput is achieved in Year 7. The safer design developed by using the CEET program to accommodate Year 7 would then be:

- One SAG mill drawing a maximum of 4538 kW at the shell followed by
- One Ball mill drawing a maximum of 5511 kW at the shell to achieve the required throughput,

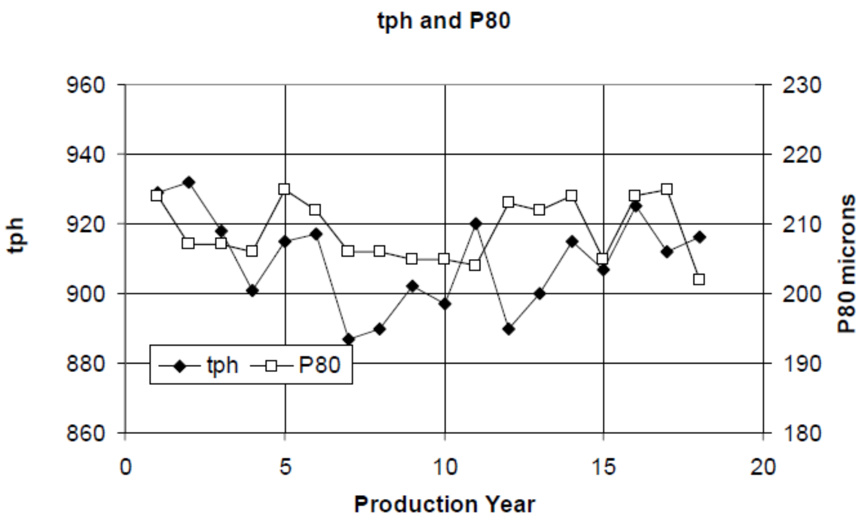

Figure 8: Adjusted average throughputs and product size

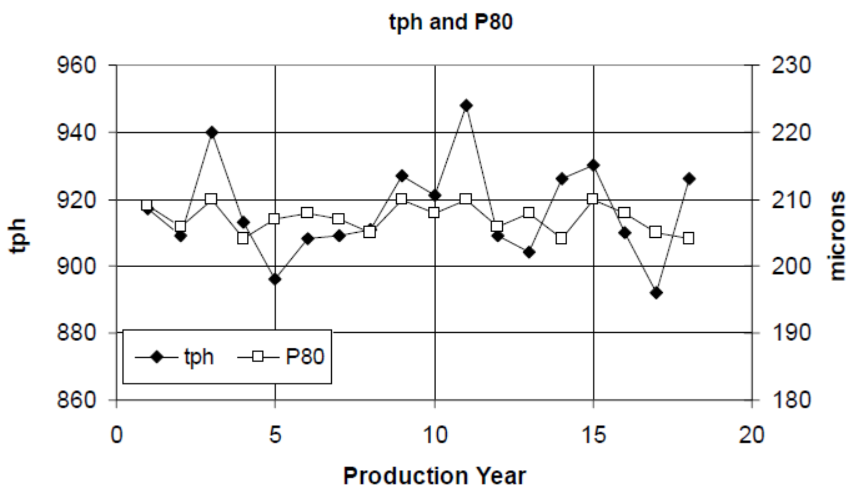

Figure 9: Average annual results of the safer design

- A 5 ft diameter crusher is needed to handle the maximum pebble load generated at any time.

After adjusting SAG screen sizes each year, as above, the minimum average annual tph can be maintained within 2% of the 906 specified, with P_{80} between 204 and 210 microns every year, as shown in Figure 9.

ERROR ESTIMATION AND SAFETY FACTORS

The geostatistical analysis assigned a precision (or statistical error) to the hardness estimate for each block of ore and each production year in the mine plan. The expected average hardness for each production year (in terms of SPI, Ci and BWi) is listed in Table 3 together with the statistical standard error for each average. There is 95% confidence that the true average lies within twice the standard error of the expected (best estimate) average, e.g. in Year 1 the average SPI should be between 36.9 and 55.5. This range of uncertainty could be reduced by testing more drill core samples that lie within or close to the blocks that will be mined in that year.

Table 3: Average annual values with error estimates of hardness

Year	# samples used	Average Ci	Ci %std err	Average SPI	SPI %std err	Average BWI	BWi %std err
1	14	23.3	14.5	46.2	10.1	12.6	3
2	22	20.6	11.8	51.4	7.8	12.3	2.5
3	20	18.7	12.7	56.9	7.5	12.1	2.5
4	20	20.2	12.1	52.9	6.8	12.6	2.3
5	18	21.9	14.4	48.3	9.9	13	2.9
6	16	21.4	14.6	49.4	10.3	12.8	3
7	25	19.2	11.3	55.1	7.3	12.4	2.2
8	31	18.9	8.5	55.9	4.8	12.3	1.7
9	28	18.9	10.4	47.2	5.5	12.2	1.9
10	26	18.3	12.1	58.1	6.1	12.2	2.2
11	23	18.1	10.9	58.5	5.4	12.1	2
12	17	21	16.7	50.1	8.8	12.8	3.2
13	11	26.2	18.6	40.7	12.8	13.9	3.9
14	15	24.7	16.4	44.4	10.7	13.7	3.4
15	13	23	15.6	48.4	10.4	13.2	3.2
16	13	22.1	21.9	51	16.8	12.8	4.6
17	14	22.2	15.7	50.6	9.7	12.9	3.1
18	11	19.7	16.5	57.2	10.2	12.1	3.2

The standard errors on the expected averages were used in a Monte Carlo simulation within the CEET program to estimate the standard error in the forecast tph for each year for the plant as designed above. The calculations also included a CEET model error based on SGS-MinnovEX' experience in application to existing operations. The resultant standard error on the average tph each year was about 4%. The expected (best estimate) average tph and 90% confidence limits on that estimate are shown in Figure 10 (90% confidence limits are within 1.64 times the standard error, typically about 6.5% of the average). Figure 10 shows that, due to the uncertainty in the average hardness values, there is a reasonable chance that the throughput could fall well below the required 906 tph. Year 16 could be the worst year with 829 tph being the lowest 90% confidence limit, i.e. there is 5% chance that the average tph will be below that level.

Consequently the plant design was enlarged again to a target of 990 tph each year (i.e. 906 * 906 / 829). This ensures that there is only a 5% chance that the average will be below 906 tph any year. This safer design now includes risk estimates and safety factors based on the possible errors in the hardness estimates as well as fluctuations in annual hardness value. The mill power requirements each year for such a design and resultant average P_{80} values are shown in Figure 11.

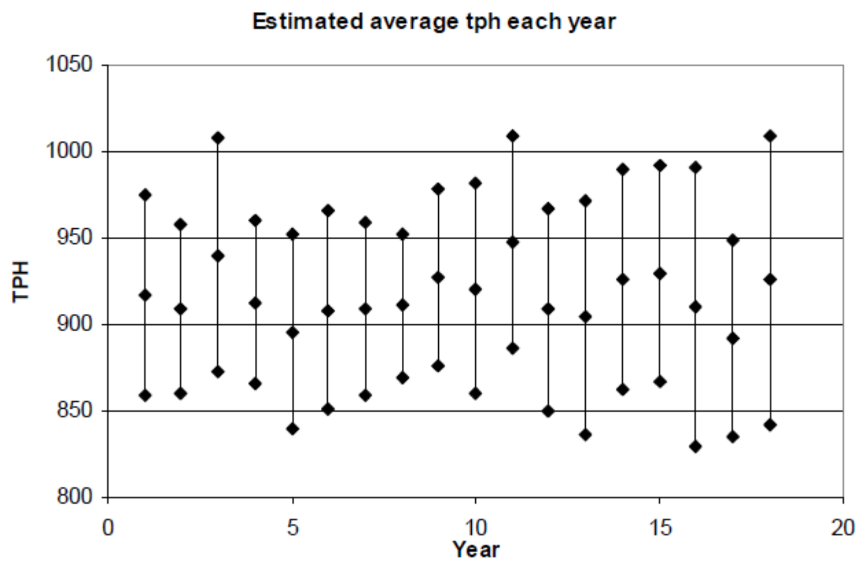

Figure 10: Expected average tph and 90% confidence limits for each production year

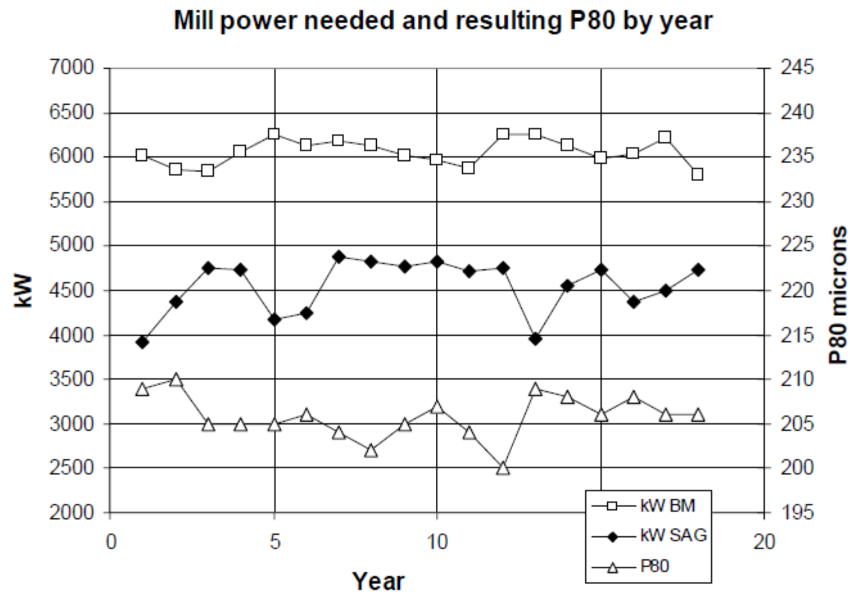

Figure 11: Mill power requirements each year to meet safer specified annual average of 990tph

The suggested equipment with safety factors is then increased to:

- A single SAG mill drawing a maximum of 4877 kW at the shell.
- A single ball mill drawing a maximum of 6265 kW at the shell.
- A 5ft pebble crusher.

The suggested SAG power draw of 4877kW assumes that operating conditions of mill load, steel load and RPM are maintained at the specified levels at all times and should be considered as the maximum sustainable power, not peak power. Under normal operating conditions in the SAG mill these values fluctuate about the specified levels. Therefore, it can be assumed that the peak power draw is at about 5% above the sustainable level (at 5121 kW) so that sufficient power is available to mill effectively at all times in order to achieve specified average tph over the long run. This can be delivered with a 28ft by 15 ft SAG mill assuming an ore s.g. of 2.7, steel load of 12%, total load of 26%, liner thickness of 4 inch and mill speed of 74% critical. The motor may be specified larger than this to allow for the SAG mill to run at higher steel load at a future date if required.

A ball mill with dimensions in the region of 20ft by 35ft should be sufficient to deliver the suggested power at a steel load of 35%.

As already discussed, the CEET determined power draw is at the mill shell and must be increased by up to 7% to allow for losses in the drive train, depending on the system. The indicated power draw at the motors then becomes 5479 kW for the SAG and 6704 kW for the ball mill.

CONCLUSIONS

A grinding circuit has been designed by a geometallurgical approach that incorporates the results from a geostatistical analysis of the sample data and ore body with a metallurgical design using a computer software package. The steps to achieving a design that incorporates safety factors and quantifies the remaining risk were:

- Measure the grindability of 100 samples that were geographically spread over the ore body and selected to represent the variability in lithology and ore types.
- Use the location of the sample points and the geological and mining plans of the ore body to conduct a geostatistical analysis that estimated grindability values for each mine block and production year with a technique that allows the determination of the precision of these estimates.
- Generate an optimum SAG and Ball mill circuit design to achieve an average 906tph at an average P_{80} of 210 microns for the ore body as a whole using the data for each block recognizing that the circuit will have bottlenecks at the SAG or the Ball mill as the ore varies in hardness.
- Predict the throughput for this design in each production year and adjust the plant conditions, such as SAG screen aperture each year to maximize throughput.
- Enlarge the mill and drive motor sizes to accommodate the year with hardest ore so that the plant delivers the specified average results in every production year.
- Conduct a Monte Carlo simulation to determine the effect of the errors in the estimated annual average hardness values and CEET design model on the expected statistical error in the predicted throughput of this enlarged equipment each year. Determine the lowest 90% confidence level of predicted throughput in any year, i.e. there is a 5% risk of the throughput being lower than this in the worst year.
- Increase the specified average throughput and re-design the plant so that the 5% risk level of throughput is equal to the specified 906tph in the worst year.
- Add a safety factor of 5% to the SAG mill motor specification to allow for operating fluctuations.
- Add up to 7% to both SAG and Ball Mill motor sizes as designed by the CEET program (which are calculated at the mill shell) to allow for typical losses in the drive train depending on the system.

The basic suggested circuit to produce an average 906 tph at a P_{80} of 210 microns over whole ore body (life-of-mine) comprised:

- A single SAG mill drawing a maximum of 4321kW at the shell.
- A single ball mill drawing a maximum of 5511 kW at the shell.
- A 5 ft pebble crusher.

The SAG and Ball mill motor sizes were increased during the design steps outlined above as summarized in Table 4. It should be remembered that although motor sizes have increased to allow for ore hardness variation over time the average expected energy consumption remains at the level determined for the basic circuit treating the ore body as a whole.

The suggested design uses 60 mm grates and a 19 mm trommel screen aperture in most years. However, due to the varying hardness of the ore the following operational changes will be required from year to year to minimize mill power specifications:

- Install a crushed pebble bypass system and/or a larger SAG screen aperture for years when the SAG mill is a bottle neck, i.e. high SPI values.
- Install a smaller SAG screen aperture for years when the ball mill is a bottle neck, i.e. high BWi values.

All of these considerations cover all but a 5% statistical risk of not delivering the specified throughput and product size during the worst production year. No further safety factors are needed.

ACKNOWLEDGEMENTS

John Fisher and staff at Adanac Moly Corp for co-operation in the design and permission to publish this paper. Michel Dagbert and staff at Geostat International for geostatistical study of the grinding data and support in understanding the technology.

Table 4: Motor Power specified for mills after various considerations

Case	SAG kW	Ball mill kW	Total kW
Average 906 tph life of mine	4321	5511	9832
Average 906 tph for every year	4538	5511	10049
906tph every year with Safety for	4877	6265	10664
Include 5% safety for fluctuation in	5121	6265	10880
Motor specs including 7% for drive	5479	6704	11642

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