APPLICATION OF THE MINNOVEX SAG POWER INDEX AT FIVE CANADIAN SAG PLANTS

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ABSTRACT

A campaign of testwork has been completed at five Canadian SAG plants, in which the objective was to provide a clear calibration of the Minnovex SAG Power Index. The index is determined through testwork with the Starkey laboratory SAG mill. Participants in the program included Highland Valley Copper, Barrick Gold's Holt-McDermott Mine, Les Mines Selbaie, Williams Mine, Quebec Cartier Mining and CANMET. The program was sponsored by the Mining Industry Technology Council of Canada (MITEC). A broad range in all variables was covered, including: mill diameter (5.0 to 9.8 m), ore throughput (53 to 1659 dmtph), power draw (1300 to 6780 kW), power draw per tph (3.6 to 26 kWh/t), and SAG product size (P_{80} from 124 to 2570 μm). At all five SAG plants, belt samples were taken during periods in which the mill was treating soft and hard ore. Multiple repeat tests showed that careful sampling over a one hour period gives results with good reproducibility. An overall relationship which correlates the Power Index to kWh/t and SAG product size has been developed.

INTRODUCTION

In June 1994, the Mining Industry Technology Council of Canada (MITEC), approved a study by MinnovEX Technologies to investigate the relationship between ore hardness measured in MinnovEX' laboratory SAG test and the power drawn in a plant to grind the same ore in a SAG mill circuit. Six participants supported the project:

- Highland Valley Copper,
- Les Mines Selbaie,
- Barrick's Holt-McDermott Mine,
- Teck Corporation's Williams Mine,
- Quebec Cartier Mining, and
- CANMET.

At each of the five mill sites samples of SAG mill feed were taken from the feed belt during stable periods of operation, and hardness measurements were made on these samples at MinnovEX. Two samples were taken for each period of plant operation. At most plants three periods of operation were sampled, and an attempt was made to obtain samples from periods having a range in ore hardness and SAG mill throughput. The contribution of CANMET was to fund the sampling variance work, which was conducted at Highland Valley Copper.

The specific objectives of this MITEC program were as follows:

1. Verify that the MinnovEX SAG Power Index (SPI) Test provides a good measure of ore hardness for a given SAG operation. This was accomplished at each site by taking samples from operating periods with soft, medium and hard ore.
2. Develop power correlation data for the operating SAG mills to establish in-plant correlation factors, and to compare results with other plants to identify similarities and differences.
3. Demonstrate that the proposed sampling procedure has good reproducibility.

This paper summarizes the results of the test program and presents a case study on how the procedure can be used for design of new SAG circuits.

BACKGROUND

Since the development of semi-autogenous grinding, the mining industry has had difficulty in obtaining the representative bulk samples which are required for grinding testwork, mill sizing and design. Even when bulk samples do represent the overall ore body, they are usually costly to obtain. In addition it often happens that ore hardness changes during normal mining cycles create periods of significant throughput variance.

Traditionally, two solutions are used to cope with hardness variation. The first is to install conventional crushing equipment in the SAG circuit to prevent build up of critical size material in the mill, which is the prime cause of reduced throughput. The second is to install blending facilities to eliminate the effect of short-term variations. In both of these instances capital and maintenance costs are increased in order to deal with the problem. In plants where crushing must be added later, the capital cost is higher than if installed initially.

The high cost and difficulty of obtaining samples in a conventional way and testing them has prompted the development of a small cost effective technique called the MinnovEX SPI Test. Previous determinations of SAG hardness required that the potential mining operation obtain a bulk sample of 20 tonnes or more for pilot plant tests, or prepare 200 kg composite samples of diamond drill core, for on line tests in a 1.5 ft. diameter mill. The volume of material involved in these tests has led to a situation where very few new SAG milling projects have done enough hardness testing to properly identify the real nature of the ore body. In addition, existing plants have no timely way to investigate ore hardness because no simple lab test equipment to do this work has been made available to the mining industry. Note that a bulk sample chosen for design should not be average hardness for the whole ore body but rather should represent say the top quartile of all hardness values in a frequency distribution analysis. Mistakes in SAG mill design have occurred because the bulk sample chosen for pilot plant testing, did not represent either average hardness or a proper and realistic design hardness. The MinnovEX SPI Test is designed to help eliminate this kind of error.

TECHNICAL DEVELOPMENT

The technical considerations and theory involved in the measurement of SAG hardness, using the SPI Test were discussed in a previous publication (Starkey et al, 1994). The key parameters of the test are summarized below:

- SAG Mill Size - 30.5 cm (1 ft) diameter by 10.2 mm (4 inches) long
- Steel Charge - 2.5 cm (1 inch) diameter balls
- Test Feed - 2 kg of dry ore crushed to 80% passing 12.7 mm
- Test Product Required - 80% passing 10 mesh (1.7 mm)

Test Procedure - Grind (dry) in stages until the product P_{80} is 10 mesh. This is a batch test with the charge returned to the mill after each stage.

Test Deliverables - The time (in minutes) required to achieve the specified size reduction.
Screen analysis of the mill discharge giving the P_{64} size.

The time determined in this test is, by analysis of first principles, a measure of the power used to create the constant size reduction. It will be shown in this paper that this time is directly proportional to plant SAG mill power when grinding to 10 mesh and that the relationship can be described by a straight line function.

The 64% passing size for the ground ore is significant because 20% is plus 10 mesh while 80% is finer. For reasons not yet understood, the majority of samples tested show very little weight in the minus 6 mesh, plus 20-mesh size range after grinding. The plus 10 mesh fraction is considered to be circulating load, and the minus 10 mesh fraction is seen to be finished product and the P_{64} is an estimate of the natural breakage (or grain) size P_{80} for the sample being tested.

In general, softer ores have natural breakage sizes in the range 400 to 800 microns while harder ores normally give a ground product size between 200 and 500 microns. This is because harder ores abrade with difficulty to a fine grain size and require more power and time in the mill to be reduced to minus 10 mesh overall.

The proposal to MITEC, to obtain field calibration data for the SPI Test was the result of a decision to use small samples of fist sized pieces of ore to represent primary crushed SAG feed. This was based on a previous observation that the absence of raw fines had only a marginal effect on the time required to grind a sample to 80% passing 10 mesh. In effect, two things were being tested: (a) the usefulness of fist sized pieces as representative samples of primary crushed SAG feed, and (b) the calibration of laboratory grind time as a function of plant SAG mill power consumption.

PROJECT PROCEDURES

All site visits were made during the period July 18 to August 26, 1994. The first day was used to assess the operation, to examine normal production variances, to set targets for soft, medium and hard ores, and to pick the circuits to be used for the test. The second day was used for instructing/taking samples and to prepare instructions for sampling, data collection and shipping.

Grinding Circuits

A summary of the mill dimensions, power draw and tonnage for the five sites is given in Table 1.

The Highland Valley Concentrator grinding circuits consist of five large SAG mills, and eight ball mills, arranged in three different configurations. The "A" circuit was chosen for this program because of the single speed drive, common configuration, and a moderate steel load of 9%. Mill dimensions are 9.75m (32') diameter x 4.72m (15.5') long.

Table 1 Summary of dimensions and capacities of SAG mills tested.

Site	Diameter (m)	Length (m)	Power Draw* (kW)	Solids dmtph*	Classifier Type	SAG Circuit P_{80} (um)*
Highland Valley	9.75	4.72	6700	1200	Screen	2000
Selbaie	8.23	3.75	3000	300	Screen	320
Holt-McDermott	5.03	5.26	1300	60	none	280
Williams Mine	6.71	3.15	2100	140	Spiral	140
Quebec Cartier	9.75	3.50	4500	1100	Screen	490

* these are approximate typical values; exact values during the sampling periods are given in Table 2

The main grinding circuit at Les Mines Selbaie consists of two mills, one SAG mill in closed circuit with an 8' x 20' vibrating screen with 700 micron deck, and one ball mill. The SAG mill is 8.23m (27') diameter x 3.75m (12.3') long.

The Holt-McDermott grinding circuit uses a large primary SAG mill which is 5.03m (16.5') diameter x 5.26m (17.25') long (grinding chamber). At the time of the test program the SAG mill was operating in open circuit (no classifier) to feed a small ball mill/cyclone circuit.

The Williams Mine grinding circuit consists of two SAG mills, operating in closed circuit with spiral classifiers, and two ball mills. These SAG mills are each 6.71m (22') diameter x 3.15m (12') long.

Quebec Cartier has six parallel lines of single stage SAG mills, operating in closed circuit with screens and recycle belts. The mills are 9.75m (32') diameter x 3.50m (11.5') long.

Plant Sampling Methods

The sampling periods for each plant were different, depending on circuit stability and other practical factors. In some cases it was decided to take samples over a one-hour period and to record the operating data relative to that period. In other cases it was decided to cut samples over a 24-hour period, as was done at Holt-McDermott. In retrospect, the 24 hour period samples were not as good or reliable as were the ones taken for one or two hours. Duplicate SAG feed samples were taken by selecting (at random) two fist sized pieces every two minutes with a shovel, and placing one piece in each pail. The objective was to fill both five gallon plastic pails by the end of the sampling period. At the same time, SAG discharge screen undersize and cyclone overflows (if applicable) were sampled. Each of these samples was screened to give SAG product P_{80} and ball mill product P_{80} values. This sample procedure was repeated for the three conditions of hardness specified.

The use of small (30 to 40 kg) samples of fist sized pieces to represent SAG mill feed is an innovation and, at the same time, an integral part of the cost effective use of the laboratory SAG test. This procedure was first used at Gol-E-Gohar in Iran and was shown to be effective in the determination of relative hardness. The measurement of feed F_{80} is a labour intensive task and was not attempted in this project. However, the fact is that most plants run a relatively constant primary crusher setting. This setting controls the top size of SAG feed which, for the plants in this study, was treated as a constant F_{80} of 152 mm (6 inches), except for Holt-McDermott where 140 mm (5.5 inches) was used.

There is no question that fine ore will improve SAG power efficiency. Similarly, coarse ore from the bottom of an ore bin will reduce throughput due to segregation. These effects have been minimized in this study by encouraging operators to take the samples during periods of stability and to comment on the visual quality of feed during each test.

For the CANMET sampling program, eight samples were taken simultaneously instead of the usual two. This was done specifically to generate statistical variance information for the sampling/testing method.

SAG Tests

Two test samples of 2 kg each were prepared from each of the plant samples, and the feed size criteria of 80% passing ½", 100% passing ¾" was checked. The standard hardness procedure was conducted on both test samples, thus, providing data for measurement of test reproducibility. For the sampling reproducibility tests, all eight samples from Highland Valley were tested once in the laboratory SAG mill.

RESULTS and DISCUSSION

A general summary of the results from the five plants is given in Table 2. From this table and from data presented earlier it can be seen that a broad range in all variables was covered:

mill diameter - 5.0 to 9.8 m (16.5 to 32 ft)
throughput - 53 to 1659 mtph solid
power draw - 1300 to 6780 kW
power draw per tph - 3.6 to 26.1 kWh/t
ore hardness (from test) - 8 to 101 minutes
SAG product P_{80} - 124 to 2570 um
lab product P_{64} - 210 to 686 um

Table 2 gives the actual values for these parameters.

Reproducibility of the Hardness Measurement:

Two sets of data are available to examine reproducibility of the hardness measurement:

1. for each plant trial two samples were taken from the SAG feed belt, and a hardness measurement was made on each; and
2. the eight samples taken simultaneously at Highland Valley Copper specifically provide information on the relative error obtained from both sampling and the test itself.

The results from these two sets of data are provided in Table 3, and are summarized as follows:

- for the replicate samples, the average difference in measured time for 11 sets of duplicate samples from four sites was 3.5 minutes, or a ± value of 1.7 minutes
- the eight samples taken at Highland Valley gave an average time of 50 minutes, with a standard deviation of 3.2 minutes, or 6.4 % relative standard deviation.

These reproducibility values are quite acceptable, and validate the process of calibrating a given SAG mill through the sampling of fist size samples from the belt.

Analysis of the Plant and Laboratory Data

A plot of SAG mill kWh/t versus lab test time is given in Figure 1. For each plant site there is a good correlation between SAG power and test time. As seen in Figure 1, the relationship is a function of the SAG product size, which is to be expected. In Figure 2, the data have been replotted to account for SAG P_{80}, by multiplying the SAG kWh/t by a particle size factor, which in this case is $P_{80}^{0.33}$, where P_{80} is in mm. The exponent of 0.33 was determined using the criteria of generating the highest value for the regression coefficient on the linear plot that includes data from Highland Valley, Selbaie, Williams and Quebec Cartier. The plot of adjusted kWh/t versus test time in Figure 2 provides an excellent fit to the data from four of the five plants. This relationship is given by:

$$\text{SAG kWh/t} = P_{80}^{-0.33}(2.2 + 0.10\,T)$$

with a correlation coefficient of 0.94 (P_{80} is in units of mm and T is in units of minutes).

The only plant that doesn't follow this relationship is Holt-McDermott. There are several possibilities which would explain this difference, including:

- The SAG mill discharge was not classified, unlike the other four plants;
- The diameter to length ratio of the Holt-McDermott SAG mill is 1.1, compared to a ratio for the other four mills between 1.8 and 2.8; and
- The ore at Holt-McDermott is extremely hard.

Further work on the Holt-McDermott SAG mill is required in order to determine which of these factors is dominant in altering the trend observed from the other four sites.

Figures 3 and 4 are projected graphs from detailed information developed for each plant. Figure 3 shows the relationship between power and time projected to a plant SAG grind of 10 mesh (to match the laboratory test). Then, to complete the analysis, Figure 4 was prepared to show the same function projected to a plant grind equal to the Lab Product Size. The slope of this line is higher due to the extra power required to do more grinding.

Table 4 summarizes the linear functions that represent the data in Figures 1 through 4. The most interesting graph is Figure 2, which incorporates a product fineness adjustment to actual plant SAG discharge size. This can be applied to any SAG product size, but since it includes a fine grinding component beyond 10 mesh, it is used to check the overall SAG power if a grind finer than 10 mesh is required, or if Bond ball will work index data is not available.

For practical reasons, Figure 3 is used currently to predict power requirements to grind an ore from 6” to 10 mesh. Adjustments for finer grinding are added according to Bond equations for calculating grinding power.

Table 4 Summary of Linear Relationships Shown in Figures 1 through 4

Figure #	Function	Description
1	$W = 0.137\,T + 2.8$	Normal grind
2	$W\ (\text{Adj.}) = 0.10\,T + 2.2$	Adjusted for product fineness
3	$W = 0.11\,T + 0.9$	Predicted for 10 mesh P_{80}
4	$W = 0.186\,T + 2.0$	P_{80} = Lab Test Size P_{64}

Table 2 Summary of Test Results
(lab grind times are the averages from two tests)

SITE	PARAMETER	SAG MILL FEED ORE TYPE Soft	 Medium	 Hard
Highland Valley	Mill Feed Rate - t/h	1659	1252	919
	SAG Mill Power Draw - kW	6380	6786	6722
	SAG Unit Power - kWh/t	3.85	5.42	7.31
	SAG Product P80 - Microns	2570	1925	1880
	Lab Grind Time - Minutes	32	43	60
	Lab Product P80 - Microns	686	481	355
Les Mines Selbaie	Mill Feed Rate - t/h	297	306	268
	SAG Mill Power Draw - kW	2555	3024	3200
	SAG Unit Power - kWh/t	8.59	9.89	11.94
	SAG Product P80 - Microns	323	337	308
	Lab Grind Time - Minutes	42	54	62
	Lab Product P80 - Microns	255	210	215
Holt-McDermott	Mill Feed Rate - t/h	63	55	53
	SAG Mill Power Draw - kW	1296	1363	1379
	SAG Unit Power - kWh/t	20.44	24.73	26.12
	SAG Product P80 - Microns	285	280	265(165)
	Lab Grind Time - Minutes	60	92	101
	Lab Product P80 - Microns	275	252	210
Williams Mine	Mill Feed Rate - t/h	152		125
	SAG Mill Power Draw - kW	2045		2068
	SAG Unit Power - kWh/t	13.47		16.53
	SAG Product P80 - Microns	160		124
	Lab Grind Time - Minutes	42		55
	Lab Product P80 - Microns	255		230
Quebec Cartier	Mill Feed Rate - t/h	1018	1164	1045
	SAG Mill Power Draw - kW	3655	4514	5005
	SAG Unit Power - kWh/t	3.59	3.88	4.79
	SAG Product P80 - Microns	515	480	460
	Lab Grind Time - Minutes	8	9	12
	Lab Product P80 - Microns	545	545	490

Table 3 Summary of Results from Sample Hardness Reproducibility Data

Data Set 1 - Duplicate Samples from Each Site

Site	Time 1	Time 2	Difference
Data Set 2 - Eight Samples from Highland Valley (CANMET Sponsored)			
	(min)	(min)	(min)
Highland Valley	36	28	8
	43	43	0
	62	60	2
Selbaie	42	40	2
	54	53	1
	67	56	11
Holt-McDermott	73	46	27
	119	92	27
	109	93	16
Williams Mine	44	40	4
	59	50	9
Quebec Cartier	9	8	1
	9	8	1
	12	12	0

Sample #	Time (min)		SAG Test P_{80} (um)	
44	46		419	
45	47		420	
46	55		369	
47B	54		385	
48	51		397	
49	48		(Outlier)	268
50	51		385	
51	49		401	
Average	50.1	min	397	um
Standard Deviation	3.2	min	19	um
Rel. Stnd. Dev.	6.4	%	5	%

Figure 1: Summary of SAG Mill kWh/t versus Laboratory Grind Time

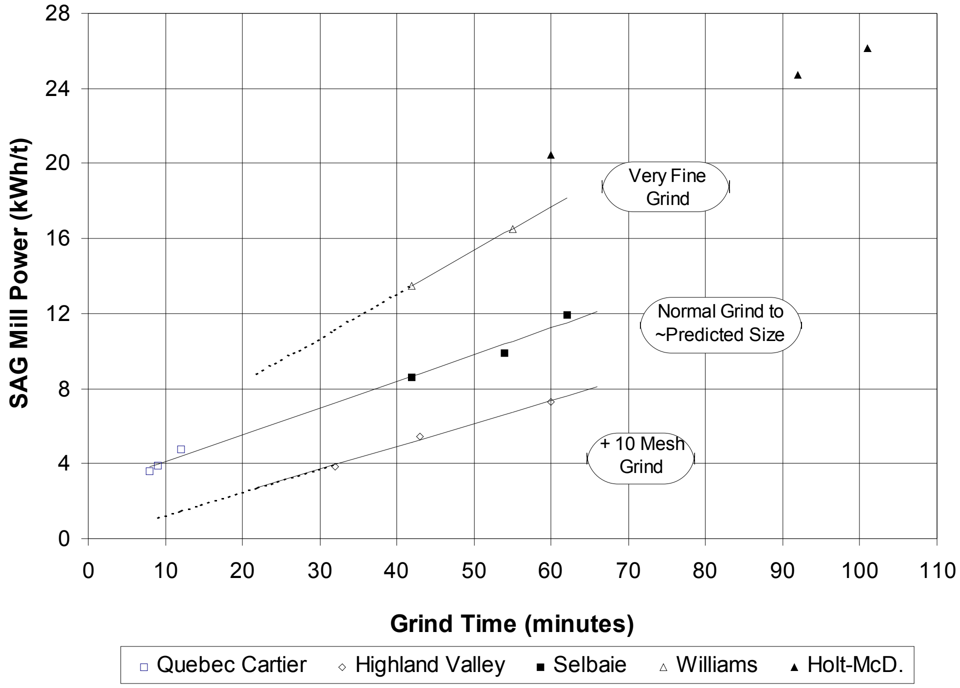


Figure 2: Plant SAG kWh/t (Adjusted for SAG product size) versus

Lab Test Time (see text for description of adjustment)

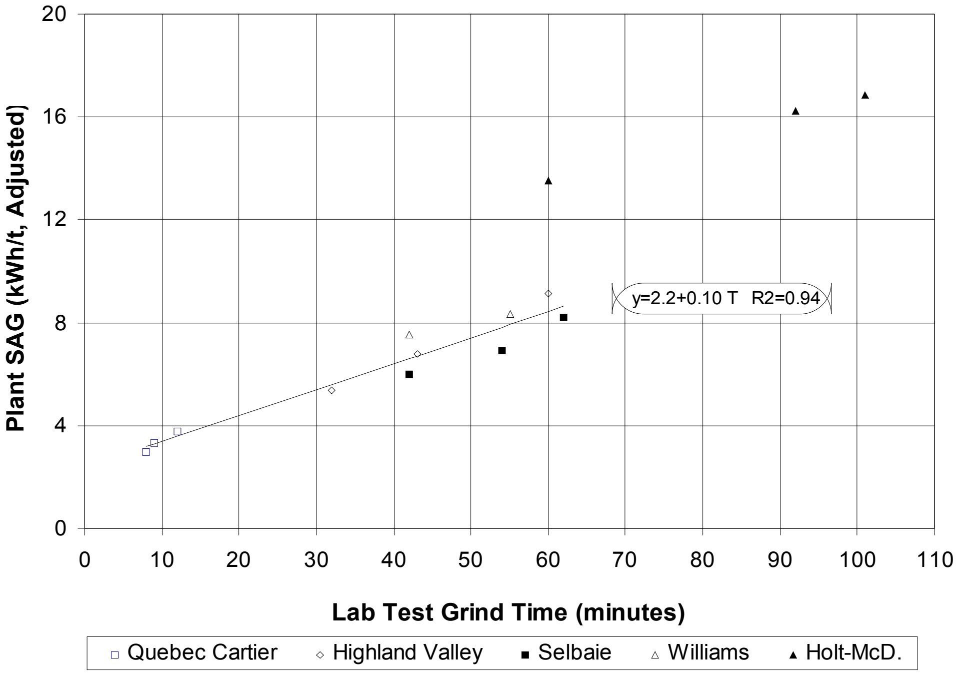


Figure 3: Calculated SAG Power versus Lab Grind Time for 10 Mesh SAG Product (P 80)

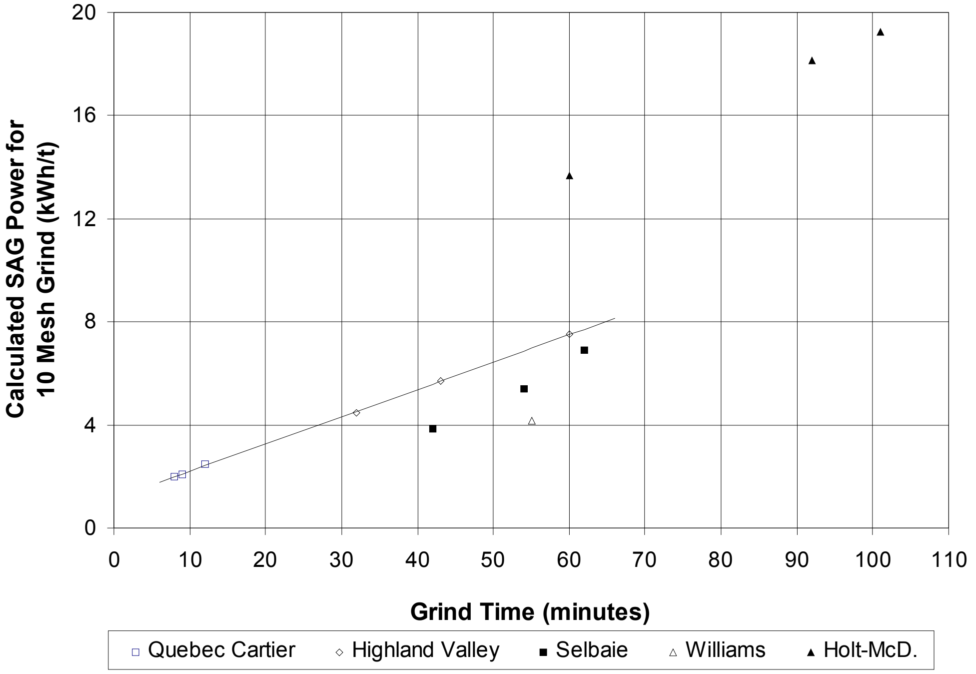
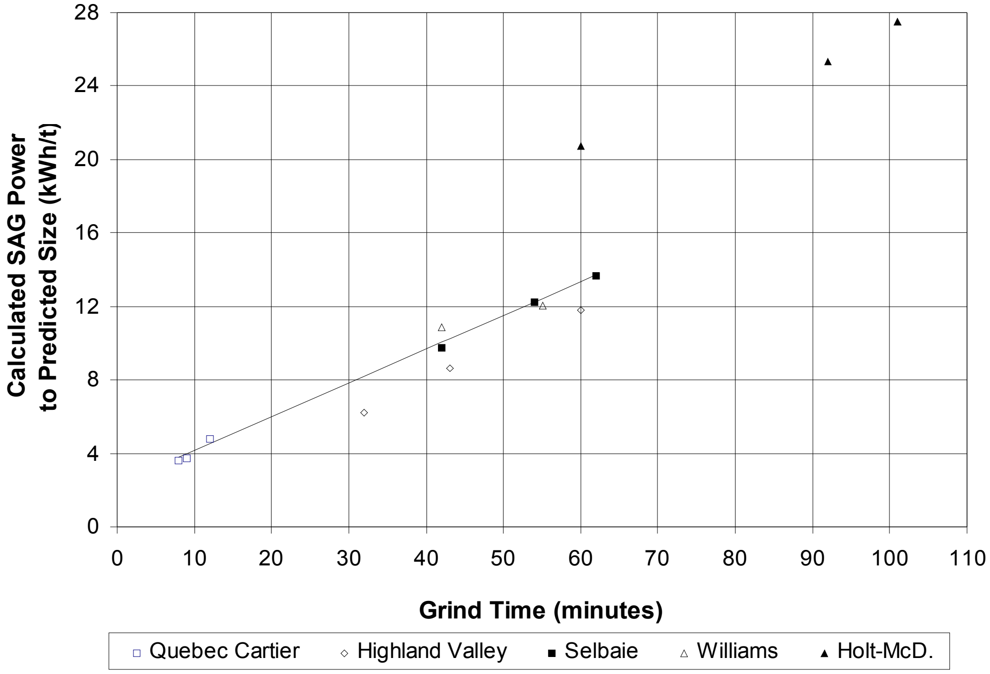


Figure 4: Calculated SAG Power versus Laboratory Grind Time for SAG Product Predicted Size



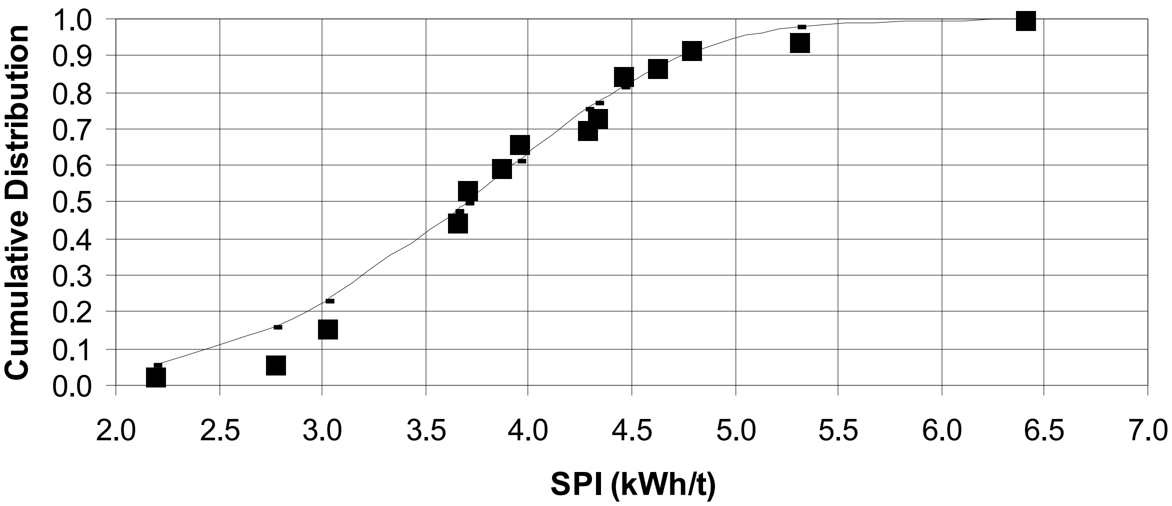
CASE STUDY - DELITA GOLD PROJECT

Since the conclusion of the MITEC work, the MinnovEX SPI Test has been used for SAG hardness measurement on a variety of projects including two new Feasibility Studies on projects 50% owned by Miramar Mining, and being conducted by a major engineering firm in Toronto. A case study on one of these projects is provided here to demonstrate how one operator is using this information to good advantage.

While Delita diamond drill core was being split for assaying, samples for SPI testing were selected. The project geologist chose three diamond drill holes which had passed through the ore zone and which contained all of the various rock types which had been observed during logging of the core. These holes, representing a total of 175 m of drilling, were divided into bench height samples of about 6 m each, with sample breaks to match the changes in rock type. In all, 24 samples were obtained, but since in some areas the rock types extended over two or three samples, composites were made to minimize the number of tests required. In all, 18 SPI Tests were done. The results of this work were calculated using the equations developed in the MITEC study and were then analyzed to show the Cumulative Distribution of SAG Power Index Values (see Figure 5).

Analysis of the data showed that the weighted average of all the samples tested produced a product size of 500 microns and required 4.0 kW/t to grind the ore from 80% passing 6 inches to 80% passing 10 mesh. Median power was 3.7 kWh/t as shown on the graph. It was also noted that since the hard quartz structures contained higher than average gold, it would be prudent to use a design power of 5 kWh/t, to grind to 10 mesh. This is equal to the top decile of recorded values. Since the Bond work index was determined to be 11.2 kWh/t, the power requirements for the SAG mill will be set to produce a product of 300 microns, the size corresponding to the hardest ores. Commercial SAG testing by another method, proved that the average power was reasonable, and that the final power selection would be conservative by usual industry standards.

Figure 5: Delita Project, Cumulative Distribution of SAG Power Index (required power for P80 of 10 mesh)



CONCLUSIONS

1. The correlation between laboratory SAG test time and plant power is excellent, as shown in Figures 1 and 2. Hence, the SPI Test is an accurate and cost effective way to obtain SAG hardness measurements.

2. Power required to grind an ore to a given size in a production SAG circuit can be predicted from laboratory SAG test results.

3. Plant throughput can be predicted from laboratory SAG test results if the circuits are operated at full load power.

4. The selection of two samples of fist sized pieces gave a relatively accurate picture of the ore being treated. Large samples representing the entire spectrum of sizes feeding a SAG mill are not required for determination of relative hardness. Laboratory SAG testing of core samples, however, will require smaller primary samples because the core itself gives the proper mixture of rock types.

5. The SPI Test offers the potential to implement mine planning control of mill production on a routine basis.

RECOMMENDATIONS

1. The SAG Power Index Test can be used to determine the power required to grind to 10 mesh. Additional power to give a finer grind should be added according to Bond ball mill grinding data, if available. If Bond ball mill work index data is not available, use the data in Figure 2 as a first estimate of SAG power required to grind to the indicated natural grain size.

2. Use the SPI Test for new projects to determine hardness variance by examining the various rock types in several continuous diamond drill intersections through an ore body. By knowing the actual variance in hardness, needed adjustments to pilot plant power can be made at the design stage. The SPI Test can be used to select locations for mining pilot plant bulk samples for pilot plant SAG testing.

3. The SPI Test can be used as a problem solving tool at any operating plant, especially where ore hardness variance is causing throughput problems due to lack of blending or other reasons.

ACKNOWLEDGMENTS

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Starkey, J., Dobby, G. and Kosick, G., “A New Tool For SAG Hardness Testing”, Proc. Canadian Mineral Processor’s Conference, Ottawa, 1994