SAG 2006

DEPARTMENT OF MINING ENGINEERING
UNIVERSITY OF BRITISH COLUMBIA
Vancouver, B. C., Canada

## SAGDESIGN TESTING – WHAT IT IS AND WHY IT WORKS

By John Starkey[1], Sami Hindstrom[2] and George Nadasdy[3]

[1]Principal Consulting Engineer, Starkey & Associates, Oakville, ON, Canada; [2]Manager, Concept Development, Outokumpu Technology, Espoo, Finland; [3]Metallurgical Engineer, Dawson Metallurgical Laboratories Inc., Salt Lake City, USA

### ABSTRACT

A robust, accurate laboratory SAG test has been needed for years. The SAGDesign Consulting Group has developed such a test. This paper also presents case studies in how it is used. Feed is prepared from ~10 kg of half core samples by crushing to 80% passing 19-mm. Grinding is then done in a 0.5 m diameter SAG mill to 80% passing 12 mesh US Standard (1.7 mm). The SAG ground product is then used for a Bond BM Work Index test. Reproducibility for SAG grinding is within 3% for duplicate tests done to date. The test has been used for predicting throughput as well as new plant design.

### BACKGROUND

The need to get accurate SAG Mill design information at a reasonable cost has been an urgent priority of the principal author John Starkey (Starkey) of Starkey & Associates for many years. This was first expressed in a tangible way with the invention of the SAG Power Index (SPI) test in 1991 and its subsequent co-development as a geo-metallurgical mapping tool, with the help of Minnovex Technologies Inc. The success of this test has been well documented in the literature and a 10 year review was recently published in the Randol Perth Forum 2005 proceedings, in a paper prepared by Chris Bennett of Minnovex.



In 2002, it appeared from a lack of published information and discussion with clients and colleagues, that the SPI test was not favored by clients for designing new mills because the test was only a 2 kg test and many samples were required to achieve desired accuracy levels. SPI testing is excellent for geo-metallurgical mapping but was not popular for new mill design. In addition, there were certain valid technical reasons that made it attractive to consider the development of a new, more robust test, specifically for SAG mill design work and the SAGDesign Test was created to fulfill this need. This paper discusses this development.

The question asked was, what is required to meet the demands of clients who did not know if they had an ore body and were doing a feasibility study to find out. Cost of the testing program and of the individual tests was a priority. In addition, the capital cost of new grinding mills required for a project was even more important, so the results had to be accurate.

Starkey then talked to Outokumpu in Denver and Dawson in Salt Lake City and agreement was reached on how to fund the development work. All three companies agreed that this would lead to better grinding mill designs so the work was started and the SAGDesign Consulting Group was formed, consisting of Outokumpu Technology Inc., Dawson Metallurgical Laboratories Inc. and Starkey & Associates.

### THE SAGDESIGN TEST

There were a number of criteria set for developing this new test. It would be called the Standard Autogenous Grinding Design or SAGDesign Test because it was specifically invented to be a standard for designing SAG/Ball Mill grinding circuits, and single stage SAG mills. The goal was also to make it so simple and basic that it would be a “Standard Test” for the mining industry. It was determined that the amount of material needed to be enough so that a Bond Ball Mill Work Index Test could be done on a constant volume of SAG ground material. This is the information that is really needed to design any grinding circuit that uses a SAG mill to produce feed for cyanidation, gravity concentration or flotation upgrading processes.

The SAG test had to duplicate commercial operating parameters. 26% Load, 11% steel (16kg), 15% ore (constant vol.), and 76% critical speed were selected. The mill was then sized so that 4.5 L (~7 kg of siliceous ore) would be needed for one test. The 18 inch diameter by 6 inch long MacPherson Mill was considered but was marginal and this could have led to a shortage of material in the following Bond test. It was therefore decided to use a 19.2 inch (488mm) diameter by 6.4 inch (163mm) long mill. Eight 1.5 inch (38mm) square lifter bars were added to match the size of the ore and balls. The ball charge is a half and half mixture of plus 2 inch (51mm) and plus 1.5 inch (38mm) diameter grinding balls.

The SAG stage feed size was selected to be the same as for a MacPherson AWi Autogenous Work Index Test or 80% passing ¾ inches (19mm), and the SAG test produces a product size that is 80% passing 1.7 mm, using repeated grinding cycles with removal of the minus 12 mesh (US Standard) fines from the batch charge after each cycle.

To duplicate the residence time in a commercial mill, the first cycle of grinding is 462 revolutions ( ~10 minutes) for hard ores (less for softer material). Material is removed from the mill for separation of the ore and steel and for screening of the ground ore at 12 mesh (US Standard). Then to prevent cushioning of the grinding process, minus 12 mesh fines are removed, before the steel and plus 12 mesh ore is returned to the mill for further grinding. Once 60% minus 12 mesh has been removed, fines removal is discontinued and the test is continued until the target of 80% passing 12 mesh is reached. The number of revolutions of the mill to achieve this end point is the SAGDesign SAG grinding result. It is expressed as revolutions, not minutes so as not to confuse the test with an SPI test where the result is measured in minutes. Because of larger steel, and fines removal, grinding time is less for SAGDesign testing.

## ACCURACY OF SAG RESULTS

Initial work was done using SPI test results for comparative examples.

The SAGDesign Test has a linear calibration equation – expressed as:

**SAG Mill Pinion Energy, kWh/t** = Revs x (16000+g)/(447.3g) **(1)**

*Where g is the weight of the ore tested – that is 4.5 liters of ore*

The equation is presented in this format to show the effect on the final result of increasing ore specific gravity (more grams per unit volume). A higher power draw results from a heavier charge but the tonnage ground is greater for increasing weight, and is reflected in the divisor of the equation and reduced kWh/t. 16,000g is the weight of steel charge used.



It is the linearity of the SAG result that makes the test so accurate, within 3% on repeat SAG tests and similar accuracy when compared to commercial and/or pilot plant SAG mill grinding.

The linearity also allows the performance of the SAGDesign Test Mill to be analysed by first principles, using a power increment for each revolution of the mill because the ore weight for the constant volume is known. Constant ore volume was chosen to match the Bond Test.

Since the performance of any SAG mill of inside the liners diameter, D can be described by the equation - Pinion Power = f ( $D^{2.5}$) it follows that a defined power increment for 1 rev. of the test mill can be derived from this relationship. Our observation is that the Energy Vs Diameter function is valid from 1 ft. to at least 40 ft. in SAG mill diameter.

The first principles analysis therefore was done to convert a test result into a power prediction for the sample by making adjustments for the fine feed (¾ inch Vs 6 inches in a commercial mill), for the SG of the ore compared to basic 2.7 SG material, and for the non-linear portion of the grinding curve as shown below in Figure 1. When this analysis yielded the same result as the empirical calibration it was concluded that the test results were valid for measuring SAG mill pinion energy.

More recently, a benchmark test has been done in the 5 ft. diameter Nordberg pilot mill in the Midland Research Center in Hibbing Minnesota. This test proved that a SAGDesign test on the pilot plant feed yielded a similar result to the actual power consumption in the pilot plant that was producing a SAG screen undersize product P80 of 1mm.

Reproducibility for SAG pinion energy has been checked 5 times to date. In every case the SAG results were duplicated with a variance of less than 3%, based on the initial test. This is clearly the result of using 7 to 8 kg of sample for a SAGDesign Test feed and having enough coarse material in each sample to properly reflect the amount of grinding required to reduce its size to 80% passing 1.7 mm.

The finished SAG ground ore includes some plus 6 mesh material. This is crushed to - 6 mesh, added to the rest of the ore, and the resulting SAG ground sample is then tested using a standard Bond Ball Mill Work Index test. Both SAG and ball mill grinding information is required for proper design because these two hardness' are not consistent with each other. The resulting Bond Wi value is about 1 to 1.5 units higher than a conventional Bond Wi result done on minus 6 mesh crushed ore.


**Figure 1 – Typical SAGDesign Test result**

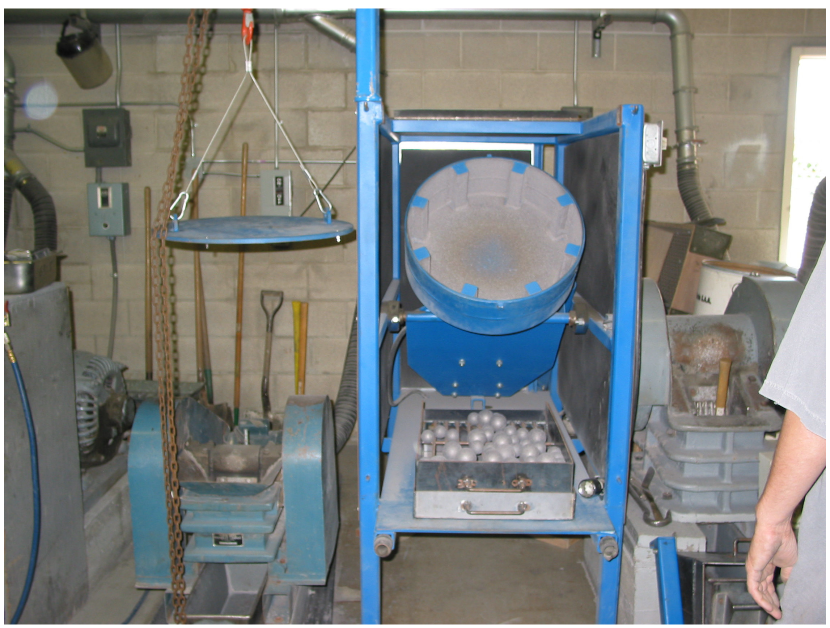

**Figure 2 – SAGDesign Test Mill**



## WHY SAGDESIGN TESTING WORKS

Sampling is a second major reason for the success of the SAGDesign testing program. Taking the samples is therefore an integral part of a SAGDesign testing program. Looking back, it is also the key to any investigation, using any test, for designing grinding mills. With the advent of geo-metallurgical mapping, we now know that the SAG hardness variability is greater than was originally thought 15 years ago. Energy requirements in many ore bodies can vary by plus or minus 50% and more, compared to average or median hardness. If the sampling done does not include the hardest ore units, the design can fail. The skill of the engineer taking the samples is the key to a good design.

Objectives for the design must be defined. Traditionally in the past, the objective was to take a "representative" sample and base the grinding mill design on the results from that sample. But many people now realize that a single sample is unlikely to be representative if the hardness variability function for the ore body is unknown. A client may request this design. But a more thorough analysis reveals that this type of design often leads to periods where production shortfalls may occur even when the sample is representative. A more rigorous approach is to design for the hardest ore so production shortfalls will never occur. But a more prudent course is to design for about the 80$^{th}$ percentile of hardness variability, and unless other reasons are stated, this is usually what the SAGDesign Consulting Group recommends for a new design.

Sampling for final grinding circuit design therefore includes a site visit by a qualified mining engineer. The ore reserves, geology and mine plan are studied. Also, an assessment of how the ore limits will vary with changing metal prices is done. The possibility of finding more ore is also looked at to see if future expansion should be allowed for in the design. In order to manage the budget for the client, the target is to get the design done with approximately 10 samples and 10 SAGDesign tests on those samples. This can vary depending on the nature of the deposit and the shape and number of the ore zones included in the mining plan. But clearly, if the ore body is known to be marginal, a budget for grinding design at the feasibility stage cannot be allowed to exceed $50,000 US and significantly less may be more appropriate.

Equally important is the accuracy of the design, especially at the Feasibility Study stage of the project. If the true size for the grinding mills is not identified at this stage of the project, the capital cost estimate for the grinding mills and the building will not be accurate.

## GUARANTEED PERFORMANCE

When the SAGDesign development work was complete it was reviewed by Prof. K. Heiskanen of Helsinki University of Technology. When this review was favorable, Outokumpu Technology (OKT) decided that they would patent the test. It was agreed that OKT would own the patent and Starkey would own the rights to use it commercially. The process guarantee of t/h and grind is offered for the mills supplied by OKT, when the mills have been designed by Starkey using the SAGDesign program. This program requires a site visit to take samples and about 10 samples to ensure that variability and hard ore has been included in the study.

There are several points regarding mill design that are worth noting. First, SAG mill power is always calculated at 26% load for sizing a SAG mill chamber. Extra power can be drawn at higher loads but results from a 32 ft diameter commercial mill and a 3 ft diameter pilot SAG mill, both showed that when a SAG mill is loaded over 26% by volume, the actual throughput tonnage drops. The results from the 3 ft diameter pilot test were published in the 2004 CMP Proceedings. This is a key point to achieving trouble free design production rates in a SAG mill.

The second point is to use classifying equipment to control the transfer size. MacPherson recommended a vibrating screen as the best way to classify SAG mill discharge and we agree with this concept. The use of ½ inch trommel screens can work well in large tonnage applications where the transfer size is about 3 mm, but in order to effectively use SAG power, it is often necessary to use screens in the range 1 – 10 mm.

Proper ball mill design sizing today is often misunderstood. Fred Bond was very specific about the use a of a diameter correction factor to allow for increased efficiency when ball mill diameter exceeds 8 ft. This factor is not included in many engineering design calculations even though benchmark testing at large installations shows conclusively that the diameter correction factor proposed by Bond is valid and perhaps even conservative. This factor is: Operating Wi = Bond Wi x $(8/D)^{0.2}$ or 0.80 x BMWi for a 24 ft diameter grinding mill. C. Rowland proposed a limiting value of 0.914 on this factor, but that value was based more on the size of mill available in his time rather than on an empirical analysis.

The result of these sizing calculations gives a larger SAG mill and a smaller ball mill than other design techniques but the total power will usually be about the same. But having the correct size of SAG mill allows optimization work or expansions, to be done with confidence.



## THEORY OF GRINDING DESIGN

A review and brief summary of grinding design theory is necessary to understand the principles of design for the SAGDesign testing program. It is based on the following premises that were discovered by the author during the development of SAG Power Index (SPI) technology when the initial SPI calibration work was being done.

Rule 1. The SAG stage of the SAGDesign Test measures the pinion energy to grind from 80% passing 6 inches (152mm) to a Transfer size T80 of 80% passing 12 mesh (US Standard) or 1.7 mm.

Rule 2. The ball mill stage of the SAGDesign Test (Bond Ball Mill Work Index Test) measures the pinion energy to grind from 80% minus 1.7 mm to about 80% minus 100 mesh (or the liberation size for that ore).

Rule 3. The adjustment of the design transfer size T80 (solids in slurry) from the SAG mill to the ball mill in the range of 0.4 to 4 mm, requires that the pinion energy for both mills be adjusted using the Bond BM Wi value. This was observed by the author from benchmark tests done.

Rule 4. Based on the above, total pinion energy in kWh/t is measured by the sum of SAG plus Ball Mill pinion energies and adjustment of the power split by changing the T80 does not alter the total design power.

Rule 5. Application of the fines correction factor (for a product finer than P80 = 70 microns) as per Bond, is applied to only that portion of the energy for grinding finer than 1.7 mm. Also, it is not recommended at this time to grind finer than P80 70 microns in a single stage SAG mill.

Rule 6. When a single stage SAG mill is designed, the benefit of large diameter is not used. It is unknown at this time if part of this factor is applicable to a single stage SAG mill. The design is conservative in this regard. Ball mill designs need to include the diameter correction factor.

Rule 7. When purchasing a single stage SAG mill, the power and the shell strength should be provided so that the mill can be converted into a ball mill if necessary in the future.

Rule 8. A SAG mill needs 10% more available energy than required for grinding and for powering the motor. A ball mill needs 5% extra power.

## CASE STUDIES

To date seven projects involving four different objectives have been completed using SAGDesign Testing. These objectives were:

To predict throughput in an existing operation (1); to Design new (or used) two stage SAG/Ball Mill Grinding circuits (3); to do benchmark testing (2); and to design a new single stage SAG mill (1).

### 1. Prediction of Throughput in an Existing Plant

A gold producer had purchased a used single stage 2.3 MW 5 m diam. x 6.1 m long SAG mill to grind the ore to 80% passing 100 mesh at a rate of 75 t/h. No testwork had been done so there was no way to comment on blending or capacity. Five samples were selected to examine the major ore types and SAGDesign testing yielded the following results.

**Table 1: SAGDesign Results for Predicting Throughput**

| ORE TYPE | SAG Test . | | Bond BM | Pinion - kWh/t - to | | | Predict |
|---|---|---|---|---|---|---|---|
| | Revs | gms | Wi-kWh/t | 10 M | 100 M | Total | dmt/h |
| Siliceous Ore | 1,944 | 6191 | 16.26 | 15.58 | 9.33 | **24.91** | **75** |
| Siliceous 2 | 2,061 | 6878 | 17.54 | 15.33 | 10.07 | **25.40** | **74** |
| Fe Mn Ore | 828 | 6657 | 14.94 | 6.30 | 8.57 | **14.87** | **126** |
| Limestone | 992 | 6600 | 11.46 | 7.60 | 6.58 | **14.18** | **133** |
| Soft Ore | 298 | 6425 | 10.48 | 2.33 | 6.02 | **8.34** | **225** |
| **50:50 Hard/Soft** | | | | | | **16.75** | **112** |

It was concluded that the tonnage could be pushed to 2700 t/d on a 50/50 blend of hard and soft ores, and perhaps more because the soft ore was much finer than normal. The client is therefore planning to handle up to 3000 t/d of blended ore because the soft ore is very fine.

### 2. New Design - Two Stage Grinding Circuits

Three projects involving new two-stage design have been completed. Two were for base metal ores, and one for iron ore.

***The first base metal project*** involving a combination of existing and new mills will be discussed first. Four SAGDesign Tests were done. Table 2 gives the basic SAGDesign test data and Table 2A the analysis of these results.



**Table 2: SAGDesign Results (Existing and New Mills)**

| ORE TYPE | SAG Test | | Bond BM | Pinion kWh/t – P80 | | |
|---|---|---|---|---|---|---|
| | Revs | gms | Wi-kWh/t | 10 M | 100 M | Total |
| Q F Gneiss | 719 | 7100 | 13.34 | 5.23 | 10.10 | **15.33** |
| C B Schist | 711 | 7260 | 12.76 | 5.09 | 9.67 | **14.76** |
| Amph. Schist | 729 | 7010 | 11.43 | 5.35 | 8.66 | **14.01** |
| Qtz. Porphyry | 903 | 6471 | 13.91 | 7.01 | 10.54 | **17.55** |
| **Average of 4** | | | | 5.67 | 9.74 | **16.41** |

**Table 2A: Predicted Tonnage for Existing and New Mills**

| Option | HP per Line | | Mill Sizes – ft. | | | | T80 | P80 | TPH/ |
|---|---|---|---|---|---|---|---|---|---|
| | SAG | BM | SAG M | | Ball M | | µm | µm | Line |
| | | | Dia | EGL | Dia | EGL | | | (1 of 2) |
| Exist’g | 6000 | 3000 | 28 | 12 | 16.5 | 19 | | | |
| 1 | “ | “ | “ | “ | “ | “ | 310 | 100 | 434 |
| 2 | “ | “ | “ | “ | “ | “ | 500 | 150 | 512 |
| 3 | “ | “ | “ | “ | “ | “ | 700 | 200 | 574 |
| With new ball mill added to the above: | | | | | | | | | |
| 1 | | 7000 | | | 20 | 26.5 | 2500 | 100 | 833 |

This analysis allowed us to predict that the existing mills (2 SAG and 2 Ball) would produce 21,000 TPD and that two new 7000 HP ball mills would be required to raise the tonnage to 40,000 TPD at the fine grind.

***The second new design project*** was a straight forward new design to produce 650 t/h of ore. Results are given in Table 3.

**Table 3: SAGDesign Results – New Mills**

| ORE TYPE | SAG Test | | Bond BM | Pinion kWh/t – P80 | | |
|---|---|---|---|---|---|---|
| | Revs | gms | Wi-kWh/t | 10 M | 200 M | Total |
| GGT 1 | 2243 | 6935 | 19.18 | 16.58 | 17.50 | 34.08 |
| GGT 2 | 1841 | 6961 | 15.42 | 13.58 | 14.07 | 27.64 |
| GGT 3 | 2341 | 7263 | 16.55 | 16.76 | 15.10 | 31.86 |
| GGT 4 | 2041 | 7013 | 17.25 | 14.97 | 15.73 | 30.71 |
| GGT 5 | 2277 | 6974 | 20.40 | 16.77 | 18.61 | 35.38 |
| CIPR 6 | 2130 | 7013 | 16.14 | 15.63 | 14.72 | 30.35 |
| CPR 7 | 1574 | 7042 | 12.93 | 11.51 | 11.79 | 23.31 |
| Average of 7 | | | | 15.12 | 15.36 | 30.48 |
| **Avg. 3 Hardest (Design)** | | | | **16.70** | **17.28** | **33.98** |
| Duplicate No. 6 | 2210 | 7427 | 18.20 | 15.59 | 16.60 | 32.19 |

The resultant design showed that to grind the hardest ore at 650 t/h, the mills required would be a 34 ft.diameter x 15 ft. long SAG mill with a 10.5 MW varispeed twin pinion drive, an MP800 in-circuit pebble crusher and a 24 ft. diameter by 32.5 ft. Long ball mill with a 10.5 MW fixed speed twin pinion drive. It was also noted that since the softer ore would be mined in the early years of the project that the pebble crusher would not be required until the soft ore was depleted, possibly in year 3.

***The third new design project*** was for a large iron ore deposit. Results are given in Table 4 below. Duplicate SAG tests were done to create material for Rougher Magnetic testing and Bond Wi tests on the conc. The average recovery of magnetics in the cobbing tests was 53.5%.

**Table 4: SAGDesign Results – New Mills**

| ORE TYPE | SAG Test | | Bond BM Wi | | Pinion kWh/t – P80 | | |
|---|---|---|---|---|---|---|---|
| | Revs | gms | Ore-kWh/t | Mags | 10 M | 325 M | Total |
| Horizon 1 (3) | 2868 | 8145 | 17.7 | | 19.01 | | 19.01 |
| Horizon 2 (3) | 3041 | 8349 | 16.1 | | 19.83 | | 19.83 |
| Horizon 3 (3) | 2665 | 8062 | 16.0 | | 17.78 | | 17.78 |
| Horizon 4 (3) | 2622 | 8864 | 15.2 | | 16.44 | | 16.44 |
| Horizon 5 (3) | 2816 | 8513 | 14.7 | | 18.13 | | 18.13 |
| Horizon 6 (3) | 2164 | 8514 | 13.0 | | 13.93 | | 13.93 |
| Horizon 7 (3) | 2308 | 8050 | 14.9 | | 15.42 | | 15.42 |
| 8 Yr 1 Comp | 2527 | 8380 | 14.7 | | 16.44 | | 16.44 |
| 9 Top 3 Comp | 2830 | 8162 | 17.3 | | 18.73 | | 18.73 |
| 10 Lower Comp | 2450 | 8620 | 14.8 | | 15.64 | | 15.64 |
| Average of 7 | 2641 | 8357 | 15.4 | | 17.22 | | 17.22 |
| **Design (9&10)** | **2651** | **8377** | **16.1** | | **17.28** | | **17.28** |
| | | | | | | (Mags) | |
| 8 Repeat | 2561 | 8443 | | 14.9 | 16.58 | 20.4 | |
| 9 Repeat | 2863 | 8268 | | 16.6 | 18.79 | 22.6 | |
| 10 Repeat | 2523 | 8600 | | 15.1 | 16.13 | 20.6 | |
| Design (9&10) | | | | | | 21.6 | |
| **Adjusted for 24 ft. dia (c/w Synchronous Motor)** | | | | | | **18.5** | |
| **Benchmark** | | | | | | | |
| Pilot plant feed | 2219 | 7926 | 16.7 | | 14.97 | | 14.97 |
| Pilot plant data corrected for tare | | | | | 15.0 | | 15.0 |

23 samples were taken. Composites were made for each horizon from 3 intersections. In addition, composites of the top 3 and lower 4 horizons were made. Together these composites represent the entire ore body.



A total of 13 SAGdesign tests were comlpeted. SAG grinding was to reduce the ore to 80% minus 1.7 mm with cobbing on the SAG product.

Using the largest SAG Mills available, it was determined that one 40 ft. diameter x 20 ft. long (EGL) mill would be able to grind approximately 1100 t/h of feed to 80% passing 1.7 mm. From this the SAG grinding equipment required for the project was determined.

Similarly it was calculated that 1 – 24 ft diameter x 32.5 ft. long ball mill would be needed to grind the rougher magnetic concentrate made from each SAG mill line, grinding from F80 1.7 mm to P80 325 mesh.

### 3. New Design – Single Stage SAG Grinding

One project was completed for a single stage SAG grind on a gold ore with a design throughput of 100 t/h. SAGDesign Test results are given in Table 5 below. A total of 9 samples were tested. These samples were taken by J.Starkey during a site visit.

**Table 5: SAGDesign Results – Single Stage SAG Mill**

| ORE TYPE | SAG Test | | Bond BM | Pinion kWh/t – P80 | | |
|---|---|---|---|---|---|---|
| | Revs | gms | Wi-kWh/t | 10 M | 200 M | Total |
| 1 Main Zone | 1438 | 7072 | 16.4 | 10.49 | 14.92 | 25.41 |
| 2 Main Zone | 1192 | 7130 | 15.8 | 8.65 | 14.40 | 23.05 |
| 3 Old Zone LG | 2207 | 6735 | 16.2 | 16.66 | 14.74 | 31.40 |
| 4 Old Zone HG | 1554 | 7069 | 16.2 | 11.34 | 14.73 | 26.07 |
| 5 New Ramp | 1949 | 7180 | 16.6 | 14.07 | 15.14 | 29.21 |
| 6 New Ramp | 1690 | 6972 | 16.8 | 12.45 | 15.31 | 27.75 |
| 7 New - Hard | 2290 | 6531 | 19.5 | 17.66 | 17.80 | 35.46 |
| 8 New - Hard | 1757 | 6824 | 16.2 | 13.14 | 14.79 | 27.92 |
| 9 New waste | 2107 | 7324 | 15.1 | 15.00 | 13.78 | 28.78 |
| Average | 1798 | 6982 | 16.5 | 13.23 | 15.07 | 28.30 |
| **Design** | | | | **14.83** | **15.26** | **30.09** |

From this data it was determined that the single stage SAG mill should be 18 ft. diameter x 27.5 ft. EGL with a 4.3 MW fixed speed drive so that the mill could be converted to a ball mill if necessary in the future.

By adding a pebble crusher the mill length could be reduced to 24 ft. but this was not recommended.

## SUMMARY - REASONS TO USE SAGDESIGN

- The SAGDesign Test program focuses on taking the proper samples. Starkey & Associates trains the process engineers how to do this.
- The SAGDesign SAG Mill operates at best commercial conditions for load (26% charge volume and 11% steel) and speed (76% critical).
- The SAG Mill is 488mm (19.2 inches) ID with a 3:1 D/L ratio.
- Uses the same feed size as MacPherson (80% minus ¾ inch).
- Robust, constant volume test uses 4.5 litres of crushed ore (or ~ 8 kg for 2.8 SG ore).
- Can be used on drill core taken deep in the ore body.
- Calibrated three ways - using SPI - first principles analysis of power drawn in the test - and a pilot plant benchmark test.
- Linear calibration ensures accuracy on hardest ores.
- Bond work index is done on SAG ground ore.
- SAGDesign test is patented by Outokumpu Technology - world wide.
- Technology is disclosed to clients - no hidden equations or "in-house" technology.
- Pilot plant is not needed to determine design grinding power.
- SAG pinion energy and Bond Ball Mill Wi do not necessarily correlate with each other so both measurements are needed for a proper grinding circuit design.
- Cost is reasonable - usually less than $50,000 US for a guaranteed performance design.
- Commercial mills designed by Starkey & Associates using the recommended program and supplied by Outokumpu Technology are guaranteed by OKT to produce design t/h and fineness.
- Reproducible – within 3% on the SAG energy needed to grind from F80 150 mm to P80 1.7 mm for duplicate tests.
- Accuracy is in the same order of magnitude (proven in a recent pilot plant benchmark test). No other grinding test gives this accuracy.



## CONCLUSIONS

The SAGDesign Test is a technically sound and reliable way to determine SAG and Ball Mill pinion energies for new grinding circuits where a SAG mill is planned to be used.

The test is the most accurate and reproducible grinding test available and has earned its name "Standard Autogenous Grinding Design (SAGDesign) Test".

Work to expand the data base will continue and any changes in the calibration will be promptly reported on our website at sagdesign.com.

The patent has added cost to the price of a SAGDesign test. For that cost, the client gets full disclosure of the technology and a process guarantee if the mills are purchased from Outokumpu. This represents excellent value added for a project

The full disclosure approach has made it possible for others to understand SAGDesign Technology and to have confidence in it.

## LOOKING AHEAD

Two seminars explaining SAGDesign technology were presented in Russia in the second quarter of 2006. These seminars were attended by undergraduate and graduate students at the Irkutsk Technical State University, and engineers from two ore testing/engineering companies in the city of Irkutsk. Because of this, both ore testing companies NTL-TOMS, and IRGIREDMET, have requested to join the SAGDesign Consulting Group and will order SAGDesign Test Mills for their laboratories in Irkutsk, Russia. These test mills will be in operation sometime during the fourth quarter of this year in 2006.

Another key area that requires more study is the selection of a SAG mill once the variability function and hardness of the hardest zones in an ore body are known. The effect on operating cost for choosing a larger mill needs to be more thoroughly understood. If it is possible for example to pay for a larger mill with operating savings in the first two years of the project life, this extra size can be an exceptionally valuable asset, especially in cases where there is a possibility of finding more ore reserves and expanding the throughput.

## REFERENCES

Rexnord Inc. Process Machinery Division. Technical Brochure describing Nordberg Grinding Mills, Ball, Rod and Pebble. 1975.

Dobby, G., and Starkey, J.H., Application of the Minnovex SAG Power Index Test at Five Canadian Plants *. SAG Conference, October 1996, Vancouver, BC.

Starkey, J.H., Getting More From Drill Core - Preliminary SAG Design. Randol Gold Forum, Monterey, CA, May 1997.

Holmes, G., Starkey, J.H., Grinding Circuit Design at Kubaka Using SPI and Bond. Proceedings of the CMP Conference, Ottawa, January 2001.

Cousin, P., Jordan, Robitaille, J., and Starkey, J.H., Design of the Agnico-Eagle Laronde Division SAG Mill. SAG Conference, October 2001, Vancouver, B.C.

Carre, R., Lakshmanan, L., May, R., and Starkey, J.H., Grinding of Agrium Phosphate Ore in a 3 ft Diameter Pilot SAG Mill, Proceedings of the CMP Conference, Ottawa, Jan. 2002.

Starkey, J., Hindstrom, S, and Orser, T., Choosing a SAG Mill to Achieve Design Performance, Proceedings of the CMP Conference, Ottawa, Jan., 2003.