# DESIGN OF THE KUBAKA GRINDING CIRCUIT USING SPI AND BOND

By

John Starkey, President, Starkey & Associates Grinding Design and Process Engineering,
and Graham Holmes, Manager of Mineral Processing, Kvaerner Metals E & C.

Paper to be presented at the Canadian Mineral Processors Conference
in Ottawa ON, January 25, 2001

## ABSTRACT

The Kinross Kubaka Project is a gold mine located in the Russian Far East. The grinding circuit, comprised of a 6.1 m diameter x 2.74 m long SAG mill and a 4.1 m diameter x 5.5 m long secondary ball mill in closed circuit with cyclones, was built using SAG Power Index and Bond Ball Mill Work Index testing to determine the grinding energy requirements. Extremely cold climatic conditions and the need to keep heated space and capital costs to a minimum, dictated a grinding circuit with no in-circuit crusher and no conveyors external to the mill. High energy requirements for both the SAG mill and the ball mill were correctly predicted and have allowed grinding production tonnage forecasts to be met. Design test data and production results are given.

## INTRODUCTION

In 1995 Davy International Canada, now Kvaerner Metals E & C, was commissioned as the Engineer and Project Manager for the Omolon Gold Mining Company, to design and construct a gold extraction plant for the Kubaka gold deposit, located in the Russian Far East. This deposit had been studied extensively in Russia during the exploration phase and a Feasibility Study was completed in 1993 by Kilborn who visited the site twice during that year to inspect facilities and to take metallurgical test samples. More samples were taken in 1995 to check ore hardness variability, as part of the final design program by Davy.

The client's objective in designing the Kubaka grinding circuit was to achieve design tonnage at all times, even when milling the hardest ore zones in the deposit. Since the samples taken in 1993 were taken as composite samples, it was necessary to take additional samples in 1995 to determine the extent of the variability. Six samples were sent to Canada for SAG Power Index (SPI) testing. Five of these were combined as a composite open pit sample, while the sixth sample was taken from the site adits as a composite sample to represent undergound ore. These two composite samples were tested to determine the MacPherson Autogenous Work Index for comparison with the SPI values.

A second design objective was to meet full production without using an in-circuit pebble crusher for critical size material in the SAG mill because the Feasibility Study had indicated that this could be a problem. Davy's design team was aware that the SPI test had been developed by Minnovex Technologies Inc. to determine specific energy in SAG milling without crushing, so Minnovex was asked to do SPI tests on the six available samples.

This paper deals with the grinding testwork, and the grinding circuit design and selection of grinding mills that resulted from this testwork.

Testwork was performed by A.R MacPherson Consultants Ltd. as part of a larger program at Hazen Research Inc., and by Minnovex Technologies Inc. MacPherson/Hazen did the MacPherson Autogenous Work Index (AWi) tests, the Bond Impact Wi test, the Bond Rod Mill Work Index (RM Wi) tests, and the Bond Ball Mill Work Index (BM Wi) tests. The SAG Power Index (SPI) tests were done at Minnovex Technologies Inc. in Toronto.

The MacPherson Autogenous test is done in an 18-inch diameter dry, air-swept Aerofall style mill, by continuously feeding ore that has been crushed to 100 % passing 1.25 inches. The final product from this test is approximately 80 % passing 300 microns and the specific energy consumed is calculated as an operating work index using Bond equations. The resulting work index is then adjusted to a commercially correlated AWi value by A.R. MacPherson Consultants. There is only one MacPherson mill in existence, located in Hazen Reseach Inc.'s facility in Denver CO.

The Bond tests are industry standard tests that can be performed in any commercial ore testing laboratory that has the required equipment. In this case these tests were done at Hazen Research.

The SPI test is done on 2 kg samples of ore crushed to 100 % passing 0.75 inches in a 12-inch diameter Starkey SAG mill. The time required to grind the sample to 80 % passing 10-mesh (1700 microns) is the SPI value in minutes. The specific energy is calculated from equations derived from commercial benchmark testing. These energy equations require input of the SPI minutes from the test and the desired SAG product size expressed as $T_{80}$ where Transfer Size $T_{80}$ refers to the SAG product size in microns transferred to the ball mill circuit.

The design procedure chosen by Davy used the SPI and Bond Ball Mill Work Index values to select the required specific energy for both the SAG mill and the ball mill. The other tests were used for comparison and to confirm the chosen result. Then, since used equipment was available in client inventory, Davy chose those mills that most closely matched the required duty.

## PRODUCTION OBJECTIVES

The goals for the new grinding circuit were clear and are summarized below. The 1,750 t/d capacity was to be the minimum when treating hard ore with no pebble crusher.

**Summary of Production Objectives**

| t/d | Availability | t/h | SAG Feed Size $F_{80}$ | Transfer Size $T_{80}$ | Product Size $P_{80}$ |
|---|---|---|---|---|---|
| 1,750 | 90 % | 81.0 | 150 mm | 1,200 µ | 53 µ |

## SAMPLE SELECTION AND GRINDING TEST RESULTS

Sample selection has always been the key to designing a successful mineral processing plant. A good deal of effort was taken to ensure the selection of meaningful samples. Three separate campaigns were carried out to investigate the grinding characteristics of Kubaka ore (and the cyanide leach for precious metals recovery).

The first program included three samples taken during the April 1993 Kilborn visit. Two samples were from underground adits while the third and largest sample was taken from the open pit. A composite was made to represent these 3 samples as Composite #1. The second program included a single composite sample (#2) taken during the August 1993 Kilborn visit.

The third lot of 6 samples was taken in 1995 as part of Davy's design confirmation work to measure ore hardness variability using SAG Power Index testing. All 6 of these samples were tested individually by Minnovex to determine the SPI values. Five of these samples were from the open pit and were later combined as composite #1, while the sixth was an underground composite sample #2. These two composite samples were then tested by MacPherson Consultants to determine the Autogenous Work Index.

The complete list of samples taken and made-up as composites is given below in Table 1.

**Table 1 - List of Samples Tested**

| No. | Identification and Description |
|---|---|
| 1 | Underground |
| 2 | Underground |
| 3 | Open Pit |
| 4* | 93 Composite #1 |
| 5 | 93 Composite #2 |
| 6** | 95 Open Pit Composite #1 |
| 7 | Open Pit |
| 8 | Open Pit |
| 9 | Open Pit |
| 10 | Open Pit |
| 11 | Open Pit |
| 12 | 95 UG Sample JQ734 |

Notes: * Denotes a composite sample made from samples 1, 2 and 3 in this list.
** Denotes a composite sample made from samples 7 to 11 inclusive.

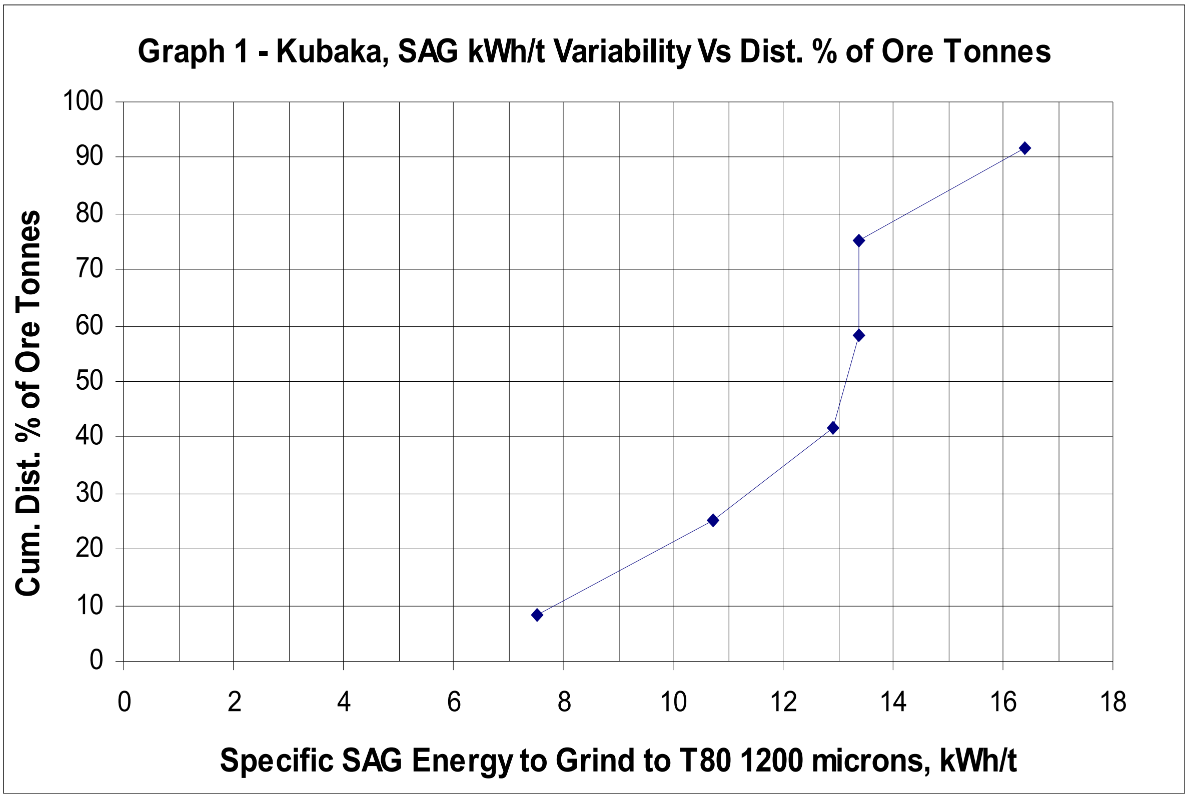
Results of all the grinding tests done on these samples are presented below in Table 2.

**Table 2 - Grinding Test Results**

| No. of Sample | Bond RM Wi 14 mesh kWh/t | Bond BM Wi 200 mesh kWh/t | Bond BM Wi 100 mesh kWh/t | MacPherson Corrected AWi kWh/t | SPI Minutes | Minnovex SAG Spec. Energy to $T_{80}$=1200μ Calc. kWh/t |
|---|---|---|---|---|---|---|
| 1 | 17.1 | 15.1 | -- | -- | -- | -- |
| 2 | 14.5 | 13.8 | -- | -- | -- | -- |
| 3 | 18.2 | 15.5 | -- | -- | -- | -- |
| 4 | 18.0 | 15.0 | -- | 17.4 | -- | -- |
| 5 | 17.1 | 15.5 | -- | 20.5 | -- | -- |
| 6 | 16.2 | 17.6 | 14.8 | 14.9 | -- | -- |
| 7 | -- | -- | -- | -- | 58 | 7.5 |
| 8 | -- | -- | -- | -- | 115 | 12.9 |
| 9 | -- | -- | -- | -- | 152 | 16.4 |
| 10 | -- | -- | -- | -- | 120 | 13.4 |
| 11 | -- | -- | -- | -- | 120 | 13.4 |
| 12 | 17.0 | 17.8 | 16.2 | 15.7 | 92 | 10.7 |
| *Average* | *16.9* | *15.8* | *15.5* | *17.1* | *110* | *12.4* |
| *Median* | *17.2* | *15.5* | *15.5* | *16.6* | *118* | *13.1* |

SPI minutes in Table 2 were converted to specific SAG energy by calculation, using the equation in the Minnovex SPI Report for Kubaka. The design team judged these values to be conservative because SPI benchmark calibration beyond 60 minutes had not been completed. (Subsequent work by Minnovex has confirmed this to be the case). The results given in Table 2 were extrapolated by extending the SPI range of the equation to include 152 minutes, the hardest sample tested.

Graph 1 plots SAG Mill Specific Energy Variability Vs Distribution % of Ore Reserve Tonnes, and is taken from data in Table 2. Each sample was assigned equal weight representation with respect to the tonnes of mineable ore in the reserves, to approximate the distribution %.




The value selected for SAG gross specific energy of 13.8 Kwh/t, based on the data available, approximately represented the top quartile of hardness variability when grinding from $F_{80}$ 150 mm to $T_{80}$ 1200 microns. It was also observed from the data that the overall variability in specific SAG energy to grind Kubaka ore from $F_{80}$ 150 mm to $T_{80}$ 1200 microns, would range from 7 to approximately 16 kWh/t for the hardest ore (based on the original equation).

More accurate energy estimates are now available for hard ores. The maximum energy, for the hardest SPI result, would now be slightly less than the design value chosen. In any case, the difference would not have been enough to change the recommended SAG mill power or size. Since the intention was to design for the hardest ore tested, it is concluded that the design goal was achieved by selecting the gross specific energy value of 13.8 kWh/t for the Kubaka SAG mill.

## DESIGN CRITERIA

The above results represent the basic ore hardness measurements that were made. Bond Work Indices (BM Wi) and the MacPherson Autogenous Work Index (AWi) were used to calculate specific energy requirements to accomplish the desired size reductions. These values for specific energy (W) in kWh/t are an estimate of the pinion power required to grind the ore and exclude electrical and mechanical losses in the motor and drive train. Such losses can vary from 2 to 10 % depending on the type of drive and motor. That in turn can impact heavily on the overall electrical power factor for the plant. Gross energy requirements calculated from work index measurements, were estimated by MacPherson Consultants and A. Stojsic, an independent Mineral Engineering Consultant, using a combined drive loss in the order of 8 %, a relatively safe and conservative number.

As reported in the SAG 96 Proceedings, the SAG mill energy requirements derived from SPI testing are in a significantly different form in that they are based on gross SAG mill power measured at the meter, and therefore include the drive train. This is practical because the majority of large mill drives use a synchronous motor(s) direct coupled to the pinion(s). It is estimated that the electrical/mechanical efficiency loss for this type of drive is in the order of 6 %. This factor should be adjusted if drives with different efficiencies are used. The initial SPI calibration work, as presented at SAG 96, was used for the Kubaka project.

### SAG Mill Design

There are many ways currently used to design a SAG grinding circuit. Techniques vary from continent to continent and from designer to designer. It was Davy's intention not to evaluate these procedures but simply to create the best design in the context of the time required to do back-up testing and to minimize the cost of such testing. Given the remote location of the project site, a full scale pilot test was not an option.

The SAG Power Index Test program offered the best combination of timing, quality and price. Results were expected to be conservative because initial SPI calibration work had just been completed and the results were known to be valid up to SPI values of 60 minutes. There were also strong indications that the emerging transfer size corrected equation would give a realistic order of magnitude estimate of the energy to grind harder ores to SAG product sizes finer than 10 mesh. This suited Kubaka because finer transfer sizes were being considered.

The attractive feature of the SPI test was that it is based on the measurement of time required to reduce the test sample to 80 % passing 10 mesh and uses benchmark calibration equations to estimate the energy required for grinding to 10 mesh and finer sizes. The definition of energy to achieve a specific size is a fundamental concept introduced by Bond for ball mill grinding and has been integrated into the SAG Power Index for semi-autogenous grinding.

A summary of the SAG mill specific energy recommendations derived from the grinding testwork, is presented below in Table 3. Design interpretations for the SAG mill, were offered by MacPherson Consultants, A. Stojsic, and Davy's design team and are also included in Table 3.

**Table 3 - SAG Mill Specific Energy Recommendations**

| Consultant | Corrected AWi kWh/t | SAG Mill Net Energy kWh/t | Pinion Power kW | Pinion Power HP | Gross HP | $T_{80}$ µ |
|---|---|---|---|---|---|---|
| MacPherson 1993 | 20.5 | 11.17 | 905 | 1214 | 1319* | 300 |
| MacPherson 1995 | 18.8 | 10.36 | 839 | 1125 | 1223* | 300 |
| Stojsic | | 12.8 | 1037 | 1390 | 1500* | 300 |
| Davy from Minnovex SPI | | 13.8** | | | 1499 | 1200 |
| *Fine SAG Grind Option* | | | | | | |
| Davy from SPI & Bond | | ~ 17.8** | | | 1933 | 300 |

Notes Table 3: * Recommended making allowance in the layout to add a pebble crusher

** Maximum gross specific SAG mill energy when measured at the meter

The above data clearly shows the different choices that were offered in deciding what power to select for the Kubaka SAG mill and in predicting the resulting transfer size that corresponded with the power selection. The variation can be explained by noting that Davy used power for hardest ores as the design basis while the other methods used average power.

To define the energy difference between 1200 and 300 micron products, calculation of the specific energy needed in a grinding mill to grind from 1200 microns to 300 microns using a Bond BM Wi of 15.5 kWh/t, shows an energy requirement of approximately 4 kWh/t. It was therefore decided to use the design transfer size $T_{80}$ of 1200 microns and to include this required power in the ball mill design.

Comparing the alternatives, Davy's design was based on SAG grinding alone with no pebble crusher and a transfer size $T_{80}$ in the order of 1200 microns. In this regard it was Davy's opinion that a transfer size of 300 microns could be achieved but over 400 HP of extra SAG power and a finer screen (with ~ 1 mm openings) would have been needed.

A summary of the SAG Mill Design Criteria recommended by Davy is given in Table 4.

**Table 4 - Summary of SAG Mill Design Criteria**

| Item | Value |
|---|---|
| Feed Size, $F_{80}$ | 150 mm |
| Transfer Size, $T_{80}$ | 1200 microns |
| Capacity | 81.0 t/h of hardest ore |
| Availability | 90 % |
| Average Throughput | 1750 t/d |
| Specific Energy | 13.8 kWh/t Gross (Direct from SPI testing) |
| Motor Power | 1119 kW or 1500 HP |
| Service Factor | Sufficient to operate at 1500 HP (Minimum 1.05) |

**Ball Mill Design**

The selection of ball mill design criteria was much more straight-forward than for the SAG mill. Bond work index testing using a 200 mesh closing screen was done on 7 samples as listed above. The median hardness for these samples was 15.5 kWh/t and that is the value chosen by Davy for ball mill design. The various design interpretations for the ball mill are given in Table 5 below.

**Table 5 - Ball Mill Specific Energy Recommendations Using Bond**

| Consultant | BM Wi kWh/t | Ball Mill Net Energy kWh/t | Pinion Power kW | Pinion Power HP | Gross HP | $T_{80}$ μ | $P_{80}$ μ |
|---|---|---|---|---|---|---|---|
| MacPherson 1993 | 15.5 | 12.03 | 974 | 1306 | 1420 | 300 | 53 |
| MacPherson 1995 | 16.6 | 13.23 | 1072 | 1437 | 1562 | 300 | 53 |
| Stojsic | 16.6 | 13.90 | 1126 | 1509 | 1616 | 300 | 53 |
| Davy | 15.5 | 15.96* | 1293 | 1733 | 1836 | 1,200 | 53 |

Note: * Includes 4 kWh/t of energy required to accommodate the coarse ball mill feed

The Davy specific energy calculations included Bond correction factors for the product being finer than 70 microns and for the mill diameter being larger than 8 ft. (A 13.5 ft. diameter ball mill was ultimately chosen).

A summary of the Kubaka Ball Mill Design Criteria recommended by Davy is given below as Table 6.

**Table 6 - Ball Mill Design Criteria**

| Item | Value |
|---|---|
| Feed Size, F80 | 1200 microns |
| Product Size, P80 | 53 microns |
| Capacity | 81.0 t/h of hardest ore |
| Availability | 90 % |
| Average Throughput | 1,750 t/d |
| Specific Energy | 15.96 kWh/t Net (Calculated from Bond).<br>16.92 kWh/t Gross |
| Motor Power | 1369 kW or 1836 HP |
| Service Factor | Sufficient to operate at 1836 HP draw |

**Summary 0f The Grinding Circuit Design**

The objective for the grinding circuit design was to achieve 81 tonnes per hour throughput when milling the hardest ores in the mine. The six samples chosen for SPI testing were not enough to say with confidence that the hardest ores had been sampled. However, it was noted that the original sampling done in 1993 showed that open pit ore was harder than the underground sample. By inference therefore one might conclude that it was essential to provide power to grind the hard ore initially because if the SAG mill was under sized and under powered, a crusher could have been added but not in time to treat the hardest ores. This could have resulted in a significant reduction in cash flow early in the project's life.

When a SAG grinding circuit fails to meet throughput predictions, undetected ore hardness variance is usually involved. The design team therefore decided to obtain SPI test data on hardness variance and to use the resulting design because it had the greatest chance for success by providing enough power on the SAG mill to grind the hardest ores. In retrospect, the use of SPI technology was an excellent choice even though hard ore calibrations had not been finished at Minnovex. By extrapolation beyond the proven SPI calibration range and by exercising good judgment in using the resulting data, Davy's design team was able to correctly predict the maximum specific energy that the SAG mill would require.

The overall grinding specific energy requirements are summarized in Table 7. The data is taken from Tables 3 and 5 above.

**Table 7 - Total Grinding Circuit Specific Energy**

| **Consultant** | **Net Energy kWh/t** | | | **Gross Power, HP** | | | **$T_{80}$** |
|---|---|---|---|---|---|---|---|
| | **SAG** | **BM** | **Total** | **SAG** | **BM** | **Total** | **μ** |
| MacPherson 1993 | 11.2 | 12.0 | 23.2 | 1319 | 1420 | 2739 | 300 |
| MacPherson 1995 | 10.4 | 13.2 | 23.6 | 1223 | 1562 | 2785 | 300 |
| Stojsic | 12.8 | 13.9 | 26.7 | 1500 | 1616 | 3116 | 300 |
| **Davy Design** | **13.0*** | **16.0** | **29.0** | **1499** | **1836** | **3335** | **1200** |
| Davy (alternate) | ~16.8* | -- | 29.0 | 1933 | 1402 | 3335 | 300 |

* net = gross/1.06

MacPherson's recommended total power was 2785 HP. Stojsic recommended approximately 3100 HP while Davy recommended 3335 HP for the combined SAG mill and ball mill power.

Stojsic's work confirmed that in his opinion the mills chosen by Davy would do the job as summarized in Table 7 above. He also observed that the ball mill would only draw about 1600 HP at a mill speed of 75 % of critical and that this would be sufficient to achieve the desired grind without trunnion modifications, as long as the SAG mill product (transferred material) was 80 % passing 300 microns.

Davy's assessment of required SAG power to achieve design tonnage was higher than Stojsic and MacPherson for the same transfer size. This was partly the result of Davy using maximum hardness while the latter two used average hardness, where these measurements relate to individual samples tested in one case, Vs composites in the others. The remaining difference was due to the conservative energy assessment in the Minnovex equations that required additional calibration work at the hardness levels that occur in the Kubaka deposit.

**EQUIPMENT SELECTION**

In order to keep capital costs to a minimum, the client wanted the design team to select used grinding mills since there was a reasonable selection of such mills available within their own sphere of influence. The mills chosen were well suited to the duty as shown in table 8 below.

**Table 8 - Grinding Mills Selected From Client Inventory**

| Mill | Dia. Ft. | L Ft. | EGL Ft. | Motor HP | Speed % Crit. | Steel Load % | Est. Gross HP Draw |
|---|---|---|---|---|---|---|---|
| SAG Mill | 20 | 9 | 7.5 | 1500 | 71 | 12 | 1460 |
| Ball Mill | 13.5 | 18 | 17.5 | 1950 | 66 | 34 | 1440 |
| c/w 27-tooth pinion instead of 24 | | | | “ | 75 | 34 | 1740 |
| c/w smaller diameter trunnion | | | | “ | 75 | 39 | 1835 |

The SAG mill selected was very close to the duty specified in the design criteria. The shell and motor size were well matched so there was no need to adjust the drive components or to change any of the major features of the mill.

The ball mill selected was unusual in that it had a large diameter trunnion and a motor that was larger than the capacity of the shell to draw power. It was in fact a mill that had originally been designed for rod mill duty. The mill speed was therefore increased from 66 % of critical speed to 75 %, by replacing the 24-tooth pinion with a 27-tooth one. Although the large diameter trunnion will not allow the mill to draw design power it was felt that since the motor power and the shell’s ability to draw required power with a smaller trunnion were compatible with the design criteria, it would be acceptable to start up without modifying the discharge trunnion arrangement.

**PLANT RESULTS**

The following data in Table 9 was submitted by Kinross staff at the Kubaka site and represents a 6-month average plant result for the period March to August 2000 inclusive. Plant data is given in the middle column. Other data derived or calculated from the plant data has been compared to the original design criteria and hardness measurements in Table 10.

The data in tables 9 and 10 demonstrates that the Kubaka grinding circuit has exceeded design production over the last 6 months by about 27% based on average hourly production.

The Kubaka mill has also met or exceeded design tonnage since start up in 1997. It has not been necessary to add an in-circuit pebble crusher because the hardest ores have been processed with no problem.

The difference between the median indicated SAG specific energy of 13.1 kWh/t, and the maximum of 16.3 kWh/t, represents a difference of approximately 24 % in the SAG mill energy or 10 % overall. This difference would be smaller using current SPI calibration data.

Other factors contributing to the high production rates achieved are discussed below.

**Table 9 - Plant Data**

| Item | Data Reported | Remarks |
|---|---|---|
| Tonnes milled | 438,235 | |
| Operating time hours | 4,245.6 | 184 days |
| Operating Time Percent | 96.1 | |
| Average SAG Feed t/h | 103.2 | |
| Tonnes milled/day | 2381 | |
| Average SAG HP | 1480 | |
| Average BM HP | 1515 | |
| SAG Feed $F_{80}$, mm | 130 | |
| SAG Discharge $T_{80}$, microns | 1000 | |
| Circuit Product $P_{80}$, microns | 65 | |
| SAG Speed, rpm | 12.5 | 71 % Critical |
| Ball Mill Speed, rpm | 16.0 | 75 % Critical |
| SAG Steel Loading % Volume | 12 - 14 | |
| SAG Total Loading % Volume | 25 - 27 | |
| BM Ball Loading % Volume | 32 - 34 | |
| SAG Discharge % Solids | 74 - 76 | |
| BM Discharge % Solids | 67 - 68 | |
| *Cyclones* | | |
| No. of 15 Inch Diam. Cyclones | 5 | |
| Cyclone Feed, % Solids | 47 - 48 | |
| Cyclone O/F, % Solids | 25 - 26 | |
| Cyclone U/F, % Solids | 67 - 68 | |
| *Steel Consumption* | | |
| 5” Balls, kg/t | 0.9 | |
| 2” Balls, kg/t | 1.2 | |

**Table 10 - Data Comparison, Actual Plant Vs Design**

| Item | Actual Reported | Range | Design | Actual/Design % |
|---|---|---|---|---|
| Average SAG Feed, t/h | 103.2 | 94 to 108 t/h | 81.0 | 127 |
| Tonnes /day | 2381 | | 1750 | 136 |
| Operating Time, % | 96.1 | | 90 | 107 |
| Average SAG Power, kW | 1104 | | 1119 | 99 |
| Gross SAG Specific Energy, kWh/t | 10.7 | 10.2 to 11.7 | 13.8 | 78 |
| Average BM Power, kW | 1130 | | 1835 | 62 |
| Gross BM Specific Energy, kWh/t | 11.0 | 10.5 to 12.0 | 16.9 | 65 |
| SAG Feed $F_{80}$, mm | 130 | | 150 | 87 |
| SAG Discharge $T_{80}$, microns | 1000 | | 1200 | 83 |
| Circuit Product $P_{80}$, microns | 65 | | 53 | 123 |
| Bond Wi, Calculated, kWh/t | 12.0 (Operating, Wio) | | 15.5 | 77 |

The final plant grind has been coarser than originally planned with the product $P_{80}$ being 65 instead of 53 microns. This is thought to be partly due to the large diameter ball mill discharge trunnion that makes it impractical to carry a large ball load in the mill. The result has been a reduction in ball mill power consumption when compared to the original design. Another contributor to low power draw in the ball mill is light density in the mill discharge, caused by a density of 67 % solids in the cyclone underflow. Based on Bond equations the coarse grind is estimated to reduce energy by about 15 % in the ball mill or 8 % overall.

Plant ball mill specific energy used is 35 % less than expected. This is equivalent to about 19 % of the overall design grinding energy. It is worth noting that Bond BM Wi tests at 100 mesh closing screen were done on the two 1995 composite samples. Comparing these results with 200 mesh Bond results showed that the coarser grind gave a lower Bond BM Wi by 2.2 kWh/t. The reason was attributed to mica in the ore that needs more energy to grind. Based on plant results it appears that liberation occurs at a coarser grind than design.

The SAG mill feed was finer than originally planned. The $F_{80}$ was 130 mm compared to the design of 150 mm. The difference in required energy (in the order of 5 % of SAG mill gross energy) was offset by a slightly finer SAG product of 1000 microns, compared to the design value of 1200 microns. At the same time the SAG mill power consumption was very close to design. It is also apparent that when maximum known hardness ore is encountered, the SAG mill will grind it at design throughput.

Any remaining differences between plant results and design, relate to the SPI calibration used and the deliberate provision to install enough SAG mill power to grind the hardest ore.

The engineering design at Kubaka included a way to conveniently sample the SAG mill product. This feature allowed the plant transfer size to be easily measured. In this way the SAG mill operation could be monitored, analysed and controlled to give acceptable results.

## CONCLUSIONS AND RECOMMENDATIONS

- The Kubaka grinding circuit design using SPI and Bond testing was successful. This method is recommended for future projects.
- The high throughput achieved compared to the design, relates to four main things. In order of increasing magnitude these are: slightly finer feed, minor overestimation of the SAG power required due to incomplete hard ore SPI calibration, coarser final product, and designing for maximum SAG hardness, not average.
- Six SPI tests were done on samples from the mine. The success of the design directly relates to the fact that these samples appeared to represent some of the hardest ores in the Kubaka deposit. This is important when only a few samples are available and the full distribution of hardness variance is not fully defined.
- The definition of SAG specific energy requirements to grind the hardest ore allowed the circuit to be designed without an in-circuit crusher. It is concluded that if the circuit had been designed for average or median SAG power instead of maximum, that an in-circuit crusher may have been needed to achieve design throughput on hard ores.
- Bond Ball Mill Work Index testing at 200-mesh gave conservative results when compared to the plant performance at a similar grind. More detailed study of fines production in the SAG mill product would be required to explain this observation.

**ACKNOWLEDGEMENTS**

The authors wish to thank Kinross Gold Corporation and Kvaerner Metals E & C for permission to publish this paper. The Kubaka plant is the first in the world to be designed using SPI data for the SAG mill design and the foresight of George Mitchell, the client's Resident Metallurgical Manager, in authorizing the SPI tests is hereby acknowledged.

**REFERENCES**

- Application of the Minnovex SAG Power Index at Five Canadian SAG Plants, by John Starkey and Glenn Dobby. International Autogenous and Semiautogenous Grinding Technology 1996, Volume 1, Page 345.

- Getting More From Drill Core, Preliminary SAG Design, by John Starkey, P. Eng. Randol Gold Forum Monterey 97, Conference Proceedings, Page 67.