DESIGN OF THE AGNICO-EAGLE LARONDE DIVISION SAG MILL

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ABSTRACT

Agnico-Eagle, Laronde Division is a dynamic and growing gold producer in the Val d'Or / Bousquet region of Quebec in Canada. Production expansion requirements were met by adding a SAG mill to an existing ball mill grinding circuit. Grinding energy requirements were determined using MacPherson Autogenous, Bond Ball Mill, and Rod Mill Work Index testing, and Minnovex SAG Power Index (SPI) testing. The hardness of present and future ore zones were studied.

Final mill design was completed by, Minnovex, SNC-Lavalin and Agnico-Eagle. The plant results were predicted accurately from the testwork that was done with regard to specific energy consumed in the SAG mill, transfer size and final product size feeding flotation.

INTRODUCTION

In 1998, Agnico-Eagle decided to expand production capability from 750,000 short tons per year to 1,300,000 TPY, initially by adding a SAG mill to the existing two-ball mill grinding circuit. As exploration results showed increasing ore reserve potential, concentrator throughput increase to 1,800,000 TPY was being studied.

At the time this project was planned, Minnovex Technologies Inc. had introduced the SAG Power Index (SPI) Test and proposed doing a suite of samples for Agnico to study hardness variations in the ore body that had been outlined, including the lower extension of the ore zone.

During the engineering phase of the project it was decided to revise the overall grinding circuit concept to the potential 1,800,000 TPY and therefore add extra energy to the new SAG mill although the ultimate production rate final decision had not been taken. This had three main advantages. The extra grinding energy and the SAG mill for 1,800,000 TPY would already be installed and could be used to reduce SAG steel consumption initially. Second, the extra capital cost and disruptions caused by a second addition to the concentrator would be avoided. Third, the total capital cost of this expansion would be lower than that for a two- stage expansion. And finally, the larger SAG mill provided would give a solid base for any further expansion of the plant should that be required in the future.

Continued enlargement of ore reserves at Agnico have in fact occurred and the SAG mill purchased in 1998 has proven to be an excellent investment for the concentrator.

FLOWSHEET

The flowsheet in use in 1998 consisted of a closed circuit conventional crushing plant feeding minus 3/8-inch ore to two fine ore bins. Plant capacity was 750,000 TPY and grinding to 80% passing 200-mesh was done in 2 parallel, 11-ft. diameter by 17-ft. long 1000 HP each, ball mills.

Classification for each ball mill line was provided by a cluster or 5-10" diameter cyclones, with Knelson concentrators treating a bleed stream from the cyclone underflow that was being fed to each ball mill. Gemini tables in each grinding line were used to clean the Knelson gravity concentrates. The primary cyclone overflows were then combined for flotation.

The changes in the flowsheet for the expansion were minimized by the addition of a single SAG mill to replace the crushing plant and to provide a fine feed for the ball mills, compatible with available ball mill capacity.

The new flowsheet consists of a truck dump feeding a belt conveyor that carries the ore to a 5000 tonne capacity, 15 m diameter coarse ore bin. Four vibrating feeders deliver the ore to the SAG Mill feed belt. SAG Mill discharge is pumped to a primary cyclone(s). Underflow from this cyclone is recycled by gravity to the SAG mill feed while the overflow is SAG product, which is transferred to the Ball Mill.

A cluster of 4-15" diameter, secondary cyclones classify the SAG ground ore into two streams, an overflow that is fine enough to be fed to flotation and an underflow that is fed to the ball mills as new feed after passing a gravity splitter to divide the feed into two approximately equal parts.

The existing ball mills were then used exactly as before, to grind the ore to its finished size, after combining the (existing) tertiary cyclone overflows with the secondary cyclone overflow to give flotation feed at 80% passing 200 mesh.

PRODUCTION OBJECTIVES

Phase 1 production objectives consisted of upgrading the existing copper flotation circuit, adding a zinc flotation circuit and a zinc concentrate dewatering, filtration and handling system. Circuit design was for 750,000 TPY with consideration for 1,300,000 TPY.

Phase 2 production objectives were to increase ore throughput from 750,000 TPY to 1,300,000 TPY while grinding the ore to the same fineness as before (P80 of 200 mesh) at a planned availability of 92.5%. In metric terms, this corresponded to an increase from 84 to 146 dmt/h.

Phase 3 objectives were the same except that the target tonnage was scheduled to increase to 1,800,000 TPY, again at 92.5% availability. This design capacity corresponded to a feed rate of 202 dmt/h.

While not part of the original design, the future plan for Agnico is to further increase the production capacity to 280 dmt/h.

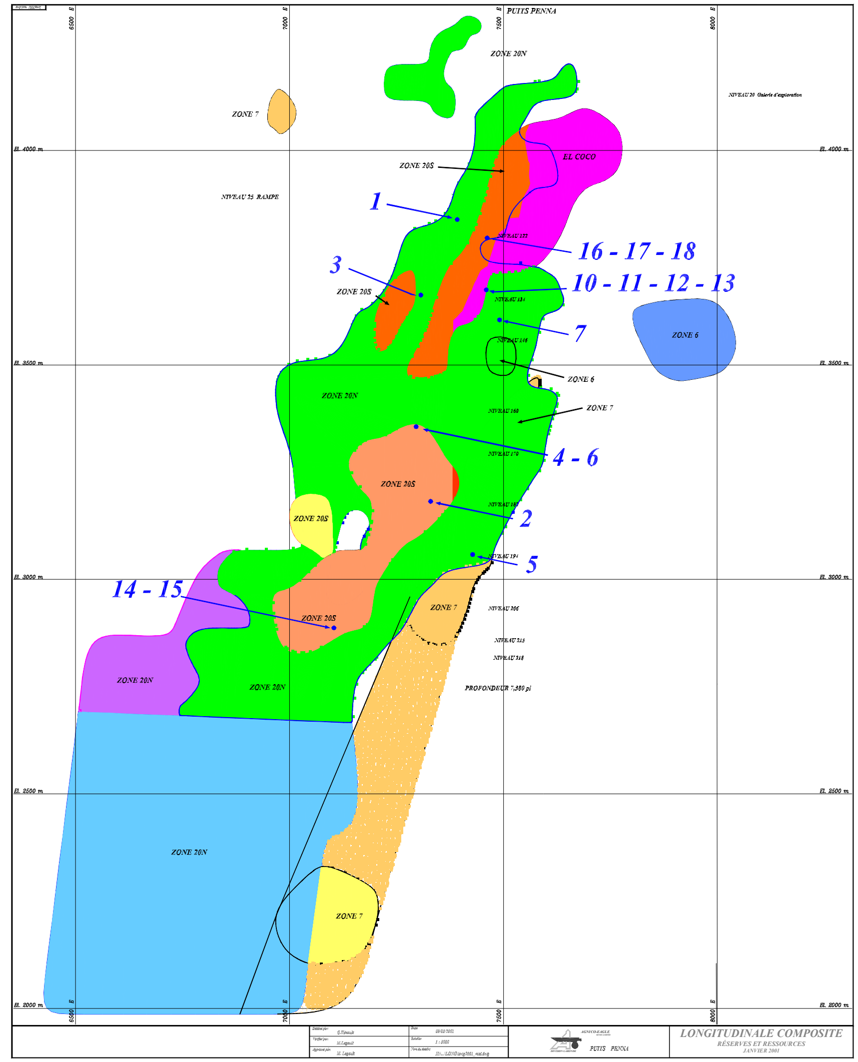
SAMPLE SELECTION AND GRINDING TEST RESULTS

A total of 18 samples were used to provide information on the hardness variability of Agnico ores. Initially seven diamond drill core samples were studied as shown in Table 1. One of these samples was not used in the final analysis for SAG mill design because this ore lay outside of the proposed mining limits.

Subsequently, 11 more drill core samples were taken as well as two composite samples representing ore from Shaft 1 (Zone 5) and Shaft 2

(Zone 6). SPI tests were by done by Minnovex on all 18 samples. A composite sample representing Shaft 3, Zone 20 N was also taken.

LONGITUDINAL COMPOSITE SECTION – Agnico-Eagle Mine



A recent longitudinal composite drawing of the Agnico mine is displayed above to show in a general way the approximate location of the samples that were selected for grinding hardness testing. Drilling in the lower part of the mine had not been completed at the time the samples were taken.

TABLE 1 - SAG Power Index Test Results

Ref. No.	Sample Description	Type of Material	SPI Min.	P64 µm	kWh/t 1.7 mm (6" Feed)
	Initial Suite of Samples				
1	20-259, 20 N Zn		30.3	255	4.39
2	20-258, 20 S		59.5	175	6.84
3	20-101 20 S	Not used.	95.9	116	9.90
4	20-258, 20 N Au		23.4	329	3.81
5	20-116A Zone 7		48.9	175	5.95
6	20-258, 20 N Zn		18.0	384	3.36
7	20-110, 20 N Zn		14.4	384	3.06
	Additional Samples				
8	Shaft 1 Comp. Zone 5	Stock Pile Grab	48.6	196	5.93
9	Shaft 2 Comp. Zone 6	Stock Pile Grab	45.8	173	5.69
10	DD Core #1 3134-02	FW Tuff	62.7	144	7.11
11	DD Core #2 3134-02	Massive Py Zn	9.90	530	2.68
12	DD Core #3 3134-02	HW Sulphide	53.7	191	6.35
13	DD Core #4 3134-02	HW Alteration	56.2	200	6.56
14	DD Core #5 20-131H	Massive Py Zn	11.7	521	2.83
15	DD Core #6 20-131H	HW Felsic Tuff	73.0	169	7.97
16	DD Core #7 3122-01	Diss Py Au	64.7	151	7.28
17	DD Core #8 3122-01	Diss Py Au	53.6	166	6.35
18	DD Core #9 3122-01	HW Felsic Tuff	83.5	137	8.86
		Average of 18	**47.4**	**244**	**5.83**

Note: kWh/t refers to a standard SAG condition with no pebble crusher and an F80 of approximately 150mm.

Other grinding tests were done by MacPherson Consultants, on the three composite samples as shown in Table 2. These tests were an Autogenous, Bond Rod Mill and Bond Ball Mill Work Index test on each of the Shaft 1 and Shaft 2 composite samples and 1 Bond Ball Mill Work Index test on the Shaft 3 Composite.

Minnovex used the Bond results supplied by MacPherson, as well as the SPI results, for their grinding circuit design. MacPherson also studied the Minnovex data and included their interpretation of this work in their design report.

Each MacPherson test required about 200 kg of sample. Each bond test needed about 10 kg of sample while each SPI test required about 5 kg of initial sample.

TABLE 2 - MacPherson Data

Sample Ref. #	Sample Description	MacPherson AWi KWh/t	Bond Work Indices Rod Mill kWh/t	Bond Work Indices Ball Mill kWh/t
	Actual Wi Test Results			
8	Shaft 1 Comp. - Zone 5	12.2	10.1	12.5
9	Shaft 2 Comp. - Zone 6	13.0	11.2	12.0
	Shaft 3 - Zone 20 N	--	--	11.8

ANALYSIS OF TEST RESULTS

Table 1 gives the SPI results for all 18 samples. The average SPI grinding time was 47 minutes, including all 18 samples. Excluding the hard sample outside the mining area, the average was 45 minutes (time to reduce 2kg of test feed from F80 ½" to T80 10 mesh). The corresponding specific energy to reduce the ore in a commercial SAG mill from F80 6" to T80 10 mesh was 5.8 and 5.6 kWh/t for the two averages respectively. (See Tables 1 and 3).

Table 1 also shows the average P64 for all 18 tests to be 244 µm. The P64 is the indicated natural product size from the SPI test. It, as well as the SPI, is a fundamental property of the sample tested. It represents the safe lower limit for the commercial SAG mill product size, without loss of efficiency.

Table 2 presents the Autogenous, Bond Rod Mill and Bond Ball Mill work indices that were provided by MacPherson Consultants.

The MacPherson actual test data related to the composite samples. Since the Minnovex data related to the hardness variability on a number of samples it was decided to base the grinding design on the Minnovex information. This was applicable because the heavy sulphide base metal samples in general tended to be much softer than the more siliceous gold rich parts of the ore body and both conditions would be encountered in the course of normal operations.

From the MacPherson test work, the Bond Ball Mill Work Index value of 12.5 kWh/t was selected as the design value by Minnovex.

Table 3 shows the data from Table 1, sorted in order of increasing hardness.

TABLE 3 - SAG Power Index Test Results - Sorted by Increasing SPI

Sample Ref.#	Sample Description	Type Material	SPI Min.	P64 µm	kWh/t 1.7mm (6" Fd.)
11	DD Core #2 3134-02	Massive Py Zn	9.9	530	2.68
14	DD Core #5 20-131H	Massive Py Zn	11.7	521	2.83
7	20-110, 20 N Zn	Initial Samples	14.4	384	3.06
6	20-258, 20 N Zn	Initial Samples	18.0	384	3.36
4	20-258, 20 N Au	Initial Samples	23.4	329	3.81
1	20-259, 20 N Zn	Initial Samples	30.3	255	4.39
9	Shaft 2 Comp. - Zone 6	Stock Pile Grab	45.8	173	5.69
8	Shaft 1 Comp. - Zone 5	Stock Pile Grab	48.6	196	5.93
5	20-116A Zone 7	Initial Samples	48.9	175	5.95
17	DD Core #8 3122-01	Diss Py Au	53.6	166	6.35
12	DD Core #3 3134-02	HW Sulphide	53.7	191	6.35
13	DD Core #4 3134-02	HW Alter.	56.2	200	6.56
2	20-258, 20 S	Initial Samples	59.5	175	6.84
10	DD Core #1 3134-02	FW Tuff	62.7	144	7.11
16	DD Core #7 3122-01	Diss Py Au	64.7	151	7.28
15	DD Core #6 20-131H	HW Fel Tuff	73.0	169	7.97
18	DD Core #9 3122-01	HW Fel Tuff	83.5	137	8.86
		Average of 17	**44.6**	**252**	**5.59**

Note: kWh/t refers to a standard SAG condition with no pebble crusher and an F80 of approximately 150mm.

Figures 1 and 2 give the same information but in graphical form where SPI and SAG Energy variability are plotted against ore tonnage distribution % respectively.

From this analysis it is seen that the median SPI hardness is 49 minutes and the corresponding SAG energy to grind the ore from F80 6" to T80 1.7mm (or 10 mesh) is 6.0 kWh/t. If the top quartile (75% of the samples tested) is considered, the energy required increases to about 7 kWh/t. At the top decile (90th percentile) the energy required is just less than 8 kWh/t.

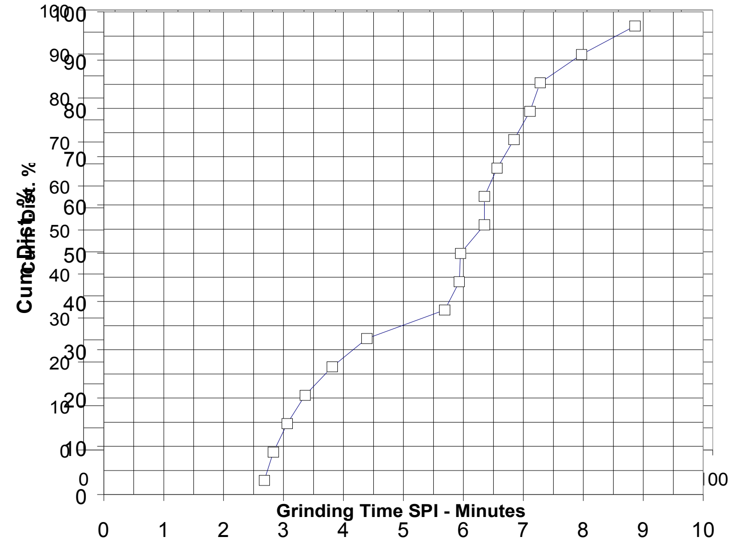


FIGURE 1 - Dist.% Vs SPI Variability for 17 Agnico Ore Samples

SAG Energy to Grind From F80 6" to T80 1.7mm, kWh/t

FIGURE 2 - Dist.% Vs SAG Energy Variability for 17 Samples

DESIGN CRITERIA

The SAG specific energy recommended for design was 8.0 kWh/t in order to provide power for the most extreme conditions of feed size and hardness that were identified. Additional specific energy of 11.5 kWh/t is required to grind the ore from T80 10 mesh to P80 200 mesh, as calculated from the Bond Ball Mill Work Index (12.5 kWh/t). Total design specific energy requirements are therefore 19.5 kWh/t.

TABLE 4 - Minnovex Grinding Design Calculations

Product Sizes	Units	Estim. Values Min.	Max	Design	Remarks
SAG Feed Size, F80	µm	100,000	152,000	**152,000**	Coarse hard ore.
Transfer Size, T80	µm	240	1,700	**1,700**	For energy calc.
Final Product Size, P80	µm	74	74	**74**	Flotation feed.

Energy from SPI, Bond	Units	Median (from SPI)	Top 75% (from SPI)	Top 90% (Design)	Remarks
SAG Energy, 6" to 10 M, SPI	kWh/t	6.0	7.0	**8.0**	See Figure 2.
Bond Ball Mill Work Index	kWh/t			**12.5**	Design value.

Ball Mill Energy,1700 -74 μm	kWh/t			**11.5**	Calculated.
Total Grinding Energy Req'd	kWh/t	17.5	18.5	**19.5**	O'all, SAG+BM

From these calculations it was determined that the total required specific energy for design purposes would be 19.5 kWh/t and that this energy would be sufficient to grind up to 90% of the ore without a pebble crusher from a feed size of F80 6 inches to a final product flotation feed size of P80 200 mesh. On the other hand it was also known that if the feed were to be finer or the ore softer than the design hardness, then extra capacity would be available.

The purpose in selecting these criteria was to ensure that the plant would always produce design tonnage, even under the most adverse conditions of ore hardness. This decision also recognized that limited data was available in the future mining areas and that in lieu of more data, the 90^{Th} percentile of hardness variability was recommended for design.

Since it is known that SAG grinds having a transfer size (T80) in the range of 3mm down to about 200 microns (in this case), are equally efficient in the use of grinding energy, a wide variety of SAG mill/ ball mill power splits were available for evaluation, prior to selection of a new SAG mill. The design options studied are given in Table 5.

TABLE 5 - Design Options Studied

Option	STPY ('000)	mt/hr	Power - HP Total	Power - HP Total x 1.15	Installed, HP SAG to T80	Installed, HP BM Exist	T80 Microns Calc.
Phase 2	1,300	146	3806	4377	2377	2000	494
Phase 3	1,800	202	5270	6060	4060	2000	238

The calculated energy from SPI and Bond are done on different bases. At the time of this project, SPI calibration was based on metered power, measured at the motor and included a drive efficiency factor of ~94%. (SPI is now shell power based). Bond equations relate to pinion power and so must be upgraded by ~8% to allow for drive losses. Since it is not possible to run a grinding mill at its rated load when no service factor is included, an allowance of 15% was added to the overall power to cover service factors, ball mill drive efficiency and SAG drive efficiency if a less efficient drive was selected. By doing this, the new grinding circuit would deliver required power under all normal operating conditions.

The criteria for Phase 2 was to add a new SAG mill and to leave the existing ball mill/gravity concentration circuit unchanged. SAG energy was therefore determined by subtracting the existing 2000 available ball mill HP from the total power required for Phases 2 & 3. Then to achieve the final grind, the transfer size would need to be controlled at 500 microns for Phase 2 and 240 microns for Phase 3.

EQUIPMENT SELECTION

Two used SAG mills were evaluated in the design stage. They are shown in Table 6 below. The 2500 HP mill was rejected because it could have only been used in Phase 2. The second was a 4600HP mill that was adequate from a power perspective but was found structurally unsound and costly from building requirement standpoint.

TABLE 6 - SAG Mill Sizes Considered

Option		Required Total HP	SAG Mill Add	SAG Mill HP	SAG Dimensions Diam.	SAG Dimensions EGL	Ball Mill Exist. HP
Phase 2	Alt. 1	4400	*Used**	*2500*	*20*	*12*	*2000*
	Alt. 2	4400	*Used**	*4600*	*28*	*10*	*2000*
	Alt. 3	4400	New	3000	22	11	2000
Phase 3	Alt. 4	6000	New	4000	24	12	2000

Note: * Denotes used available equipment that was not purchased.

The best option was to select a new 4000 HP SAG mill and provide the necessary power for Phase 2 with a single addition of new equipment. However, because of the information available at the time, a 10% safety factor was introduced into the final SAG mill design criteria. Therefore selection of a 4500 HP drive motor was made. The shell dimensions needed to draw this power under load conditions of about 15% steel were 24 ft. in diameter by 12 ft. long EGL.

Final design of the grinding circuit and the classification system was done by SNC-Lavalin. In order to cope with the observed wide variance in ore hardness as well as staged throughput operation, it was decided to add a vari-speed drive to the SAG mill.

The classification system chosen by SNC-Lavalin was a primary 33-inch diameter cyclone, designed to produce the target SAG product as cyclone overflow at a T80 size of 240 microns. Two cyclones were installed with the second, a 26-inch diameter unit, chosen for lower initial feed rate, standby duty, and partly to allow for uncertainty. The design included a cyclone changeover to a second 33-inch unit, once Phase 3 tonnage was reached.

A cluster of 4-15-inch diameter cyclones for secondary classification was then added to remove slimes directly for flotation feed and to provide dense cyclone underflow feed slurry to a gravity splitter that provides equal feed to the two mall mills. This configuration allowed the existing cyclones to operate as tertiary cyclones to complete the grinding circuit.

PLANT RESULTS

Plant results are presented in Table 7 below. Based on the first 6 months of operation at full capacity, the average production has been 210 dmt/h at an availability of 94.4%. Power consumption in the SAG mill has been low, averaging 1350 kW or 1810 HP and the average speed of the mill has been a consistent 8.59 rpm or 55% of critical. This is due to soft fine ore being fed to the SAG mill during this period.

Although no measurement of the SAG feed fineness has yet been made it is evident that the feed 80% passing size is closer to 4 inches than 6 inches. Based on available data this would result in an energy consumption of about 10% less than would be expected for F80 6 inch feed. The average transfer size of material from the SAG mill to the ball mill was observed to be 244 microns (T80).

In order to understand this performance in terms of the original testwork, a graph (see Figure 3), was prepared to show the ore hardness variability at the plant T80 of 244 microns.

TABLE 7 - Plant Results from November 1, 2000 to April 30, 2001

Item	Units	Monthly Avg. Min.	Monthly Avg. Max.	6 Month Average	Remarks
SAG MILL					
Oct. 1 to Apr. 30	Days	28	31	181	6 Months
SAG Feed	F80 mm	75	125	100	Est. values
SAG Feed	Dry t/h	208	212	210	Fix @ 217wt/h
Daily Variance	Dry t/h	157	213		
SAG Power, DCS	KW	1306	1416	1350	At motor.
Daily Variance	KW	1084	2016		
SAG Spec. Energy	kWh/t	6.27	6.68	6.43	F80 to T80
Daily Variance	kWh/t	< 6	> 12		
Transfer Size	T80 µm	227	260	244	Prim. Cycl. OF
CheckSAG Power					
SAG Motor	amps	411	430	421	Max. = 550A
SAG kW, Calc.	KW	1350	1484	1411	4160v PF 75.6
SAG Details					
SAG Feed / Month	tonnes	136725	150969	143692	
Average	t/d	4410	4983	4763	5250 SDTPD
Operating Time	Hr/mo.	668	722	684	
Availability	%	87.0	99.4	94.4	
SAG Speed	RPM	8.06	9.06	8.59	Crit Speed 15.6
SAG Speed	% Crit.	51.5	57.9	54.9	Max 85% Crit.
Bearing pres. Fd.	Psi	631	669	643	
Bearing pres. Dis.	psi	661	710	677	
Estim. Steel Load	% Vol	10	11.9	10.6	
Estim. Total Load	% Vol	-- na --	-- na --		
Estim. Circ. Load	% Feed	279	406	337	4 month avg.
SAG Discharge	%solids	83	84	83.8	4 month avg.
Water Added	Cu. m/h	80	96	87	SAG feed
Prim. Cyclone UF	%Solids	-- na --	-- na --	89.3	Recycle SAG fd
Prim. Cyclone OF	%Solids	-- na --	-- na --	60.7	To Sec. Cyclones
BALL MILL					
Primary Cycl. OF	T80 µm	227	260	244	SAG Product
Sec CyUF to BM,P80	µm	-- na --	-- na --	303	Feed to Ball Mill
Ball Mill Discharge	% solids	82	84	82.8	Average 2 mills
Ball Mill 1 Power	kW	685	738	709	Equal to 950 HP
Ball Mill 2 Power	kW	693	729	713	Equal to 957 HP
Total BM Power	kW	1378	1467	1422	Equal to 1907 HP
Operating Wi	kWh/t			13.0	Bond BM Wio
BM Cyclone UF	% solids	86	87	86.7	Average 2 mills
BM Cyclone OF	% solids	34	39	36.7	Average 2 mills
Estim. Circ. Load	%New Fd	-- na --	-- na --	310	To BM SecCy UF
Sec Cy OF P80	µm	-- na --	-- na --	69.0	SAG Dis. to flot.
BM Cycl OF P80	µm	-- na --	-- na --	78.0	From screen data
Final Product	P80 µm	70.1	76.9	74.0	Flotation Feed

The actual plant performance (with 10% added to energy consumed) is shown below in Figure 3.

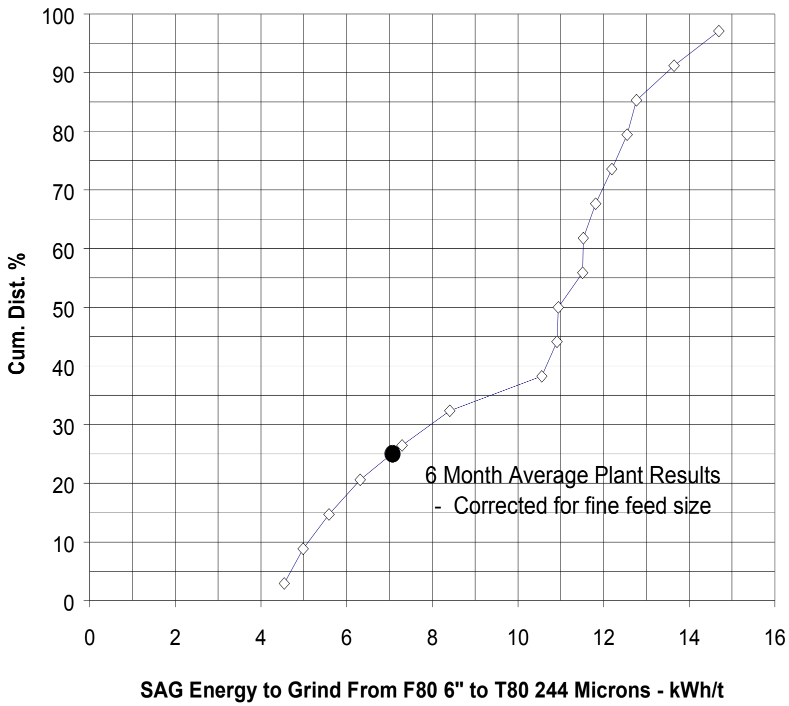


FIGURE 3 - Dist. % Vs SAG Energy Variability for 17 Agnico Samples

This indicates that some of the softest ores have been milled during the first six months of operation. The actual hardness appears to lie on about the 25th percentile of hardness variability. This is consistent with the nature of the ore that was mined during this period. When harder ores are encountered, it will be necessary to speed up the SAG mill in order to input the required energy.

Ball mill performance has been remarkably close to design expectations. The SAG product T80 averaged 244 microns (Vs 238 design), the flotation feed was exactly 80% passing 200 mesh, and the calculated operating work index for the ball milling circuit was 13.0 kWh/t (Vs 12.5 design). Total energy consumed was 1906 HP (Vs 2000 HP installed).

CONCLUSIONS AND RECOMMENDATIONS

The Agnico-Eagle SAG mill design using Minnovex SPI and Bond Ball Mill Work Index results, to determine energy requirements has led to a robust, highly effective grinding circuit.

Performance has been as expected and the mine is positioned for further expansion by adding additional ball milling capacity.

At 55% critical speed the SAG mill is providing for abrasion/attrition grinding only. 72 to 75% speed is required for impact breakage to occur.

When harder ores are processed, the SAG mill speed will need to be increased. This will allow input of design energy and will create an impact breakage environment that will be needed to grind harder ores.

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