

Paper for the CMP Conference, Ottawa, January 22, 2002

Grinding of Agrium Phosphate Ores in a 3' Diameter Pilot SAG Mill

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Key Words: Agrium, 3 Ft. Diameter, Pilot SAG Mill, Grinding, Energy, Efficiency

ABSTRACT

The Agrium Kapuskasing Phosphate Operation mines and processes up to 6,000 t/d of phosphate ore. Run-of-mine crushing to minus 6 inches is done in a toothed roll-crusher, while grinding is done in a SAG/ball mill circuit with no coarse recycle classification of the SAG mill discharge. The primary grinding mill is an 18 ft. diameter x 9 ft. EGL, 1500 HP variable speed SAG mill and the secondary mill is a 13 ft. diameter x 21 ft. long, 2000 HP fixed speed, ball mill. When hard ore was treated, the SAG mill restricted the tonnage that could be ground. When soft ore was treated, the ball mill and spiral classifier overloaded and restricted throughput.

Recommendations from a plant benchmark and an ore hardness testing program, on how to better utilize installed energy in the Agrium SAG mill when treating soft ore, and how to obtain best results when treating hard ore, were checked in a pilot plant investigation in the 3 ft. diameter Starkey-PRO Pilot SAG Mill. Correlation between the ore hardness testing and the results from the 3' Pilot SAG mill was very good. In addition, the work indicated the results that could be expected for the different ore types when using either smaller SAG discharge grates and/or a vibrating screen with 10 mesh square opening cloth.

INTRODUCTION

Agrium Kapuskasing Phosphate Operation consists of a 6800 t/d open pit mine and a concentrator, near the Town of Kapuskasing in Northern Ontario. The two major ore types are sandy ore and cemented ore. Sandy ore is fine, soft and easy to grind in the SAG mill while cemented ore is harder, more blocky and difficult to grind in the SAG mill. The ratio of sandy to cemented ore in the deposit is thought to be in the order of 80:20 but can range as high as 50:50, so it was important for the grinding circuit to have the ability to treat sandy ore alone.

Design throughput rates were 350 t/h but actual plant throughput was limited to about 225 t/h for sandy ore, due to ball mill limitations, and less for cemented ore due to coarse, hard feed. Amec was working for Agrium on plant improvements and hired Starkey & Associates to assess the performance of the grinding circuit and to make recommendations for throughput increases.

The grinding circuit consists of an 18 ft. diameter by 9 ft. EGL 1,500 HP vari-speed SAG mill and a 13 ft. diameter by 21 ft. long, 2,000 HP ball mill. The SAG mill was equipped with ¾" slotted grates and a 5/8" trommel screen. This allowed coarse material to pass through the screen to the ball mill circuit and also resulted in a significant tonnage of scats being rejected to the floor. The SAG mill was also found to be running at less than 50% of critical speed and physical overloaded conditions were often encountered. The Robicon vari-speed controller is set to draw full power at 78% critical speed and the power available decreases proportionally as the speed is reduced. The motor has a 1.15 service factor that allows it to run at full power without tripping.

The ball mill operated in closed circuit with a spiral classifier and carried a large circulating load from the classifier that resulted in unstable operation of the classifier. At 75% critical speed this ball mill can be expected to draw 1840 HP with a 40% ball load.

Operating conditions were erratic due to the combination of ore changes and overloading in the SAG mill that causes the speed to automatically reduce at about 1700 HP draw, well above the

power required for effective grinding in this mill. There was no interlock of feed tonnage to SAG power, and the SAG feed belt speed was fixed. Tonnage is manually set by a controller on the apron feeder feeding the roll crusher and is interlocked with a belt scale on the feed belt.

Ore blending from crusher feed stockpiles of sandy and cemented ores was not regularly done because of varying metallurgical quality of the two major ore types and the need to produce quality concentrates.

Plant Grinding Flowsheet

The actual plant grinding circuit is described in Figure 1 below.

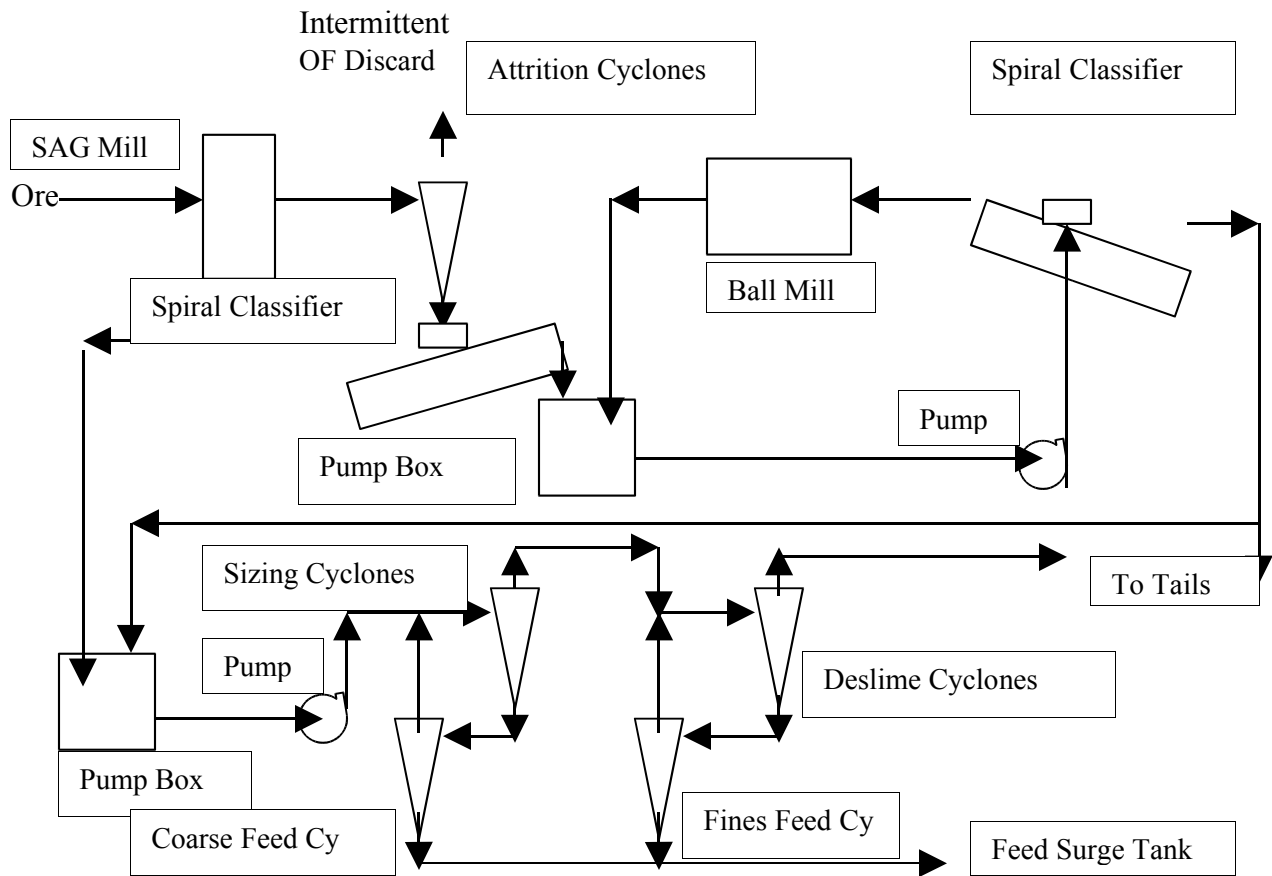


Figure 1 - Simplified Grinding Flowsheet at Agrium

During the period of this investigation, sandy ore alone was being treated and the attrition cyclones were being operated with no deslime overflow to discard.

INITIAL TESTS

The program undertaken by Amec started with a study of existing data. This was followed by two trips to Kapuskasing, first to study the actual operation and to acquire samples for specific laboratory tests on mine and mill samples, and second to take benchmark samples and data from the operating plant.

The first lab tests were done on seven samples of diamond drill core, mill feed stockpiles and trommel reject material. Seven SAG Power Index (SPI) tests and five Bond Ball Mill Work Index tests were done. Specific Gravity tests were also done on each of the seven samples. SPI values ranged from 17 to 40 minutes with the average being 29 minutes. This ore is quite soft by comparison with most gold and base metal ores. Bond Ball Mill Wi values varied from 10.0 to 13.5 kWh/t (at 100 mesh). Specific gravity values were steady, averaging 2.9 g/cc plus or minus 0.1 unit. Of the samples tested, the trommel reject sample was the hardest and heaviest.

A benchmark test was then done on sandy ore by taking samples of grinding circuit slurry flows and recording data from the plant. A summary of the interpretation of this data is given below.

Table 1 - Summary of Benchmark Data Analysis

<u>Ore Type</u>	<u>For T80 of 500 microns</u>		<u>For T80 of 750 µm</u>	
	<u>SAG t/h*</u>	<u>Ball Mill t/h</u>	<u>t/h</u>	<u>Limited by</u>
Sandy Ore	288	372	304	Ball Mill
Cemented Ore	172	290	192	SAG Mill
Mix 80/20	273	355	291	Ball Mill
Mix 60/40	258	339	277	Ball Mill

Note: * In each case the circuit would be limited by the SAG mill.

The results were not considered to be conclusive since the plant was only operating at a feed rate of 165 dmt/h on sandy ore at a reduced SAG speed and power draw (44% and 842 HP respectively). Nevertheless it was possible to estimate in a realistic way what the plant should have been able to grind, given the ore hardness, throughput and power and the feed size measurements that were taken as part of the benchmarking program, if the proper ancillary conditions were to be improved.

Initial Recommendations

Recommendations were then made to improve the plant throughput and grinding performance.

- Close the SAG discharge grates from 0.75 to 0.5 inches.
- Install a 1.5 mm screen in closed circuit with the SAG mill discharge to treat Sandy ore.
- Speed up the SAG mill to 75% speed since only 56% of the available HP was being used.
- Leave the 5/8" trommel, seats will stop when the grates are closed.
- Ball mill efficiency will be improved using the screen, by eliminating large circulating loads.

- Sandy ore throughput will increase from the estimated maximum of 225 to about 350 t/h.
 - t/h of SAG feed will vary with the ore type and the amount (& SPI) of the coarse fraction.
- The recommended plant flowsheet is shown below as Figure 2.

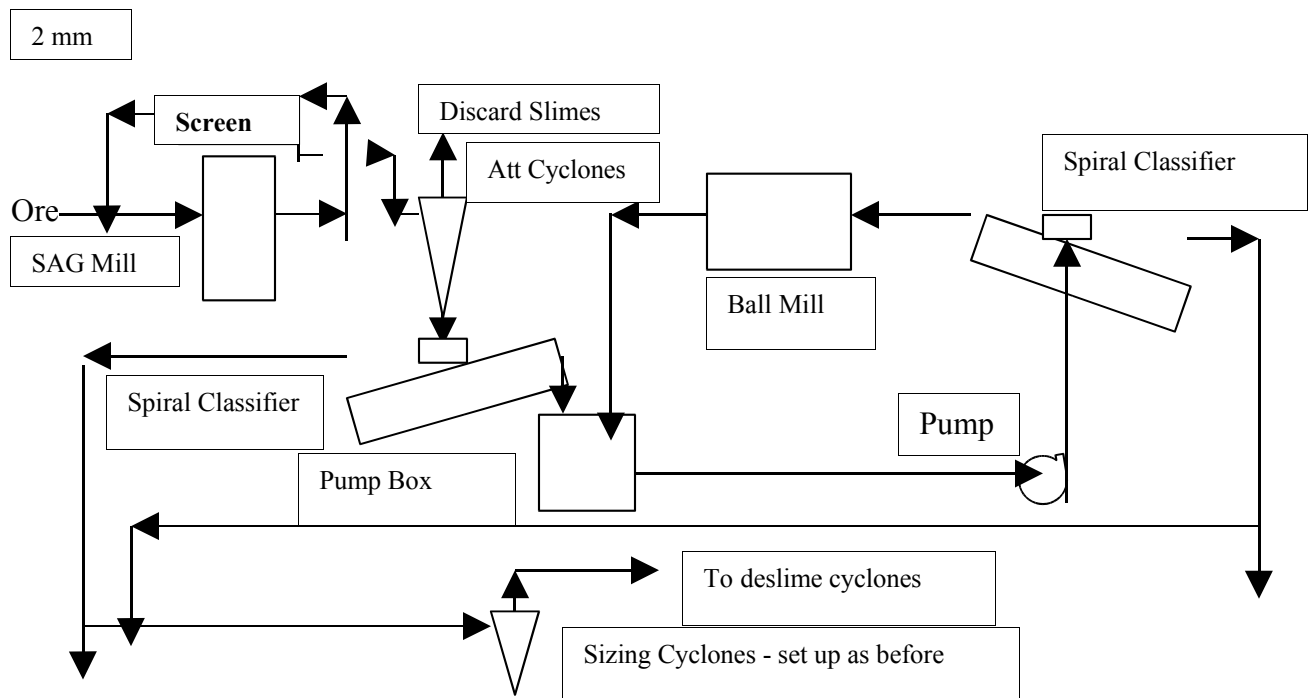


Figure 2 - Proposed Flowsheet Including the SAG Closed Circuit Screen

PILOT PLANT SET-UP

Agrium requested proof that predictions made would be valid. Amec, working with Process Research ORTECH then proposed to run a series of SAG pilot plant tests in the new 3 ft. diameter Starkey-PRO* pilot SAG mill to test the responses to the proposed plant changes.

*Patent applied for.

The new SAG mill was created by replacing the shell on a 3 ft. diameter by 2-½ ft. ball mill with a new spool piece. The new spool piece has no liners, and a grinding chamber with dimensions of 36” diameter by 15” long (EGL). Holes were cut in the shell to allow peripheral discharge of slurry that passed through the 10 mm slotted grate openings provided. A hole was left in the center of the grate diaphragm to allow direct tape measurement of the charge level in the mill by inserting the tape through a discharge port. The mill is fed using a long pitch 1-½ inch high advancing spiral flight mounted in the 6” diameter feed trunnion liner. This feeder was capable of handling the minus 3” feed provided, with very little difficulty.

Feed was prepared by screening the as received ore on three inch cloth, then passing the plus 3” fraction through a jaw crusher with a 3 inch closed side setting to prevent over-crushing. By keeping the original fines and the crushed coarse fraction separate it was easy to maintain the integrity of feed in each pail by adding proportional weights of the two components.

Objectives

The following objectives were set for the pilot plant program.

- Confirm results predicted from the previous benchmark and laboratory work.
- Prove that smaller ½” grates will not result in a large reduction in tonnage.
- Prove that a closed circuit 10 M screen will work and not cause a large decrease in tonnage.
- Treat sandy ore alone
- Treat cemented ore alone
- Treat a 60/40 blend of sandy/cemented ore.
- Make a coarser product, using the whole circuit and/or the SAG mill alone.

Pilot Plant Flowsheet

The full grinding flowsheet used in the pilot plant, is shown below in Figure 3.

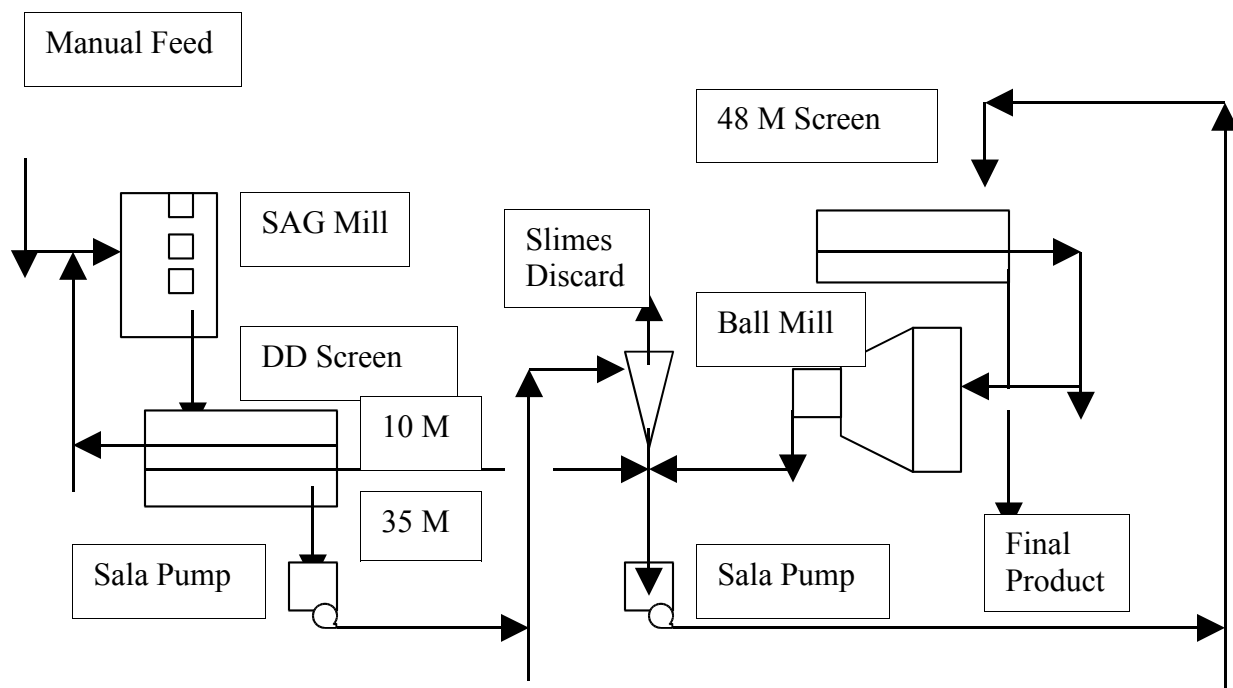


Figure 3 - Pilot Plant Flowsheet for 3 Ft. Diameter SAG Mill Testing

The pilot plant operation used manual feeding of pre-weighed pails of the ore being tested. The plus 10 mesh screen oversize was also handled manually by weighing each amount of oversize produced during the period that the feed was added. In this way a precise measure of circulating load was obtained for each test conducted. Then, by stopping the mill periodically for about 15 seconds, the charge level was measured and the feed rate adjusted to correct a rising or dropping charge load. For these tests, the ball charge was set at 10% of mill volume using 2” diameter steel balls.

Bulk Samples Tested

Three bulk samples were sent for testing as shown in the following table. A second sample of cemented ore was requested because severe ice contamination in the first cemented sample resulted in an unusually low weight of material received. The first sample was also judged by the client's on-site representative to be much finer than normal cemented ore.

Table 2 - Bulk Samples Received

<u>Ore Sample</u>	<u>Weight</u> <u>Dry kg</u>	<u>Samples Received</u>		<u>Pilot Plant Feed F80</u>	
<u>Inches</u>		<u>% + 3"</u>	<u>F80</u>	<u>mm</u>	
Sandy Ore	6,000	7	0.75	16	0.6
Cemented Ore #1	3,500	12	2.4	40	1.6
Cemented Ore #2	5,000	40	4.4	65	2.6
60 / 40 Blend				54	2.1

(All passing 3 inches)

From the original SPI testing it was known that the SPI for sandy ore (3" pieces) was likely to be about 17 minutes while for cemented ore it was likely to be in the order of 35 minutes. More tests would be required to properly characterize these ore types but for the purpose of this study, the data was considered to be relevant.

Pilot Plant SAG Only Flowsheet

During the course of the testing, a SAG mill only flowsheet was used as well. (See Figure 4).

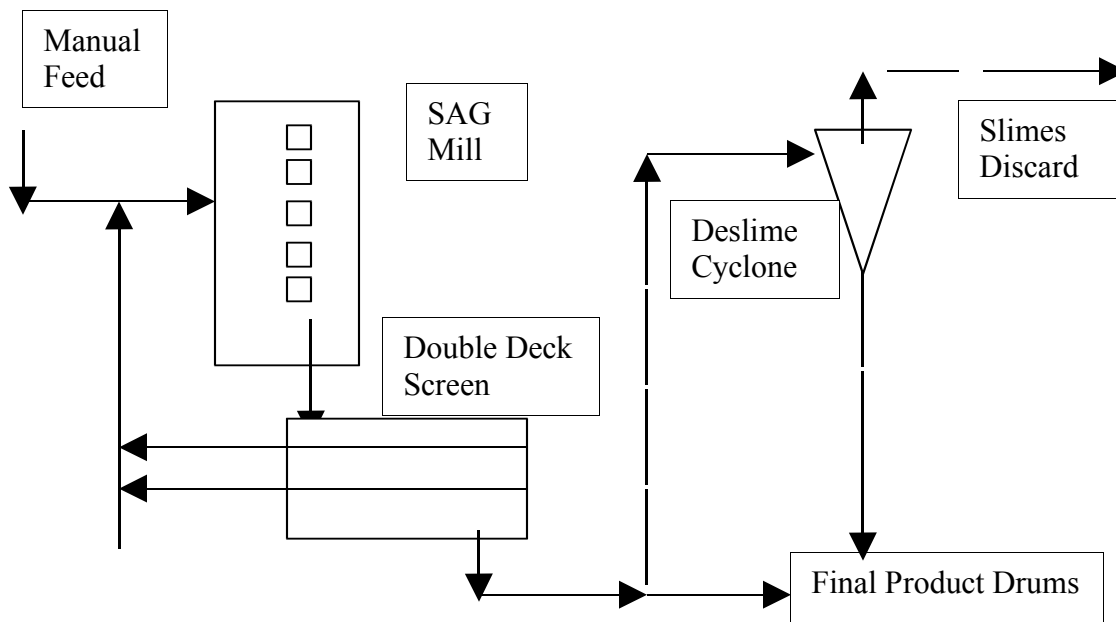


Figure 4 - Pilot Plant SAG Only Flowsheet

PILOT PLANT TESTS

Ten tests and 4 additional sub-tests were done on 3 ores and 1 blend as indicated above. Some of the tests were done to set up and test the equipment configuration and the rest to gather required data. A second 35 mesh deck was added to the 30" diameter SAG discharge 10 mesh screen to prevent plugging of the deslime cyclone. The final product cyclone was replaced with a 48 mesh 48" diameter screen to provide steady feed to the ball mill. This screen was reduced to 28 and finally 20 mesh during the investigation to produce a coarser final product.

The complete list of tests and key results are given below in Table 3.

Table 3 - Complete List of Pilot Plant Tests and Key Results

<u>Test</u>	<u>Ore</u>	<u>SAG</u> <u>kg/h</u>	<u>Weight % of Feed</u>			<u>T80</u> <u>µm</u>	<u>Product</u> <u>%-100M</u>	<u>Circuit/Remarks</u>
			<u>O/S</u>	<u>Slime</u>	<u>Product</u>			
1	Sandy	96	8 (no recycle)					Preliminary test
2	Cement-1	204	12 (no recycle)					Preliminary test
3	Cement-1	265	25	28	72	388	94	Full, 48 Mesh screen
4	Cement-2	141	34	21				Mill level too high
5	Cement-2	165	20 (no deslime)		100			Mill level not steady
6	Cement-2	174	24	10	90	315	80	Full, 28 Mesh screen
7A	6/4 Blend	256	32	4				Mill level not steady
7B	6/4 Blend	290	12 (no recycle)		88	361	44	SAG only 10 Mesh
8A	6/4 Blend	268	18	12	88	339	53	Full, 20 Mesh screen
8B	6/4 Blend	268	18 (no deslime)		100			SAG only 10 Mesh
9	6/4 Blend	278	45 (no deslime)		100			SAG only 20 Mesh
10A	Sandy	437	17 (no recycle)		83	447	43	SAG only 3/8" grate
10B	Sandy	380	40 (no deslime)		100	324	43	SAG only 20 Mesh
10C	Sandy	382	52 (no deslime)		100			Duplicate test
	(Sandy		404	12		100		Estim. for SAG 10M)

Note: Key tests are shown in **bold** print.

Comparing the open circuit SAG grinding of sandy ore at minus 3/8", with 10 M and 20 M recycle classification of the SAG mill discharge, showed that throughput would be a maximum of 437 kg/h for the 3/8" grate discharge and would reduce to 380 kg/h as the product became finer. Even with the 20 mesh screen and a recirculating oversize load of 52%, the throughput was only reduced by 13%. The second sample of cemented ore was clearly difficult to grind and throughput was reduced to 174 kg/h when treating this ore. Predictably, the 60/40 blend of sandy/cemented ore yielded a throughput of 268 kg/h.

In the pilot plant therefore the key to good production was moving the material through the SAG mill without allowing coarse (plus 10 mesh) particles to get into the ball mill circuit. The ball mill therefore was used to make a finished product of the desired size (80% passing 100 mesh in this case). As the requirement to make a coarser product was introduced, the need for ball mill grinding was reduced to the point where the ball mill was not needed to make a 40% minus 100 mesh final product as long as the SAG screen was reduced to 20 mesh. In practice, best throughput will occur with a coarser SAG screen (or small grate discharge) and the ball mill in service to complete the grind to the required size.

Predicted Plant Results from Pilot Tests

The results from the pilot plant were used to predict plant throughput results when treating ores similar to the ones tested in this program (see Table 4 below). This was done in two ways. Actual power drawn by the pilot mill was measured and converted to HP consumed. In addition, the power drawn by the three foot diameter mill was calculated from basic principles and was in reasonable agreement with measured power. It was then necessary to estimate the reduction in power required in the plant that was caused by pre-crushing of the ore to all passing 3 inches for the pilot mill. Because the ores were quite fine as received, a factor of 10% was allowed for this. It is fair to say that as more projects are done, the correlations will improve, but this first effort is considered to be conservative and reasonable duplication in the plant is expected.

Table 4 - Predicted Plant Results

<u>Test</u>	<u>Ore</u>	<u>SAG</u> <u>t/h</u>	<u>Wt. % of Feed</u>		<u>T80</u> <u>µm</u>	<u>Product</u> <u>%-100M</u>	<u>Circuit/Remarks</u>
			<u>O/S</u>	<u>Product</u>			
Estim.	Sandy	350	12	90	500	80	Full circuit 10M SAG
6	Cement-2	147	24	90	315	80	Full circuit 10M SAG
8A	6/4 Blend	227	18	88	339	53	Full circuit no screen
10B	Sandy	322*	40	100**	324	44	SAG only 20M

Notes: * SAG closed with 20 mesh screen
 ** no deslime or ball mill included

These results are considered to be conservative in terms of throughput predictions. It is clear however that the sandy ore can be processed at full design tonnage. Both pilot plant testing and the benchmark tests showed essentially the same result.

SUMMARY

- The pilot plant campaign was successful. Throughputs recorded were relevant to predicting what will happen in the full-scale plant using smaller grates and a 10 mesh screen.
- Operating responses in the pilot plant were normal. In all cases the load could be controlled in the range of 25 to 27% for maximum throughput by adjusting the feed rate.
- Recycling the screen oversize created circulating loads of about 20% as expected.
- Compared to 3/8" open circuit grate discharge, a 10 mesh screen will eliminate coarse pieces from ball mill feed. Reduction in pilot plant process feed rate was in the order of 7%.
- When the plant SAG mill load increases, the speed and power are automatically reduced. It is therefore important not to overload the SAG mill in order to get maximum production.
- Maximum plant speed is 78% critical and the motor service factor is 1.15. Best grinding occurs at 75% of critical speed.
- Must use full power (1500 HP) for best SAG results in the plant.
- Feed rate will vary with the number and the hardness of the hard pieces in the SAG mill feed. This was the main difference between the two cemented ore samples.
- 2" steel in the pilot SAG mill worked well on minus 3" feed in the 3 ft. diameter mill.

CONCLUSIONS

- When treated alone, sandy ore throughput will be limited by the ball mill capacity, not the SAG mill. Design feed rate of 350 t/h will only be achieved on sandy ore if a screen is added.
- A 10 M screen is required to treat 100% sandy ore at design throughput. This will allow the SAG mill to do more work and relieve the load on the ball mill.
- Ore blends with 40% or more of cemented ore are SAG limited and should be treated without the screen for best results.
- If budget constraints prevent installation of the screen, the best alternative is to decrease grate size from 3/4" to 1/2".
- The plant SAG mill is capable to run steady at 1500 HP. The speed will have to be increased to 75% to come close to this power draw.
- Coarser final product grinds will result in higher t/h in the existing plant.
- Cost of the SAG pilot plant test program was on budget and much lower than could have been achieved in a 6 ft. diameter test. In fact, the fineness of the ore and the high throughput would have made it very difficult to run this program in a 6 ft. mill.

RECOMMENDATIONS

- Determine ratio of sandy/cemented ore in the mine before making final decision on equipment. In the meantime, reduce the grate size to 1/2".
- Run the SAG mill at 75% critical speed when treating cemented ore blends to maximize SAG throughput.
- Replace 18 tooth pinion with 17 teeth so that the SAG motor will draw 1500 HP at 75% critical speed.

- Blend ores for best overall grinding results. If blending is difficult due to the mine schedule, add the screen and cut it in when Sandy ore is fed.
- Cut back on the size of steel in the plant - 5" is too big. Performance and liner life will be improved.
- Use 3 ft. pilot SAG mill for future testing. The quality of feed samples will be greatly improved and the cost of getting the samples will be reduced.

ACKNOWLEDGEMENTS

Thanks are given to Agrium Kapuskasing Phosphate Operation for permission to present this paper, Amec Simons Mining & Metals for ordering the testwork, and Process Research ORTECH for supporting the 3 ft. diameter concept and providing the facilities.