IMPROVING TACONITE PROCESSING PLANT EFFICIENCY BY COMPUTER SIMULATION

Final Report

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ABSTRACT

This project involved industrial scale testing of a mineral processing simulator to improve the efficiency of a taconite processing plant, namely the Minorca mine. The Concentrator Modeling Center at the Coleraine Minerals Research Laboratory, University of Minnesota Duluth, enhanced the capabilities of available software, Usim Pac, by developing mathematical models needed for accurate simulation of taconite plants. This project provided funding for this technology to prove itself in the industrial environment.

As the first step, data representing existing plant conditions were collected by sampling and sample analysis. Data were then balanced and provided a basis for assessing the efficiency of individual devices and the plant, and also for performing simulations aimed at improving plant efficiency. Performance evaluation served as a guide in developing alternative process strategies for more efficient production. A large number of computer simulations were then performed to quantify the benefits and effects of implementing these alternative schemes. Modification of makeup ball size was selected as the most feasible option for the target performance improvement. This was combined with replacement of existing hydrocyclones with more efficient ones. After plant implementation of these modifications, plant sampling surveys were carried out to validate findings of the simulation-based study. Plant data showed very good agreement with the simulated data, confirming results of simulation. After the implementation of modifications in the plant, several upstream bottlenecks became visible. Despite these bottlenecks limiting full capacity, concentrator energy improvement of 7% was obtained. Further improvements in energy efficiency are expected in the near future. The success of this project demonstrated the feasibility of a simulation-based approach. Currently, the Center provides simulation-based service to all the iron ore mining companies operating in northern Minnesota, and future proposals are pending with non-taconite mineral processing applications.

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EXECUTIVE SUMMARY

This project involved industrial scale testing of a mineral processing simulator to improve the efficiency of a taconite processing plant, namely the Minorca mine. The Concentrator Modeling Center at the Coleraine Minerals Research Laboratory, University of Minnesota Duluth, acquired a mineral processing simulator, Usim Pac, in 1999. The simulator was later improved by developing mathematical models needed for accurate simulation of taconite plants. This enhanced the capabilities of the software to be able to simulate a large variety of process modifications in taconite plants, which have unique flow sheets largely different from conventional mineral processing operations. The Center had the experience needed for such a study since it had already been involved in collecting and analyzing plant data, developing models and carrying out computer simulations of plants to search for cost effective technologies to improve plant efficiencies. Despite very promising simulation results, the findings were yet to be implemented in the plants. This project provided funding for this technology to prove itself in the industrial environment and created incentives for others to follow suit in making more efficient use of energy consumed.

The first step of the project was collection of data representing existing plant conditions by sampling and sample analysis. The data were then mass balanced to obtain a coherent ore and water balance, providing a basis for assessing the efficiency of individual devices and the plant. This evaluation served as a guide in developing alternative process strategies for more efficient production. Computer simulation was then used to evaluate the benefits and effects of implementing these alternative schemes. By analyzing the results of the simulation study, the most feasible performance improvement option was selected as the change of makeup ball size from 2-inch to 1½-inch. This would be coupled with the replacement of existing cyclones with more efficient ones. These recommendations were implemented at the plant by the management. The positive effects of these modifications were clearly visible in overall plant performance. After modifications were implemented at the plant, plant sampling surveys were carried out to verify results of simulations for two different ore blends processed at the plant. These studies showed that the simulator was capable of accurately simulating plant performance despite large modifications and changes in operating conditions.

The plant was able to reach the target throughput increase of 10%. However, several upstream problems were observed. The management addressed some of these issues. After all the modifications were implemented, an energy efficiency

improvement of 7% was observed in the concentrator. Although this meets the objective of this project, further improvement in energy efficiency is expected from on-going process improvements stemming from this simulation-based study.

The project has also fulfilled its objective of proving an emerging technology in plant scale application, thereby promoting its widespread use. As a result of this project, the Center was approached by all the iron ore mining companies in northern Minnesota to carry out simulation-based analyses of process efficiency improvement ideas that emerged through their engineering staff. Interest in using the Center's simulation service and expertise has now expanded beyond iron ore application. Currently, three proposals for non-taconite simulation studies are awaiting final approval.

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1. INTRODUCTION

The iron ore industry of northern Minnesota and the Upper Peninsula of Michigan processes approximately 240 million long tons of crude ore per year to produce 55 million long tons of pellets for use in U.S. blast furnaces. The processing of this crude ore requires approximately 120 KWH/LT of product for size reduction, classification, and separation to recover about 90 to 95% of the iron values at concentrate grades of 63 to 67% Fe, and silica levels of 4 to 6%. This represents in excess of 7 billion KWH per year.

Due to the relatively low value of the product and the scale of these operations, it is essential that they be operated as efficiently as possible to remain competitive. It is therefore important to the operating companies that crude ore dilution be eliminated, that iron losses be minimized, that the separation of iron oxides from waste minerals be as complete as possible and that production rates be maximized to reduce unit energy consumption and cost.

Because of this need to develop and maintain an efficient production operation, there has been an enthusiastic interest on the part of operating iron ore companies to examine their mineral concentration processes in some detail to determine if improvements could be made that would reduce cost, increase production and/or improve product quality. One way of inexpensively looking at the effects of process modifications or changes in operating conditions and evaluating their results is through the use of unit operations mathematical models, which are tied together sequentially in such a way as to permit the computer simulation of the integrated size reduction and mineral separation process from crude ore to final concentrate. While the application of modeling and simulation has provided significant benefits in the processing of base metal ores, its application to the processing of magnetic taconite has been held back by the need to incorporate the modeling of mineral liberation into the comminution models for size reduction steps, which occur between the several stages of magnetic separation.

In 1997, under the auspices of the Iron Ore Cooperative Research Program, iron ore mining companies operating on the Iron Range in northern Minnesota decided to work as a consortium in establishing expertise in the development of mathematical models of individual taconite concentration operations and their use to simulate portions of the integrated concentration process. This led to the establishment in 1998 of the Concentrator Modeling Center within the Coleraine Minerals Research Laboratory (CMRL) of the University of Minnesota Duluth. The Center acquired mineral processing software, Usim Pac, hired an expert, and became fully operational in 1999. Since then, it has been developing the missing mathematical models needed for reliable simulation of taconite plants by collecting plant data and evaluating performance.

Initially, the Center carried out plant simulations using available data to illustrate potential benefits of simulation to improve process efficiency. Although the simulation results indicated that efficiency of the plants could be substantially improved by making minor/major flow sheet/operating condition modifications in plants, none of the recommendations were implemented in the plants. This was due to the fact that simulations were based on old plant data representing conditions several years ago, and plant engineers were reluctant to rely on a technology that was yet to prove itself in a plant scale taconite operation. Development of two essential mathematical modeling components, along with impressive initial simulation results, softened the resistance. Eventually, Ispat Inland Mining Company[*] decided to take the risk and try to improve plant performance utilizing the simulation-based approach offered by the Center. This required updating plant data by fresh sampling and sample analysis. The work started in 2001, but it was abandoned later due to financial difficulties resulting from prevailing depressed market conditions. The objective of this project was to complete this work, thereby illustrating that the efficiency of taconite processing plants could be significantly improved by using simulation as a tool.

Once it was shown that taconite plants could be successfully simulated and this technology could improve plant performances appreciably, it was expected that all the mining companies in northern Minnesota would make extensive use of the simulator. The technology would also be transferred to iron mines in the upper Michigan peninsula. In the long term, the Center aimed to provide simulation-based service to all types of mineral processing operations. The first target would be Cu-Zn and Platinum group minerals processing operations that are scheduled to begin operation in Minnesota within the next three to four years. This could lead to providing service all around the United States.

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[*] Ispat Inland Mining Company changed its name to Mittal Steel USA – Minorca Mine Inc. in 2006.

1.1 Proposed Technical Concepts

Taconite processing differs from other conventional mineral processing operations in that magnetic taconite is separated from its waste as soon as a considerable amount of waste is liberated, and this relies heavily on magnetic separation. Separation of waste as coarse as possible is energy efficient, since it prevents unnecessary grinding of waste. Despite being energy intensive, most of the plants are using processes that were designed in the mid to late 1960's. Since then, there have been many advances in technology and processing knowledge that could reduce energy consumption by as much as 20 percent. However, making plant changes to test these concepts is very costly and time consuming. Having accurate models of various unit operations would allow the companies to focus on the most promising changes and would give them confidence to implement them. This concept led to the establishment of the Concentrator Modeling Center in 1998.

The initial task of the Center was to evaluate existing capabilities of available software in simulating taconite processing plants. For this purpose, a large variety of flow sheet and operating conditions were simulated using data available from a number of taconite plants. The study included a plant that had recently modified its flow sheet, and reported large efficiency improvements. Using the improved performance data as a basis, the simulator was able to successfully ascertain less efficient performance prevailing prior to the modification. Another success of the simulator was to mimic the on-line control system used in another plant. A simulation study indicated that plant efficiencies could be improved by 5-10%, 0.1-0.3%, and 0.5-3.0% in terms of throughput, waste (silica) grade, and iron recovery, respectively. Such improvements required moderate modifications and achieved energy consumption levels the same as present, if not less. However, the software failed to produce the expected trends when major flow sheet changes were simulated. This failure was due to the fact that the effects of changes in liberation characteristics were not taken into account by the software.

Over the period 1998 through 2002, the Center developed a liberation model and a "pseudo liberation" approach to magnetic separator modeling, and mathematical models for hydroseparators and fine screens. The incorporation of these models into the software was completed in 2002. Then it was possible to reliably simulate a wide variety of flow sheet/operating condition modifications. When the current project started, the Center was ready to demonstrate its capabilities.

1.2 Expected Benefits

The primary objective of this proposal was to make more efficient use of available equipment. This would result in increased capacity with the same level of total energy consumption, thereby reducing energy consumed per unit of production. This would be achieved by making better use of grinding equipment, which typically expends 40-60% of the total energy consumed in a mineral processing plant. A preliminary study had shown that 25-30% of ore fed to the ball mill is mostly liberated iron ore particles, which did not require further grinding at all. This unnecessary grinding was caused by inherent inefficiencies of classifying and fine screening equipment. A simulation-based approach offered the possibility of investigating various options to correct this problem without causing any upset in the plant. Other benefits would include achieving the most efficient use of concentration equipment by optimizing flow sheet/operating conditions. For example, the flotation circuit could be modified in such a way that loss of fine high-grade iron particles into waste streams would be reduced. Increasing recovery by efficiently operating separation equipment would also contribute to lowering of energy per unit production.

The main form of energy used in taconite processing plants is electricity. Approximately 120 KWH of electricity is consumed to produce 1 long ton (LT) of concentrate. Based on the assumption that production capacity of the plant could be increased by 7% through improved grinding and iron recovery at the same total energy consumption level and product quality, unit energy consumption is expected to decrease to 112 KWH/LT.

Increased capacity of the taconite concentration plant will utilize the ample capacity of the subsequent operation, i.e. the pelletizing plant. The main source of energy used in pellet firing operations is natural gas. Increasing feed rate by 7% is expected to reduce natural gas consumption per unit of production by 3.5%.

Based on a preliminary study, it was expected that implementation of simulation-based modifications in a taconite plant could result in 5-10% capacity, 0.5-3% iron recovery and 0.1-0.3% lower silica improvements. These figures would be larger if major modifications were also considered. The prevailing average cost of pellet production in 2002 was $32.65 per long ton. The aim was to lower this figure by $1 in the short term and gradually by $2 in the long term, totaling an annual savings of $40-100 million. Direct environmental benefits of this project would be marginal. Increased iron recovery could slightly reduce the amount of solid waste (approx. 1%).

1.3 Project Goals and Scope

This project would use an enhanced version of a mineral processing simulator, Usim Pac, to improve efficiency of a taconite processing plant. Following establishment of current efficiency levels for each device used in the Ispat Inland Taconite plant, simulations would be carried out to explore the effects of a number of process modifications to improve overall efficiency. Simulation results would form the basis for economic evaluation and selection of the most promising alternatives for plant implementation. Then the plant flow sheet/operating conditions would be modified in line with the findings of the simulation study. Eventually, performance of the modified circuit would be compared to the simulation prediction. Plant validation of simulation results was expected to lead to wider use of simulation for improving efficiency of taconite processing plants.

1.4 Statement of Objectives

The objective of this study was to improve plant efficiency by increasing the capacity by 5-10% at the same total energy level. Results would be used as a case study to illustrate the benefits of a simulation-based approach for improving taconite plant efficiencies.

1.5 Work Plan

When the project started, the plant had already been sampled when processing one of the two ore blends that fed to the plant during different periods during one year. Analysis of these samples had been partially completed. The project started with analysis of the remaining samples of the first blend. Originally, the following tasks were anticipated:

1. Sample Analysis 1 (First Blend)
2. Plant Sampling and Data Acquisition 2 (Second Blend)
3. Sample Analysis 2 (Second Blend)
4. Mass Balancing and Performance Evaluation 1 & 2
5. Performance Assessment and Development of Alternative Strategies
6. Simulation Study
7. Economic Assessment of Simulation Data
8. Plant Modifications
9. Plant Sampling and Data Acquisition 3

10. Sample Analysis 3
11. Mass Balancing and Performance Analysis 3
12. Assessment of Efficiency Improvements
13. Report Writing

Later, two more tasks were added to the list due to the need to assess plant performance after partial implementation of modifications at the plant. An additional plant sampling survey was carried out and samples were analyzed.

1.6 Key Personnel

Initially, key personnel for the project were William M. Bond, Dr. Salih Ersayin and John Arola. Later, Rick Aaseng of Mittal Steel USA – Minorca Mine Inc. , Bob Strukel, a contract metallurgical engineer at the Minorca Mine, and Bruce Kettunen of Noramco Engineering, contributed to the project.

William M. Bond, Division Manager of Business and Technology - Minorca Mine coordinated the project. Salih Ersayin, principal researcher for the University of Minnesota - Coleraine Minerals Research Laboratory performed mass balancing, performance evaluation, and computer simulation work. He also participated at plant sampling surveys as an observer and provided advice in improving the quality of samples. John Arola, senior staff engineer, Operating Technology – Minorca Mine, supervised plant sampling surveys. Rick Aaseng, Plant Area Manager – Minorca Mine, John Arola and Bruce Kettunen were involved in developing the performance improvement ideas. Bob Strukel supervised the validation sampling, assisted in implementation of the plant modifications and practice changes, and contributed additional ideas to enhance the results of the recommended plant changes.

2. BASELINE CONDITIONS

A prerequisite to a simulation-based study is detailed definition of baseline conditions. This requires sampling of each stream within a plant or circuit while it is running under relatively steady state conditions, as well as recording the operating variables during sampling. Sample analysis provides raw data needed as input for the mathematical models of unit operations. Raw data are mass balanced and then used as a basis for simulations. Baseline data would also be useful in comparing performance before and after some modifications are implemented in a plant. Details of the baseline study for this project are presented below.

2.1 Processing of Taconite Ore at the Minorca Mine

The plant annually processes approximately 9 million long ton (Mt) of iron ore to produce 2.8 Mt of iron ore pellets containing 4% silica. Two different ore blends are fed to the plant during different periods of a year. Processing steps from mining to pellet production are illustrated in Figure 1. The first step of the processing is crushing. This is followed by three parallel lines of magnetic separation circuits which typically produce magnetic concentrate containing 6-7% silica. Magnetic concentrate coming from the three lines is combined and fed to the flotation circuit for further separation of silica-bearing gangue minerals. Eventually, flotation concentrate of less than 4% silica is produced. Flotation concentrate is sent to the balling circuit to form green balls. The last step of the processing is induration, which produces the final product, i.e. fired pellets, for shipping.

The balling and induration circuits had 10% ample capacity. Therefore, this plant was classified as “concentrate limited.” This implied that the plant was capable of producing 10% tonnages of pellets if magnetic separation and flotation circuits could deliver sufficient amounts of concentrate to feed these two successive units. Magnetic separation and flotation circuits were the focal point of this project. The objective was to find the most feasible plant flow sheet/operating condition modification option to increase the throughput of these circuits by 10%. This would be achieved with the current levels of total energy consumption; thereby a reduction in energy per unit production was targeted.

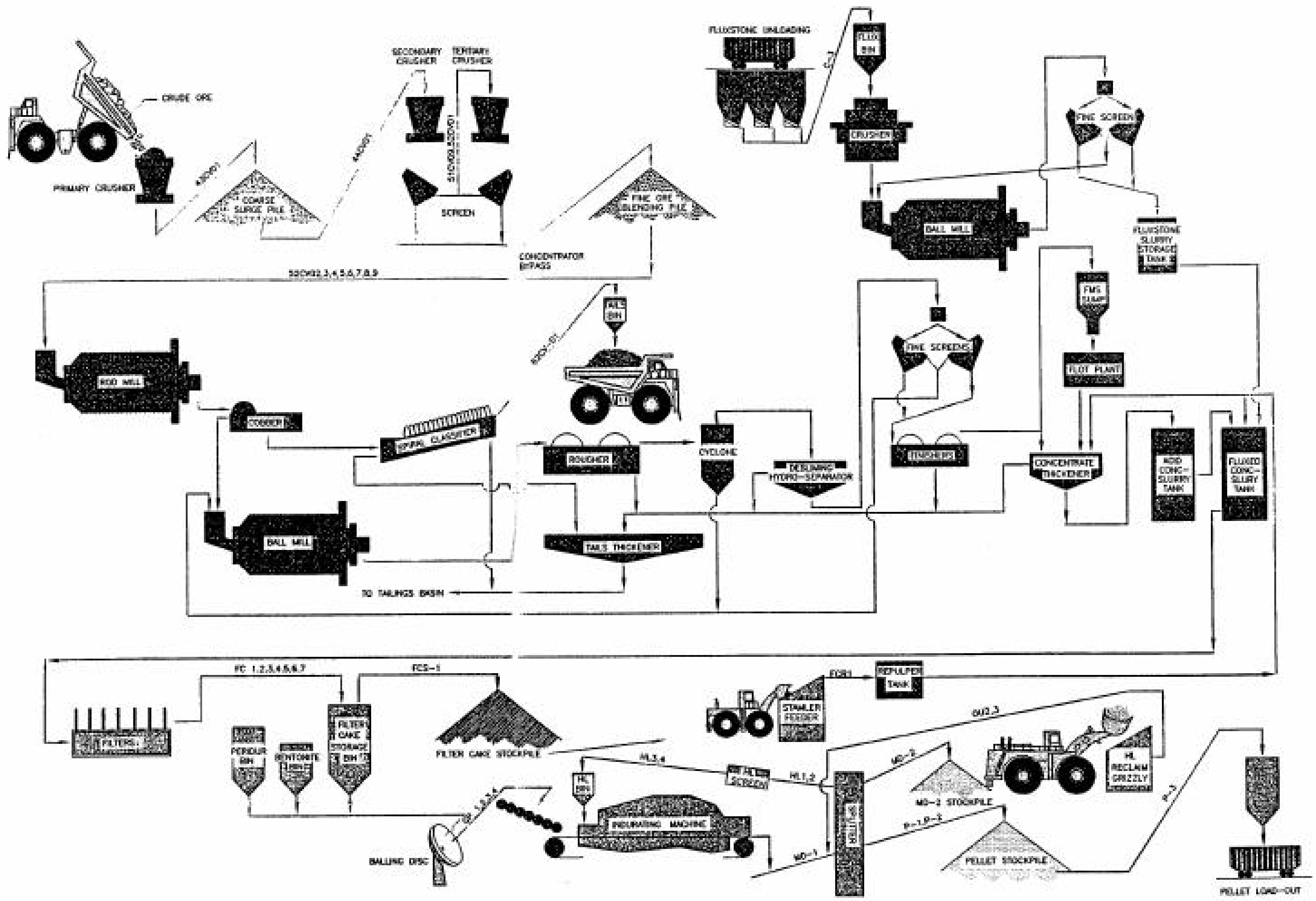

Figure 1. Flow sheet of mining, processing and pellet making steps at the Minorca mine

Detailed flow sheets of magnetic separation and flotation circuits are illustrated in Figures 2 and 3. As shown in Figure 2, the first processing step in the magnetic separation circuit is rod mill grinding. This is followed by the first stage of magnetic separation, cobbers. Cobber magnetic concentrate is fed to the ball mill circuit, which has the rougher magnetic separators within the closed circuit grinding loop. Hydrocyclone overflow is sent to a hydroseparator for separation of fine gangue particles. Hydroseparator underflow is fed to fine screens to separate coarse particles bearing high ratios of silica. Fine screen undersize goes to the final stage of magnetic separation, finishers, while oversize is circulated to the ball mill for further grinding and, hence, liberation. Finisher concentrate is the magnetic circuit product containing 6-7% silica.

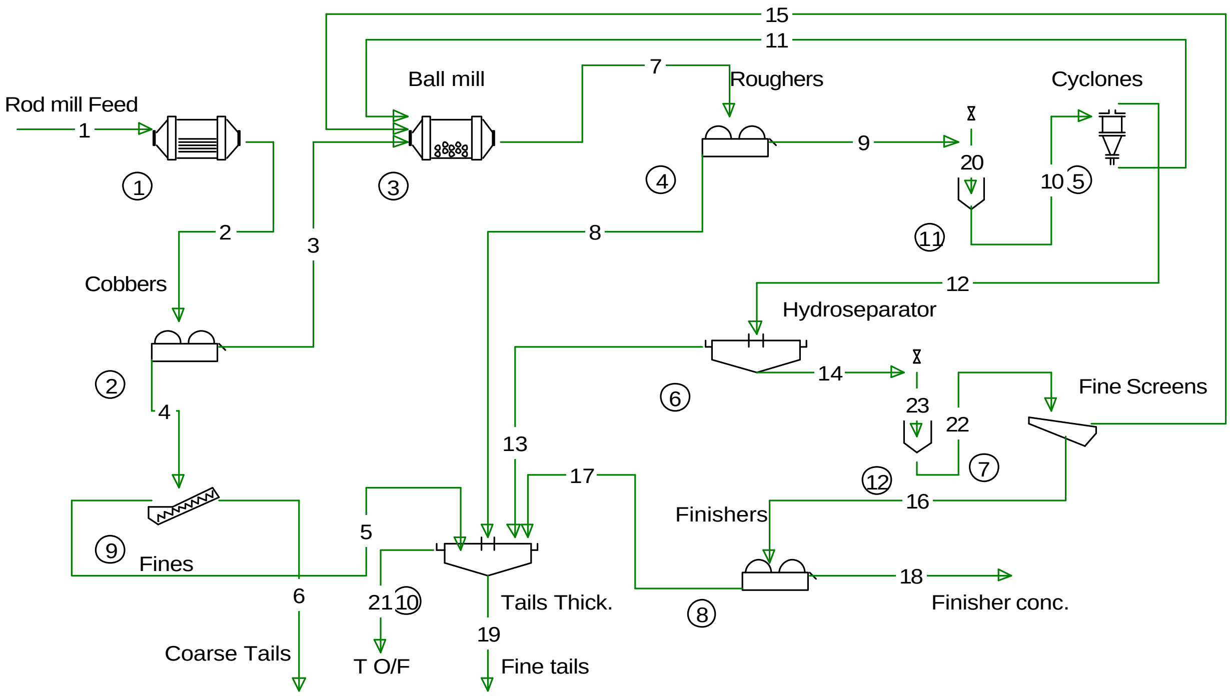

Figure 2. Flow sheet of magnetic separation circuit at the Minorca Mine

The flotation circuit includes two parallel banks of rougher flotation cells (Figure 3). Each bank has four flotation cells. Rougher concentrate is the final product and is sent to concentrate thickeners mainly for dewatering. Rougher tails are further processed to recover magnetic iron values lost in this stream. Rougher tails are first treated by dewatering magnetic separators and are then sent to a thickener for dewatering. Thickener underflow is fed to a regrind ball mill to liberate magnetite particles. The regrind ball mill discharge is treated by a three-cell scavenger circuit to recover iron-bearing particles from this stream. Scavenger concentrate is circulated back to rougher flotation cells. All tailing streams from the flotation circuit are combined and fed to a fine tails thickener for dewatering.

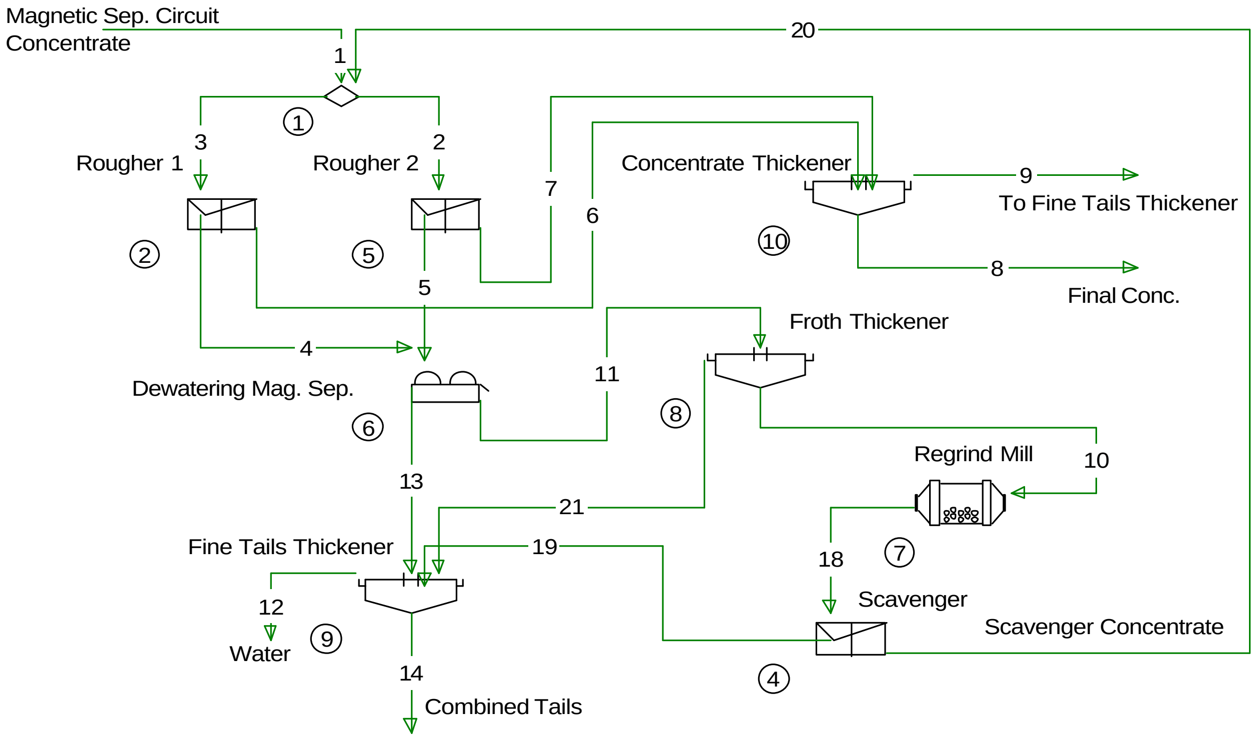

Figure 3. Flow sheet of flotation circuit at the Minorca mine

As in any taconite processing plant, ore feed to the plant contains several iron-bearing minerals. Process flow sheets are designed to recover only magnetite (ferromagnetic iron-bearing mineral). Therefore, performance of taconite plants is assessed on the basis of magnetic iron (mag iron) recovery rather than the total iron in the feed ore. Magnetic iron in an ore sample is determined by using a Satmagan device that measures magnetic force generated by the sample and calibrates it with standard samples of known magnetic iron content. Magnetic iron is also referred to as Satmagan iron.

2.2 Plant Sampling and Sample Analysis

Two plant sampling surveys were planned while the plant was processing different ore blends was planned. A blend of lower cherty 4 (LC4) and upper cherty 3 (UC3) ore horizons is identified as Blend 1, and lower cherty 5 (LC5) and upper cherty 1 (UC1) as Blend 2. Sampling for Blend 1 took place on March 11, 2001, and for

Blend 2 on September 14, 2002. Line 3 of the magnetic separation circuit was selected for this study.

All the streams within the magnetic separation circuit (Figure 2), from rod mill feed to magnetic concentrate were sampled. In addition to the main streams, products of each magnetic separator drum were sampled separately. Simulation of the flotation circuit required kinetic data. Therefore, flotation circuit sampling included individual cell lip and inside the cell samples as well as samples from the remaining main streams. All the points sampled in the flotation plant are illustrated in Figure 4. One of the parallel rougher banks was sampled and it was assumed that both banks had the same performance.

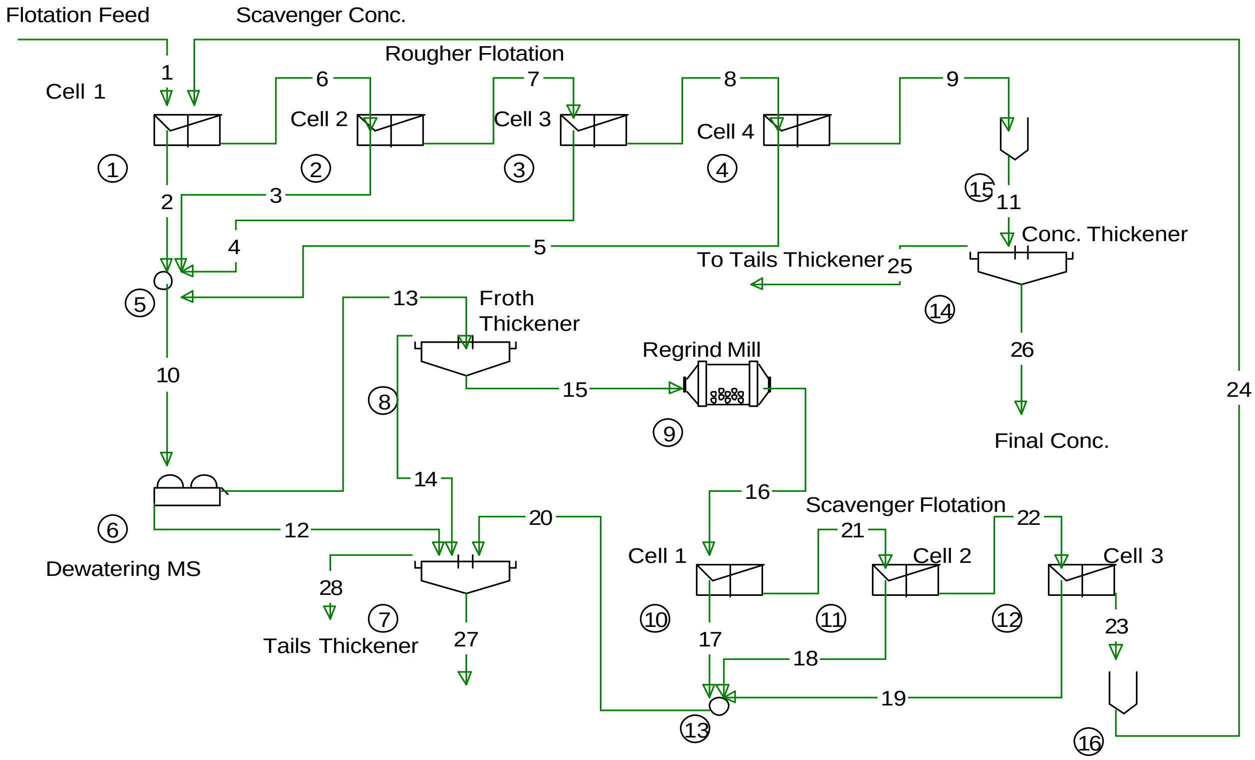

Figure 4. Flotation circuit flow sheet illustrating all the streams sampled

Sampling was carried out during an entire shift at one-hour intervals. Eventually samples from each point were combined, then filtered and dried at the plant lab. They were transferred to the Coleraine Minerals Research Lab for sample analysis. These included size analysis and size by size chemistry for total iron, Satmagan iron, and silica. Tyler standard sieves in ^{2}v series ranging from ¾-inch (18.9mm) to 500 mesh (25 micron) were used. For each sample, the top screen size was selected in line with the expected size range. Samples were demagnetized prior to screening. As a standard screening procedure, samples were first wet screened through a 500 mesh screen, then dry screened using a set of screens covering the range of expected size distribution. Samples from the flotation circuit were also processed by micro sieving to separate the -10 micron fraction. This would enable treatment of the very fine fraction as a separate size component in flotation models. Head samples, as well as size fractions, were analyzed for total iron, magnetic (Satmagan) iron and silica.

Rod mill feed rates measured during sampling surveys were 350 and 315 LTPH for Blend 1 and Blend 2, respectively. Major operating conditions are presented in Table 1. Raw data consisting of size distribution and size by size total iron, Satmagan iron, and silica were mass balanced. Solid flow rates of streams were calculated using the mass balancing algorithm of Usim Pac, on the basis of measured rod mill feed rates. Although they were sampled, rod mill feed, spiral classifier products, and fine tails thickener underflow were not included in the mass balancing. In general, data quality was good. However, mass balancing around cobbers was problematic due to the difficulty in obtaining a representative sample from the rod mill discharge. For this reason, a different point was used during the sampling for Blend 2. The new point provided a more reasonable sample, but its quality still did not meet the expectations. Similar, but much less pronounced, problems were observed around hydrocyclones and the flotation circuit concentrate thickener for Blend 2. For this reason, flotation circuit concentrate thickener was excluded from mass balancing of Blend 2 flotation plant data. Since this was the last unit in the flow sheet, it did not have any effect on mass balancing for the rest of the circuit.

Table 1. Major operating variables recorded during baseline sampling surveys

Operating Variable (Unit)	**Recorded Value**	
	Blend 1	**Blend 2**
Rod Mill Feed Rate (LTPH)	350	315
Rod Mill Power Draw (kW)	1,564	1,540
Ball Mill Power Draw (kW)	3,700	3,716
Cyclone Pressure (psi)	25.0	23.0
Cyclone Feed % Solids	46.0	41.0
Hydroseparator U/F % Solids	56.5	54.7
Hydroseparator U/F Rate (GPM)	1,576	1,151

2.3 Mass Balancing and Performance Evaluation

Mass balanced data are presented in Appendices A, B, C and D for magnetic and flotation circuits of Blend 1 and 2 respectively. Results of mass balancing are summarized in Tables 2, 3, 4 and 5 in the same order as the Appendices. Based on mass balanced data, magnetic iron recovery/loss for each concentration step was calculated. These values are given in Table 6. Magnetic iron recoveries were better when Blend 1 was processed. The difference was mainly due to higher losses at the cobbing stage. This is believed to be due to ore mineralogy, hence, liberation characteristics, rather than operating conditions.

Table 2. Magnetic separation circuit baseline mass balance summary for Blend 1

Stream	Flow Rate (LTPH)	% Mag Iron (Satmagan)	% Total Iron	% Silica
Feed	350	25.7	33.6	45.4
Cobber Conc.	237	37.3	42.7	34.1
Cobber Tails	113	1.5	14.5	69.1
Ball Mill Disch.	1536	47.3	51.5	23.2
Rougher Conc.	1454	50.2	53.9	20.4
Rougher Tails	82	1.5	13.2	71.8
Cyclone O/F	303	54.4	56.6	18.2
Cyclone U/F	1152	49.0	53.1	21.0
Hydrosep. O/F	13	1.3	11.5	68.7
Hydrosep. U/F	290	56.8	58.6	16.0
Fine Screen O/S	148	51.0	53.5	22.5
Fine Screen U/S	142	63.6	64.6	9.1
Finisher Tails	7	6.1	23.4	56.0
Finisher Conc.	135	65.4	65.9	6.8

Table 3. Flotation circuit baseline mass balance summary for Blend 1

Stream	Flow Rate (%)	% Mag Iron (Satmagan)	% Total Iron	% Silica
Feed	100	64.2	65.8	6.91
Rougher Con.	94.4	66.8	67.9	4.13
Rougher Tail	13.5	39.4	46.9	32.1
Dewater. MS Tail	1.2	14.3	32.0	48.5
Froth Thick. Tail	0.1	16.7	28.3	56.0
Scavenger Feed	12.2	42.1	48.6	30.3
Scavenger Tail	4.3	21.8	31.7	54.9
Scavenger Con.	7.8	53.3	58.4	16.7
Con. Thick. Tail	0.1	20.5	36.5	22.9
Combined Tails	5.6	20.1	30.9	53.5
Final Concentrate	94.3	66.8	67.9	4.12

Table 4. Magnetic separation circuit baseline mass balance summary for Blend 2

Stream	Flow Rate (LTPH)	% Mag Iron (Satmagan)	% Total Iron	% Silica
Feed	315	22.8	34.4	43.8
Cobber Conc.	197	35.5	44.4	32.0
Cobber Tails	118	1.7	17.8	63.4
Ball Mill Disch.	912	45.0	52.4	21.6
Rougher Conc.	831	49.2	55.8	17.6
Rougher Tails	81	1.4	18.0	62.8
Cyclone O/F	181	54.7	59.4	14.4
Cyclone U/F	650	47.7	54.8	18.4
Hydrosep. O/F	4	5.2	18.5	58.9
Hydrosep. U/F	177	55.8	60.3	13.4
Fine Screen O/S	65	46.4	53.0	21.5
Fine Screen U/S	112	61.3	64.5	8.6
Finisher Tails	6	3.4	23.1	48.4
Finisher Conc.	106	64.8	67.0	6.2

Table 5. Flotation circuit baseline mass balance summary for Blend 2

Stream	**Flow Rate (%)**	**% Mag Iron (Satmagan)**	**% Total Iron**	**% Silica**
Feed	100	64.2	65.4	6.05
Rougher Con.	96.1	65.9	66.7	4.35
Rougher Tail	7.3	40.2	47.4	29.5
Dewater. MS Tail	0.3	11.8	30.4	43.1
Froth Thick. Tail	0.4	26.3	37.2	44.1
Scavenger Feed	6.5	42.3	48.9	27.9
Scavenger Tail	3.2	23.3	33.4	48.2
Scavenger Con.	3.3	59.8	62.9	8.4
Con. Thick. Tail	N/A	N/A	N/A	N/A
Combined Tails	3.9	24.0	34.0	51.4
Final Concentrate	96.1	65.9	66.8	4.25

Table 6. Baseline plant performance summary for Blend 1 and 2

Stream	**Mag Iron Recovery/Loss (%)**		**Flow Rate (%)**	
	1st Blend	**2nd Blend**	**1st Blend**	**2nd Blend**
Cobber Tails	1.9	2.8	32.5	37.5
Rougher Tails	1.2	1.6	23.4	25.0
Hydrosep. O/F	0.2	0.3	3.7	1.3
Finisher Tails	0.4	0.3	1.9	2.0
Magnetic Con.	96.3	95.0	38.6	33.5
Flotation Tails	1.7	1.4	2.2	1.3
Flotation Con.	94.6	93.6	36.4	32.2

Mass balanced data were also used to calculate operating Bond work indices of both blends for rod and ball milling. It was found that both blends had almost the same rod mill operating work index value. Calculation of ball mill operating work indices was a complicated task, since the circuit had an additional circulating load from fine screen oversize and some tails were separated within the closed grinding circuit. Therefore, two sets of operating work indices were calculated. One assumed that the ball mill was running as an open circuit device, hence, calculations were based on combined feed (F80) to the ball mill and ball mill discharge (P80), whereas the other considered the circuit as if it was a conventional ball mill circuit by calculating the operating work index using fresh feed (cobber concentrate) and hydrocyclone overflow. Both sets produced contradictory results.

Closed circuit calculation found that Blend 1 had a lower operating work index, while open circuit calculations indicated otherwise. These values, together with the standard laboratory ball mill Bond work indices for a 200 mesh (74 micron) test sieve, are presented in Table 7.

Table 7. Baseline conditions and ball mill work indices for the two blends

Ore Type	Closed Circuit Grinding Calculation					
	Power Draw (kW)	Feed Rate (LTPH)	F_{80}	P_{80}	W_{oi}	W_i (Lab Test)
Blend 1	3700	236	1534	67	16.2	13.9
Blend 2	3716	197	1635	64	18.4	15.6
	Open Circuit Grinding Calculation					
Blend 1	3700	1536	450	280	19.1	13.9
Blend 2	3716	912	405	190	17.8	15.6

As shown in the table, the laboratory determined work indices were lower than operating work indices for both blends. This is most probably due to the standard sieve used for the tests being coarser than the actual product size at the plant, i.e. 64-67 vs. 74 micron. The trend between the ore blends implies that the closed circuit based calculation of the operating work index might be a more reliable measurement of plant scale grindability.

The magnetic circuit had high magnetic iron recoveries of 96.3 and 95.0% for Blend 1 and Blend 2 respectively, with much of the losses occurring in cobber and rougher tails. The circulating load ratio (hydrocyclone underflow to overflow) around the ball mill circuit was 380% for Blend 1, while for Blend 2, it was 360%. Plant data also showed that existing hydrocyclones were performing poorly, i.e. they had a bypass of over 40% (Figure 5). A smaller fraction of the circulating loads was coming from the fine screens. Due to density effect, bypassing fines were low in silica. Plant data showed that hydrocyclone underflow contained approximately 25% concentrate quality material (Table 8), unnecessarily circulated back to the ball mill.

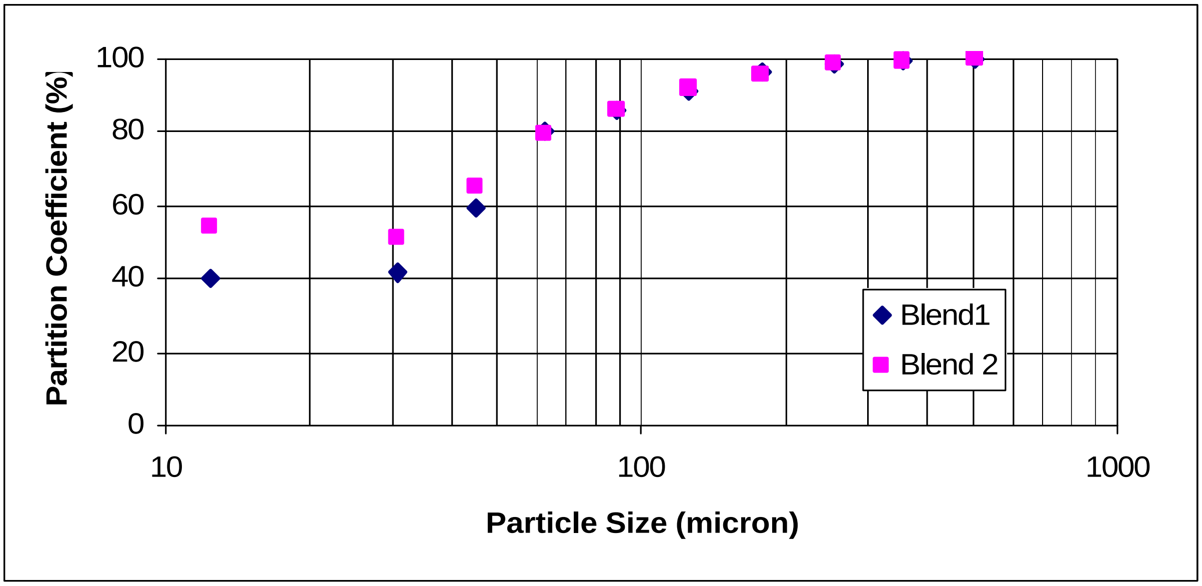

Figure 5. Hydrocyclone partition curves for Blend 1 and Blend 2 during baseline sampling surveys

Table 8. Silica content of size fractions in hydrocyclone underflow stream

Size (micron)	Weight (%)	Silica (%)
150	42.4	36.9
105	15.2	23.5
75	14.2	12.2
53	12.6	5.0
38	5.5	4.1
25	2.5	3.0
-25	7.6	4.8

As shown in Figure 6, fine screening efficiency was not good either. Since these devices also act as a concentration device separating coarse silica, screening efficiency was a compromise to obtain low silica in the magnetic concentrate. Operating them at high feed % solids results in a finer product containing lower silica, which also creates high bypass. Therefore, this was not considered as a performance concern.

The flotation circuit has four tailing streams. These are dewatering magnetic tails, froth thickener overflow, concentrate thickener overflow, and scavenger tails. As shown in Table 9, the only major tailing stream is the scavenger tails, dewatering magnetic separator tails being the other significant source of tailing separation. The other two devices are essentially thickeners, which unintentionally separate the particles loaded on un-burst bubbles. The objective was to determine if significant magnetic iron losses occur due to transfer of froth layer on top of these two thickeners to tail streams. It was found that particles staying in the froth layer and eventually ending up in tail streams are high in silica and unliberated particles. Although marginal, their separation in tailing streams is beneficial in terms of lowering silica grade. They do not appear to be a significant source of magnetic iron loss. Overall flotation recoveries were very high, 98.2 and 98.5%, indicating that there was not much room for recovery improvements.

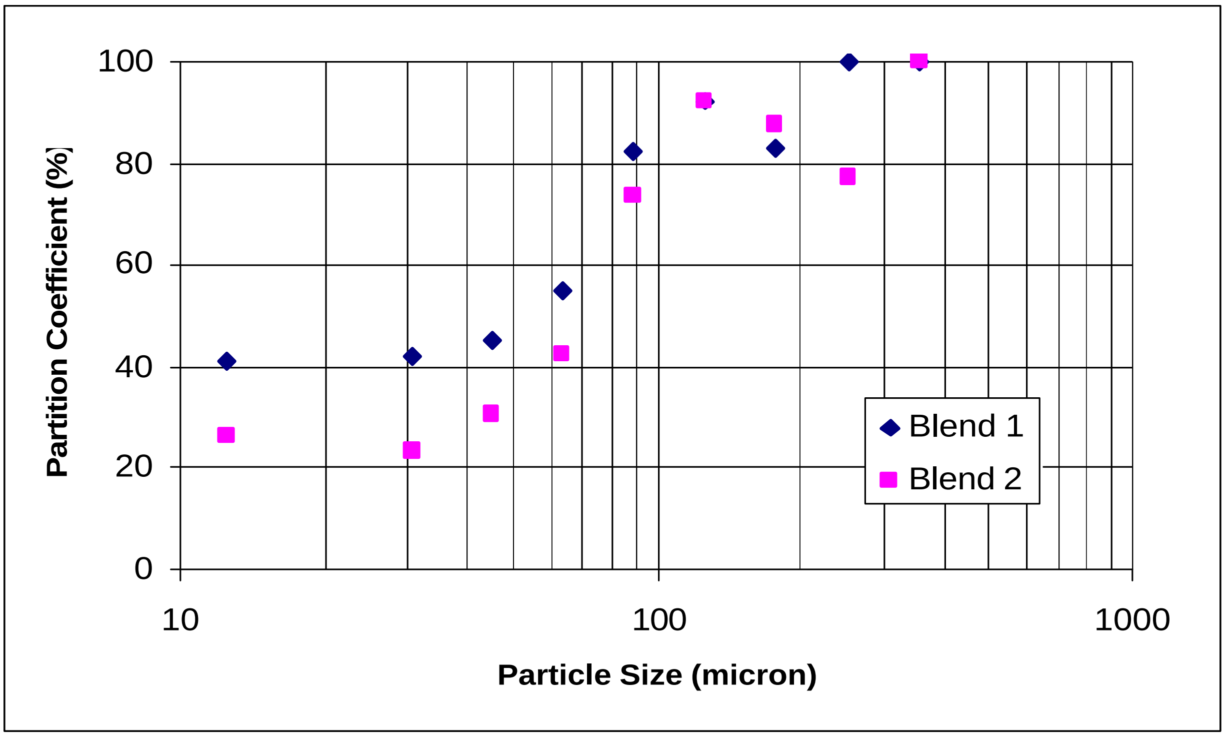

Figure 6. Fine screen partition baseline curves for Blend 1 and 2 sampling surveys

Table 9. Baseline flotation circuit performance for the two blends

Stream	**Mag Iron Recovery/Loss (%)**		**Flow Rate (%)**	
	1st Blend	**2nd Blend**	**1st Blend**	**2nd Blend**
Dewater. MS Tails	0.3	0.1	1.2	0.3
Froth Thick. Tails	0.03	0.2	0.1	0.4
Scavenger Tails	1.5	1.2	4.3	3.2
Con. Thick. Tails	0.02	N/A	0.1	N/A
Final Concentrate	98.2	98.5	94.3	96.1

The flotation circuit was able to produce concentrates with identical silica grades from the two blends. This was mainly achieved by the automatic control system based on flotation concentrate silica. However, flow rates within the circuit were somehow different. Blend 2 had higher weight and magnetic iron recovery, which was accompanied by lower rougher and dewatering magnetic separator tail flow rates. This type of behavior is probably due to the lower reagent dosages and flotation feed being finer for Blend 2.

Since the circuit had circulating loads with regrinding between them, it was difficult to follow size by size performance within the circuit. Nevertheless, size by size silica recoveries and magnetic iron losses into the rougher and scavenger tailings are illustrated in Figures 7 and 8, respectively. In general, size by size silica and magnetic iron curves follow the same trend, possibly indicating that it is a function of the collector dosage regime regulated by the control system. It is also interesting to see that flotation was more effective in separating fine silica, despite the fact that coarse fractions had a much higher silica grade.

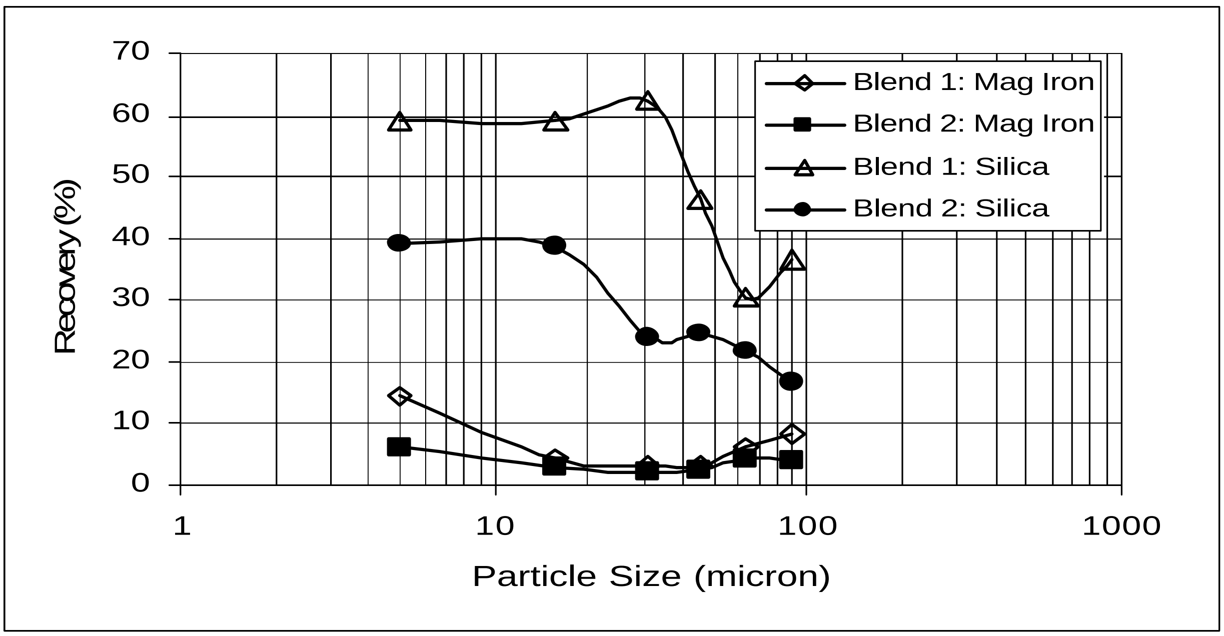

Figure 7. Size by size silica and magnetite recovery into combined rougher tailing stream for the two blends

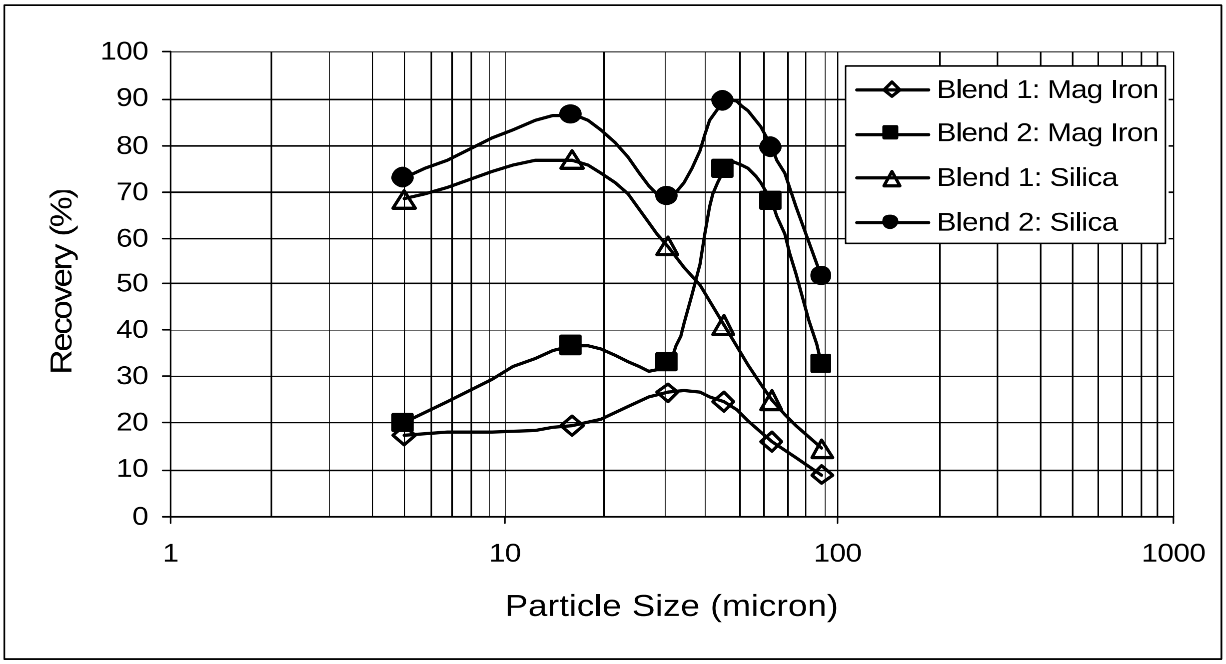

Figure 8. Size by size silica and magnetite recovery into combined scavenger tailing stream for the two blends

2.4 Identifying Bottlenecks

Since the objective was to increase plant throughput, identification of circuit bottlenecks limiting capacity was crucial. Discussions involving the project team members and control room operators led to identification of three criteria that control the rod mill feed rate. These were: pumping capacity of hydrocyclone feed pump, processing capacity of fine screens (volumetric flow rate of hydroseparator underflow stream) , and flotation concentrate silica. Mass balanced data for Blend 1 corresponded to the maximum limits for the first two, which were 1450-1500 t/h at 46% solids and 1600 GPM (or 300 t/h at 55% solids), respectively. Flotation concentrate silica is primarily controlled by adjusting amine rates. However, when this type of control fails to provide the desired level of silica, the rod mill feed rate is reduced. This action eventually provides finer feed with lower silica to the flotation circuit and, consequently produces concentrate with desired silica level. Based on these findings, lowering the circulating loads was selected as the primary target for creating room for throughput increase. Presence of other bottlenecks required that this should be achieved without substantially increasing downstream flow rates and size distributions, starting form hydrocyclone overflow stream, even with the increased throughput rates.

3. SIMULATION STUDY

The study involved simulation of both magnetic and flotation circuits. Focus was on the magnetic circuit. The objective was to increase plant throughput by 10%, thereby making use of ample capacity that exists in this pellet plant. It should be noted that this was a team effort. It involved plant engineers Bill Bond, John Arola, Rick Aaseng, and lately as a contract engineer, Bob Strukel, and Noramco Engineering, as represented by Bruce Kettunen. Technicians and control room operators also contributed to the project. Without the support of the management, this project could not have been accomplished. The team analysed all the available laboratory, pilot and plant scale test data to develop a list of process improvement alternatives. Eventually, a large list of alternatives for the magnetic circuit performance improvement emerged. There was very little leeway and only a few alternatives for the flotation circuit improvements. Therefore, flotation simulations were limited to application of the pre-classification concept in the plant, and quantifying the effects of increased throughput on the flotation circuit performance. Details of the simulation study are presented separately for each circuit below.

3.1 Magnetic Circuit Simulations

3.1.1 Alternatives for Improved Performance

As noted above, performance evaluation indicated that the ball mill grinding circuit was the major bottleneck limiting plant throughput. In order to increase throughput, the circulating load needed to be reduced. This could be achieved through improved grinding, hydrocyclone classification and/or, to a lesser degree, fine screening.

Several alternatives were considered for improved grinding efficiency. Existing electric motors driving ball mills had ample power. This could create an opportunity to increase the power draw of the mills by increasing ball load in the mill and/or critical speed. However, these modifications would not be the primary choice because their implementation would also increase the power draw by the ball mills. Analysis of ball mill data indicated that the existing makeup ball charge was too coarse. Use of finer balls could increase the rate of fines production, thereby reducing circulating loads. Another option for grinding efficiency was to increase feed percent solids. Increased feed percent solids would increase retention time in the mill and result in improved grinding efficiency. However, this was a variable difficult to control, since it required control of percent solids in all streams feeding the ball mill, i.e., cobber concentrate, hydrocyclone underflow and fine screen oversize. Nevertheless, plant operators could try to keep feed percent solids high, if substantial benefits could be obtained by such a strategy.

For improved classification efficiency, the primary option was double hydrocycloning (Figure 9), which implied a secondary separation of fines in the existing hydrocyclone underflow by a second set of hydrocyclones. Later, several other alternatives emerged. These were: retrofitting existing 15-inch cyclones to improve their efficiencies; use of more efficient cyclones; and replacing hydrocyclones with more efficient size separation devices, known as Stack Sizers. One hydrocyclone manufacturer claimed that the efficiency of the existing cyclones could be improved by retrofitting, which involved converting the existing constant angle conical part to two conical sections with two different angles. It was also suggested that a new set of larger diameter cyclones with two conical parts could provide further improvements in terms of efficiency. A radical solution to the inefficiency problem would be the use of Stack Sizers, which are essentially high capacity screens with durable screen panels. In recent years, they have emerged as an alternative to hydrocyclones and are very efficient size separation devices.

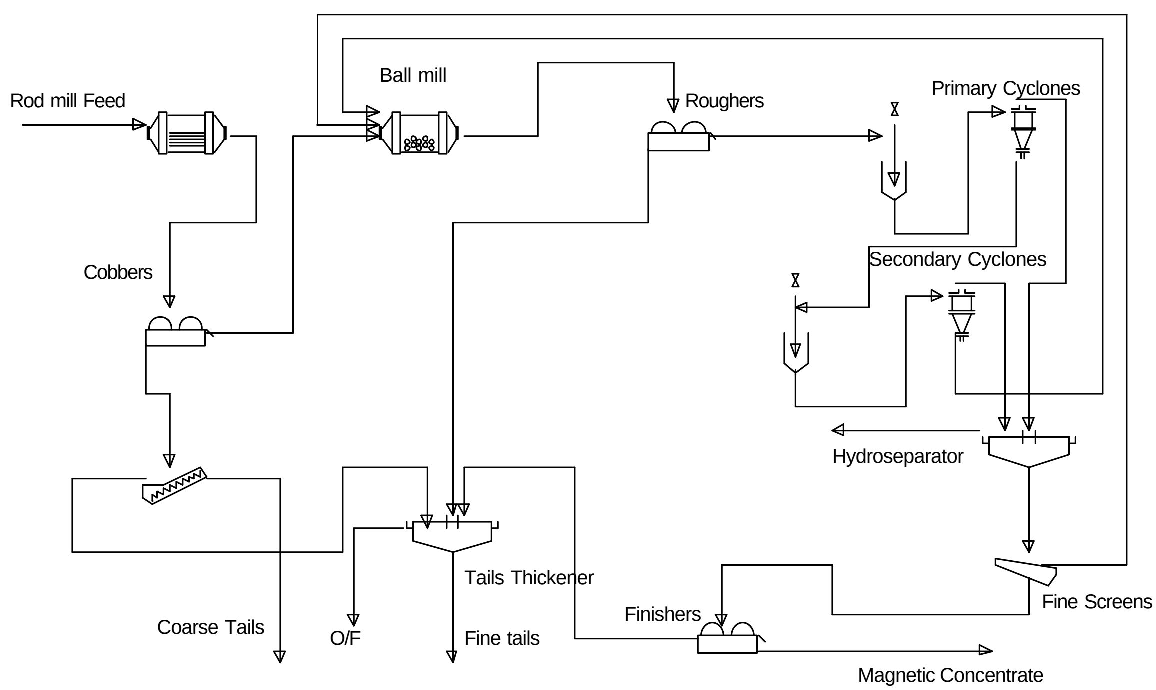

Figure 9. Modified flow sheet for the simulated alternative of double hydrocycloning

Other alternatives for improved efficiency were: dry cobbing; separate grinding of fine screen oversize; and fine screen feed dilution. In dry cobbing, rod mill feed would be treated by magnetic separators, and the magnetic fraction would be fed to the plant. This had a potential to increase concentrate production by eliminating a substantial portion of silica-bearing particles from the plant feed. As a result, feed grade would be higher and grinding energy would be better spent on particles that could easily be beneficiated. Since fine screen oversize is relatively fine material, it is not expected to go through an efficient grinding and liberation process when it is circulated back to the ball mill, which is designed for a much coarser feed. An alternative is to have a separate grinding circuit for this stream (Figure 10). Vertical mills are successfully used in this type of application, and substantial improvements in throughput have been reported (Benner 1998). Such a modification would directly reduce the load on the ball mill circuit. Although it is known that diluting fine screen feed would increase the magnetic concentrate silica, this could decrease the load on the ball mill by reducing the fine screen oversize rate as a result of lower bypass and increased cut size. A small increase in silica could be handled by the flotation process, if benefits are proven to be reasonably high.

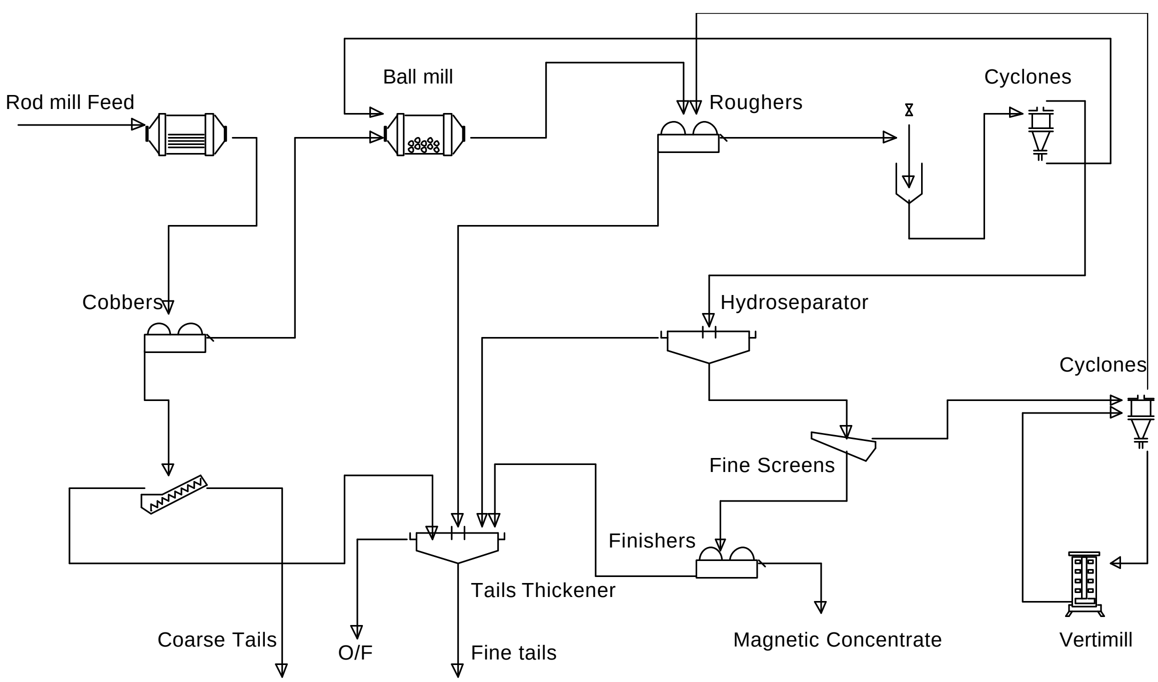

Figure 10. Modified flow sheet for the simulated alternative of separate grinding of fine screen oversize

3.1.2 Modeling and Simulation

Usim Pac was used for simulations. Usim Pac has a number of models for each unit operation (BRGM, 2003). The Concentrator Modeling Center had an enhanced version of this software, which included models developed by the Center specifically for reliable taconite plant simulations. Details of the models used in simulations are summarized below.

<u>Rod Mill Model</u>

The most developed rod mill model available in Usim Pac, Rod mill (3), was used for this purpose. The model combines a complete kinetic model with an energetic approach to grinding. It takes separate account of the grinding matrix B and the selection matrix S. The grinding, or breakage, matrix is calculated from batch scale grinding tests. The selection, or breakage rate, matrix is represented by a function, the coefficients of which are determined by model fitting. The energetic approach makes it possible to compute the energy consumed by the mill using the empirical formula developed by Allis Chalmers for dimensioning mills. This energy is then integrated into a formula resulting from the kinetic approach. The transport of material in the mill is characterized by the number of perfect mixers in series. The breakage function is modeled by a function of the following form:

$$B_{ij} = f_j \left(\frac{x_{i-1}}{x_j} \right)^{g} + (1 - f_j) \left(\frac{x_{i-1}}{x_j} \right)^{b}$$

where:

B_{ij}: cumulative breakage function

x_i: Upper limit of size class i

Φ_j: breakage parameter, function of size of the particles to be milled and defined by:

$$f_j = f_1 \left(\frac{x_i}{x_1} \right)^{-d}$$

α, β, δ, and ϕ_1 are parameters of the model.

The selection function is modeled by a single parameter function of the following form:

$$S_i = S_1.\exp\left(a_1 \ln\frac{d_i}{d_1} + a_2\left(\ln\frac{d_i}{d_1}\right)^2\right)$$

where:
d_i : dimension of the particles in the particle size class i.

The link between the kinetic approach and the energy available for grinding is provided by the following relationship:

$$S_1 = S_1^E.\frac{P}{H}$$

where:
P : the energy available for grinding
H : the total mass contained in the mill
S_1^E : the normalized parameter of the selection function.

A previous study had determined the breakage parameters for a number of ores by carrying out batch scale grinding tests (Benner, 2000). Model parameters that were determined by this study for the Minorca ore were used for defining breakage parameters of both magnetite and gangue. It was assumed that both mineral components would have the same breakage function. Best fit selection function parameters were calculated separately for magnetite and gangue using the model fit algorithm of the simulator and Blend 1 rod mill data. They were then used to predict the product size distribution for Blend 2 rod mill data.

Fit of the model to Blend 2 product size distributions is illustrated in Figure 11. Compared to the fit to Blend 1 size distribution, there seemed to be no significant difference between the fits. Therefore it was concluded that the same set of model parameters would be used for both blends.

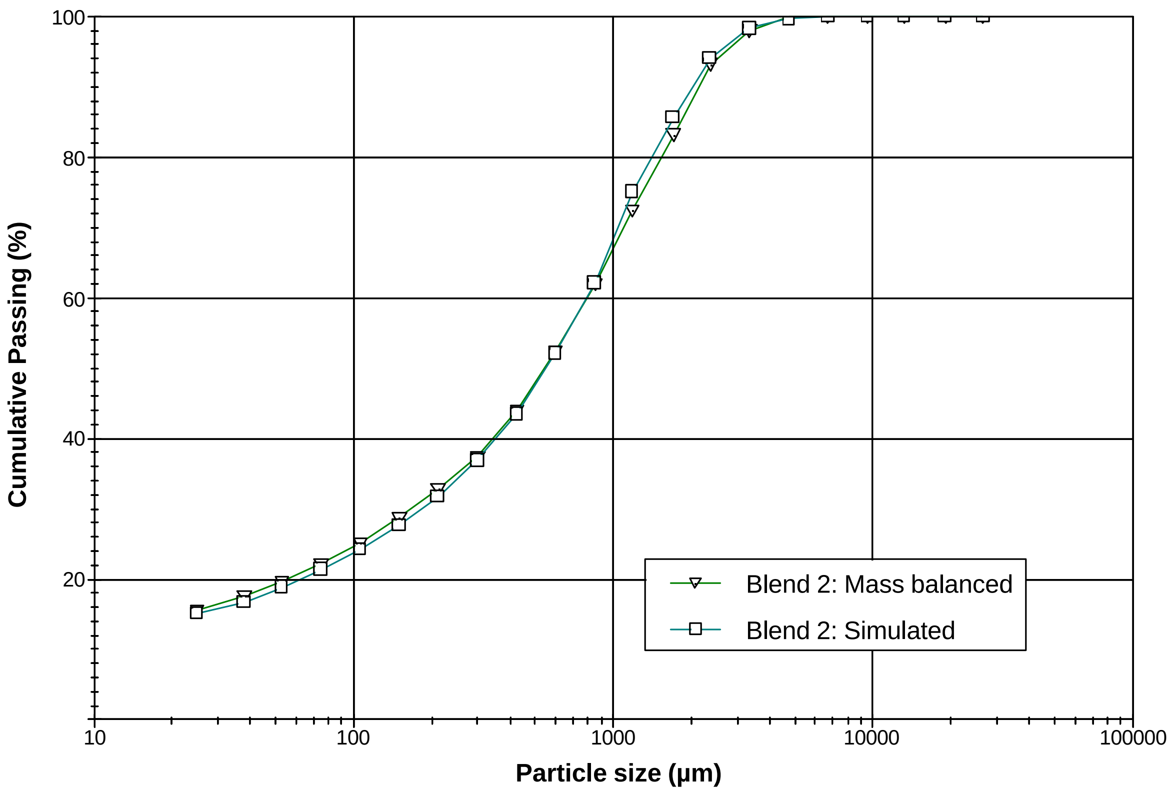

Figure 11. Mass balanced and simulated size distributions of Blend 2 rod mill products. Simulated size distribution was calculated using best fit model parameters for Blend 1 data.

<u>Ball Mill Model</u>

The Usim Pac model chosen for ball milling was Ball mill (3). In principal, this was the same as the Rod mill (3) model used for rod milling. It is based on breakage and selection functions. The ball mill model differs from the rod mill model in regard to the formula used to compute the power available for grinding.

The same set of breakage parameters used for rod milling is also used for ball milling. Selection function parameters were calculated using the model fit algorithm of Usim Pac for each mineral component. When best fit model parameters for Blend 1 were used for predicting performance for Blend 2, it was found that predicted size distribution was close, but there were relatively large discrepancies in the coarse size range. It would be desirable if such an effect could be simulated by modifying only one parameter. It appeared that the most suitable choice for such a purpose would be the normalized parameter of the selection function, S_1^E. As a next step, all the other parameters of the model were kept constant and the best fit value of this parameter was calculated for each mineral component using the model fit algorithm of Usim Pac. Fit of the model to both ball mill distributions is illustrated in Figure 12.

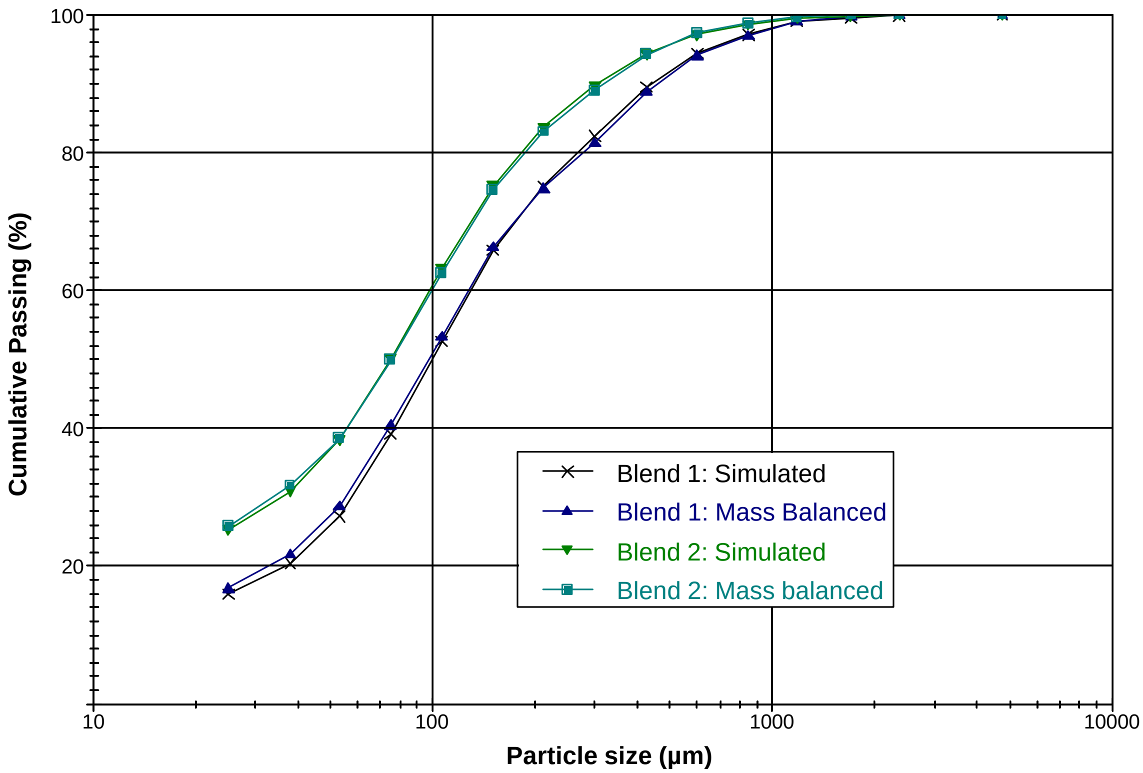

Figure 12. Mass balanced and simulated size distributions of ball mill discharge product size distributions for the two blends

<u>Hydrocyclone Model</u>

Although the hydrocyclone model used in this study was the well-established Plitt model (Hydrocyclone (2)) (Plitt, 1976), extreme variations in operating conditions, i.e. feed rate, grade, % solids and size distributions created question marks for its capability to simulate both conditions using the same set of model parameters. The Plitt model is considered as empirical. It is a three-parameter model defining the shape of a partition curve for classification. Model parameters are empirically related to hydrocyclone geometry and operating conditions. Calibration parameters provide flexibility for a user to modify each model parameter to obtain a refined fit to a specific application. For a given set of design and operating conditions and calibration parameters, the model calculates a separate partition curve for each mineral component based on user-defined densities. The following equation is used by the Plitt model to define the shape of a partition curve for classifiers:

$$Y_c(d) = 1 - \exp\left[-0.693\left(\frac{d}{d_{50c}}\right)^m\right]$$

where:
d : particle size
Y_c : proportion of the particle population of size d which reports to the cyclone underflow, excluding short circuiting fraction
d_{50c} : corrected d_{50}
m : parameter characterizing the sharpness of the classification and is related to imperfection as follows:

$$I = 0.5\left(2^{\frac{1}{m}} - 0.415^{\frac{1}{m}}\right) \approx 0.77/m$$

Model parameters d50c, m and bypass are calculated by a set of empirical equations. Model fit involves modifying these parameters using corresponding calibration parameters to improve the fit. The empirical equations defining the relationships between model parameters and operating/design conditions can be found elsewhere (Plitt, 1976).

The mass balanced partition curves of the two blends had similar shape, with apparent differences in cut size and bypass. Contrary to expectations, one set of model parameters was not able to satisfactorily predict the performance for both blends. Therefore, different sets of calibration parameters were calculated for each set and used in simulations.

Fine Screen Model

A fine screen model that was developed at the Coleraine Minerals Research Lab by carrying out pilot scale test work on a Derrick unit (Pletka, 2004) was used in simulations. The model is based on partition curves for two components, magnetite and gangue. The equations defining the relationships between the operating conditions and model parameters for each component are given below:

For magnetite,

$R_m = 71.034 - 3.643\, f + 3.014\, F - 0.741\, OS + 0.041\, (f\, .OS) + 0.037\, f^2$

$d_{50cm} = 94.614 - 0.943\, f + 0.483\, S + 2.424\, F - 135.58\, (F/f)$

$m_m = 0.00161 + 0.002\, f + 0.0002\, S + 0.003\, OS$

For gangue,

$$R_g = 93 - 4.525 f + 3.21 F - 1.356 OS + 0.056 (f.OS) + 0.045 f^2$$

$$d_{50cg} = 89.546 - 0.902 f + 0.442 S + 1.988 F - 108.47 (F/f)$$

$$m_g = 0.031 + 0.00196 f - 0.00003 S + 0.0028 OS$$

where,
f : % solids in feed
F : feed rate (t/h)
OS : % screen oversize in feed
S : screen aperture size in micron

The model has calibration parameters to fine-tune the model parameters for a specific application. Its ability to predict fine screen performance using another set of plant data was tested. The two sets of plant operating conditions showed large deviations particularly in terms of feed flow rate and size distribution. This presented a challenge for the newly developed model.

The model was used to predict fine screen performance for Blend 2 by modifying best fit model parameters of Blend 1 for variations in operating conditions. The results were amazingly good (Figure 13). Not only did it provide a good fit to actual partition curves, but it also resulted in a satisfactory fit to weight split and product size distributions.

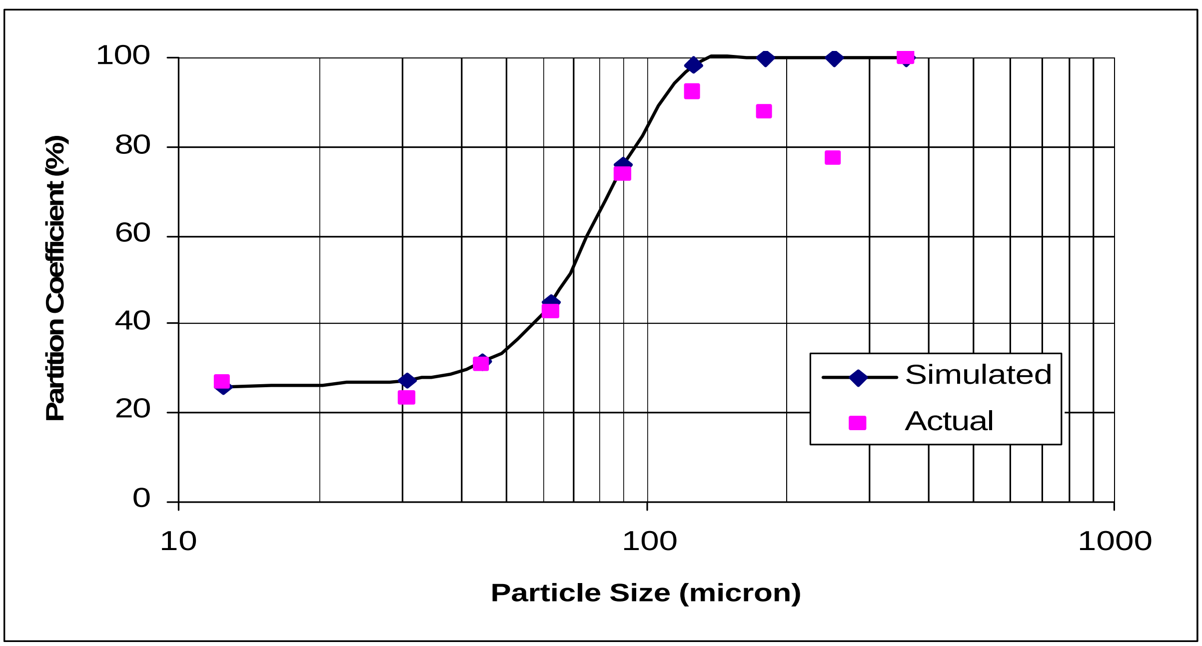

Figure 13. Simulated and actual fine screen partition curves for Blend 1

Magnetic Separator Model

The pseudo liberation model developed by the Concentrator Modeling Center was used in magnetic separator simulations. Details of this model of magnetic separators were given elsewhere (Ersayin, 2004). It assumes that, for a given ore mineralogy, magnetite grade of feed to a magnetic separator reflects its liberation, hence, separation characteristics. The model uses cubic spline functions to define the variation of component recovery by particle size. Three sets of plant data obtained from three different stages of magnetic separation at the plant are then used to construct a plant operating surface which forms the basic concept for modeling. For a given feed grade, the particle size recovery curve is calculated through exponential interpolation.

Hydroseparator Model

A hydroseparator model was also developed by the Center (Ersayin, 2003). A hydroseparator is essentially a classifying device. The partition curve per component type of approach was used for modeling. Mathematical equations describing partition curves are the same as the hydrocyclone model above, and this one also has three model parameters: d50c, bypass, and imperfection. It differs from the hydrocyclone model since it uses a pseudo liberation approach to describe variations in model parameters with changes in feed characteristics. In its current form, the model does not have the capability to simulate variations in feed rate and feed % solids. As was the case in magnetic separator modeling, the hydroseparator model assumes that ore consisted of two components, namely magnetite and gangue.

This model is based on several sets of plant data obtained from different plants and operating conditions. Data analysis showed that magnetite d50c and imperfection and gangue imperfection were independent of feed grade. The relationship between the rest of the model parameters and feed grade is defined by the following equations:

$$R_m = 89.69 + 0.239\, f_m - 0.0014\, f_m^{2}$$

$$R_g = 0.004\, f_m^{2.692}$$

$$d_{50cg} = -146.63 + 6.2\, f_m - 0.049\, f_m^{2}$$

where R_m and R_g are magnetite and gangue bypass respectively and f_m is the magnetite grade of feed (%).

For magnetite d50c, a mean value of 45 microns was used as a constant. Imperfection constants (*m*) were 0.41 and 0.2 for magnetite and gangue, respectively.

Small deviations from the functions describing the relationships and model constants are assumed to be mainly due to differences in operating conditions. To account for these variations, model parameters are adjusted using calibration parameters.

<u>Other Modeling Related Issues</u>

For simulation of dry cobbing, data from a pilot scale test were used to calculate rod mill feed characteristics for this option (Wu, 1997). For double cycloning, hydrocyclone retrofitting and 20-inch cyclones, expected performance and equipment data provided by hydrocyclone vendors were used to modify model parameters of the Plitt model available in Usim Pac. A similar approach was used for Stack Sizer modeling; Derrick provided test data for the screen mesh (0.15 mm) to be used in the study. Test data were converted to partition curves for each component. These curves formed the mathematical basis for the simulations. As noted above, Usim Pac uses a kinetic model combined with an energetic approach for rod and ball mill grinding. The model adjusts grinding rates in line with the variations in power draw, which could arise due to changes in operating conditions. However, this model does not have the capability to simulate the effect of makeup ball size. To overcome this deficiency, size distributions for different makeup ball sizes generated by the JK ball mill model (Napier-Munn et al, 1996) were used to devise a coupling for such an effect. For the screen oversize grinding, a ball mill model with similar grinding parameters as the (primary) ball mill was used. The objective of this particular simulation was to have a size distribution from this separate circuit similar to the magnetic circuit. The number of hydrocyclones and their geometry were adjusted until the objective was achieved.

<u>Basis for Simulations</u>

For simulation purposes, it was assumed that the ore consisted of two components, namely magnetite and gangue. Mass balanced magnetic iron grades were converted to magnetite on the basis of atomic weights, dividing by 0.7236. The rest is considered gangue. Eventually, empirical equations developed using mass balanced data were employed to calculate silica in each stream after magnetite-gangue based simulations were performed.

As a first step, the current operation was simulated. Initially, the best fit model parameters for each unit were calculated individually. Then, model parameters were fine tuned to obtain a satisfactory fit between simulated and actual flow rates, grades and size distributions. Fine-tuning was a major task around the ball mill to match operating data with simulated, due to a number of circulating streams. Finally, an excellent fit to all three types of data was obtained.

As a summary, the list of simulations carried out is presented below:

- Dry Cobbing
- Hydrocyclone Efficiency Improvements
  - Double Cycloning
  - Retrofitting the Existing Cyclones
  - 20-inch Cyclones
  - Stack Sizers Replacing Hydrocyclones
- Ball Mill Efficiency Improvements
  - Makeup Ball Size – 1¾-& 1½-inch
  - Increased Ball Charge
  - Increased Critical Speed
  - Feed percent Solids
- Fine Screen Feed Dilution
- Fine Screen Oversize Grinding

The initial plan was to choose the most promising alternatives and carry out detailed simulations on a selected list of modifications. For each alternative, complete plant simulations were carried out. To simplify comparisons, existing operating conditions were kept constant for the rest of the plant. The effect was then measured by three criteria: ball mill discharge rate, magnetic iron recovery, and silica in magnetic concentrate.

3.1.3 Results of Magnetic Circuit Simulations

Results of the simulation study are summarized in Tables 10 and 11 for Blend 1 and Blend 2, respectively. Several simulations were carried out to quantify the effects of increased ball charge, critical speed and feed percent solids in ball milling, and feed dilution in fine screens. For these variables, only one set of simulation results is presented in Tables 10 and 11. Their prevailing and simulated values are presented in Table 12.

Table 10. Summary of primary simulation results for Blend 1

Performance Improvement Alternative	**Ball Mill Discharge Rate (t/h)**	**Magnetic Concentrate**	
		Recovery (%)	**Silica (%)**
Current	1536	96.2	6.96
Dry Cobbing	1542	96.6	6.92
Double Hydrocycloning	1245	96.1	7.35
Hydrocyclone retrofit	1296	96.1	7.31
20-inch Hydrocyclones	1149	96.0	7.65
Stack Sizers (0.15 mm)	1039	96.2	7.24
1¾ - inch Makeup Balls	1299	96.2	6.93
1½ - inch Makeup Balls	1085	96.2	7.00
Increased Ball Charge (38%)	1395	96.3	6.99
Increased Critical Speed (0.75)	1282	96.3	7.00
Ball Mill Feed % Solids (72%)	1386	96.3	6.99
Fine Screen Feed Dilution (52 %)	1382	96.2	7.28
Separate Grinding of Fine Screen O/S	835	96.2	6.53

Table 11. Summary of primary simulation results for Blend 2

Performance Improvement Alternative	**Ball Mill Discharge Rate (t/h)**	**Magnetic Concentrate**	
		Recovery (%)	**Silica (%)**
Current	910	94.9	6.16
Dry Cobbing	766	95.4	6.14
Double Hydrocycloning	639	94.6	6.73
Hydrocyclone retrofit	709	94.6	6.55
20-inch Hydrocyclones	725	94.6	6.43
Stack Sizers (0.15 mm)	506	94.3	6.90
1¾ - inch Makeup Balls	839	95.0	6.13
1½ - inch Makeup Balls	729	95.1	6.12
Increased Ball Charge (38%)	615	95.0	6.18
Increased Critical Speed (0.75)	817	95.1	6.19
Ball Mill Feed % Solids (72%)	764	95.1	6.23
Fine Screen Feed Dilution (52 %)	866	95.0	6.40
Separate Grinding of Fine Screen O/S	699	95.1	5.98

Table 12. Prevailing and simulated values of operating variables

Variable	Prevailing		Simulated
	Blend 1	Blend 2	
Volumetric Ball Load (%)	34	34	38
Fraction of Critical Speed	0.667	0.667	0.75
Ball Mill Feed % Solids	68.8	65.2	72
Fine Screens Feed % Solids	56.5	54.7	52

In general, all the alternatives had a certain degree of potential to reduce the circulating loads around the ball mill, thus creating room for increased throughput. For the dry cobbing alternative, the rod mill feed rate had to be reduced to 330 t/h to maintain the existing level of circulating load. This was due to feed being a higher grade. Since the bottleneck was in the ball milling process, separation of silica gangue by dry cobbing did not substantially alleviate the loads around the ball mill. Nevertheless, simulations showed that dry cobbing would increase the rate of concentrate production as a result of increased feed grade to the rod mill.

Increasing ball mill power draw by increased ball load or critical speed would produce similar benefits. However, increased ball load would require narrowing the diameter of the discharge ring, since the ball mill had a tendency to discharge balls when ball charge exceeded 35%. The other option required replacement of the pinion shaft. Benefits of increased feed percent solids would be relatively small, with the risk of increasing viscosity beyond a point that could deteriorate grinding efficiency. The most significant benefits would be obtained by simply changing ball size from 2-inch to 1½ - inch.

Of the three hydrocyclone efficiency improvement alternatives, double hydrocycloning produced a benefit similar to retrofitting. It was found that 20-inch cyclones would produce more efficient hydrocycloning. This would appreciably reduce the ball mill load and create significant room for increased throughput.

Although use of Stack Sizers showed a very large decrease in the ball mill load, detailed data indicated that downstream flow rates would be almost doubled even with the prevailing rod mill feed rates. A cut size coarser than the existing resulted in higher downstream flow rates. This implied that this alternative requires not only the replacement of hydrocyclones with Stack Sizers, but also doubling the downstream equipment sizes.

Diluting fine screen feed generated relatively small benefits with increased silica in the magnetic concentrate, indicating that this option might be used as a relief when the circuit is overloaded. Separate grinding of fine screen oversize appeared to have a large potential to increase plant throughput.

3.1.4 Additional Simulations and Detailed Results

A number of simulations were carried out to examine thoroughly the most promising alternatives. The objective was to examine the downstream effects of these modifications as well as to determine their impacts on plant throughput. Additional simulations for the magnetic separator circuit included the effects of makeup ball sizes and mixtures, volumetric ball charge, increased critical speed, use of more efficient hydrocyclones, and variations in rod mill feed size distributions. A simulation-based assessment of current plant control strategy was also carried out. These simulations were focused on Blend 1, since its baseline data were very close to the limits of plant bottlenecks. Some of the modifications were also tested on Blend 2 data. In general, the same trends were observed for both blends.

3.1.4.1 Ball Size Simulations

Because of the cost issues, makeup ball sizes larger than 1½-inch and mixtures of balls were considered. Additional simulations were carried out to quantify the benefits of using 1¾-inch make up balls and a mixture of 40% 1½- and 60% 2-inch balls.

For simulations, all the other operating conditions were kept the same as at the time of plant sampling, and ball mill grinding parameters were adjusted for ball size. After simulation of the current rod mill feed rate (350 LTPH), the feed rate was gradually increased until the ball mill discharge rate approximately matched the current rate. In the case of 1½-inch make up ball size simulation, even when the rod mill feed rate was increased 10%, the ball mill discharge rate was still below the current level. Since a 10% increase was the target, the feed rate was not increased further. Results of these simulations are presented in Tables 13-15. In the tables, “Base” refers to mass balanced plant data for Blend 1 and “Simulated” are the results of simulations reflecting changes in plant performance for potential plant implementation.

Table 13. Detailed results of simulations with 100% 1½-inch makeup balls

Rod Mill Feed Rate: 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1084	47.5	46.4	23.9	25.0		
Rougher Tails	82	81	1.4	1.4	70.0	69.9	1.3	1.3
Cyclone O/F	302	268	54.4	54.3	16.9	17.1		
Hydrosep. Tails	13	14	1.3	1.5	70.0	69.9	0.2	0.2
Finisher Tails	6	7	6.1	5.9	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.6**	**6.96**	**6.83**	**96.2**	**96.2**

Rod Mill Feed Rate: 385 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	121	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1470	47.5	46.7	23.9	24.7		
Rougher Tails	82	94	1.4	1.5	70.0	69.8	1.3	1.4
Cyclone O/F	302	306	54.4	54.7	16.9	16.7		
Hydrosep. Tails	13	15	1.3	1.3	70.0	70.0	0.2	0.2
Finisher Tails	6	7	6.1	5.9	65.2	65.5	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.6**	**6.96**	**6.82**	**96.2**	**96.0**

Table 14. Detailed results of simulation with 100% 1¾-inch makeup balls

Rod Mill Feed Rate: 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1299	47.5	46.9	23.9	24.5		
Rougher Tails	82	82	1.4	1.4	70.0	69.9	1.3	1.3
Cyclone O/F	302	289	54.4	54.4	16.9	17.0		
Hydrosep. Tails	13	13	1.3	1.4	70.0	70.0	0.2	0.2
Finisher Tails	6	6	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.5**	**6.96**	**6.93**	**96.2**	**96.2**

Rod Mill Feed Rate: 367 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	367	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	117	1.5	1.5	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1529	47.5	47.1	23.9	24.3		
Rougher Tails	82	89	1.4	1.5	70.0	69.9	1.3	1.4
Cyclone O/F	302	307	54.4	54.6	16.9	16.7		
Hydrosep. Tails	13	13	1.3	1.3	70.0	70.1	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**141**	**64.4**	**64.5**	**6.96**	**6.90**	**96.2**	**96.2**

Table 15. Detailed results of simulations with mixture of40% 1½ and 60% 2-inch makeup balls

Rod Mill Feed Rate: 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1356	47.5	47.0	23.9	24.4		
Rougher Tails	82	82	1.4	1.4	70.0	69.9	1.3	1.3
Cyclone O/F	302	293	54.4	54.4	16.9	16.9		
Hydrosep. Tails	13	13	1.3	1.3	70.0	70.0	0.2	0.2
Finisher Tails	6	6	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.4**	**6.96**	**6.94**	**96.2**	**96.2**

Rod Mill Feed Rate: 362 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	362	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	116	1.5	1.5	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1524	47.5	47.1	23.9	24.2		
Rougher Tails	82	87	1.4	1.4	70.0	69.9	1.3	1.3
Cyclone O/F	302	305	54.4	54.6	16.9	16.8		
Hydrosep. Tails	13	13	1.3	1.3	70.0	70.1	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**139**	**64.4**	**64.5**	**6.96**	**6.92**	**96.2**	**96.1**

Results showed that use of 1½-inch makeup balls could increase the plant throughput by 10%. The use of 1¾-inch balls or ball mixtures of 1½- and 2-inch balls would have lesser benefits, with increases in throughput by 4-6%.

3.1.4.2 Volumetric Loading of Ball Charge

The current volumetric ball charge for Blend 1 was 34%, which corresponded to a power draw of 3760 KW. The volumetric ball charge was increased to 38%, and simulations were carried out for rod mill feed rates of 350 (current) and 360 LTPH. Results are summarized in Table 16. Magnetic concentrate size distributions were very similar to Blend 1 plant data in both cases.

Table 16. Detailed results of volumetric loading ball charge simulations

Volumetric ball charge : 38%
Power Draw : 3980 KW
Feed Rate : 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1395	47.5	47.2	23.9	24.1		
Rougher Tails	82	82	1.4	1.4	70.0	70.0	1.3	1.2
Cyclone O/F	302	298	54.4	54.3	16.9	17.1		
Hydrosep. Tails	13	13	1.3	1.4	70.0	69.9	0.2	0.2
Finisher Tails	6	6	6.1	6.1	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.4**	**6.96**	**6.99**	**96.2**	**96.3**

Volumetric ball charge : 38%
Power Draw : 3980 KW
Feed Rate : 360 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	360	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	116	1.5	1.5	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1539	47.5	47.3	23.9	24.0		
Rougher Tails	82	86	1.4	1.4	70.0	70.0	1.3	1.3
Cyclone O/F	302	309	54.4	54.5	16.9	16.9		
Hydrosep. Tails	13	13	1.3	1.4	70.0	70.0	0.2	0.2
Finisher Tails	6	7	6.1	6.1	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**139**	**64.4**	**64.4**	**6.96**	**6.96**	**96.2**	**96.2**

Results showed that increasing the volumetric loading of the ball charge from 34% to 38% would increase plant throughput by 10 LTPH.

3.1.4.3 Critical Speed Simulations

Simulations were carried out only for Blend 1 data. All simulations were carried out at the same operating conditions as those prevailing during the plant sampling, except the critical speed.

To determine the potential throughput increase, the rod mill feed rate was gradually increased until simulated circulating loads around the ball mill reached the rate experienced during the baseline sampling period. Results of simulations summarizing the effect of increasing the critical speed of the ball mill at the plant are presented in Table 17.

Table 17. Detailed results of critical speed simulations

Critical speed = 75%

Feed Rate = 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1282	47.5	47.1	23.9	24.3		
Rougher Tails	82	81	1.4	1.3	70.0	70.0	1.3	1.2
Cyclone O/F	302	293	54.4	54.2	16.9	17.2		
Hydrosep. Tails	13	14	1.3	1.5	70.0	69.9	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.4**	**6.96**	**7.00**	**96.2**	**96.3**

Critical speed = 75%

Feed Rate = 368 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	368	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	117	1.5	1.5	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1520	47.5	47.2	23.9	24.1		
Rougher Tails	82	88	1.4	1.4	70.0	70.0	1.3	1.3
Cyclone O/F	302	314	54.4	54.4	16.9	16.9		
Hydrosep. Tails	13	14	1.3	1.4	70.0	70.0	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**142**	**64.4**	**64.4**	**6.96**	**6.97**	**96.2**	**96.2**

Critical speed = 80%

Feed Rate = 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1189	47.5	46.9	23.9	24.5		
Rougher Tails	82	81	1.4	1.3	70.0	70.0	1.3	1.2
Cyclone O/F	302	288	54.4	54.1	16.9	17.3		
Hydrosep. Tails	13	14	1.3	1.5	70.0	69.8	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.4**	**6.96**	**7.01**	**96.2**	**96.3**

Table 17. (continued)
Critical speed = 80%
Feed Rate = 378 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	378	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	120	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1535	47.5	47.2	23.9	24.2		
Rougher Tails	82	91	1.4	1.4	70.0	70.0	1.3	1.3
Cyclone O/F	302	321	54.4	54.5	16.9	16.9		
Hydrosep. Tails	13	15	1.3	1.4	70.0	70.0	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**146**	**64.4**	**64.4**	**6.96**	**6.97**	**96.2**	**96.2**

Increased critical speed has a potential to increase plant throughput. Such increase in throughput will be approximately 5 and 8% for critical speeds of 75 and 80% respectively, if circulating loads are considered as the only bottleneck. Such increases in throughput are not expected to create any upsets in recovery and concentrate silica. However, simulations also indicate that the hydrocyclone overflow rate, hence hydroseparator underflow rate, will be higher with increased feed rates than what was experienced during the plant sampling. This could limit the increase in throughput to lower rates. Simulations showed that capacity increases will stay 2 and 3.5% level for 75 and 80% of critical speed, respectively, when this flow rate was considered as the main limiting factor.

3.1.4.4 Simulation-Based Study of Control Strategies

A series of simulations was carried out to investigate the reaction of the magnetic circuit to some of the current plant control strategies. Two strategies considered in the study were to manipulate: (1) cyclone pressure or (2) rod mill feed rate to have finer/coarser concentrate. A combination of the two was also investigated. Open circuit hydrocyclone simulations were also carried out to reflect the plant's immediate reaction to a step change, and to provide comparison for plant performance when it reaches a steady state operation. Simulations were carried out using a currently available database for two blends processed at the plant and were repeated for each ore blend. The effect of fine screening conditions on the size of magnetic concentrate was also briefly studied.

Hydrocyclone Pressure Drop

These simulations were carried out by changing hydrocyclone feed solids rather than setting a pressure value beforehand. This was more convenient with the available software. A model had been developed for the latter mode of simulations, but it required fine tuning for accurate calculations. Nevertheless, this approach generated the same effect.

Results of simulations are summarized in Tables 18 and 19 for Blend 1 and Blend 2, respectively. The first rows in the tables are the baseline conditions for the corresponding blend. Cyclone feed rates reflect the circulating load for a given condition. The size fraction of – 500 mesh was chosen as a criterion to indicate variations in size distributions. Size variations in both hydrocyclone overflow and magnetic concentrate were recorded.

Table 18. Summary of simulation results reflecting the effects of some control actions on plant performance for Blend 1

Rod Mill Feed Rate (LTPH)	Cyclone			-500 mesh (%)	
	Feed Rate (LTPH)	Pressure (psi)	Feed Solids (%)	Cyclone O/F	Magnetic Concentrate
350	**1441**	**Base**	**46**	**49.4**	**58.2**
350	1398	+2	44	50.9	58.7
350	1396	+5	42	52.7	59.3
350	1440	+12	40	54.7	60.2
350	1548	+0.5	48	48.3	57.9
350	1709	+2.5	50	47.9	58
340	1296	-5	46	49.7	58.6
340	1250	0	41.5	53.3	60
330	1165	-10	46	50.0	59.1
330	1440	0	39	55.9	61.5

Table 19. Summary of simulation results reflecting the effects of some control actions on plant performance for Blend 2

Rod Mill Feed Rate (LTPH)	Cyclone			-500 mesh (%)	
	Feed Rate (LTPH)	Pressure (psi)	Feed Solids (%)	Cyclone O/F	Magnetic Concentrate
315	**830**	**Base**	**41**	**53.0**	**61.7**
315	828	+2	39	54.5	62.3
315	833	+4.5	37	56.2	63.1
315	839	-1.5	43	51.6	61.2
315	853	-2.5	45	50.4	60.8
305	762	-2	41	53.5	62.3
305	760	0	38.5	55.3	63.1
325	903	+2	41	52.5	61.2
325	918	0	44	50.5	60.4

First, it was found that it was not possible to reduce the cyclone pressure by varying feed % solids to the cyclone for Blend 1. Changes in both directions resulted in an increase in cyclone pressure. Surprisingly, feed dilution lowered the circulating loads to an optimum point, after which an increase was observed with further dilution. Lowering cyclone pressure does not necessarily lower the circulating load when the rod mill feed rate is kept constant. This phenomenon appears to be confusing. Analysis of detailed simulation data revealed that this is a result of the effect of fine screening efficiency on the circulating loads. For Blend 1, the base conditions corresponded to already overloaded screens. Increasing hydrocyclone cut size by increasing cyclone feed % solids resulted in rapidly decreasing screening efficiency and circulation of a higher ratio of fine screen feed back to the ball mill. Eventually, this results in cyclone pressure being higher when the circuit reaches its steady state operation. When fine screens had relatively low loads, hence higher screening efficiency (Blend 2), cyclone pressure reacted in the expected manner. However, this did not result in lower circulating loads.

A step change in cyclone pressure drop initially generates a big effect on size distributions of hydrocyclone overflow (Tables 20 and 21), and, hence, magnetic concentrate. As a comparison of plant simulations (Tables 18 and 19) with open circuit cyclone simulations shows (Tables 20 and 21), this effect gradually becomes much smaller as the plant reaches its steady state of operation. This confirms what is observed at the plant. To generate a 1% steady state increase in the -500 mesh fraction in the final concentrate could require a 4-5 psi increase in cyclone pressure.

Table 20. Open circuit hydrocyclone simulations reflecting the initial effect of step change in hydrocyclone operating pressure for Blend 1

Hydrocyclone			
Feed Rate (LTPH)	Pressure (psi)	Feed Solids (%)	- 500 mesh in O/F
1441	**Base**	**46**	**49.4**
1441	+3.5	44	52.9
1441	-3	48	46.1

Table 21. Open circuit hydrocyclone simulations reflecting the initial effect of step change in hydrocyclone operating pressure for Blend 2

Hydrocyclone			
Feed Rate (LTPH)	Pressure (psi)	Feed Solids (%)	- 500 mesh in O/F
830	**Base**	**41**	**53.0**
830	+2	39	55.6
830	-1.5	43	50.5

Rod Mill Rate

Rod mill feed rate, on the other hand, has a more significant effect on the size structure of the magnetic concentrate. Its effect on the circulating load is also predictable. For a given rod mill feed rate, two simulations were carried out: constant feed % solids and constant pressure. Having the hydrocyclone feed % solids constant with a 10 LTPH reduction in rod mill feed rate produced a small effect (0.4-0.6%) on the -500 fraction in the magnetic concentrate, whereas constant pressure resulted in nearly a 2% increase. Increasing the feed rate had a reverse effect in a similar magnitude. This implies that keeping hydrocyclone feed % solids constant while rod mill feed rate is increased could be a smoother operation than keeping the cyclone pressure constant. When finer magnetic concentrate is desired, it could be beneficial to combine the two, i.e lower rod mill feed rate at the prevailing pressure. A more radical approach could be lowering the feed rate while the pressure set point is increased.

Fine Screen Feed % Solids

Simulations aimed at investigating the potential effect of increased feed % solids on the magnetic concentrate size distribution. One simulation for each blend was carried out. It was found that a 2% increase in fine screen feed % solids results in 0.5% higher -500 fraction in the magnetic concentrate. Increased feed % solids could also have increased heavy media effect and could provide additional benefits. This was not thoroughly examined. Although its effect on size distribution is small, it could be used as an alternative method for plant control. However, simulation data also indicated that when Blend 1 plant sampling was carried out, the plant was running with very high circulating load and fine screen feed rates. These conditions resulted in screen efficiency being compromised. An increase in feed % solids led to further deterioration in screen efficiency. When Blend 2 was processed, the plant was running at low circulating loads and low feed rates to fine screens. In such conditions, plant control involving fine screens becomes a viable alternative, but there might not be much room to maneuver when the circuit is already overloaded.

Conclusions Control Strategy Study

Simulations showed that a step change in cyclone pressure could have an immediate effect on the size structure of the magnetic concentrate, but this effect becomes much less significant when the plant reaches steady state operation. This confirms the observations at the plant. However, it was also found that the total ball mill circulating load could not be directly correlated to cyclone pressure. On the other hand, variations in rod mill feed rate have a direct and more significant effect on the size structure of magnetic concentrate and circulating loads. This makes it favorable for plant operators to use it as a control variable when finer/coarser product size distribution is desired. Fine screen control also has some potential to be used to control product quality.

3.1.4.5 Hydrocyclone Replacement

Simulations were carried out to quantify the benefits of replacing existing 15-inch cyclones with new 20-inch cyclones. Two vendors, Krebs (gMax) and Weir (Cavex), provided simulated hydrocyclone data for their products. Their simulations were based on mass balanced circuit data for Blend 1. The samples were taken in September 2001. Initially, there was a difference between simulated hydrocyclone overflow size distributions presented by the two vendors. Krebs was asked to modify their data to make these compatible with the data provided by Weir. Eventually, both cyclone manufacturers' overflow size distributions were essentially the same (Figure 14). However, there was some difference in terms of partition curves (Figure 15). It seemed that lower bypass with Krebs cyclones compensated for the coarser cut size and eventually produced the same size distribution with very similar weight split. Both sets of data were incorporated into Usim Pac and used for plant simulations.

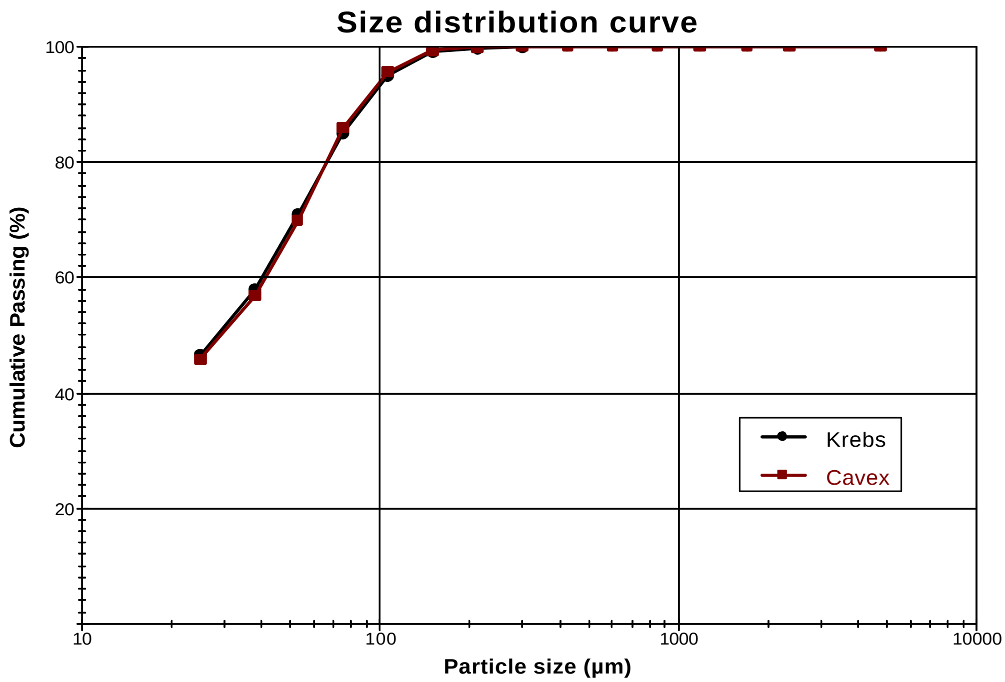

Figure 14. Vendor simulated hydrocyclone overflow size distribution curves of 20 inch Krebs and Weir (Cavex) cyclones.

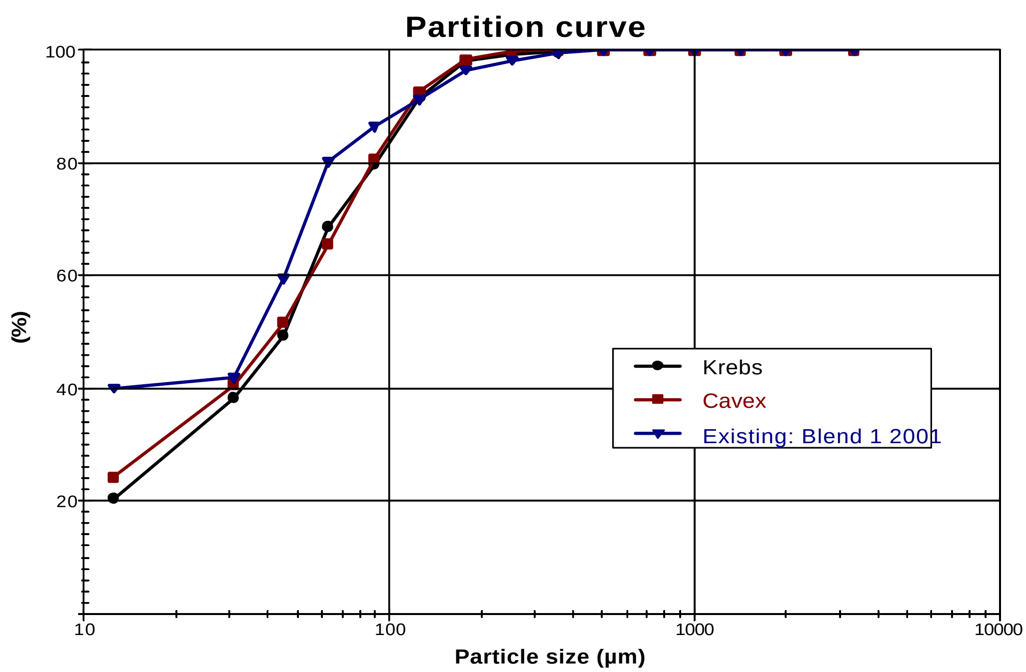

Figure 15. Vendor simulated partition curves of 20-inch Krebs and Weir (Cavex) cyclones as compared to existing cyclones

For each cyclone type, four simulations were carried out:

1. Blend 1 baseline conditions with the new cyclones
2. Blend 1 baseline conditions with rod mill feed rate increased so as to give the same amount of ball mill discharge rate
3. Blend 1 baseline conditions with 1½-inch makeup balls and new cyclones.
4. Blend 1 baseline conditions with 1½-inch makeup balls, new cyclones and a rod mill feed rate of 385 LTPH (10% increase)

All the simulations were carried out by keeping all the other conditions constant. For hydrocyclone feed % solids, the percentages recommended by the vendors were used and kept constant for all four simulations. Results of these simulations are presented in Table 22.

Table 22. Detailed results of hydrocyclone replacement simulations

Cyclones : 5 x gMax 20-inch
Rod mill feed rate : 350 LTPH
Makeup ball size : 2-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1140	47.5	47.1	23.9	24.3		
Rougher Tails	82	80	1.4	1.6	70.0	69.8	1.3	1.4
Cyclone O/F	302	292	54.4	53.9	16.9	17.5		
Hydrosep. Tails	13	15	1.3	1.7	70.0	69.6	0.2	0.3
Finisher Tails	6	6	6.1	6.1	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.3**	**6.96**	**7.07**	**96.2**	**96.0**

Comments: Final product was slightly coarser (P80 50 micron), although hydrocyclone O/F was almost the same.

Cyclones : 6 x Cavex 20-inch
Rod mill feed rate : 350 LTPH
Makeup ball size : 2-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	1157	47.5	47.1	23.9	24.3		
Rougher Tails	82	80	1.4	1.6	70.0	69.8	1.3	1.4
Cyclone O/F	302	290	54.4	53.8	16.9	17.6		
Hydrosep. Tails	13	15	1.3	1.7	70.0	69.6	0.2	0.3
Finisher Tails	6	7	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.2**	**6.96**	**7.17**	**96.2**	**96.0**

Comments: Final product was slightly coarser (P80 50 micron), although hydrocyclone O/F was almost the same.

Table 22. (continued)

Cyclones : 5 x gMax 20-inch
Rod mill feed rate : 382 LTPH
Makeup ball size : 2-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	382	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	120	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1530	47.5	47.7	23.9	23.7		
Rougher Tails	82	92	1.4	1.7	70.0	69.7	1.3	1.6
Cyclone O/F	302	310	54.4	54.3	16.9	17.1		
Hydrosep. Tails	13	16	1.3	1.7	70.0	69.7	0.2	0.3
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**147**	**64.4**	**64.4**	**6.96**	**6.99**	**96.2**	**95.8**

Comments: Final product was slightly coarser (P80 50 micron). 3% higher hydroseparator feed rate.

Cyclones : 6 x Cavex 20-inch
Rod mill feed rate : 382 LTPH
Makeup ball size : 2-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	382	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	120	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1515	47.5	47.6	23.9	23.8		
Rougher Tails	82	92	1.4	1.7	70.0	69.7	1.3	1.6
Cyclone O/F	302	305	54.4	54.2	16.9	17.2		
Hydrosep. Tails	13	15	1.3	1.7	70.0	69.7	0.2	0.3
Finisher Tails	6	7	6.1	5.9	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**147**	**64.4**	**64.3**	**6.96**	**7.09**	**96.2**	**95.8**

Comments: Final product was slightly coarser (P80 51 micron). Only 1% higher hydroseparator feed rate

Cyclones : 5 x gMax 20-inch
Rod mill feed rate : 350 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	840	47.5	46.1	23.9	25.3		
Rougher Tails	82	80	1.4	1.6	70.0	69.7	1.3	1.4
Cyclone O/F	302	262	54.4	54.1	16.9	17.3		
Hydrosep. Tails	13	16	1.3	1.8	70.0	69.6	0.2	0.3
Finisher Tails	6	6	6.1	6.0	65.2	65.3	0.4	0.4
Magnetic Con.	**135**	**134**	**64.4**	**64.6**	**6.96**	**6.76**	**96.2**	**95.9**

Comments: Finer final concentrate (P80= 46 micron)

Table 22. (continued)

Cyclones : 6 x Cavex 20-inch
Rod mill feed rate : 350 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	114	1.5	1.5	69.9	69.9	1.9	1.9
Ball Mill Discharge	1535	872	47.5	46.2	23.9	25.2		
Rougher Tails	82	80	1.4	1.6	70.0	69.7	1.3	1.4
Cyclone O/F	302	262	54.4	54.1	16.9	17.3		
Hydrosep. Tails	13	15	1.3	1.7	70.0	69.7	0.2	0.3
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**134**	**64.4**	**64.5**	**6.96**	**6.86**	**96.2**	**96.0**

Comments: Finer final concentrate (P80= 46 micron)

Cyclones : 5 x gMax 20-inch
Rod mill feed rate : 385 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	121	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1115	47.5	46.3	23.9	25.0		
Rougher Tails	82	92	1.4	1.7	70.0	69.7	1.3	1.6
Cyclone O/F	302	296	54.4	54.3	16.9	17.1		
Hydrosep. Tails	13	17	1.3	1.7	70.0	69.7	0.2	0.3
Finisher Tails	6	7	6.1	5.9	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.6**	**6.96**	**6.84**	**96.2**	**95.8**

Comments: Finer final concentrate (P80= 47 micron). No downstream problems. Rod mill feed rate can be increased further.

Cyclones : 6 x Cavex 20-inch
Rod mill feed rate : 385 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	121	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1137	47.5	46.3	23.9	25.0		
Rougher Tails	82	92	1.4	1.7	70.0	69.7	1.3	1.5
Cyclone O/F	302	294	54.4	54.2	16.9	17.1		
Hydrosep. Tails	13	17	1.3	1.7	70.0	69.7	0.2	0.3
Finisher Tails	6	7	6.1	5.9	65.2	65.5	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.5**	**6.96**	**6.93**	**96.2**	**95.8**

Comments: Finer final concentrate (P80= 47 micron). No downstream problems. Rod mill feed rate can be increased further.

In terms of plant performance, there was no significant difference between the two cyclones. The task could be carried out by five 20-inch Krebs cyclones or six 20-inch Weir cyclones. In terms of pressure drops, both vendors claimed that their hydrocyclones will operate at lower pressures than the conventional ones. However, in some cases, their pressure predictions were close to the conventional ones with the same geometry. Since these new designs are not expected to fit conventional hydrocyclone pressure equations, pressure predictions from Usim Pac were regarded as qualitative or the highest that could be expected.

It was expected that the actual separation with either cyclone would not be as good as the vendors predicted. There could be some coarse particles escaping into the overflow stream due to the fact that these particles have relatively lower density (low magnetite content). The actual bypass might not be as good as they predicted either. In any case, 20-inch cyclones will provide better performance and could operate at lower pressures than the existing ones.

To quantify the effects of the potential inefficiency problems, another set of simulations was carried out by increasing bypass and decreasing sharpness by 10%. This could be regarded as a worst case scenario. Results are presented in Table 23. Both cyclones performed almost identically under these conditions. Data showed that circulating loads and hydrocyclone overflow rates would be slightly increased. It was also found that cyclone inefficiency could slightly increase magnetic concentrate silica. Since circulating loads were still well below 2001 rates, this did not seem to be a concern. Increases in hydrocyclone overflow rates could be neutralized by changing the cut size. Relatively low circulating loads create room for such a maneuver. This option was not simulated.

Table 23. Detailed results of simulations with deteriorated cyclone efficiency

Cyclones : 5 x gMax 20-inch
Rod mill feed rate : 385 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	121	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1262	47.5	46.5	23.9	24.9		
Rougher Tails	82	92	1.4	1.6	70.0	69.8	1.3	1.5
Cyclone O/F	302	322	54.4	54.3	16.9	17.0		
Hydrosep. Tails	13	17	1.3	1.5	70.0	69.8	0.2	0.3
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.5**	**6.96**	**6.89**	**96.2**	**95.9**

Comments: Final product is finer (P80 = 47 micron). 7% increase in Hydrocyclone overflow rate.

Table 23. (continued)

Cyclones : 6 Cavex 20inch
Rod mill feed rate : 385 LTPH
Makeup ball size : 1½-inch

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	121	1.5	1.6	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1274	47.5	46.5	23.9	24.9		
Rougher Tails	82	93	1.4	1.6	70.0	69.8	1.3	1.5
Cyclone O/F	302	317	54.4	54.3	16.9	17.1		
Hydrosep. Tails	13	16	1.3	1.5	70.0	69.9	0.2	0.2
Finisher Tails	6	7	6.1	5.9	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.4**	**6.96**	**6.96**	**96.2**	**95.9**

Comments: Final product is finer (P80 = 47 micron). 5% increase in hydrocyclone overflow rate.

3.1.4.6 Coarser Feed to the Rod Mill

Increased plant throughput was expected to create potential problems in the ore crushing circuit. Considering the possibility of the crushing circuit not being able to deliver higher throughputs, a solution then could be to increase the rod mill feed size. Simulations were used to quantify the impact of such a potential course of action on the magnetic circuit performance. An artificial coarser rod mill size distribution was generated, and its effect on the magnetic circuit performance was studied. The size distribution of artificially generated rod mill feed, together with the current size distribution (Blend 1) are presented in Figure 16.

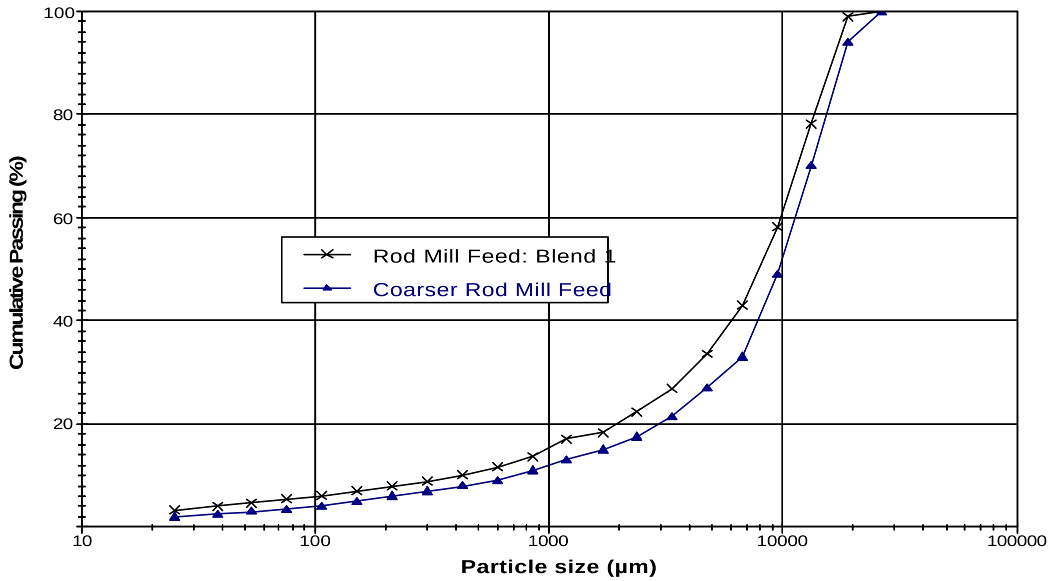

Figure 16. The baseline (Blend 1) and artificially generated coarser rod mill feed size distributions

As shown in Figure 16, the +1/2 inch fraction in rod mill feed was increased from 21.8% to 30%. Simulations were performed at feed rates of 350 and 385 LTPH with a makeup ball size of 1½-inches. Results of coarser rod mill feed simulations were compared to corresponding simulations with the baseline (Blend 1) rod mill feed size distributions. The possibility of ball mill feed (cobber concentrate) becoming too coarse for 1½-inch make up balls was investigated. Results of simulation with coarser feed with 1½ inch make up balls are presented in Tables 24 and 25.

Table 24. Detailed results of a simulation showing the effect of coarser feed to the rod mill for a feed rate of 350 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	350	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	111	1.5	1.5	69.9	69.8	1.9	1.9
Ball Mill Discharge	1535	1133	47.5	46.3	23.9	25.1		
Rougher Tails	82	84	1.4	1.4	70.0	69.9	1.3	1.3
Cyclone O/F	302	271	54.4	54.2	16.9	17.2		
Hydrosep. Tails	13	14	1.3	1.5	70.0	69.8	0.2	0.2
Finisher Tails	6	7	6.1	6.0	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**135**	**64.4**	**64.5**	**6.96**	**6.85**	**96.2**	**96.1**

Table 25. Detailed results of a simulation showing the effect of coarser feed to the rod mill for a feed rate of 385 LTPH

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery/ Loss (%)	
	Base	Simulated	Base	Simulated	Base	Simulated	Base	Simulated
Rod Mill Feed	350	385	25.8	25.8	45.5	45.5	100.0	100.0
Cobber Tails	114	118	1.5	1.6	69.9	69.7	1.9	1.9
Ball Mill Discharge	1535	1549	47.5	46.7	23.9	24.7		
Rougher Tails	82	97	1.4	1.5	70.0	69.8	1.3	1.5
Cyclone O/F	302	308	54.4	54.7	16.9	16.7		
Hydrosep. Tails	13	15	1.3	1.4	70.0	70.0	0.2	0.2
Finisher Tails	6	7	6.1	5.9	65.2	65.4	0.4	0.4
Magnetic Con.	**135**	**148**	**64.4**	**64.6**	**6.96**	**6.84**	**96.2**	**95.9**

Although simulations show that plant throughput could still be increased by 10% even when coarser ore is fed to the plant, since the ball mill discharge rate goes above the current value, it would be wise to lower the target to 8-9% for such conditions. It should also be noted that these simulations did not take into account any changes in grindability. In the case of ore becoming harder to grind, particularly in the ball mill, this would automatically lower the target increase in throughput. This option was not simulated.

Variations in ball mill feed size distribution with feed rate and coarser rod mill feed are illustrated in Figure 17. While the current rod mill feed size and feed rate produce a ball mill feed size of 80% passing 1700 micron, a 10% increase in feed rate increases the number to 1900 micron. When the increase in feed rate is coupled with coarser rod mill feed, it becomes 2000 micron. This size was used, together with a 2 unit increase in Bond ball mill work index (16 KW/LT), to calculate the optimum ball size. It was found that a 1½-inch makeup ball was still within the limits. However, further increase in either parameter would be hard to tolerate.

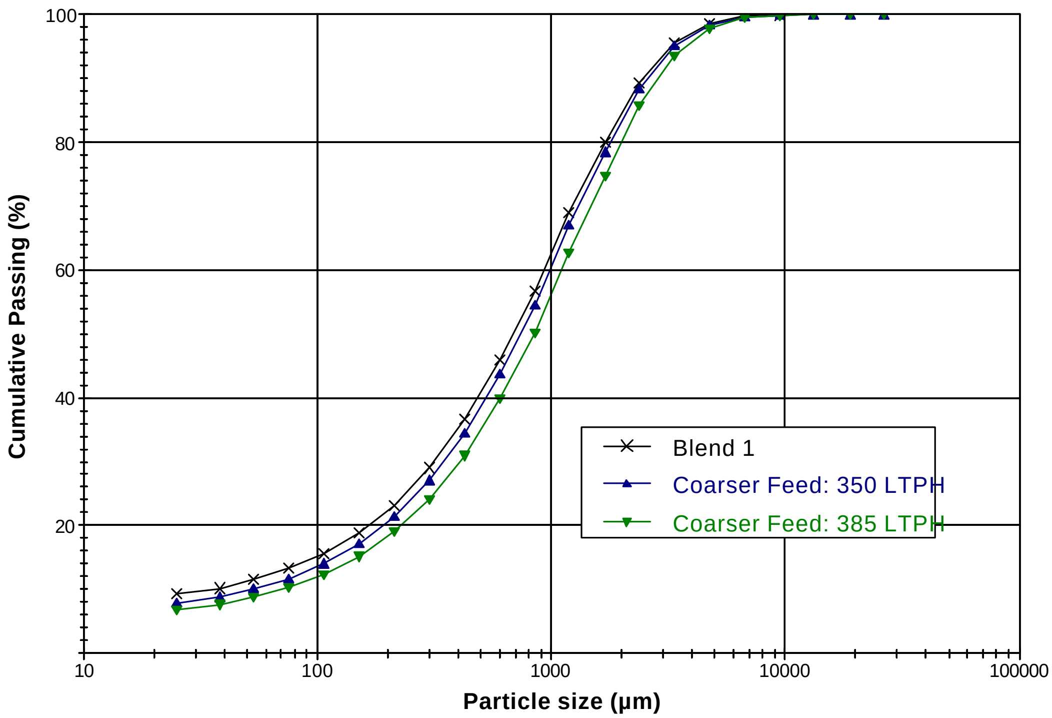

Figure 17. Variation of the ball mill feed size distribution with coarser rod mill feed size distribution and increased feed rate

3.2 Flotation Circuit Simulations

The primary objective of flotation circuit simulations was to quantify benefits from the implementation of the pre-classification concept in this plant. Pre-classification is separation of fine and coarse fractions in the feed to flotation circuit, and differential treatment of these fractions. The benefits of this mode of processing were studied by Iwasaki et al (1991), and Wu and Bleifuss (1997), and proved beneficial in terms of recovery. The concept was later modified by Wu (1998) by applying magnetic separation to the fine fraction separated by a hydrocyclone, while the coarse fraction was treated by flotation. Such modification made the process economically more feasible to retrofit to an existing plant. Hydrocycloning and further cleaning of the fine fraction by magnetic separation did not require large space and capital investment. Since the feed rate to the flotation circuit would be approximately halved, substantial savings could be achieved through reduced reagent consumption. Very recently, this type of processing was partially implemented in an iron ore processing plant, and a 4.7% increase in magnetic iron recovery and 23.6% decrease in reagent consumption were reported (Frosaker, 2004). The success of this particular plant with flotation feed pre-classification aroused interest among plant operators having flotation circuits in their plants in northern Minnesota. One of the potential places for a similar application was the Ispat Inland plant. Actual benefits from such a process modification would depend on baseline conditions as well as the circuit flow sheet.

The simplified flow sheet of the flotation circuit is shown Figure 18. The circuit consists of two stages of flotation. Two parallel banks of roughers, each with four $25m^3$ flotation cells produce the final concentrate. The combined tails initially go through two stages of dewatering, i.e. dewatering magnetic separation, and thickening, before they are further ground in a regrind ball mill. The discharge from the ball mill is the feed to the scavenger bank, which consists of three $25m^3$ cells. Scavenger float is the final flotation circuit tails, while scavenger concentrate is circulated back to the rougher circuit.

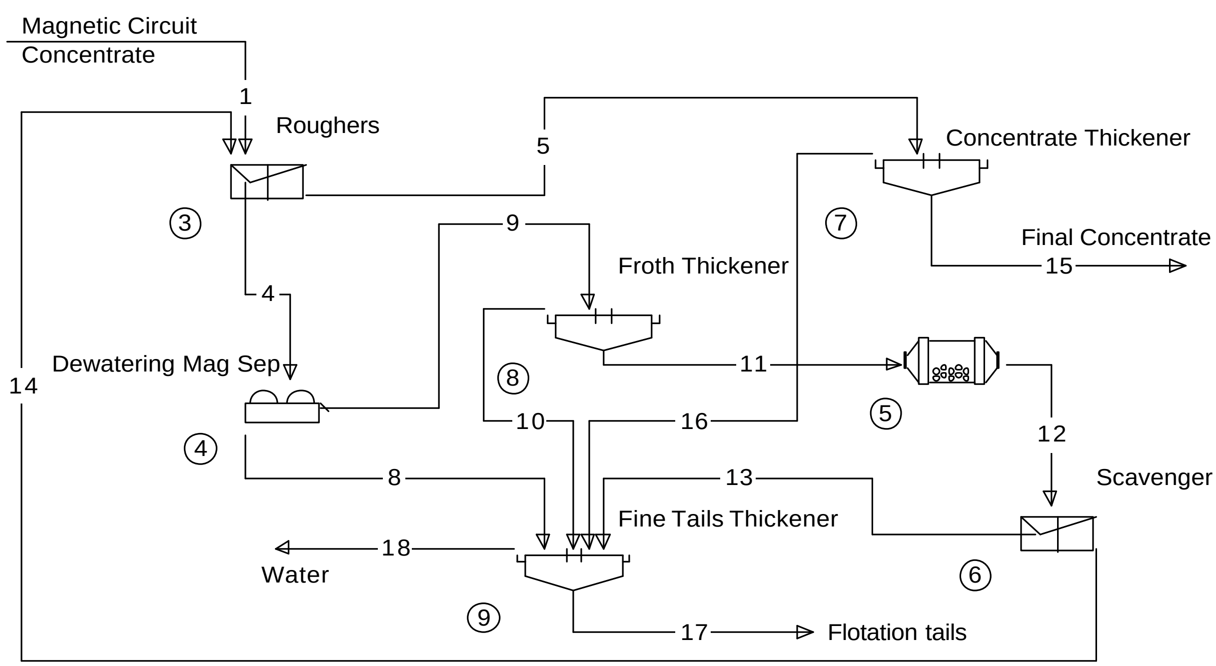

Figure 18. Simplified flow sheet of flotation circuit at the Minorca mine

The flow sheet of the proposed pre-classification circuit is presented in Figure 19. Flotation circuit data that were generated by intensive plant sampling surveys formed the basis for the simulation. As a remainder, a performance summary of the circuit is presented in Table 26. In general, flotation recoveries for both blends were high.

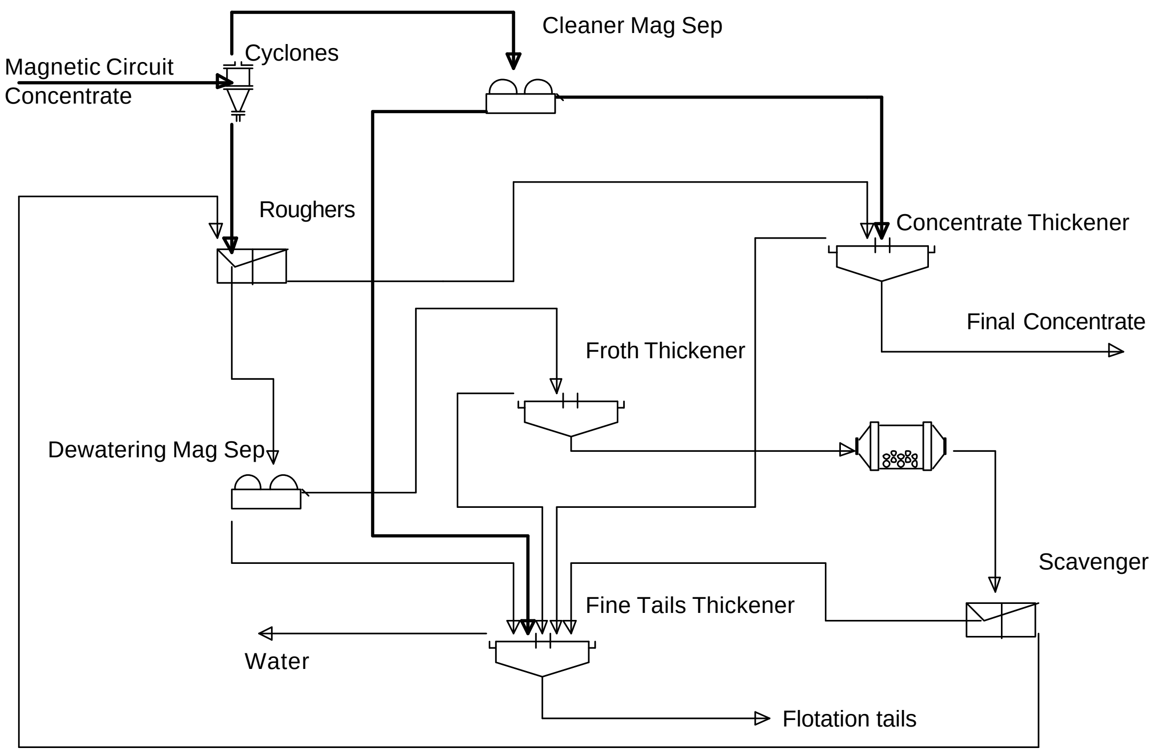

Figure 19. Flow sheet of flotation feed pre-classification circuit. Bold lines show modifications to existing circuit

Table 26. Flotation circuit performance summary for Blend 1 and Blend 2

Stream	Magnetic Iron Recovery (%)		Flow Rate (%)	
	Blend 1	Blend 2	Blend 1	Blend 2
Dewatering Mag. Sep. Tails	0.3	0.1	1.2	0.3
Froth Thickener O/F	0.1	0.2	0.1	0.4
Scavenger Tails	1.4	1.2	4.3	3.2
Concentrate Thickener O/F	0.1	0.0	0.1	0.1
Final Concentrate	98.1	98.5	94.3	96.0

As was true for the magnetic separation circuit, simulations assumed that the flotation feed had two components, namely magnetite and gangue. Mass balanced magnetic iron assays were converted to magnetite on the basis of atomic weights (dividing by 0.7236) and the rest was assumed as gangue, which included mostly silica-bearing minerals, but also a small fraction of iron carbonates and hematite. Simulations were carried out using Usim Pac mineral processing simulation software. A pre-classification circuit would require hydrocyclone separation of flotation feed into fine and coarse fractions. The coarse fraction would follow the existing route of processing, while the fine fraction would be directed to magnetic separators for further refining.

Total circuit simulation required models of the hydrocyclone, magnetic separator, thickener, ball mill and flotation bank. Pilot scale test data were already available for hydrocycloning the flotation feed and magnetic separation of fines (Wu, 1998). This data set was used for the selection of suitable hydrocyclones for such a circuit and for defining its performance. The same data were also the basis for defining the performance of the magnetic separator that would be processing hydrocyclone overflow. For hydrocyclone modeling, the number of cyclones was modified for the selected hydrocyclone size until a partition curve split similar to the pilot scale test data was obtained. A simple separator model was used for the magnetic separator treating hydrocyclone overflow, and the dewatering magnetic separator and froth thickener. Concentrate thickener and fine tails thickener were excluded from simulations due to low quality data from concentrate thickener overflow, and alos due to the fine tails thickener being a pure solid-liquid separation device. For regrind ball milling, a ball mill model already available within the Usim Pac library was calibrated with the plant data and used in simulations. In terms of modeling, the challenge was flotation. For this purpose, a new model was developed and added to the Usim Pac model library. Details of this model are presented below.

3.2.1 Flotation Model

Usim Pac has a well developed flotation model capable of handling the variation of flotation rate parameters with particle size. However, this model was not flexible enough to handle the type of particle size – recovery relationship encountered in iron ore (silica) flotation, particularly for magnetite. The existing functional form could not be fitted to this type of data. Therefore, a kinetic model with discrete size by size parameters was incorporated into Usim Pac for this purpose. A kinetic model based on fast, slow and non-floating components was tested on plant data. The general form of the model equation is given below:

$$P_{i,j} = F_{i,j} \,.\, Rinf_{i,j} \,.\, \left[f_{ij} \,.\, \left[1 - \frac{1}{(1 + ks_{i,j}.t)}\right] + (1 - f_{ij})\left[1 - \frac{1}{(1 + kf_{i,j}.t)}\right] \right] \quad (1)$$

Where:

$P_{i,j}$:	Flow rate of component j and size class i in the froth
$F_{i,j}$:	Flow rate of component j and size class i in the feed
$Rinf_{i,j}$:	Maximum possible recovery for component j and size class i
f_{ij}:	Slow floating fraction for component j and size class i
$ks_{i,j}$:	Flotation rate for slow floating fraction of component j and size class i (min^{-1})
$kf_{i,j}$:	Flotation rate for fast floating fraction of component j and size class i (min^{-1})
t:	Mean residence time in the cell (min)

First, its ability to simulate the existing flotation circuit was tested. Simulation provided an excellent fit to the plant data in terms of flow rates, size distributions and chemistries. Results of this simulation are presented Table 27. The model was then used to simulate pre-classification application at the plant, and the effects of increased plant throughput on the flotation circuit.

Table 27. Simulated and actual performance of the flotation circuit (Blend 1)

STREAM	Flow Rate (LTPH)		Mag Iron (%)		Silica (%)		Recovery (%)	
	Actual	Sim.	Actual	Sim.	Actual	Sim.	Actual	Sim.
Feed	360	360	64.2	64.2	6.88	6.88		
Rougher Tails	48	48	39.7	39.5	32.6	32.7		
Dewater. MS Con	44	43	42.4	42.3	29.4	29.6		
Dewater. MS Tail	4	5	14.4	14.2	48.5	48.6	0.3	0.3
Froth Thick. O/F	0.7	0.7	16.1	16.2	57.6	57.6	0.1	0.1
Scavenger Tails	15	15	21.6	22.3	53.8	53.1		
Scavenger Con	28	28	54.1	53.9	15.9	16.1	1.4	1.4
Final Concentrate	340	340	66.8	66.8	4.14	4.14	98.2	98.2

3.2.2 Simulation of Pre-classification Circuit

First, the current circuit operation was simulated separately for each blend. Despite the circulating load, fine tuning of the model parameters describing performance of individual devices did not require major adjustments. The fit was excellent in terms of chemistry and flow rates and very good for size distributions.

The next step was the simulation of a modified circuit. Since no kinetic data were available to describe how particles would behave in a modified flotation circuit, two different assumptions were made in order to simulate the circuit. First, it was assumed that each component/size would behave the same as the existing. This was named as the worst case scenario, because bench scale tests had shown that better selectivity and recovery could be achieved with lower reagent dosages when pre-classified feed was treated in flotation (Wu, 1998). The benefit of pre-classification under these conditions would only be the increased retention time. The second scenario assumed that there would be improvement in size by size silica recoveries, and this could result in increased magnetic iron losses due to the unliberated nature of most particles in flotation feed. This was simulated by a 10% increase in maximum possible recoveries ($Rinf_{i,j}$) for all components and sizes. Based on laboratory scale test data, this was a more realistic simulation of a pre-classification circuit.

Results of simulation are summarized in Tables 28 and 29 for Blends 1 and 2, respectively. Regression equations based on mass balanced data were used to convert simulated magnetite grades to % silica in concentrates. Simulated performance of both blends was similar. Data show that there would be 0.3-0.6% improvement in terms of magnetic iron recovery, as well as substantial reductions in reagent consumptions. It would be conservative to assume that the same reagent dosages would be used after the implementation of a modified circuit in the plant. However, even with the same reagent levels, a decrease of 43-45% reagent consumption would be expected due to reduced flow rates to the flotation circuit. With the worst case scenario, silica in the final concentrate was only 0.2% higher than the current levels. Although improved silica separation following pre-classification is expected, this could easily be reduced with increased reagent dosages. Based on these findings, a conservative estimate of reagent benefits would be 40%, whereas with expected improvements in pre-classified flotation, the reagent benefits could go up to 60%.

Table 28. Summary of simulation results for Blend 1. Pre-classification 1: current kinetic parameters; Pre-classification 2: current flotation rates with 10% increased infinite recoveries for both magnetite and gangue

Option	Recovery (%)	Mag. Iron in Final Concentrate (%)	Silica in Final Concentrate (%)
Current	98.1	66.8	4.14
Pre-classification 1	98.8	66.6	4.33
Pre-classification 2	98.6	66.9	4.07

Table 29. Summary of simulation results for Blend 2. Pre-classification 1: current kinetic parameters; Pre-classification 2: current flotation rates with 10% increased infinite recoveries for both magnetite and gangue

Option	Recovery (%)	Mag. Iron in Final Concentrate (%)	Silica in Final Concentrate (%)
Current	98.5	65.9	4.31
Pre-classification 1	98.9	65.9	4.33
Pre-classification 2	98.8	66.1	4.16

The data were also analyzed in terms of final product size distributions. Flotation concentrate goes through subsequent filtration, pelletizing, and induration steps. Changes in size distributions could have an impact on the performance of these processes. Finer feed could create problems in filtration, although it could be beneficial for pelletizing and induration. Nevertheless, it was important to point out potential problems that might occur as a result of this modification at the plant. Simulated pre-classified circuit final concentrate size distribution was compared to mass balanced data. It was found that there was no significant difference in terms of size distributions. Since only a small fraction of flotation feed goes through the ball mill, increased residence time in this mill did not have significant impact on the final product distribution.

Results showed that application of pre-classification at the Ispat Inland plant flotation circuit could increase the recovery by 0.3-0.5% with substantially (40-60%) reduced reagent consumptions.

3.2.3 Increased Feed Rate to the Flotation Circuit

As a result of simulation-based modifications in the magnetic circuit, approximately a 10% increase in rod mill feed rate and magnetic concentrate flow rate is expected. An increase in magnetic concentrate flow rate would reduce the residence time in the flotation circuit and would result in deterioration in flotation circuit performance. Deterioration in product quality, i.e. increased silica in final concentrate, could be controlled by increased amine addition. However, it would help the management to have quantified information about the expected effects of such changes in the circuit. Simulations were carried out to simulate the effect of an increased feed rate to the flotation circuit. This was a relatively easy simulation, since there was not any change in the circuit flow sheet. Therefore, it did not require any test work to define the performance changes expected after the modification. An increased feed rate would reduce the residence time in rougher flotation cells, the regrind ball mill and scavenger cells. This could easily be handled with the simulator. A counter measure to increase the residence time could be the increased feed % solids to the flotation circuit, which could provide the same residence time by proper adjustment. If this adjusted level of solids stays within acceptable limits, there would be less worry for plant managers for adverse effects of the increased rod mill feed rate on the flotation circuit.

Simulations were repeated for both blends and carried out to simulate these two conditions, namely 10% increase in feed rate and required % solids to neutralize the adverse effects due to reduced residence. The database used for simulation represented feed % solids of 24.2% and 28% for Blend 1 and 2, respectively. Results of increased feed rate simulations are summarized in Table 30, which shows that a 10% increased feed rate to the flotation circuit would increase final concentrate silica by 0.05-0.1%, indicating that the flotation circuit has ample capacity to handle the increased feed rate. Further simulations showed that a 2-2.5% increase in flotation feed % solids would counteract this adverse effect to provide the same performance. These numbers show that the flotation circuit could easily handle the expected increase in rod mill feed rate.

Table 30. Results of simulations showing the effect of 10% increase in feed rate to the flotation circuit

	Blend 1		Blend 2	
Feed Rate	Baseline	10% Increased	Baseline	10% Increased
Recovery (%)	98.2	98.3	98.6	98.6
Silica (%)	4.14	4.24	4.31	4.36

3.3 Selection of Most Feasible Alternative

After examining all the simulation data and considering costs involved in implementing each alternative, use of 1½-inch makeup balls appeared to be the most feasible option to implement at the plant. It had a large potential to increase throughput. Although finer balls were more expensive, benefits would easily pay for the additional cost. This alternative also had several advantages; it did not require a capital investment; it would not increase the power draw; no downstream problem was expected; and it was easy to implement. Consequently, this option was selected as primary for plant implementation. It was also concluded that the current hydrocyclones should be replaced by more efficient ones. Such an implementation would guarantee the target throughput against fluctuations in feed grade ore grindability and other ore related variations. It would also have the benefits of eliminating pumping capacity being a bottle neck. This was because the pump overhead would be lower due to a much lower cyclone operating pressure drop, resulting in lower cyclone wear and lower pumping power draws, hence, increasing energy efficiency.

4. VALIDATION OF SIMULATION RESULTS

For validation of simulation study results, three plant sampling surveys were carried out. One of these was preliminary validation and was carried out when partial modification to 1½-inch makeup balls had taken place. The objective was to confirm the accuracy of simulations, as well as to examine if there was any significant change in ore characteristics since the start of the project. Final validation sampling surveys were carried out after the major recommendation, change of makeup ball size, was fully implemented in the plant. When the validation sampling for Blend 1 was carried out, the only modification that had been implemented at the plant was the makeup ball size change. Following full implementation of this change, some upstream problems became visible. The mining operation and crushing unit were not able to provide the increased throughput and existing cobber separators would have higher magnetic iron losses at the expected feed rates. Plant management developed a long-term program to overcome these problems. Over the period, most of these solutions were gradually implemented at the plant. However, completion of all of the upstream work will take some time. The validation sampling for Blend 2 took place after the new cyclones were installed and one of the three existing cobber magnetic separators was replaced with a new one with better efficiency and higher capacity. Therefore, benefits of the modifications have been achieved gradually, and further efficiency improvements as a result of these changes are expected in the near future. Nevertheless, all validation sampling surveys provided plant data that confirmed the findings of simulation studies. Details of the validation studies are presented below.

4.1 Preliminary Validation Study

As a precautionary move, initially, one of the lines was partially (40%) converted to 1½-inch makeup ball size. After running for a period of four months without any upsets in the line, it was decided to carry out limited plant sampling to examine if such a modification was producing the expected benefits. This plant sampling would also reveal if there was any change in ore properties over the three-year period since the first plant sampling survey was carried out. Two parallel lines (Lines 1 and 3), with and without modification, were sampled while the plant was processing Blend 1 on April 1, 2004. During the sampling period, the modified line (Line 1) was already running at 10 LTPH higher rod mill feed rate, despite this historically being a lower throughput line. Samples went through size and head chemistry analyses. Raw data from the two lines were mass balanced and performance was compared to the original data and used as a basis for the validation and simulation study. Mass balanced data are presented in Appendix E and summarized in Tables 31 and 32.

Detailed examination of plant data indicated that there was no significant change in the performance of the line without the modification since the first Blend 1 plant sampling was carried out. The only differences noted were the cobber and rougher magnetic separator performance. It was found that: currently, less tails were separated at the cobbing, and this was balanced with more tails rejection at the roughers. It was suggested that this could have occurred as result of changes in mineralogy, in operating practice, or both. Davis tube tests were performed on the cobber products. Test data were compared to the original set of data. Results showed that there was not significant change in terms of liberation. Therefore, it was concluded that operating practices were the dominant factor in this behavior. Nevertheless, this did not create a problem in assessing the effects of modifications, since cobbers on the two lines were operating in a similar fashion.

Table 31. Plant performance summary for the preliminary validation sampling

Stream	**% Mag Iron Recovery/ Loss**		
	Blend 1	Line 1	Line 3
Cobber Tails	1.9	1.9	2.3
Rougher Tails	1.2	2.0	1.9
Hydroseparator O/F	0.2	0.2	0.2
Fine Screen U/S	96.7	95.9	95.6

Mass balanced flow rates and size distributions were used to simulate the ball mill with a 30% 1½-inch makeup ball charge. A very good fit between measured and simulated size distributions was observed (Figure 20). Bond tests were also performed and indicated that there had not been any significant change in ball mill grindability of the cobber concentrates despite a three-year difference between the two sampling periods. Encouraged by the observed throughput increase in this particular line, it was decided to convert all three lines at the plant to use 1½-inch makeup balls.

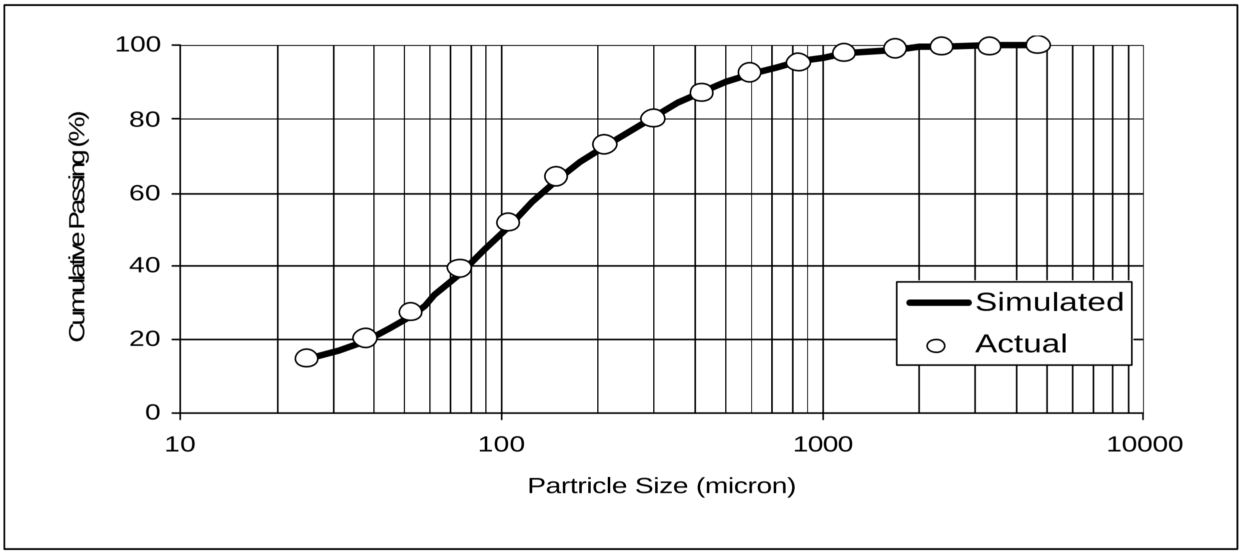

Figure 20. Ball mill discharge size distributions: Simulated vs. actual after 40% 1½-inch makeup ball charge

Table 32. Mass balanced data from the preliminary validation sampling in comparison with the baseline data for Blend 1

Stream	**Flow Rate (LTPH)**			**% Total Iron**			**% Silica**		
	Blend 1	Line 1	Line 3	Blend 1	Line 1	Line 3	Blend 1	Line 1	Line 3
Feed	350	360	350	33.6	32.1	32.7	45.4	46.8	47.9
Cobber Conc.	237	263	251	42.7	38.2	39.2	34.1	39.8	38.7
Cobber Tails	113	97	98	14.5	15.6	16.0	69.1	65.8	71.4
Ball Mill Disch.	1536	1313	1252	51.5	48.1	49.6	23.2	28.1	25.1
Rougher Conc.	1454	1194	1140	53.9	51.4	52.9	20.4	24.1	20.9
Rougher Tails	82	119	113	13.2	15.0	16.1	71.8	68.2	67.0
Cyclone O/F	303	199	237	56.6	55.1	56.2	18.2	19.6	18.2
Cyclone U/F	1152	994	903	53.1	50.7	52.1	21.0	25.0	21.6
Hydrosep. O/F	13	13	12	11.5	13.3	13.0	68.7	65.3	67.0
Hydrosep. U/F	290	186	225	58.6	58.0	58.5	16.0	16.3	15.6
Fine Screen O/S	148	55	98	53.5	49.1	53.6	22.5	28.1	21.8
Fine Screen U/S	142	131	127	64.6	61.9	62.3	9.1	11.3	10.8

4.2 Final Validation Study

4.2.1 Blend 1

Final plant sampling for Blend 1 was carried out, after the plant had operated with 1½-inch makeup balls for approximately one year. During this period, plant throughput measurements clearly indicated that more than a 10% increase in throughput was achieved. This increase resulted in a decrease in energy used per ton of concentrate production. However, it also became apparent that upstream unit operation would have problems in supplying the increased ore demand by the plant. Unfortunately, plant sampling had to be carried out during such a period. The line was running with a rod mill feed rate of 360 t/h. This was higher than expected throughput without the modification, but it fell short of the target rod mill feed rate of 385 LTPH. Nevertheless, plant data could still validate the simulation no matter what the feed rate was. Major operating conditions recorded during Blend 1 validation sampling are presented in Table 33.

Table 33. Major operating conditions during Blend 1 validation sampling

Operating Variable (Unit)	**Recorded Value**
Rod Mill Feed Rate (LTPH)	360
Rod Mill Power Draw (kW)	1525
Ball Mill Power Draw (kW)	3725
Cyclone Pressure (psi)	20
Cyclone Feed % Solids	46
Hydroseparator U/F % Solids	55
Hydroseparator U/F Rate (GPM)	1351

Plant sampling and sample analysis followed the same procedure as the initial sampling. The only difference was that size by size chemical analyses were limited to magnetic (Satmagan) iron only. Operating conditions were recorded and raw data were mass balanced. Raw and mass balanced data for the magnetic circuit are presented in Appendix F. Calculated flow rates and a summary of magnetic circuit performance are given in Tables 34 and 35, respectively. Mass balanced data were used for comparison with simulations.

Table 34. Summarized mass balance of validation sampling data for Blend 1

Stream	**Flow Rate (LTPH)**	**Mag Iron (%)**	**Total Iron* (%)**	**Silica* (%)**
Feed	360	25.2	33.0	44.2
Cobber Concentrate	253	35.2	41.8	34.2
Cobber Tails	107	1.62	12.1	67.2
Ball Mill Discharge	1240	46.4	50.7	24.2
Rougher Conc.	1133	50.7	54.4	20.3
Rougher Tails	107	1.72	13.0	67.3
Cyclone O/F	277	55.9	58.3	15.8
Cyclone U/F	856	49.0	53.6	20.6
Hydroseparator O/F	9	2.36	13.1	65.8
Hydroseparator U/F	268	57.6	60.2	14.0
Fine Screen O/S	131	51.6	54.1	21.3
Fine Screen U/S	137	63.3	64.6	8.98
Finisher Tails	5	11.0	25.3	50.0
Finisher Conc.	132	65.3	66.6	6.67

* Not included in mass balancing

Table 35. Performance summary for validation sampling for Blend 1

Stream	**Flow Rate (%)**	**Recovery (%)**
Cobber Tails	29.8	2.0
Rougher Tails	29.6	2.0
Hydroseparator O/F	2.4	0.2
Finisher Tail	1.4	0.6
Magnetic Concentrate	36.8	95.2

Although no modifications were implemented in the flotation circuit, validation plant sampling included this circuit to examine any changes occurring as a result of possible changes in mineralogy and increased throughput. However, during the plant sampling survey, a froth stability problem occurred and sampling of the flotation circuit was cut short. Later, it was found out that the circuit upset was due to a mechanical problem that was fixed. Nevertheless, the samples were analyzed and mass balanced. Raw and mass balanced flotation data are presented in Appendix G and summarized in Table 36. A comparison of baseline to validation data shows that magnetic iron and mass recoveries were lower during the the validation sampling period. This most probably was due to higher amounts of amine added to the circuit as a result of the mechanical problem experienced during sampling. The same phenomenon also caused the froth stability problem. Otherwise, no significant change in flotation performance was observed.

Table 36. A summary of Blend 1 flotation circuit mass balance for validation sampling as compared to baseline study

Stream	**Mag Iron Recovery/Loss (%)**		**Flow Rate (%)**	
	Baseline	**Validation**	**Baseline**	**Validation**
Dewater. MS Tails	0.3	0.2	1.2	0.5
Froth Thick. Tails	0.03	0.3	0.1	0.5
Scavenger Tails	1.5	2.6	4.3	5.6
Con. Thick. Tails	0.02	N/A	0.1	N/A
Final Concentrate	98.2	96.9	94.3	93.5

Plant sampling conditions were simulated using model parameters determined from the original data. The following data representing the new conditions were modified: rod mill feed rate, rod mill feed size distribution, rod and ball mill charge levels, and hydrocyclone and fine screen feed % solids. Mill charge levels were not directly measured. Instead, they were adjusted for the recorded power draws. As shown in Table 37, this simulation provided a very good fit to mass balanced data in terms of flow rates, grades, and recovery, validating the findings of the original simulations.

Table 37. A comparison of simulated and actual performance of the magnetic circuit after the modifications were implemented at the plant

Performance criteria	**Simulated**	**Actual**
Feed Rate (t/h)	360	360
Ball Mill Discharge Rate (t/h)	1228	1239
Hydrocyclone Pressure (psi)	20.2	20
Fine Screen Feed Rate (gpm)	1363	1351
Magnetic Concentrate		
80% Passing Size (micron)	44	45
Magnetic Iron (%)	65.0	65.3
Recovery (%)	96.0	95.2

Comparison of simulated and actual data was also carried out for individual pieces of equipment. As had occured with the limited plant sampling data taken after partial (40%) modification of makeup ball size, the magnetic separators showed unsatisfactory deviations from the simulated data. Each piece of equipment was individually simulated, and simulated size distributions of major streams were compared to actual (Figure 21). Particularly, the simulated size distribution of the ball mill discharge provided an excellent fit to the actual. Others were also very good. These findings validated the simulation results.

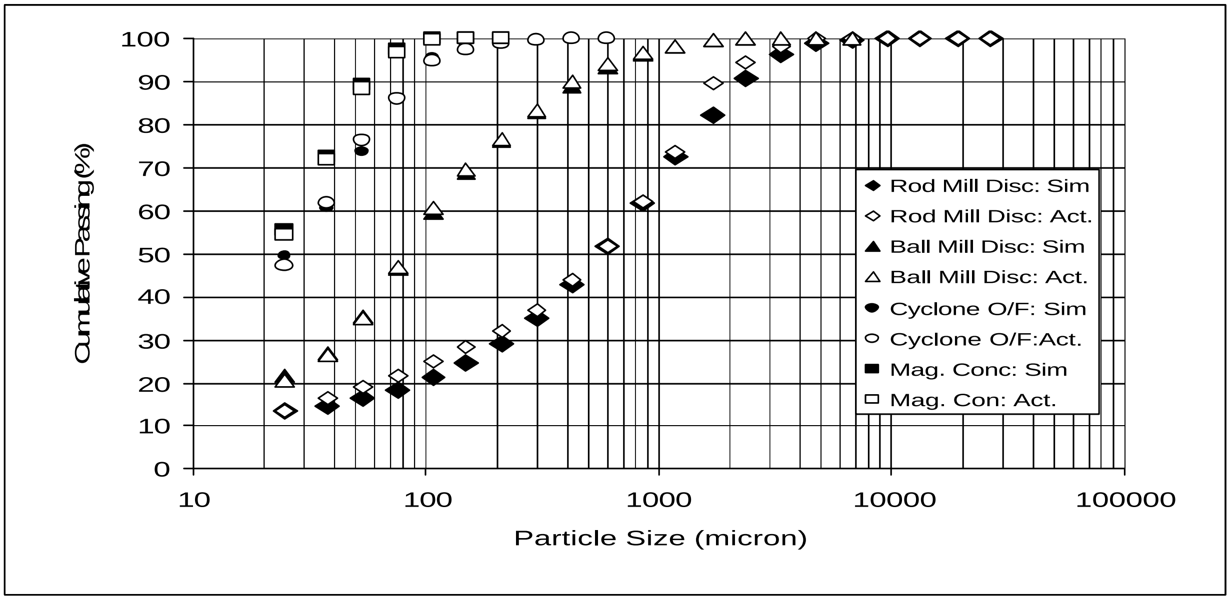

Figure 21. Simulated and actual size distributions of major streams in the circuit after implementation of 100% 1½-inch makeup ball size modification

4.2.2 Blend 2

Sampling for Blend 2 took place in Line 3 on November 1, 2005. By this time, the existing 15-inch cyclones had been replaced by more efficient 20-inch gMax cyclones, and installation of the new cobber magnetic separators was in progress. Replacement of the existing cobber magnetic separator was mainly undertaken due to the inability of existing magnetic separators to efficiently process the increased flow rates resulting from higher throughput. They were also old and required a high level of maintenance. The new cobber separators would be able to handle the expected flow rates and provide higher magnetic recovery at this stage of separation. Prior to sampling, one of the two new cobber separators had been installed and was processing 1/3 of the rod mill discharge. The rest of the stream was still being processed by the old cobbers. It was thought that plant sampling under these conditions would provide an opportunity to compare the performance of old and new cobber separators, as well as validating results of simulations. The Line was running at 360 LTPH feed rate. This corresponded to an increase of 45

LTPH (14.3%) for this blend, as compared to the baseline study. Major operating conditions during sampling are presented in Table 38.

Table 38. Major operating conditions during Blend 2 validation sampling

Operating Variable (Unit)	**Recorded Value**
Rod Mill Feed Rate (LTPH)	360
Rod Mill Power Draw (kW)	1425
Ball Mill Power Draw (kW)	3795
Cyclone Pressure (psi)	14.1
Cyclone Feed % Solids	49.2
Hydroseparator U/F % Solids	55.5
Hydroseparator U/F Rate (GPM)	1342

Raw and mass balanced data for the Blend 2 validation study are presented in Appendices H and I for the magnetic and flotation circuits, respectively. A summary of mass balanced data for the magnetic separation circuit is presented in Table 39. Performance of the magnetic and flotation circuits is summarized in Tables 40 and 41.

Table 39. Summarized mass balance of validation sampling data for Blend 2

Stream	**Flow Rate (LTPH)**	**Mag Iron (%)**	**Total Iron* (%)**	**Silica* (%)**
Feed	360	23.0	34.0	45.3
Old Cobber Feed	205	22.3	35.8	41.2
New Cobber Feed	155	24.0	37.3	38.9
Old Cobber Con	137	31.9	42.6	32.2
New Cobber Con	134	27.7	39.6	38.0
Old Cobber Tails	68	2.9	19.9	62.6
New Cobber Tails	21	1.2	168	63.9
Classifier Sands	61	3.0	19.5	64.3
Classifier Fines	28	1.4	16.1	63.4
Ball Mill Discharge	1189	40.4	49.8	27.6
Rougher Conc.	1058	45.2	52.8	22.7
Rougher Tails	132	1.5	18.3	67.6
Cyclone U/F	820	42.8	49.5	26.4
Cyclone O/F	238	53.3	57.5	16.2
Hydroseparator O/F	8	2.0	17.1	63.5
Hydroseparator U/F	229	55.2	59.6	13.5
Fine Screen O/S	99	48.7	53.4	20.9
Fine Screen U/S	131	60.1	64.0	7.89
Finisher Tails	8	2.2	1.47	44.8
Finisher Conc.	123	63.8	66.4	5.79

* Not included in mass balancing

Table 40. Performance summary for validation sampling as compared to baseline data for Blend 2

Stream	**Flow Rate (%)**		**Recovery (%)**	
	Baseline	Validation	Baseline	Validation
Old Cobber Tails	N/A	18.9	N/A	2.4
New Cobber Tails	N/A	5.9	N/A	0.3
Total Cobber Tails	37.5	24.8	2.8	2.7
Rougher Tails	25.0	36.6	1.6	2.4
Hydroseparator O/F	1.3	2.3	0.3	0.2
Finisher Tail	2.0	2.2	0.3	0.2
Magnetic Concentrate	33.5	34.1	95.0	94.5

Table 41. A summary of Blend 2 flotation circuit mass balance for validation sampling as compared to baseline study

Stream	Mag Iron Recovery/Loss (%)		Flow Rate (%)	
	Baseline	Validation	Baseline	Validation
Dewater. MS Tails	0.1	0.3	0.3	0.7
Froth Thick. Tails	0.2	0.1	0.4	0.2
Scavenger Tails	1.2	2.4	3.2	5.9
Final Concentrate	98.5	97.2	96.2	93.3

Compared to the baseline study, magnetic iron recoveries both in magnetic and flotation circuits were slightly lower. Recovery decrease in magnetic circuits appears to stem from rougher magnetic separators. This might have been a result of the transition period while cobbers were being replaced. It was expected that it would take some time to optimize operation of the new separators. Although the new cobber separators had much higher magnetic iron recovery (Figure 22), they were separating much less of the gangue minerals, particularly at the coarse size range (Figure 23). It is plausible that lower feed grades to roughers due to inefficient separation of gangue in the new cobber separator was at least partially responsible for high magnetic iron losses at this stage. Higher feed rates and changes in mineralogy might have played some role in lowering the magnetic circuit recovery.

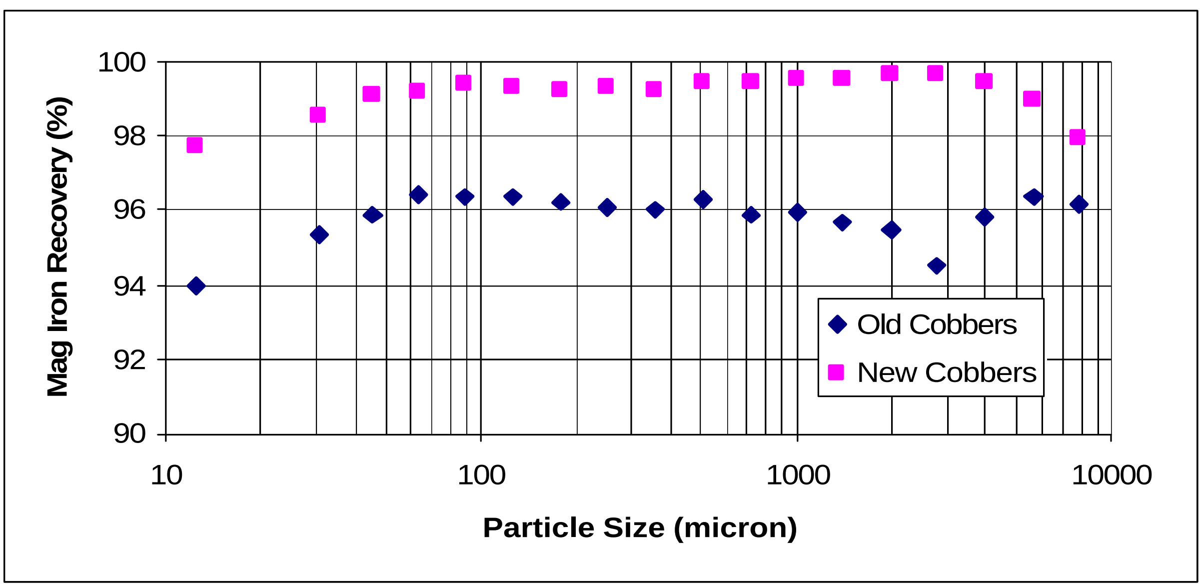

Figure 22. A comparison of size by size magnetic iron recoveries in old and new cobbers

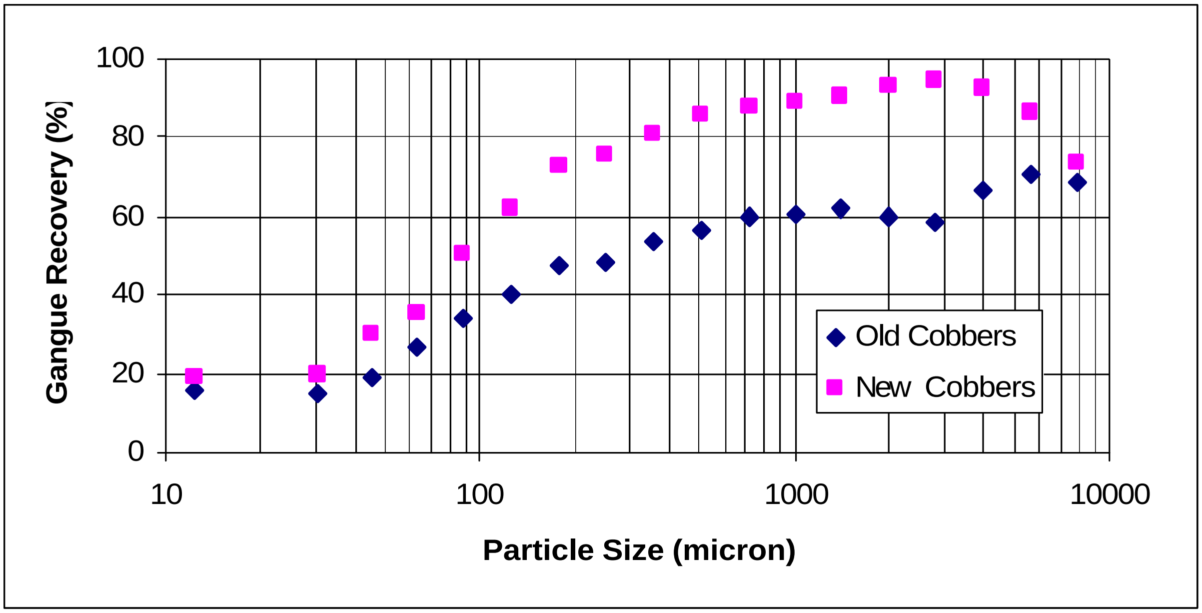

Figure 23. A comparison of size by size gangue recoveries in old and new cobbers

In the flotation circuit, a major source of magnetic iron losses was from the scavenger cells. Losses in scavenger tails were doubled. This was probably due to mineralogy requiring higher levels of amine addition to get the same level of silica in the final concentrate.

Although it was expected that a magnetic circuit simulation based on baseline data for Blend 2 would not provide a satisfactory fit to the validation data, particularly due to new equipment installations on the line, a circuit simulation was carried out to determine the capability of the simulator under such extreme conditions. Considering the circumstances, the fit to the major performance data was surprisingly good (Table 42). However, examination of individual unit data showed deviations that, for the most part, had been expected. It appeared that performance variation created by the cobber magnetic separators was balanced out by the roughers. This eventually provided a good fit to the actual plant performance data.

Table 42. A comparison of simulated and actual performance of the magnetic circuit for Blend 2 after the modifications were implemented at the plant

Performance criteria	**Simulated**	**Actual**
Feed Rate (t/h)	360	360
Ball Mill Discharge Rate (t/h)	1180	1189
Hydrocyclone Pressure (psi)	17.0	14.1
Fine Screen Feed Rate (gpm)	1068	1342
Magnetic Concentrate		
80% Passing Size (micron)	49	50
Magnetic Iron (%)	64.5	63.8
Recovery (%)	94.7	94.5

Performance of individual pieces of equipment was also analyzed using simulation as a tool. Individual devices were simulated using mass balanced feed data and operating conditions recorded during plant sampling. This analysis is presented below.

Rod Mill

As compared to the baseline study, the rod mill power draw was substantially lower, feed rate was higher and feed size distribution was slightly coarser. As expected, much coarser rod mill discharge was produced. This could have been due to increased feed rate, lower power draw, changes in feed size distribution, and changes in ore grindability. Rod mill operation during validation sampling was simulated using model parameters representing the baseline data. Such a simulation took into account the effects of the first three factors excluding grindability. Simulated and actual, as well as the baseline, rod mill discharge size distributions are presented in Figure 24. Large difference between actual simulated validation sampling size distributions imply that changes in ore grindability are likely to be a factor for having coarser rod mill discharge size distribution. Absence of such a shift in size during Blend 1 validation sampling at the same feed rates rules out a plausible explanation that rod mill overloading might have been the cause of the problem.

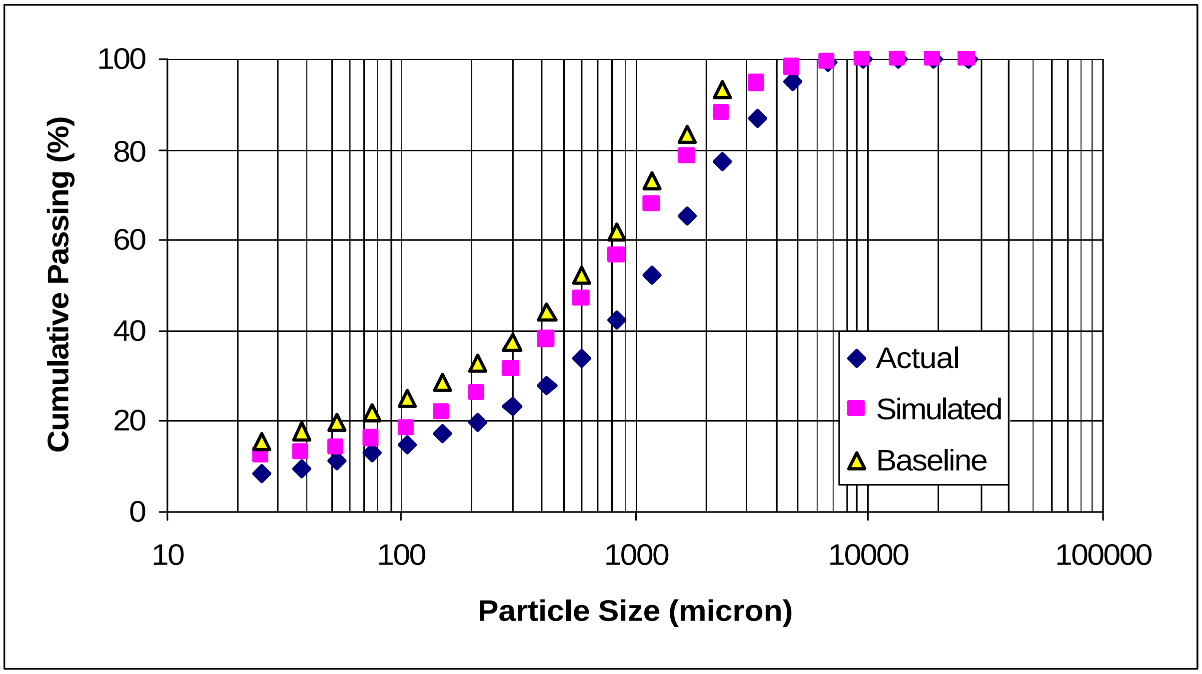

Figure 24. Actual, simulated and baseline size distributions of rod mill discharge stream for Blend 2

Since the ball mill was the focus of the study, cobber concentrates were used for determining changes in grindability. Laboratory work indices of these samples did not indicate any large shift in ore grindability. However, operating work indices calculated from the plant data indicated a large shift (from 26 to 36 KWh/LT). The contradictory findings between the two observations could be due to separation of hard to grind gangue particles during the cobbing stage. Nevertheless, having a coarser size product from the rod mill would have implications for the downstream unit operations, particularly the ball mill operation. It would be recommended that the actual cause of such an increase in rod mill discharge size distribution should be further investigated and the rod mill power draw should be kept at its maximum by having sufficient rod charge in the mill to minimize downstream adverse effects.

<u>Old cobbers</u>

Actual and simulated performances of old cobbers are compared in Figures 25 and 26, which indicates that cobber performance had deteriorated over the two-year period. Iron recoveries were substantially lower, while there was slight deterioration in separation efficiency of fine gangue particles. This provided further justification for the replacement of old cobbers.

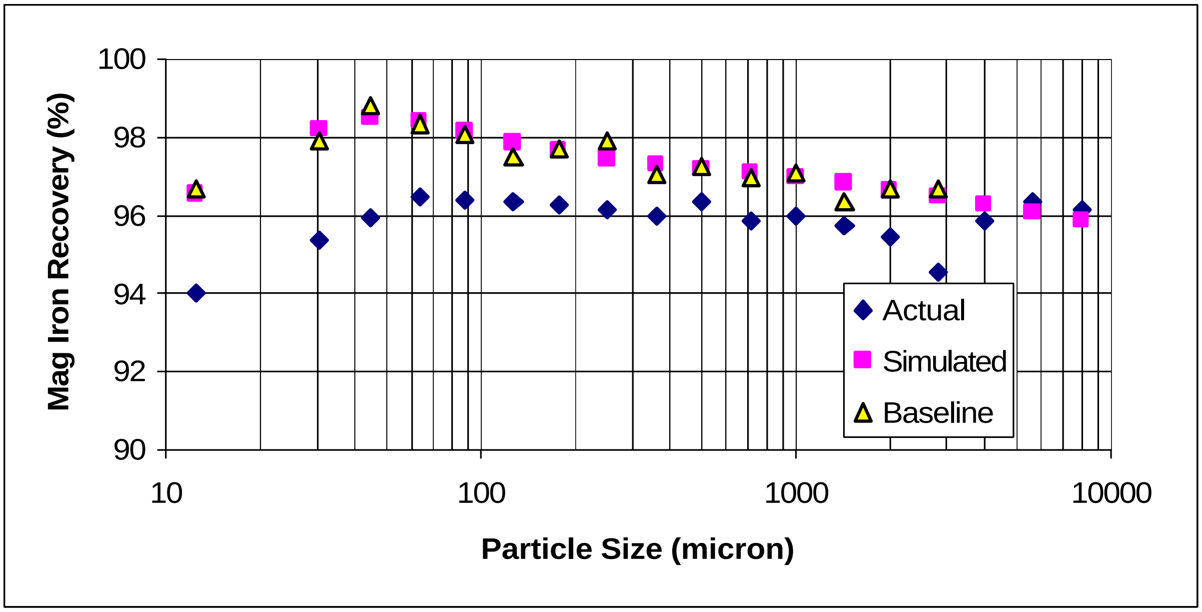

Figure 25. Actual and simulated Blend 2 validation sampling magnetic iron recoveries in old cobbers as compared to the baseline data

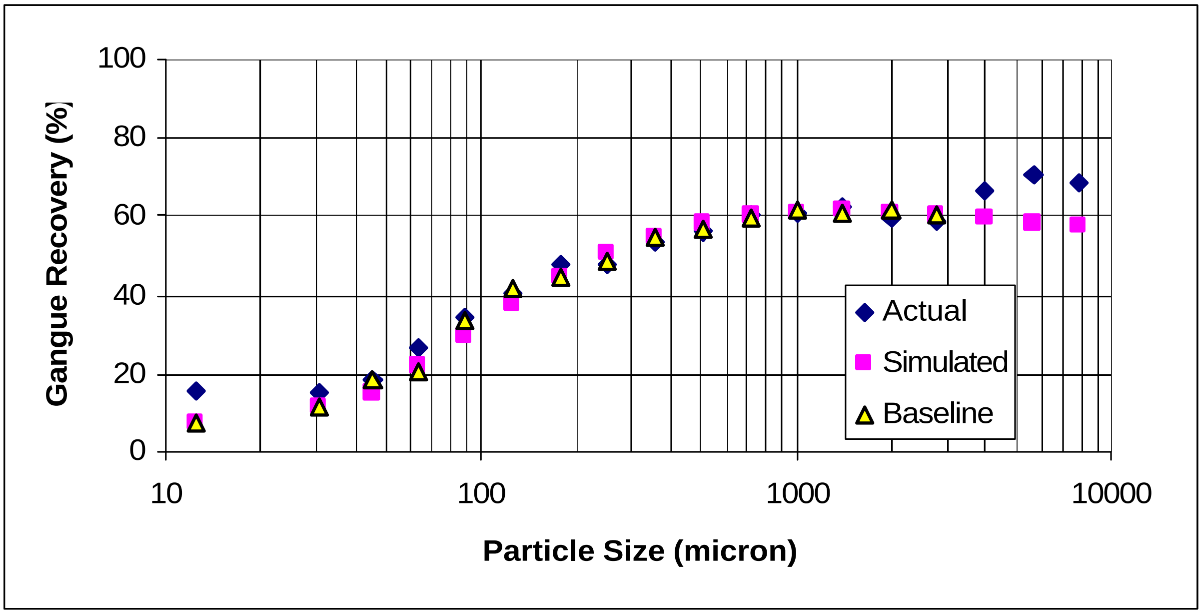

Figure 26. Actual and simulated Blend 2 validation sampling gangue recoveries in old cobbers as compared to the baseline data

Ball mill

Actual and simulated ball mill discharge distributions are illustrated in Figure 27. Although the two data sets appear to be similar, there appears to be some deviation at the coarse end. The actual ball mill discharge had higher amounts of very coarse particles as compared to simulated. Ball mill data were examined to find possible causes of this deviation. It was found that the fresh feed (combined cobber concentrates) to the ball mill was much coarser than baseline and what was anticipated when makeup ball size was modified. Data analysis also indicated that this was partially due to the rod mill power draw being lower than average. Power draw was 12% lower than the average rod mill power draw of 1600 kW, which in practical terms implies that rod charge in the mill was too low. As noted above, changes in ore mineralogy might have contributed to such an increase in fresh feed size distribution to the ball mill. These findings were brought to the attention of plant engineers. Due to the coarseness of the ball mill discharge stream, there was a tendency among the plant engineers to switch to partial addition of coarser makeup balls. It was suggested that rod mill power draws should be kept high and cobber concentrate size distribution should be monitored, before any modification is implemented at the plant.

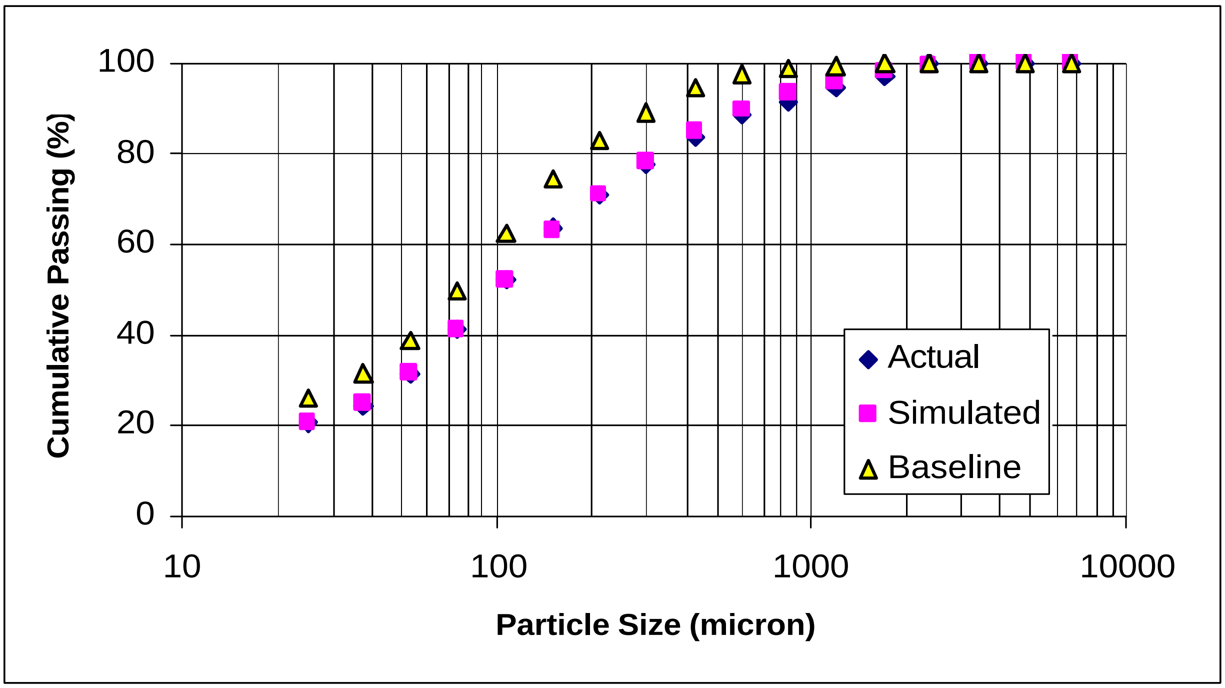

Figure 27. Actual and simulated size distributions of the ball mill discharge size distributions during the Blend 2 validation sampling as compared to the baseline data

<u>Rougher Magnetic Separators</u>

Actual and simulated magnetite and gangue recoveries are illustrated in Figures 28 and 29. Despite overall magnetic iron recovery being higher than the baseline for this ore, the simulated magnetite recoveries had a very good fit to the actual. This implies that higher magnetic iron losses were mostly due to inefficient separation of gangue particles at the cobbing stage. In terms of gangue separation, efficiency was better at the fine size range, but worse at the coarse end. Lower efficiency for coarse sizes was probably due to changes in mineralogy. The overall fit of the simulated data to actual plant data was satisfactory.

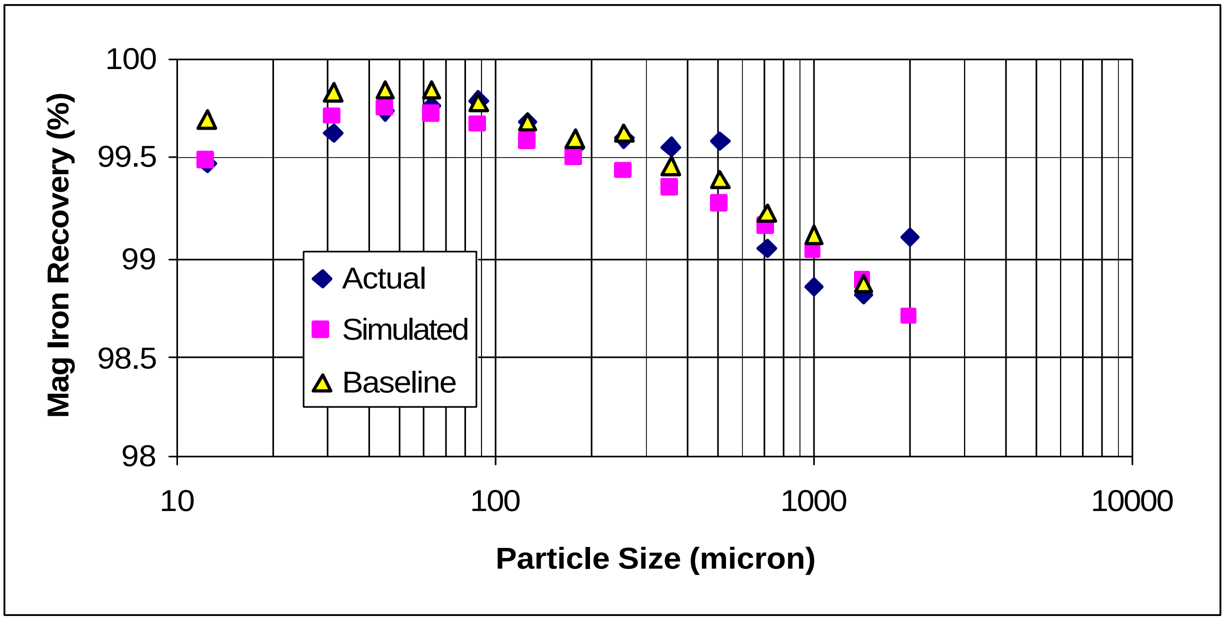

Figure 28. Actual and simulated Blend 2 validation sampling magnetic iron recoveries in rougher magnetic separators as compared to the baseline data

Hydrocyclones

After the installation of new hydrocyclones, their performance was monitored. Initial data indicated that they would not deliver the expected separation efficiency. After the initial period, the apex size of the new cyclones was changed from 4-inch to 3½-inch and this lowered the bypass substantially, though it was still higher than anticipated prior to the installation. Blend 2 validation sampling was carried out after the plant started using 3½-inch apex sizes. It was also observed that rubber apexes were wearing out fast, increasing to 4¾-inches after several months of use before they were replaced. Blend 2 validation sampling was carried out after the plant started using 3½-inch apex sizes.

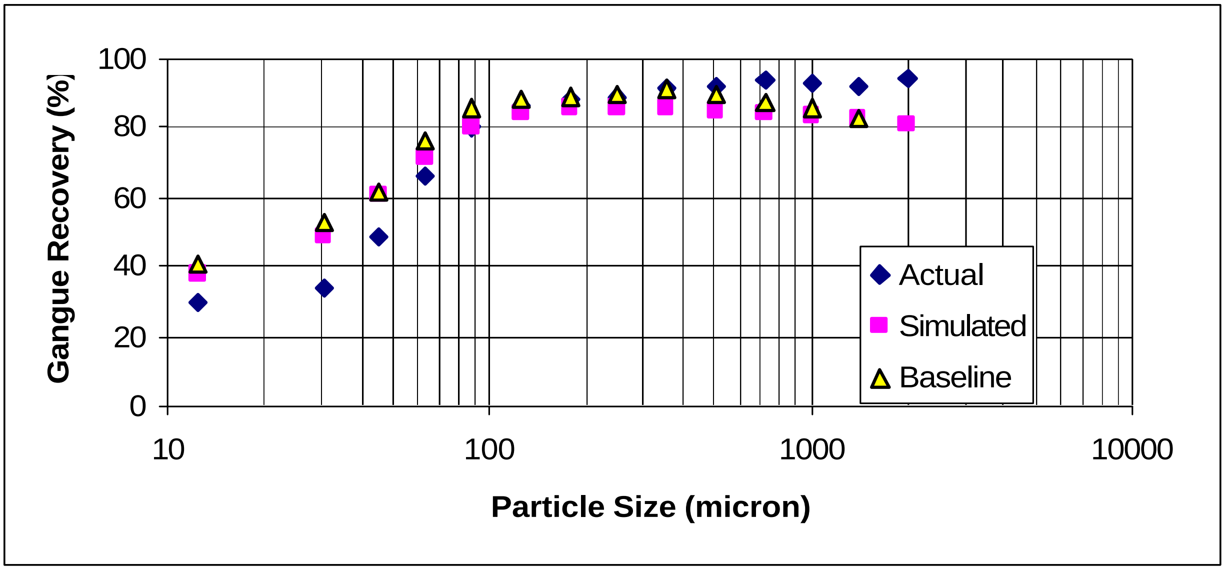

Figure 29. Actual and simulated Blend 2 validation sampling magnetic iron recoveries in rougher magnetic separators as compared to the baseline data

However, the new cyclones had a much lower operating pressure for the same size separation. This enabled variable speed pumps to operate at lower speeds to transport the same volume of slurry, thereby providing energy benefits.

Partition curves for Blend 2 validation and baseline sampling periods are compared in Figure 30. It shows that new cyclones reduced the bypass by about 15%. However, even with the new cyclones, bypass was still in the high range at 40%. It appears that the shape of the partition curve did not change, implying that imperfection was almost the same. In terms of overflow size distributions, the validation sampling data were slightly coarser, particularly on the fine end (Figure 31). Although the new cyclones did not deliver the expected results, there was substantial improvement in the performance and energy efficiency. For further improvement of hydrocyclone performance, the available hydrocyclone database was examined. This investigation concluded that the magnetization of fine particles in rougher magnetic separators could be a major factor causing the high bypass. Mineral-based partition curves revealed that gangue bypass was much lower than magnetite. This implied that magnetically flocculated fine particles were behaving like a coarse particle within the hydrocyclone eventually leaving it in the underflow stream. This also explained why the magnetic iron contents of fine fractions were substantially higher than the corresponding sizes in the overflow stream. This finding led to a recommendation that demagnetizing coils should be installed around the pipe feeding the cyclones. It is expected that such a coil will be installed in the plant very soon. This will provide further energy benefits by eliminating unnecessary grinding of fine liberated magnetite particles.

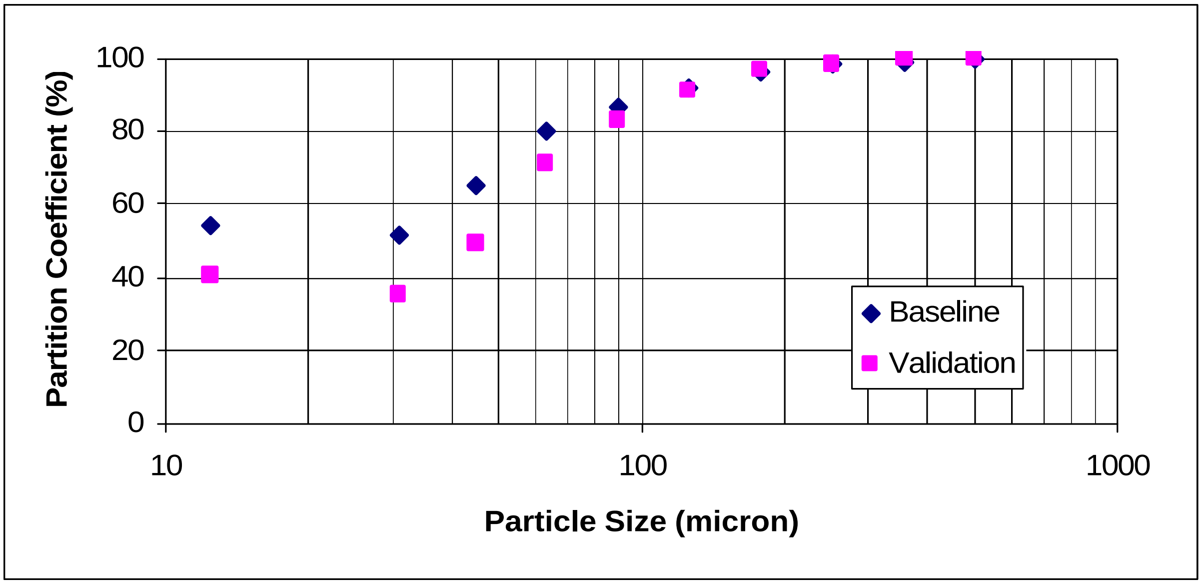

Figure 30. A comparison of baseline (old) and validation (new) hydrocyclone performances

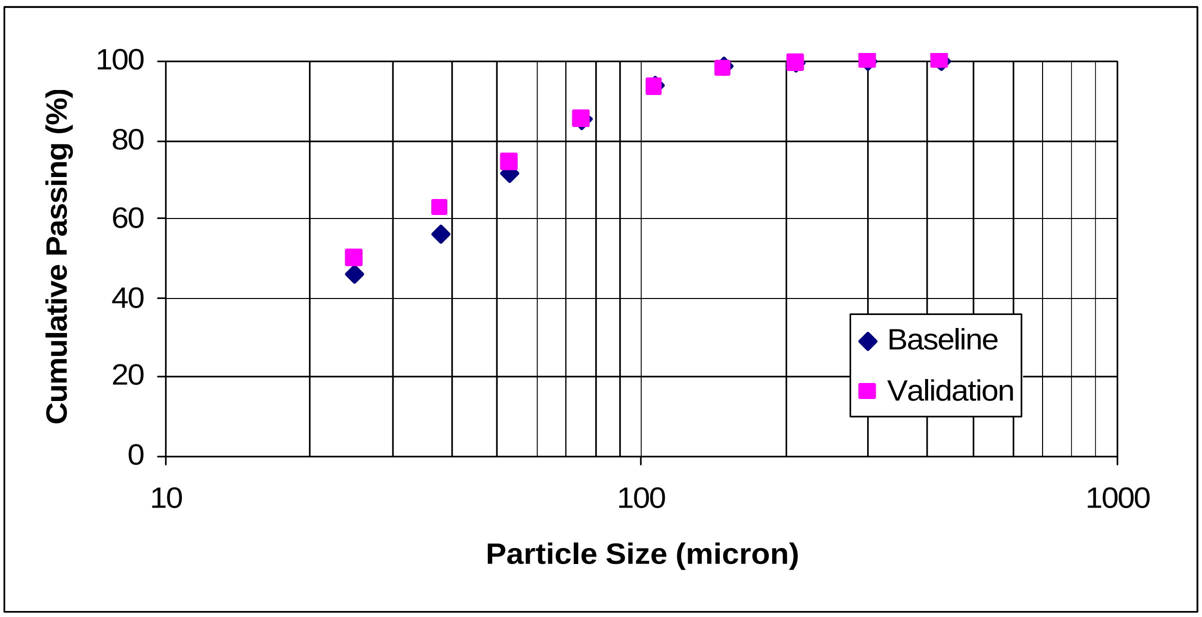

Figure 31. A comparison of baseline (old) and validation (new) hydrocyclone overflow size distributions

Hydroseparator

Despite the large difference between the baseline and validation sampling operating conditions and performance, there was excellent agreement between the simulated and actual partition curves of the hydroseparator, Figure 32. As expected, a good fit between the flow rates was also observed.

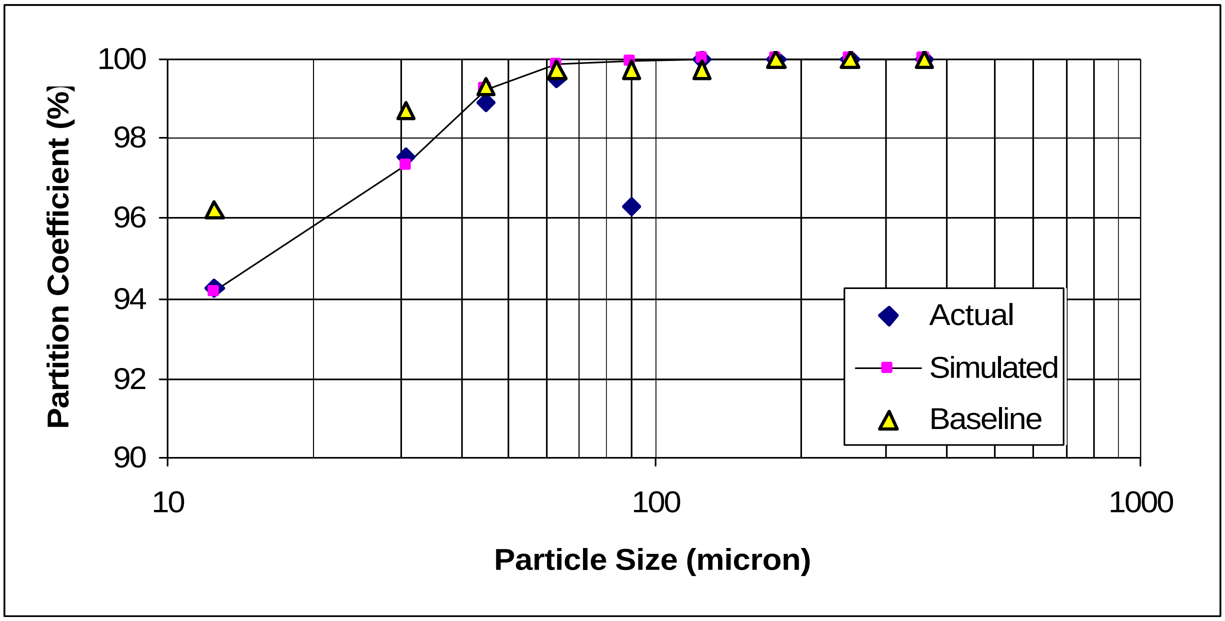

Figure 32. Actual and simulated performance of hydroseparator during validation sampling as compared to the baseline data

Fine Screens

The fine screen model provided a good fit to the validation data (Figure 33). Minor deviations observed for bypass and cut size were attributed to the presence of two Smart Screens in the stack of eight fine screens. The model was developed for Derrick-type fine screens, and during the baseline sampling for Blend 2, eight screens of this type were running. The model was able to simulate the large variation in feed rate and particle size distribution as well as minor variation in feed % solids.

Finishers

Simulated and actual performances of finisher magnetic separators are illustrated in Figures 34 and 35. In general, the fit was satisfactory. Close examination of data revealed that actual iron recoveries were slightly higher than simulated, whereas gangue separation efficiency was slightly compromised. The difference between these two observations is typical of higher % solids in the magnetic separators, which was not accounted for in the model.

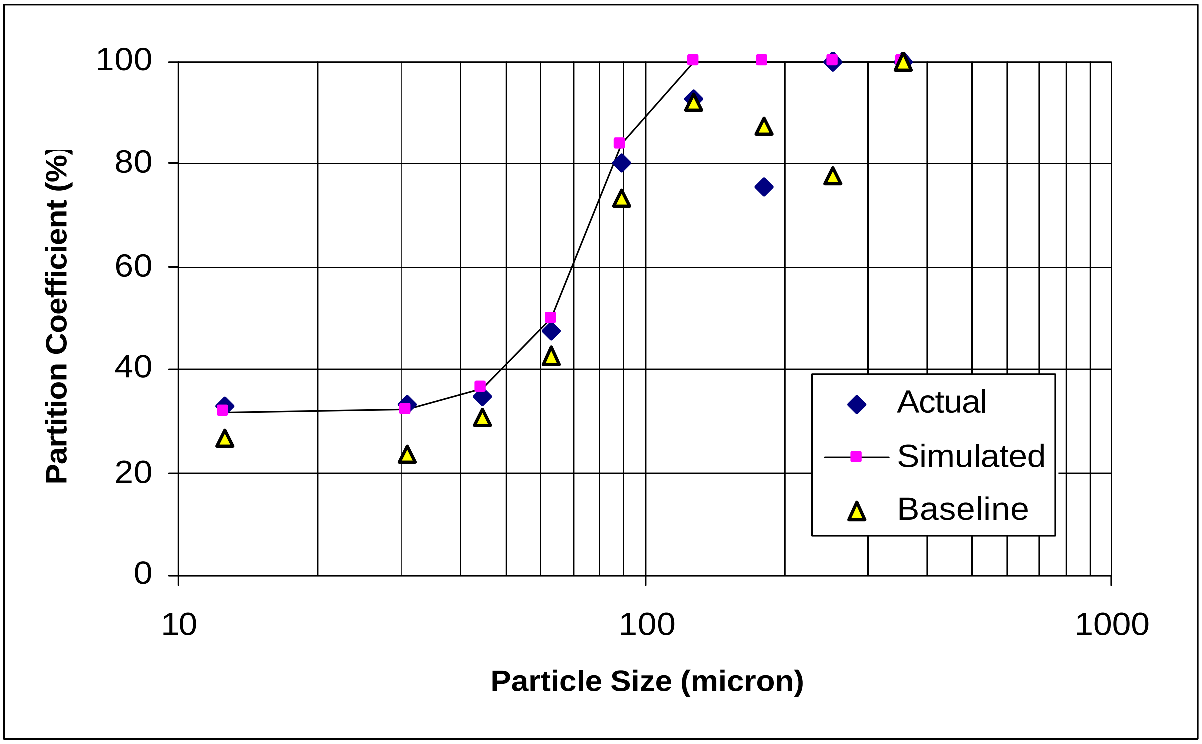

Figure 33. Actual and simulated performance of fine screens during validation sampling as compared to the baseline data.

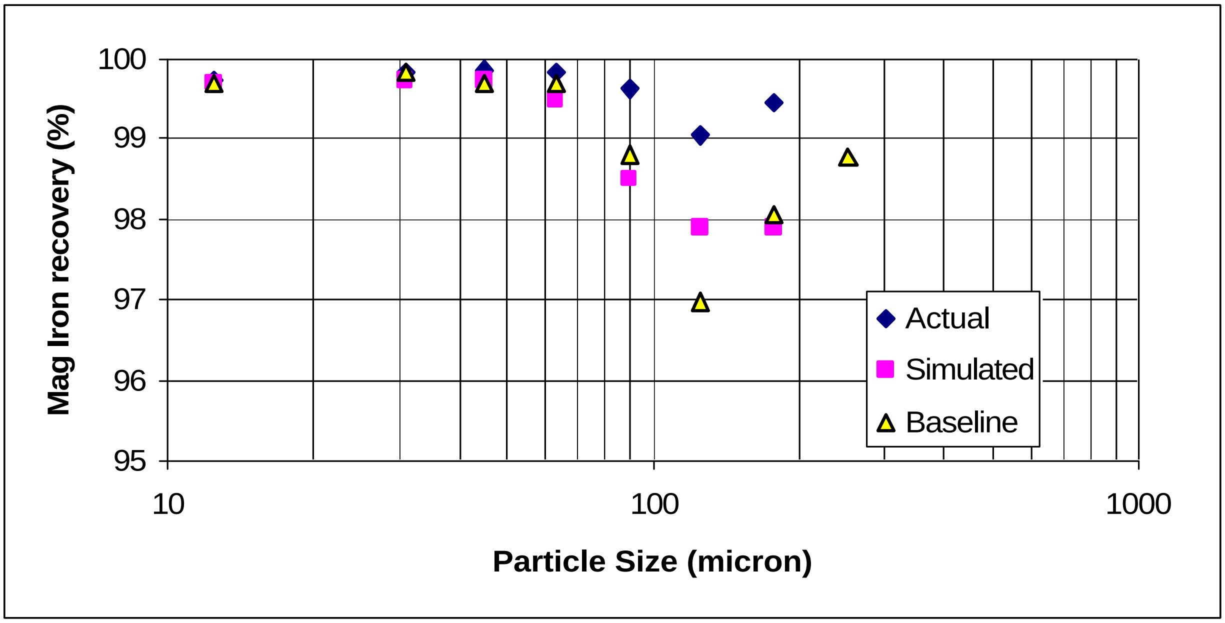

Figure 34. Actual and simulated Blend 2 validation sampling magnetic iron recoveries in finisher magnetic separators as compared to the baseline data

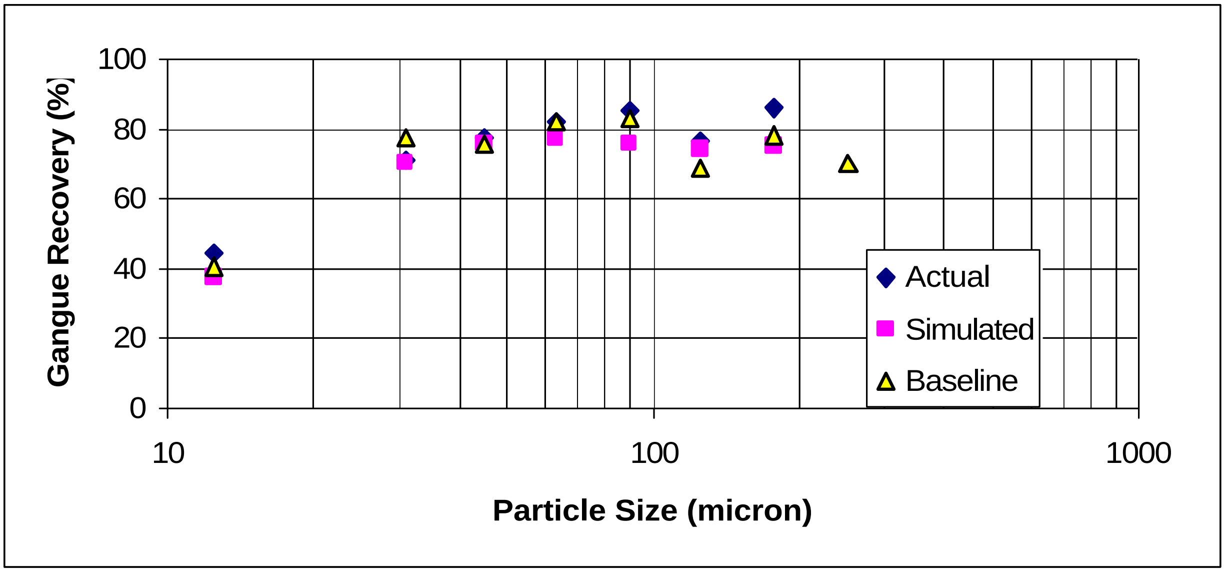

Figure 35. Actual and simulated Blend 2 validation sampling gangue recoveries in finisher magnetic separators as compared to the baseline data

In conclusion, Blend 2 validation sampling had double benefits: It not only confirmed the findings of the simulation study, but also provided clues for further improvements. In general, the fit of simulated data to the actual plant data was very good. The only major deviation was observed at the rod mill, and this appeared to be due to the change in ore grindability.

5. IMPROVEMENTS IN ENERGY EFFICIENCY

Two studies were carried out by plant engineers to compare the energy efficiencies of the plant before and after simulation-based modifications were implemented. Reports of these studies are presented below.

5.1 Study 1: 1-1/2 Inch Grinding Ball Benefit Evaluation

The conversion schedule to 1-1/2" balls was as follows:

Line 1 – November 2003 – Begin charging 40% 1-1/2" balls
Line 1 – February 2004 – Begin charging 100% 1-1/2" balls
Line 2 – April 2004 – Begin charging 100% 1-1/2" balls
Line 3– August 2004 – Begin charging 100% 1-1/2" balls

shows data from periods "before" and "after" conversion to 1-1/2" grinding balls. It includes data from each line, since the transitions occurred at different times. The change in the energy consumption per ton of feed (kWh/T) is a measure of the improvement in grinding efficiency. (Note - The kWh/T values only include grinding energy consumed in the rod mills and ball mills)

Table 43. A comparison of grinding energy use
before and after the conversion to 1½-inch makeup balls

	Ball Size	Months Included	kWh/T	RMF Mag Fe	% -325 M	kWh/T % Reduction
Combined	**All 2'**	1/02 - 10/03	16.26	23.51	80.31	
Data	**Transition**	11/03 - 12/04	15.05	23.94	78.17	7.43%
	All 1-1/2"	1/05 - 3/05	15.08	23.48	83.52	7.26%
Line 1	**2"**	1/02 - 10/03	17.35	23.51	80.51	
	1-1/2"	5/04 - 3/05	14.76	23.86	78.38	14.92%
Line 2	**2"**	1/02 - 3/04	16.14	23.27	80.64	
	1-1/2"	7/04 - 3/05	15.19	23.61	78.92	5.89%
Line 3	**2"**	1/02 - 9/04	15.34	23.69	79.01	
	1-1/2"	1/05 - 3/05	14.67	23.48	84.84	4.32%

Included in the table are the average rod mill feed magnetic irons and concentrate %-325 mesh grinds. These data are included because variations in feed grade and concentrate grind are related to mill feed rates. For example, to produce a finer grind, an operator will reduce feed tonnage, which increases the energy consumption per ton of feed. Also, a higher crude iron content in the feed will result in a higher cobber recovery; therefore, mill feed rates must be reduced to maintain the same concentrate grind. With adequate operating data, these relationships can be defined, and data can be normalized to the same feed grade and concentrate grind.

The raw data clearly show that grinding energy consumption per ton of rod mill feed is lower as a result of the change to 1½-inch grinding balls. The smaller balls provided more contact points for grinding, thus improving grinding efficiency. When a relationship is developed between crude grade, concentrate grind, and feed rates, the data can be normalized to get a more accurate estimate of grinding efficiency improvement.

Rod mill feed magnetic iron content was fairly consistent during the study period. Small variations observed are inconsequential for this evaluation. Correcting for the finer grinds associated with the 1½-inch ball data would result in a slightly greater benefit than shown in the raw data.

5.2 Study 2: Minorca Energy Conservation Report

The plant produces 2.9 millions tons of iron ore pellets annually. This requires 9 million tons of taconite to be ground to remove the magnetic iron out of the ore. As the rock gets finer in size, the amount of energy to further grind the ore also increases. This is why concentrating has the highest energy demand for producing iron ore pellets, as shown below:

	Energy Consumption per ton (%)
Mining	2%
Crushing	6%
Concentrating	52%
Pelletizing	39%
Misc	1%

In 2004, a computer simulation predicted that smaller grinding balls would improve grinding efficiency. Improved grinding efficiency reduces the power required to grind the ore to an acceptable size for liberation. Figure 36 supports the computer model that better grinding efficiency did occur with the smaller grinding balls.

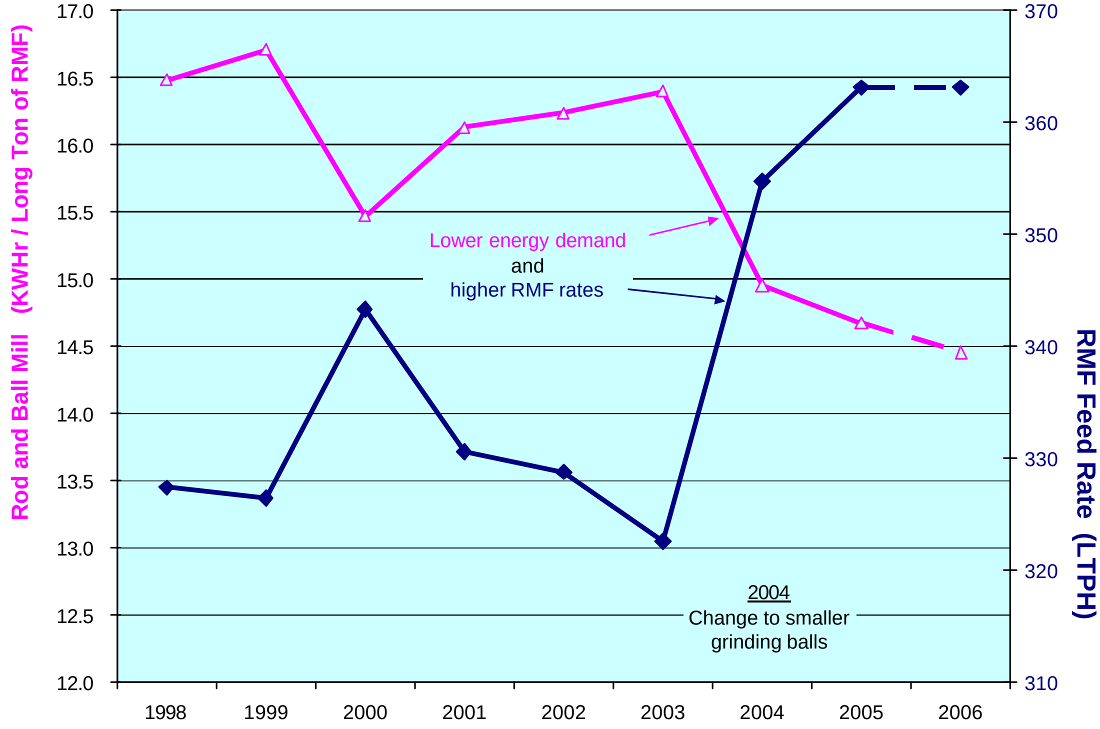

Figure 36. Changes in grinding energy consumption before and after the makeup ball size change was implemented in the plant

Figure 37 below shows that the average monthly KWH consumption in the concentrator has dropped since 1998. The chart also shows that the concentrator's KWH usage per pellet ton decreased significantly with the smaller grinding balls in 2004. The reduction of 3 KWH per pellet ton provides an annual cost savings of $300,000.

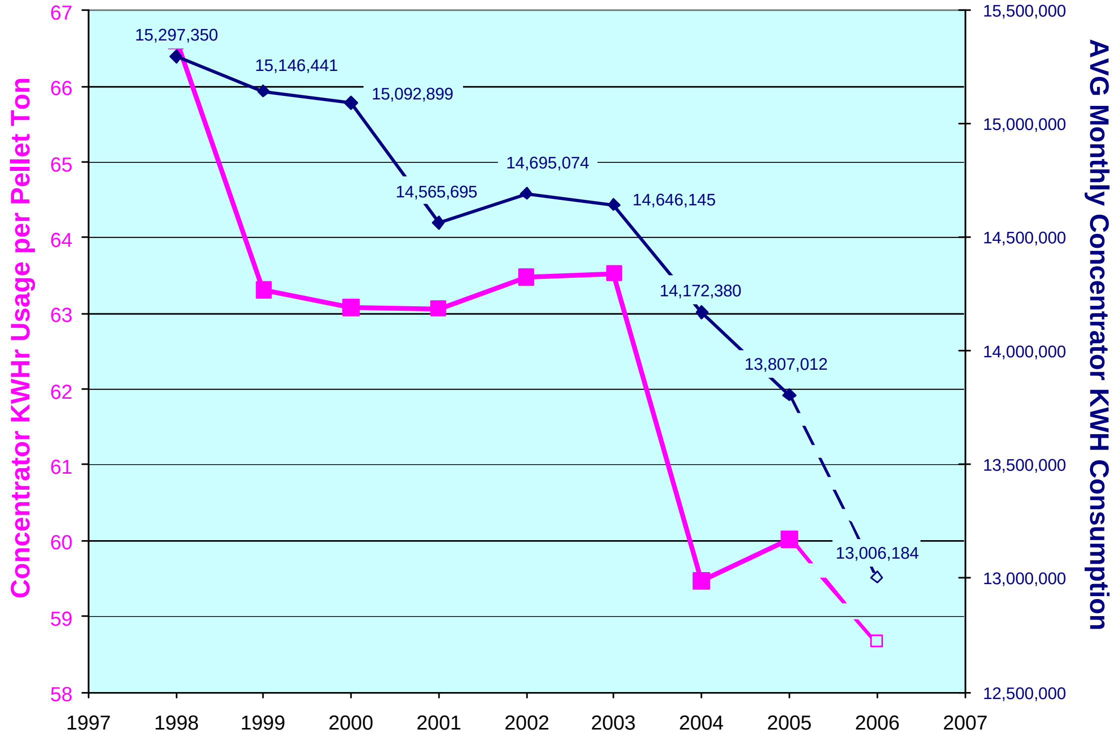

Figure 37. Changes in amount of concentrator energy used for production of pellets

The present goal for the plant is to reduce energy usage another 6% by 2008.

6. COMMERCILIZATION OF THE TECHNOLOGY

The objective of this project was to demonstrate the capabilities of a new technology, so that it would have widespread use. From this standpoint this project has been a great success. This project has shown that computer simulation can reliably be used for improving performance in taconite processing plants. After presenting the findings of this study, the Center has become the address for quantifying the benefits of any process improvement ideas and new technologies for taconite plant operators. A number of company-funded simulation projects were performed by the Center. These included Stack Sizer applications in various plants; rod mill feed size effects; makeup-ball size effects; simulation-based investigation of seasonal variation of plant performance and potential solutions, as well as modification of current plant flow sheets. The Center currently has a number of proposals submitted to mining companies for future work. These proposals were demanded by the industry. Therefore, they have a very high possibility of being funded. The Center activities also reached beyond taconite operations. Currently, three non-taconite simulation study proposals are awaiting funding.

The Center also has been funded to work on projects of common interest to most taconite plants. These were simulation-based studies of known process improvement ideas. Simulation provided quantified benefits for these ideas to generate incentives for plant performance improvements. Findings of these projects were presented to plant engineers at conferences. The Center is currently working on a project to illustrate whether hydrocyclones can be controlled to provide improved liberation of hydrocyclone overflow streams. Findings of this study will be presented at the Duluth symposium in April 2007.

The success of this project also helped the Center to obtain funding for further improvement of the software. The Center has developed new and improved models for hydrocyclones, Stack Sizers, flotation and sump for a constant hydrocyclone pressure during the duration of this project. The current objective is to take the software to the next phase; i.e. liberation based simulation. From this project that is being carried out by the Center, liberation-based simulation for taconite plants will become a reality. Other model improvement projects that are being carried out by the Center include improved magnetic separator and hydroseparator models.

7. CONCLUSION

This project clearly showed that it was possible to simulate a taconite plant using an enhanced version of Usim Pac mineral processing software. With the help of simulation technology, current performance of the plant was assessed, bottlenecks were identified, and potential performance improvement ideas were evaluated. Quantified benefits determined by simulations created a basis for comparing various performance improvement options and selection of the most feasible one.

The target for performance improvement was to increase plant throughput by 10%. It was expected this would be obtained at similar total energy consumption to the prevailing level. A concentrator energy savings of 7% was anticipated.

Following plant sampling studies to determine baseline conditions and a database for the simulation study, the project team assessed plant performance, identified existing problems and eventually came up with ideas for improved performance. These ideas were tested through simulations. By analyzing the results of the simulation study, the most feasible performance improvement option was selected as the change of makeup ball size from 2-inch to 1½-inch. This would be coupled with the replacement of existing cyclones with more efficient ones. These recommendations were implemented at the plant by the management. The positive effects of these modifications were clearly visible in overall plant performance. After modifications were implemented at the plant, two more plant sampling surveys were carried out to verify the results of simulations for two different ore blends processed at the plant. These studies showed that the simulator was capable of accurately simulating plant performance despite large modifications and changes in operating conditions.

The plant was able to reach the target throughput increase of 10%. However, several upstream problems were observed. These included inability of current mining and processing equipment to deliver and process the increased throughput. Management addressed most of these issues, by adding another truck to their fleet, revising the crushing circuit and installing new cobber magnetic separators at the plant. Completion of these modifications took a very long time, during which gradual improvements in energy efficiency were recorded. After the modifications were implemented in the plant, an energy efficiency improvement of 7% was observed in the concentration circuits. Although this meets the objective of this project, further improvement in energy efficiency is expected from on-going process improvements stemming partially from this simulation-based study.

The project has also fulfilled its objective of proving an emerging technology in plant scale application, thereby promoting its widespread use. As a result of this project, the Center was approached by all the iron ore mining companies in northern Minnesota to carry out simulation-based analyses of process efficiency improvement ideas that emerged through their engineering staff. Interest in using the Center's simulation service and expertise already expanded beyond iron ore applications. Currently, three proposals for non-taconite simulation studies are awaiting final approval.

8. ACKNOWLEDGEMENTS

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APPENDIX A

BLEND 1 BASELINE SAMPLING SURVEY

MAGNETIC CIRCUIT

RAW AND MASS BALANCED DATA

Rod Mill Discharge

Flow Rate: 350 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	5.90	6.56	23.30	23.61	31.80	32.06	46.64	46.89
2360	9.10	9.52	24.10	24.29	32.40	32.67	46.15	46.49
1700	5.40	5.64	24.90	25.18	32.90	32.95	45.67	46.33
1180	16.70	16.86	24.00	24.73	32.40	33.03	46.39	47.15
850	10.20	10.14	23.60	23.76	32.10	32.14	46.87	47.81
600	9.00	8.79	23.40	23.61	32.00	32.19	47.08	47.84
425	7.50	7.18	22.30	22.15	31.00	30.94	48.32	49.35
300	4.90	4.67	25.80	25.92	34.00	34.17	44.04	44.97
212	4.40	4.25	25.10	25.14	33.50	33.54	44.90	45.81
150	3.90	3.70	25.80	25.85	34.00	34.10	44.66	45.24
106	2.80	2.64	34.00	33.20	39.40	38.94	38.21	39.22
75	2.80	2.74	38.50	38.44	43.60	43.65	36.00	34.62
53	2.40	2.42	36.50	37.20	41.30	42.01	35.35	34.84
38	2.40	2.30	37.80	37.24	42.60	42.06	34.14	35.29
25	12.60	12.60	26.10	26.86	33.40	34.13	43.38	42.86
	Head Chemistry		**25.58**	**25.83**	**33.50**	**33.74**	**44.89**	**45.42**

Cobber Concentrate

Flow Rate: 236.5 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	7.60	7.42	29.52	29.95	36.30	36.95	40.61	40.45
2360	11.00	10.92	29.52	30.47	36.30	37.50	40.61	40.26
1700	6.50	6.44	31.51	31.96	37.20	37.86	40.38	39.90
1180	18.80	18.83	30.92	32.23	37.00	38.75	40.62	39.96
850	10.90	10.93	30.92	31.98	37.00	38.34	40.62	39.82
600	9.10	9.16	32.31	33.15	38.60	39.65	38.60	37.93
425	6.90	6.97	32.31	33.28	38.60	39.69	38.60	37.69
300	4.30	4.34	38.00	40.83	43.11	45.99	32.00	29.64
212	3.80	3.83	40.39	40.85	45.50	46.01	30.26	29.66
150	3.40	3.43	42.00	40.80	47.11	45.95	28.00	29.82
106	2.40	2.44	51.70	52.51	55.49	56.21	18.59	18.10
75	2.60	2.62	58.40	59.17	60.59	61.35	13.65	13.62
53	2.20	2.19	60.00	60.11	60.70	60.81	11.93	11.69
38	2.00	2.02	61.50	61.82	62.00	62.32	10.28	10.12
25	8.50	8.46	56.00	57.38	56.80	58.20	16.78	16.74
	Head Chemistry		**36.56**	**37.51**	**41.83**	**42.98**	**34.59**	**34.07**

Cobber Tails

Flow Rate: 113.5 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	4.90	4.75	3.00	3.00	16.10	16.13	67.95	67.85
2360	6.70	6.60	3.00	3.00	16.10	16.06	68.05	68.01
1700	4.00	3.97	2.30	2.30	16.20	16.37	68.28	68.02
1180	12.80	12.77	1.70	1.70	15.40	15.47	69.50	69.25
850	8.50	8.49	1.70	1.70	15.40	15.50	69.48	69.24
600	8.00	8.02	0.90	0.90	14.40	14.42	71.59	71.43
425	7.60	7.61	0.90	0.90	14.30	14.24	71.70	71.60
300	5.30	5.34	0.70	0.70	14.20	14.17	71.07	70.90
212	5.10	5.13	0.70	0.70	14.10	14.12	71.15	70.94
150	4.20	4.25	0.70	0.70	14.20	14.16	71.28	71.19
106	3.10	3.07	1.20	1.20	10.70	10.32	73.96	74.21
75	3.00	3.00	0.80	0.80	11.70	11.51	72.50	72.74
53	2.90	2.91	1.20	1.20	12.50	12.47	71.19	71.21
38	2.90	2.89	1.50	1.50	12.60	12.59	72.02	71.88
25	21.00	21.21	1.50	1.50	14.10	14.13	64.68	64.58
	Head Chemistry		**1.50**	**1.49**	**14.48**	**14.47**	**69.19**	**69.06**

Ball Mill Discharge

Flow Rate: 1536.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	0.20	0.20	34.57	34.06	40.40	39.92	37.28	38.55
1700	0.70	0.70	34.57	34.70	40.40	40.40	37.28	37.86
1180	2.20	2.15	34.57	34.94	40.40	40.58	37.28	37.62
850	2.90	2.79	34.57	34.72	40.40	40.35	37.28	37.55
600	5.40	5.33	34.57	34.80	40.40	40.41	37.28	37.46
425	7.40	7.39	34.57	34.73	40.40	40.35	37.28	37.55
300	6.60	6.59	36.84	37.00	42.50	42.59	33.24	34.42
212	8.50	8.51	36.84	36.89	42.50	42.50	33.24	34.60
150	13.00	12.99	42.92	42.12	47.80	47.08	26.98	27.43
106	12.80	12.86	51.73	51.54	55.40	55.32	18.46	18.55
75	11.50	11.79	60.90	60.89	62.20	62.64	10.22	9.95
53	6.90	6.97	60.00	60.90	61.60	62.51	11.30	10.70
38	5.00	4.99	59.00	59.57	60.30	61.39	12.81	12.15
25	16.90	16.73	55.00	56.43	57.20	58.79	16.20	15.01
	Head Chemistry		**47.65**	**47.97**	**51.40**	**51.79**	**23.23**	**23.17**

Rougher Tails

Flow Rate: 81.9 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	0.30	0.34	2.80	2.80	15.68	15.66	71.04	71.02
1700	0.80	0.70	2.80	2.80	15.74	15.75	70.80	70.77
1180	1.60	1.62	2.80	2.80	15.75	15.73	70.71	70.70
850	1.80	1.82	2.80	2.80	15.73	15.71	70.73	70.73
600	2.90	2.91	2.80	2.80	15.72	15.66	70.78	70.80
425	4.60	4.55	2.80	2.80	15.73	15.61	70.75	70.80
300	5.50	5.42	1.60	1.49	15.10	14.82	69.44	69.46
212	7.90	7.79	1.60	1.49	15.09	14.73	69.43	69.49
150	9.80	9.64	1.30	1.05	14.27	13.68	71.85	72.03
106	8.20	8.13	1.60	1.76	14.10	14.23	72.61	72.80
75	7.50	7.37	1.00	0.80	14.30	13.47	70.00	69.35
53	6.70	6.74	1.00	0.90	12.53	12.23	73.04	73.19
38	7.50	7.67	1.00	0.55	11.60	10.89	72.17	72.31
25	34.90	35.32	1.30	1.28	13.70	10.88	72.00	72.72
	Head Chemistry		**1.48**	**1.39**	**14.03**	**12.79**	**71.47**	**71.75**

Rougher Concentrate

Flow Rate: 1454.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	0.20	0.19	36.92	37.19	42.01	42.34	35.06	35.30
1700	0.70	0.70	36.20	36.49	41.43	41.79	35.83	36.02
1180	1.80	2.18	36.00	36.28	41.27	41.62	36.04	36.24
850	2.70	2.85	35.84	35.86	41.15	41.23	36.21	36.35
600	5.50	5.46	35.73	35.76	41.06	41.15	36.33	36.46
425	7.70	7.55	35.80	35.81	41.12	41.19	36.25	36.42
300	6.60	6.65	38.23	38.63	43.49	43.86	32.16	32.82
212	8.40	8.55	38.34	38.71	43.58	43.93	32.05	32.81
150	13.10	13.18	43.93	43.81	48.90	48.45	25.33	25.59
106	13.10	13.13	53.00	53.28	56.27	56.76	16.00	16.66
75	12.10	12.04	63.05	62.96	64.41	64.33	7.82	7.90
53	7.10	6.99	64.52	64.16	66.02	65.24	7.39	7.30
38	5.00	4.84	65.00	64.84	65.50	65.90	6.77	6.77
25	16.00	15.68	64.00	63.43	65.10	64.87	7.67	7.69
	Head Chemistry		**50.81**	**50.60**	**54.14**	**54.00**	**20.00**	**20.43**

Hydrocyclone U/F

Flow Rate: 1152.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	0.30	0.24	36.00	37.19	41.30	42.34	36.00	35.30
1700	1.10	0.89	36.00	36.49	41.32	41.79	36.00	36.02
1180	2.80	2.76	36.00	36.28	41.32	41.62	36.00	36.24
850	3.50	3.59	36.00	35.86	41.32	41.23	36.00	36.35
600	6.50	6.90	36.00	35.76	41.32	41.15	36.00	36.46
425	9.10	9.48	36.00	35.88	41.32	41.25	36.00	36.30
300	8.30	8.25	36.00	38.90	41.32	44.12	36.00	32.34
212	10.80	10.42	36.00	39.21	41.32	44.41	36.00	31.91
150	15.20	15.19	44.86	46.29	51.00	50.87	23.46	22.15
106	14.20	14.33	56.91	57.52	60.80	60.52	12.17	11.85
75	12.60	12.21	67.08	66.27	67.30	67.21	5.04	4.66
53	5.50	5.25	68.87	66.59	69.07	67.40	4.08	4.46
38	2.50	2.56	68.28	66.97	68.60	67.65	3.96	4.00
25	7.60	7.93	66.87	66.25	67.90	67.11	4.84	4.88
	Head Chemistry		**49.19**	**49.69**	**53.06**	**53.31**	**21.88**	**21.02**

Hydrocyclone O/F

Flow Rate: 302.5 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.20	0.19	25.00	23.77	30.41	29.36	60.54	59.27
300	0.70	0.57	25.00	23.76	30.41	29.60	60.54	59.06
212	1.70	1.43	25.00	24.62	30.41	30.23	60.54	57.77
150	6.00	5.50	17.78	17.72	23.70	22.98	62.30	61.71
106	8.90	8.56	27.15	26.24	33.70	32.73	46.89	47.34
75	11.80	11.42	50.20	49.49	53.40	52.63	20.92	21.10
53	13.90	13.61	61.30	60.59	62.40	62.06	11.27	11.48
38	13.20	13.52	64.00	63.31	65.00	64.64	8.80	8.77
25	43.60	45.20	61.50	61.54	63.70	63.36	9.83	9.56
	Head Chemistry		**53.84**	**54.02**	**56.54**	**56.55**	**18.97**	**18.21**

Hydroseparator U/F

Flow Rate: 12.9 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	0.50	0.50	4.00	3.67	10.93	9.60	72.00	70.00
75	1.70	1.70	3.67	3.67	9.60	9.60	75.00	70.00
53	8.50	8.51	2.50	3.67	8.43	9.59	70.00	70.00
38	15.10	15.08	1.15	1.15	10.50	10.34	69.30	69.49
25	74.20	74.22	1.20	1.00	12.60	11.66	67.54	68.31
	Head Chemistry		**1.36**	**1.31**	**11.87**	**11.24**	**68.16**	**68.67**

Hydroseparator U/F

Flow Rate: 289.7 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.20	0.20	25.95	23.77	31.60	29.36	51.64	59.27
300	0.50	0.60	25.95	23.76	32.60	29.60	51.64	59.06
212	1.30	1.50	25.92	24.62	31.57	30.23	51.64	57.77
150	5.20	5.75	17.03	17.72	22.80	22.98	62.74	61.71
106	8.60	8.92	24.72	26.29	32.18	32.78	46.59	47.28
75	11.20	11.85	50.00	49.78	52.80	52.90	20.00	20.79
53	13.80	13.83	62.40	62.15	63.40	63.50	9.74	9.88
38	14.00	13.45	67.20	66.41	67.50	67.35	5.63	5.74
25	45.20	43.90	66.90	66.10	67.60	67.26	4.90	5.14
	Head Chemistry		**57.39**	**56.37**	**59.26**	**58.57**	**14.89**	**15.96**

Fine Screen O/S

Flow Rate: 148.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.30	0.39	21.70	23.77	27.40	29.36	56.10	59.27
300	0.80	1.17	21.70	23.76	27.40	29.60	56.10	59.06
212	2.50	2.44	21.70	22.94	27.40	28.52	56.10	61.11
150	10.80	10.40	17.08	16.58	21.60	21.79	61.24	63.29
106	14.40	14.34	25.58	24.99	31.80	31.62	48.86	48.52
75	13.10	12.81	47.94	49.34	51.10	52.43	21.69	21.42
53	12.00	12.14	61.10	62.07	62.60	63.52	10.60	10.53
38	11.00	11.12	66.80	66.91	67.00	67.77	6.08	6.04
25	35.10	35.19	66.80	67.44	67.20	68.45	5.36	5.28
	Head Chemistry		**50.72**	**51.27**	**53.07**	**54.01**	**22.33**	**22.50**

Fine Screen U/S

Flow Rate: 141.7 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.30	0.52	31.70	32.93	37.10	38.72	42.92	41.28
150	1.00	0.90	31.70	31.52	37.10	37.47	42.92	42.59
106	3.70	3.26	31.70	32.28	37.10	38.14	42.92	41.60
75	11.10	10.86	51.10	50.33	53.10	53.49	19.53	20.01
53	15.70	15.60	62.60	62.22	62.80	63.49	9.56	9.35
38	15.60	15.88	67.30	66.04	67.50	67.03	5.57	5.51
25	52.60	53.00	67.40	65.17	68.20	66.43	5.08	5.04
	Head Chemistry		**63.04**	**61.70**	**64.02**	**63.34**	**9.36**	**9.13**

Finisher Tails

Flow Rate: 6.7 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	1.00	1.09	4.65	4.64	13.43	13.58	73.90	73.84
150	2.44	2.87	4.65	4.65	13.43	13.65	73.90	73.70
106	8.09	8.15	4.62	4.61	13.38	13.56	74.04	73.86
75	15.64	15.48	3.65	3.66	15.51	15.45	69.06	69.08
53	11.56	11.30	6.06	6.04	21.76	23.47	56.00	56.22
38	7.64	7.60	11.58	11.57	30.58	30.59	45.74	46.00
25	53.61	53.51	6.50	6.53	23.50	22.46	49.31	49.53
	Head Chemistry		**6.18**	**6.18**	**21.43**	**21.03**	**55.75**	**55.99**

Finisher Concentrate

Flow Rate: 135.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.20	0.49	36.49	36.04	41.70	41.49	33.00	37.70
150	0.90	0.80	36.49	36.27	41.70	41.68	33.00	37.08
106	3.30	3.02	36.49	35.96	41.70	41.41	33.00	37.31
75	10.80	10.63	54.80	53.68	56.40	56.22	16.20	16.49
53	16.60	15.81	65.20	64.20	65.30	64.90	7.50	7.70
38	17.90	16.28	68.00	67.29	68.10	67.86	4.58	4.58
25	50.30	52.97	69.60	68.08	69.70	68.61	2.83	2.83
	Head Chemistry		**65.53**	**64.43**	**66.02**	**65.42**	**6.69**	**6.82**

APPENDIX B

BLEND 1 BASELINE SAMPLING SURVEY

FLOTATION CIRCUIT

RAW AND MASS BALANCED DATA

Flotation Feed

Flow Rate: 100 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.30	0.21	42.00	43.53	50.20	50.27	23.85	23.10
150	0.50	0.52	42.00	43.56	50.20	50.24	23.85	23.18
106	2.90	2.84	42.00	41.52	50.20	48.09	23.85	26.49
75	8.80	8.85	42.00	42.70	50.20	49.31	23.85	24.62
53	15.70	15.77	63.00	62.87	64.50	64.59	8.27	8.39
38	18.80	17.37	67.50	66.85	68.30	67.55	4.41	5.13
25	23.48	23.44	69.80	68.49	70.40	69.22	3.02	3.21
10	29.52	31.00	67.90	68.75	69.40	69.57	2.58	2.75
	Head Chemistry		**64.26**	**64.17**	**66.26**	**65.81**	**6.58**	**6.92**

Rougher Cell 1 Tails

Flow Rate: 5.4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.09	14.73	14.19	21.00	20.36	69.44	70.07
150	0.40	0.34	14.73	14.41	21.00	20.72	69.44	69.56
106	5.50	5.30	14.73	14.59	21.00	20.89	69.44	69.36
75	12.60	12.71	14.73	14.52	21.00	20.72	69.44	69.51
53	12.70	12.59	19.62	19.61	26.80	26.52	59.50	60.19
38	12.30	12.08	23.91	24.50	33.20	33.60	51.76	51.14
25	17.39	14.51	33.41	35.30	47.50	45.78	27.35	28.90
10	39.01	42.38	58.62	58.59	63.40	63.54	9.14	9.50
	Head Chemistry		**36.85**	**38.06**	**44.39**	**44.79**	**35.16**	**34.78**

Rougher Cell 2 Tails

Flow Rate: 4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	16.32	15.80	21.80	21.23	69.66	70.24
150	0.70	0.58	16.32	15.76	21.80	21.29	69.66	70.05
106	4.40	4.31	16.32	16.15	21.80	21.67	69.66	69.74
75	10.50	10.44	16.32	16.08	21.80	21.54	69.66	69.85
53	11.30	11.45	20.09	19.81	28.00	27.57	59.70	60.44
38	11.60	11.96	24.48	24.75	34.60	35.47	48.60	47.61
25	15.62	14.42	37.05	37.73	48.70	48.50	28.05	28.54
10	45.78	46.76	56.37	56.05	62.20	62.56	11.04	11.11
	Head Chemistry		**39.27**	**39.35**	**46.69**	**46.96**	**32.76**	**32.69**

Rougher Cell 3 Tails

Flow Rate: 3 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Balance	Raw Data	Mass Balance	Raw Data	Mass Balance	Raw Data	Mass Balance
212	0.10	0.10	15.58	15.16	21.50	21.04	69.10	69.59
150	0.40	0.37	15.58	15.26	21.50	21.21	69.10	69.34
106	4.90	4.83	15.58	15.35	21.50	21.32	69.10	69.26
75	11.10	10.88	15.58	15.31	21.50	21.22	69.10	69.36
53	11.00	11.11	20.38	19.98	29.40	29.00	52.87	53.91
38	10.00	11.34	25.38	24.90	37.70	38.99	42.94	41.94
25	13.92	13.91	42.38	42.45	52.30	52.86	20.00	19.99
10	48.58	47.45	58.56	57.88	64.30	64.72	8.67	8.67
	Head Chemistry		**41.70**	**40.90**	**49.07**	**49.15**	**28.51**	**28.86**

Rougher Cell 4 Tails

Flow Rate: 1 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.90	0.73	19.22	17.17	27.00	24.75	60.46	62.86
150	0.90	0.84	19.22	18.72	27.00	26.57	60.46	60.82
106	6.80	6.69	19.22	18.97	27.00	26.83	60.46	60.64
75	11.20	10.87	19.22	19.02	27.00	26.80	60.46	60.66
53	10.50	10.47	23.06	22.81	32.50	32.39	49.95	50.35
38	9.90	11.17	29.74	29.15	40.60	41.61	37.20	36.52
25	11.64	12.52	42.08	41.36	54.20	54.80	19.55	19.46
10	48.16	46.71	58.16	57.49	64.10	64.33	8.27	8.31
	Head Chemistry		**42.08**	**41.30**	**49.96**	**50.07**	**27.16**	**27.29**

Rougher Cell 1 Con.

Flow Rate: 103 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.40	0.20	40.73	44.24	48.30	51.00	28.02	21.96
150	0.50	0.50	40.73	43.96	48.30	50.69	28.02	22.52
106	2.50	2.70	40.73	42.45	48.30	49.13	28.02	24.93
75	8.20	8.42	40.73	43.61	48.30	50.31	28.02	23.11
53	15.00	15.27	61.14	63.28	63.20	65.09	10.97	7.73
38	18.10	16.92	66.00	67.19	67.30	67.99	4.54	4.54
25	21.95	23.25	68.36	68.93	70.80	69.58	2.77	2.82
10	33.35	32.75	67.90	68.77	70.00	69.64	2.28	2.54
	Head Chemistry		**63.49**	**64.70**	**66.15**	**66.34**	**7.09**	**6.21**

Rougher Cell 2 Con.

Flow Rate: 99 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.20	0.20	41.69	44.75	49.20	51.53	26.05	21.09
150	0.40	0.49	41.69	45.22	49.20	52.00	26.05	20.39
106	2.40	2.64	41.69	44.08	49.20	50.84	26.05	22.15
75	8.00	8.34	41.69	44.91	49.20	51.67	26.05	20.89
53	15.10	15.41	62.60	64.51	64.70	66.15	8.08	6.24
38	17.80	17.11	67.50	68.32	68.30	68.86	4.12	3.40
25	22.33	23.58	68.50	69.65	69.20	70.07	2.18	2.22
10	33.77	32.22	68.00	69.47	69.80	70.03	2.04	2.07
	Head Chemistry		**64.31**	**65.66**	**66.36**	**67.07**	**6.00**	**5.21**

Rougher Cell 3 Con.

Flow Rate: 96 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.20	45.93	45.19	53.30	51.99	20.53	20.37
150	0.60	0.50	45.93	45.93	53.30	52.73	20.53	19.24
106	2.80	2.57	45.93	45.78	53.30	52.58	20.53	19.37
75	8.50	8.26	45.93	46.14	53.30	52.93	20.53	18.89
53	17.00	15.55	65.21	65.51	68.40	66.99	5.34	5.17
38	17.80	17.29	68.80	69.21	69.40	69.47	2.67	2.60
25	20.69	23.89	70.83	70.15	71.20	70.38	2.00	1.90
10	32.51	31.74	68.53	70.01	70.13	70.28	1.87	1.76
	Head Chemistry		**65.78**	**66.44**	**67.91**	**67.64**	**4.87**	**4.46**

Rougher Cell 4 Con.

Flow Rate: 94.4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.20	45.72	46.68	52.52	53.43	18.00	18.11
150	0.50	0.49	45.72	46.60	52.60	53.37	18.00	18.22
106	2.50	2.51	45.72	46.80	52.60	53.56	18.00	17.79
75	7.90	8.23	45.72	46.65	52.60	53.43	18.00	18.09
53	16.00	15.62	65.12	65.92	67.30	67.32	5.23	4.74
38	18.80	17.38	69.87	69.58	70.40	69.72	2.50	2.29
25	20.92	24.05	70.20	70.37	70.40	70.51	1.90	1.76
10	33.28	31.52	68.58	70.28	69.40	70.41	1.70	1.62
	Head Chemistry		**66.09**	**66.80**	**67.61**	**67.89**	**4.25**	**4.13**

Combined Rougher Tails
Flow Rate: 13.5 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.16	14.48	15.98	20.95	22.64	70.68	66.69
150	0.30	0.47	14.48	15.82	20.95	22.07	70.68	68.10
106	4.50	5.06	14.48	15.70	20.95	21.95	70.68	68.27
75	11.60	11.48	14.48	15.51	20.95	21.61	70.68	68.72
53	12.50	11.73	19.20	20.03	28.35	27.86	59.43	58.05
38	11.70	11.79	24.54	25.10	34.01	36.05	47.77	46.78
25	14.10	14.15	37.94	38.09	48.05	48.90	27.72	26.00
10	45.20	45.17	56.93	57.58	62.25	63.62	10.03	9.64
	Head Chemistry		**38.74**	**39.38**	**45.89**	**46.90**	**33.12**	**32.12**

Rougher Concentrate
Flow Rate: 94.4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	1.00	0.20	47.03	46.68	53.10	53.43	17.80	18.11
150	0.70	0.49	47.03	46.60	53.10	53.37	17.80	18.22
106	2.40	2.51	47.03	46.80	53.10	53.56	17.80	17.79
75	7.70	8.23	47.03	46.65	53.10	53.43	17.80	18.09
53	13.70	15.62	65.51	65.92	66.60	67.32	5.00	4.74
38	17.30	17.38	69.25	69.58	69.50	69.72	2.30	2.29
25	24.46	24.05	70.20	70.37	70.40	70.51	1.80	1.76
10	32.74	31.52	70.25	70.28	70.90	70.41	1.65	1.62
	Head Chemistry		**66.68**	**66.80**	**67.85**	**67.89**	**4.16**	**4.13**

Dewatering Magnetic Separator Tails
Flow Rate: 1.2 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.40	0.46	8.00	8.27	14.00	14.42	72.00	73.89
150	0.60	0.59	8.00	8.01	14.00	14.02	72.00	72.86
106	3.00	2.89	8.00	8.01	14.00	14.04	72.00	72.89
75	7.90	7.11	6.89	6.90	12.89	12.94	69.46	70.64
53	9.70	9.76	8.34	8.35	18.30	18.37	65.00	64.78
38	11.40	11.81	9.67	9.67	23.40	23.66	62.87	62.59
25	20.00	21.18	15.00	14.99	33.50	34.18	44.00	43.06
10	47.00	46.19	18.00	18.17	39.00	40.44	40.00	38.37
	Head Chemistry		**14.24**	**14.33**	**31.06**	**31.98**	**49.44**	**48.46**

Dewatering Magnetic Separator Concentrate

Flow Rate: 12.3 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.13	14.80	18.71	21.00	25.55	66.42	64.14
150	0.30	0.45	14.80	16.83	21.00	23.12	66.42	67.49
106	4.40	5.27	14.80	16.12	21.00	22.39	66.42	68.02
75	12.10	11.91	14.80	16.02	21.00	22.13	66.42	68.61
53	12.30	11.92	20.03	20.98	28.40	28.63	59.00	57.50
38	11.90	11.78	25.88	26.63	36.08	37.28	46.41	45.21
25	15.00	13.46	42.00	41.69	51.50	51.19	26.00	23.34
10	43.90	45.07	59.00	61.58	64.00	65.97	9.20	6.73
	Head Chemistry		**40.25**	**41.86**	**47.16**	**48.38**	**31.94**	**30.51**

Froth Thickener O/F

Flow Rate: 0.1 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	12.00	12.01	20.50	20.51	66.89	66.92
150	3.30	3.14	12.00	11.99	20.50	20.49	66.89	67.23
106	3.30	3.29	12.00	12.00	20.50	20.51	66.89	66.97
75	5.50	5.50	12.00	12.00	20.50	20.51	66.89	66.93
53	10.00	10.00	10.44	10.44	19.01	19.02	69.54	69.53
38	20.00	20.08	10.08	10.08	20.30	20.32	68.16	68.13
25	17.90	17.95	18.00	18.00	30.50	30.53	50.00	49.96
10	39.90	39.94	22.50	22.52	36.00	36.07	46.00	45.92
	Head Chemistry		**16.72**	**16.74**	**28.28**	**28.34**	**56.05**	**56.00**

Froth Thickener U/F

Flow Rate: 12.1 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.13	16.52	18.76	22.70	25.59	65.52	64.12
150	0.40	0.43	16.52	17.18	22.70	23.30	65.52	67.51
106	6.10	5.29	16.52	16.15	22.70	22.40	65.52	68.02
75	11.50	11.98	16.52	16.04	22.70	22.14	65.52	68.62
53	12.40	11.94	22.61	21.06	31.00	28.70	54.55	57.40
38	10.60	11.70	29.44	26.91	38.90	37.56	43.23	44.81
25	15.00	13.41	42.00	42.01	51.00	51.47	24.00	22.98
10	43.90	45.12	58.50	61.92	63.30	66.23	7.50	6.38
	Head Chemistry		**40.90**	**42.11**	**47.52**	**48.58**	**30.10**	**30.25**

Regrind Ball Mill Discharge

Flow Rate: 12.1 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
150	0.30	0.17	14.69	15.69	22.60	22.83	67.36	66.94
106	2.10	1.98	14.69	16.73	22.60	24.25	67.36	64.99
75	5.30	4.89	14.69	16.28	22.60	23.69	67.36	65.78
53	7.20	7.18	18.46	18.11	27.30	27.02	60.52	60.77
38	9.10	9.83	22.46	22.34	33.40	32.66	50.25	53.25
25	18.89	18.84	39.60	34.78	48.40	42.27	35.00	38.57
10	57.11	57.11	55.00	54.12	62.30	59.16	13.92	15.35
	Head Chemistry		**43.40**	**42.11**	**51.47**	**48.58**	**28.68**	**30.25**

Scavenger Cell 1 Tails

Flow Rate: 2.6 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
150	0.10	0.10	10.48	10.39	16.90	16.68	75.72	76.20
106	0.60	0.60	10.48	10.38	16.90	16.57	75.72	76.44
75	2.50	2.61	10.48	10.38	16.90	16.61	75.72	76.42
53	6.40	6.45	11.72	11.79	17.90	18.12	74.78	74.64
38	13.00	12.66	11.71	11.79	19.50	19.78	72.42	72.00
25	28.40	27.81	13.25	13.53	21.40	22.32	69.04	67.93
10	49.00	49.76	31.25	31.74	39.30	40.55	42.92	41.43
	Head Chemistry		**21.68**	**22.16**	**29.55**	**30.61**	**57.26**	**55.97**

Scavenger Cell 2 Tails

Flow Rate: 1.3 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
150	0.30	0.32	11.95	11.71	17.60	17.27	73.36	74.24
106	0.70	0.70	11.95	11.85	17.60	17.40	73.36	73.90
75	3.70	3.81	11.95	11.80	17.60	17.36	73.36	74.05
53	8.60	8.72	12.16	12.22	17.70	17.81	72.86	72.87
38	14.50	14.61	12.38	12.55	20.60	20.90	68.12	67.91
25	24.60	24.56	13.83	13.97	23.30	23.81	61.96	61.17
10	47.60	47.29	28.78	29.40	39.40	39.90	41.54	40.73
	Head Chemistry		**20.50**	**20.80**	**29.82**	**30.16**	**54.61**	**54.13**

Scavenger Cell 3 Tails

Flow Rate: 0.4 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
150	0.20	0.20	13.05	12.99	20.30	20.21	66.96	67.25
106	1.20	1.18	13.05	13.00	20.30	20.16	66.96	67.44
75	5.00	5.00	13.05	12.99	20.30	20.17	66.96	67.43
53	10.00	10.03	12.00	12.02	19.30	19.35	72.70	72.67
38	14.80	14.78	13.44	13.51	22.10	22.24	70.92	70.79
25	21.00	21.26	15.66	15.65	28.44	28.86	61.40	60.96
10	47.80	47.55	32.67	32.77	43.50	43.58	32.92	32.77
	Head Chemistry		**22.93**	**22.94**	**33.27**	**33.37**	**50.68**	**50.59**

Scavenger Combined Tails

Flow Rate: 4.3 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.18	10.60	11.38	15.60	17.38	77.70	74.18
106	0.60	0.68	10.60	11.26	15.60	17.41	77.70	74.17
75	3.90	3.20	10.60	11.28	15.60	17.41	77.70	74.23
53	8.30	7.48	12.10	11.97	19.30	18.17	73.50	73.76
38	14.60	13.45	12.40	12.22	20.90	20.40	69.30	70.53
25	24.90	26.20	14.60	13.82	25.90	23.25	61.60	65.47
10	47.50	48.80	31.90	31.15	42.20	40.64	37.70	40.42
	Head Chemistry		**22.10**	**21.82**	**31.88**	**30.74**	**53.12**	**54.90**

Scavenger Cell 1 Con.

Flow Rate: 9.6 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.19	16.02	16.50	23.80	23.77	65.30	65.54
106	2.40	2.35	16.02	17.17	23.80	24.78	65.30	64.19
75	5.50	5.51	16.02	17.04	23.80	24.60	65.30	64.42
53	7.40	7.38	19.89	19.60	28.80	29.13	58.06	57.48
38	10.20	9.06	28.85	26.34	40.00	37.55	45.57	46.15
25	13.10	16.40	45.32	44.55	52.20	51.44	23.00	25.07
10	61.20	59.11	60.38	59.23	63.80	63.41	8.99	9.40
	Head Chemistry		**48.60**	**47.52**	**54.02**	**53.45**	**22.75**	**23.27**

Scavenger Cell 2 Con.

Flow Rate: 8.2 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.30	0.17	17.65	17.95	25.30	25.74	63.06	62.90
106	2.90	2.61	17.65	17.39	25.30	25.09	63.06	63.78
75	5.40	5.78	17.65	17.58	25.30	25.35	63.06	63.41
53	7.00	7.17	20.77	21.02	31.00	31.30	54.21	54.53
38	9.10	8.18	30.14	30.23	42.70	42.25	39.17	40.01
25	13.20	15.12	50.73	52.39	58.20	58.52	16.29	15.82
10	62.10	60.98	62.69	62.88	66.20	66.29	5.69	5.57
	Head Chemistry		**51.34**	**51.74**	**57.02**	**57.13**	**18.47**	**18.40**

Scavenger Cell 3 Con.

Flow Rate: 7.8 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.16	19.11	18.27	26.50	26.09	62.38	62.62
106	2.80	2.69	19.11	17.49	26.50	25.20	62.38	63.70
75	5.60	5.82	19.11	17.79	26.50	25.59	62.38	63.23
53	6.50	7.02	22.00	21.70	32.40	32.20	53.35	53.17
38	7.80	7.84	31.33	31.88	43.10	44.22	36.70	36.98
25	13.20	14.79	56.54	55.16	61.10	60.76	12.20	12.42
10	63.90	61.68	64.39	64.10	68.00	67.21	4.39	4.47
	Head Chemistry		**54.13**	**53.25**	**59.27**	**58.38**	**16.11**	**16.72**

Scavenger Concentrate
Flow Rate: 7.8 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.16	19.00	18.27	27.53	26.09	61.92	62.62
106	2.10	2.69	19.00	17.49	27.53	25.20	61.92	63.70
75	5.30	5.82	19.00	17.79	27.53	25.59	61.92	63.23
53	6.50	7.02	20.50	21.70	31.00	32.20	54.22	53.17
38	7.70	7.84	28.00	31.88	41.40	44.22	38.52	36.98
25	16.30	14.79	55.65	55.16	61.10	60.76	12.45	12.42
10	62.00	61.68	64.50	64.10	68.40	67.21	4.79	4.47
	Head Chemistry		**53.97**	**53.25**	**59.63**	**58.38**	**16.13**	**16.72**

Concentrate Thickener O/F
Flow Rate: 0.1 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.20	0.20	17.77	17.76	28.60	28.58	43.50	43.54
150	0.60	0.60	17.77	17.76	28.60	28.58	43.50	43.55
106	5.80	5.36	17.77	17.76	28.60	28.58	43.50	43.56
75	9.20	8.08	17.77	17.76	28.60	28.58	43.50	43.54
53	10.80	9.19	10.37	10.37	21.60	21.46	36.18	36.39
38	15.00	20.48	19.34	18.25	35.40	41.97	22.09	20.77
25	22.90	25.23	23.50	22.79	35.60	38.81	17.00	16.69
10	35.50	30.87	25.00	24.43	37.00	39.24	16.00	15.78
	Head Chemistry		**21.09**	**20.51**	**33.45**	**36.54**	**23.67**	**22.88**

Floation Concentrate
Flow Rate: 94 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.50	0.20	46.67	46.70	53.60	53.45	17.00	18.09
150	0.70	0.49	46.67	46.62	53.60	53.39	17.00	18.19
106	2.50	2.51	46.67	46.85	53.60	53.61	17.00	17.75
75	8.30	8.23	46.67	46.67	53.60	53.44	17.00	18.08
53	15.40	15.62	65.60	65.95	67.70	67.34	4.20	4.72
38	17.40	17.38	69.88	69.62	69.98	69.74	2.20	2.27
25	21.30	24.05	70.00	70.40	70.10	70.52	1.70	1.75
10	33.90	31.52	70.40	70.31	70.50	70.43	1.60	1.61
	Head Chemistry		**66.64**	**66.83**	**67.87**	**67.91**	**3.97**	**4.12**

Combined Flotation Tails
Flow Rate: 6 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.40	0.10	9.61	8.35	16.10	14.55	76.80	73.74
150	0.20	0.33	9.61	10.21	16.10	16.73	76.80	72.24
106	1.30	1.22	9.61	9.64	16.10	15.87	76.80	73.10
75	4.60	4.09	9.61	9.66	16.10	15.83	76.80	72.67
53	7.80	8.03	11.86	10.98	19.40	18.24	68.18	71.30
38	11.80	13.24	12.63	11.66	21.50	21.03	67.96	68.92
25	23.00	24.94	15.36	14.10	26.50	25.36	55.14	61.13
10	50.90	48.05	32.98	28.31	42.70	40.52	40.00	40.09
	Head Chemistry		**23.36**	**20.10**	**32.93**	**30.95**	**51.37**	**53.54**

APPENDIX C

BLEND 2 BASELINE SAMPLING SURVEY

MAGNETIC CIRCUIT

RAW AND MASS BALANCED DATA

Rod Mill Discharge

Flow Rate: 315 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	6.78	6.78	23.23	22.99	35.23	34.82	44.19	43.49
2360	10.00	10.01	23.33	22.96	35.35	34.73	44.19	43.53
1700	4.73	4.73	22.19	22.07	34.72	34.46	43.20	44.19
1180	16.43	16.49	22.40	21.84	34.09	33.10	43.43	45.43
850	9.55	9.56	22.17	21.89	33.91	33.39	43.43	45.37
600	8.43	8.41	22.20	21.94	34.34	33.87	44.03	45.15
425	6.63	6.62	21.95	21.78	34.13	33.80	44.03	45.40
300	4.51	4.50	24.56	24.45	36.47	36.27	41.89	42.30
212	4.18	4.16	23.86	23.83	35.87	35.77	41.89	43.27
150	3.76	3.74	23.26	23.30	35.35	35.34	41.89	44.03
106	2.79	2.78	27.01	26.95	39.71	39.60	37.97	37.65
75	2.56	2.56	31.43	31.35	41.69	41.60	33.50	32.57
53	2.01	2.03	36.13	35.93	43.52	43.40	34.67	29.62
38	2.01	2.01	33.32	33.29	42.65	42.62	36.16	35.82
25	15.63	15.62	19.58	19.40	31.44	31.26	47.38	45.94
	Head Chemistry		**23.08**	**22.82**	**34.86**	**34.43**	**43.33**	**43.75**

Cobber Concentrate

Flow Rate: 196.7 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	7.82	7.81	31.28	30.92	41.26	40.64	36.02	36.79
2360	11.66	11.65	31.08	30.54	41.17	40.24	36.02	37.11
1700	5.43	5.43	29.90	29.62	40.65	40.16	36.02	36.32
1180	18.99	19.13	30.24	29.27	40.20	38.58	36.50	37.76
850	10.83	10.87	30.47	29.88	40.40	39.44	36.50	37.10
600	9.31	9.31	31.36	30.88	41.94	41.11	35.82	36.45
425	7.17	7.17	31.64	31.25	42.19	41.53	35.82	36.24
300	4.71	4.69	37.02	36.76	47.19	46.77	28.56	28.83
212	4.14	4.14	37.77	37.47	47.88	47.43	28.56	28.71
150	3.58	3.58	38.31	38.00	48.37	47.94	28.56	28.62
106	2.59	2.57	45.89	45.85	56.84	56.70	17.74	17.84
75	2.24	2.23	56.69	56.69	61.24	61.23	12.07	12.13
53	1.92	1.89	60.06	60.98	62.55	63.46	8.75	8.83
38	1.65	1.65	63.75	63.72	65.43	65.40	7.59	7.60
25	7.96	7.90	59.68	59.41	62.91	62.62	12.03	12.16
	Head Chemistry		**36.02**	**35.51**	**45.24**	**44.43**	**31.29**	**31.96**

Cobber Tails

Flow Rate: 118.3 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	5.07	5.08	2.72	2.72	19.86	19.94	60.39	60.61
2360	7.26	7.29	2.79	2.80	19.93	20.07	60.39	60.60
1700	3.57	3.55	2.84	2.84	19.84	19.94	64.44	64.21
1180	12.22	12.09	2.30	2.30	18.42	18.69	66.06	65.61
850	7.45	7.38	2.30	2.31	18.37	18.56	66.06	65.64
600	6.96	6.93	1.98	1.98	17.57	17.71	64.90	64.60
425	5.75	5.71	1.98	1.98	17.53	17.65	64.90	64.52
300	4.19	4.18	1.43	1.43	16.58	16.64	67.56	67.44
212	4.24	4.20	1.43	1.43	16.51	16.60	67.56	67.17
150	4.07	4.01	1.43	1.43	16.47	16.58	67.56	66.94
106	3.13	3.14	1.24	1.24	16.33	16.34	64.46	64.60
75	3.08	3.11	1.11	1.11	18.23	18.19	56.32	56.97
53	2.16	2.26	1.03	1.03	15.61	15.44	54.00	58.58
38	2.60	2.61	1.40	1.40	18.76	18.74	65.24	65.39
25	28.27	28.47	0.94	0.94	16.81	16.79	60.14	61.51
	Head Chemistry		**1.72**	**1.72**	**17.72**	**17.80**	**63.04**	**63.37**

Ball Mill Discharge

Flow Rate: 911.6 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
1700	0.30	0.31	27.10	26.97	39.10	37.97	38.63	39.63
1180	0.90	0.92	27.10	27.31	39.10	38.24	38.63	39.28
850	1.40	1.42	27.10	27.54	39.10	38.43	38.63	39.04
600	3.10	3.09	27.10	27.83	39.10	38.65	38.63	38.73
425	5.20	5.29	27.10	27.96	39.10	38.76	38.63	38.63
300	5.80	5.93	32.10	31.47	42.40	42.01	32.77	32.84
212	8.30	8.47	32.10	31.33	42.40	41.90	32.77	33.00
150	12.10	12.09	36.30	36.50	46.50	46.81	26.52	26.57
106	12.90	12.61	45.00	44.95	53.20	53.55	19.29	19.23
75	11.40	11.35	54.30	54.90	59.50	60.11	12.31	12.47
53	6.30	6.85	57.50	57.96	60.90	61.34	11.76	11.57
38	6.80	5.91	56.70	57.09	60.80	61.14	13.04	12.56
25	25.50	25.77	52.90	53.35	57.50	58.61	16.68	15.42
	Head Chemistry		**44.84**	**44.98**	**52.15**	**52.44**	**21.81**	**21.58**

Rougher Tails

Flow Rate: 81.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
1700	0.40	0.40	2.65	2.65	17.78	18.60	68.23	67.40
1180	0.90	0.95	2.64	2.64	17.78	18.56	68.29	67.53
850	1.20	1.28	2.64	2.64	17.79	18.55	68.31	67.58
600	2.20	2.23	2.64	2.64	17.72	18.52	68.30	67.53
425	3.40	3.43	2.63	2.64	17.66	18.60	68.28	67.36
300	4.10	4.03	1.92	1.93	17.97	18.54	66.98	66.41
212	6.30	6.15	1.93	1.94	17.90	18.81	66.97	66.03
150	8.20	8.05	1.92	1.93	17.07	18.25	64.74	63.43
106	7.90	7.71	1.78	1.78	17.01	17.90	62.63	61.59
75	7.50	7.33	1.47	1.47	17.19	18.42	62.51	61.03
53	6.00	6.00	1.18	1.18	16.07	16.87	64.56	63.78
38	6.40	6.76	0.92	0.92	15.68	16.51	63.61	63.15
25	45.50	45.68	0.98	1.01	16.50	17.93	62.57	61.48
	Head Chemistry		**1.40**	**1.41**	**16.81**	**17.96**	**63.86**	**62.84**

Rougher Concentrate

Flow Rate: 830.7 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
1700	0.35	0.30	29.80	30.11	39.64	40.47	36.77	36.05
1180	1.00	0.92	29.50	29.80	39.39	40.23	37.19	36.43
850	1.46	1.43	29.50	29.72	39.40	40.17	37.26	36.55
600	3.10	3.18	29.40	29.56	39.30	40.03	37.42	36.76
425	5.30	5.47	29.40	29.51	39.31	39.99	37.53	36.88
300	6.08	6.11	34.70	33.36	44.63	43.52	29.89	30.68
212	8.65	8.69	34.80	33.36	44.70	43.49	29.80	30.72
150	12.60	12.48	38.80	38.67	48.88	48.61	23.96	24.26
106	13.40	13.08	48.00	47.43	55.81	55.60	16.47	16.80
75	11.75	11.74	58.30	58.15	62.72	62.64	9.11	9.51
53	6.59	6.94	63.00	62.75	65.34	65.09	6.70	7.16
38	6.46	5.83	63.20	63.44	66.09	66.18	6.87	6.84
25	23.26	23.83	63.90	63.12	67.14	66.20	5.94	6.81
	Head Chemistry		**49.69**	**49.23**	**56.19**	**55.81**	**17.15**	**17.56**

Hydrocyclone O/F

Flow Rate: 180.6 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
1700	0.37	0.39	30.40	30.11	41.90	40.47	36.50	36.05
1180	1.09	1.17	30.40	29.80	41.90	40.23	36.50	36.43
850	1.55	1.83	30.40	29.72	41.90	40.17	36.50	36.55
600	3.70	4.06	30.40	29.56	41.90	40.03	36.50	36.76
425	6.45	6.93	30.40	29.53	41.90	40.02	36.50	36.82
300	7.02	7.72	30.40	33.44	41.90	43.60	36.50	30.54
212	10.70	10.66	30.40	33.64	41.90	43.78	36.50	30.21
150	15.24	14.70	40.70	40.31	50.45	50.26	21.74	21.82
106	14.79	14.45	49.60	50.46	58.57	58.33	13.72	13.62
75	12.63	11.99	61.70	60.92	65.56	64.73	7.39	7.21
53	6.46	5.77	65.50	65.05	67.00	66.65	5.44	5.39
38	3.63	3.83	66.10	64.33	67.80	67.38	5.57	5.94
25	16.37	16.53	64.30	63.91	65.80	66.77	6.62	6.14
	Head Chemistry		**47.88**	**47.71**	**55.14**	**54.82**	**19.18**	**18.44**

Hydrocyclone O/F

Flow Rate: 180.6 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.30	0.23	25.80	26.43	36.80	36.57	43.83	43.44
300	0.40	0.33	25.80	26.64	36.80	36.67	42.83	42.74
212	1.00	1.61	25.80	26.59	36.80	36.66	42.83	42.84
150	4.80	4.52	18.90	19.46	30.00	29.21	53.81	52.83
106	5.60	8.18	27.90	28.15	38.20	38.21	38.05	37.02
75	12.40	10.87	47.20	47.15	54.10	54.36	18.86	18.66
53	14.60	11.12	57.70	58.44	61.60	62.16	10.78	10.47
38	10.50	13.04	61.80	62.49	64.50	64.90	7.83	7.79
25	50.40	50.12	60.60	62.19	65.60	65.53	7.87	7.62
	Head Chemistry		**54.22**	**54.69**	**59.75**	**59.36**	**14.15**	**14.37**

Hydroseparator O/F

Flow Rate: 4.0 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.60	0.60	37.10	37.15	46.60	46.75	27.81	27.91
106	1.00	1.00	37.10	37.14	46.60	46.66	27.81	27.82
75	1.40	1.40	37.10	37.20	46.60	46.67	27.81	27.71
53	3.60	3.60	37.10	37.33	46.60	47.10	27.81	27.21
38	7.50	7.70	7.57	7.57	15.10	15.14	65.20	65.17
25	85.90	85.70	2.46	2.46	15.90	16.64	61.74	60.77
	Head Chemistry		**5.13**	**5.15**	**17.87**	**18.52**	**59.76**	**58.91**

Hydroseparator U/F

Flow Rate: 176.6 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.30	0.23	27.50	26.43	37.60	36.57	41.19	43.44
300	0.50	0.33	27.50	26.64	37.60	36.67	41.19	42.74
212	1.30	1.65	27.50	26.59	37.60	36.66	41.19	42.84
150	4.20	4.61	19.70	19.41	28.60	29.16	51.03	52.91
106	7.90	8.34	27.80	28.12	38.00	38.18	36.52	37.05
75	11.10	11.08	46.90	47.18	54.10	54.38	18.65	18.63
53	9.90	11.29	59.00	58.59	62.90	62.26	10.31	10.35
38	14.60	13.16	62.00	63.22	65.10	65.56	7.64	7.03
25	50.20	49.31	64.10	64.55	67.00	67.46	5.54	5.52
	Head Chemistry		**55.88**	**55.82**	**60.37**	**60.29**	**12.88**	**13.36**

Fine Screen O/S

Flow Rate: 64.8 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.50	0.64	24.20	26.43	32.40	36.57	49.59	43.44
300	0.70	0.71	24.20	24.76	32.40	34.86	49.59	45.88
212	4.00	3.94	24.20	25.49	32.40	35.63	49.59	44.48
150	12.80	11.55	18.60	18.23	28.10	27.98	54.25	54.70
106	17.40	16.74	26.50	25.65	36.40	35.97	38.15	39.26
75	12.80	12.88	44.20	44.73	52.60	52.19	20.62	19.73
53	9.80	9.45	56.20	56.21	61.20	62.04	11.36	10.68
38	7.50	8.32	61.30	59.06	64.60	63.73	7.82	8.54
25	34.50	35.77	63.60	63.27	66.60	66.97	6.22	5.60
	Head Chemistry		**45.95**	**46.37**	**52.16**	**52.98**	**22.65**	**21.51**

Fine Screen U/S

Flow Rate: 111.8 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
300	0.20	0.12	32.80	33.22	42.00	42.98	33.21	31.75
212	0.40	0.32	32.80	34.38	42.00	43.96	33.21	31.12
150	0.90	0.58	32.80	33.05	42.00	42.80	33.21	32.23
106	3.60	3.47	32.80	35.03	42.00	44.39	33.21	30.88
75	9.90	10.03	48.50	49.00	55.70	56.01	18.31	17.81
53	12.90	12.36	59.50	59.65	62.00	62.37	10.00	10.20
38	15.30	15.96	64.30	64.48	65.70	66.12	6.56	6.58
25	56.80	57.16	64.50	65.01	66.80	67.64	5.83	5.49
	Head Chemistry		**60.62**	**61.29**	**63.65**	**64.52**	**9.11**	**8.63**

Finisher Tails
Flow Rate: 6.3 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
300	0.30	0.33	2.45	2.45	18.96	18.06	55.56	56.89
212	0.60	0.71	5.37	5.33	21.74	21.08	55.70	56.67
150	1.90	1.87	5.46	5.45	21.87	20.57	55.60	57.09
106	4.60	5.84	4.40	4.37	18.84	18.61	60.59	61.10
75	10.39	10.46	2.41	2.41	16.75	16.79	61.84	61.82
53	11.04	9.87	3.89	3.91	19.92	19.56	56.47	56.27
38	7.23	7.39	4.40	4.39	23.03	22.29	52.69	53.72
25	63.94	63.54	3.17	3.18	24.71	25.31	43.79	42.84
	Head Chemistry		**3.37**	**3.38**	**22.87**	**23.09**	**48.81**	**48.43**

Finisher Concentrate
Flow Rate: 105.5 LTPH

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
300	0.10	0.10	39.40	39.09	48.40	47.74	25.65	26.95
212	0.30	0.30	39.40	38.58	48.40	47.27	25.65	27.42
150	0.50	0.50	39.40	39.20	48.40	47.75	25.65	26.68
106	3.30	3.33	39.40	38.26	48.40	47.11	25.65	27.70
75	10.10	10.01	52.00	51.93	58.40	58.48	15.05	15.05
53	13.70	12.51	62.10	62.29	64.50	64.39	8.11	8.02
38	16.40	16.47	66.30	66.10	67.60	67.30	5.25	5.31
25	55.60	56.78	68.50	69.16	69.80	70.48	2.99	2.98
	Head Chemistry		**64.37**	**64.77**	**66.66**	**67.01**	**6.23**	**6.24**

APPENDIX D

BLEND 2 BASELINE SAMPLING SURVEY

FLOTATION CIRCUIT

RAW AND MASS BALANCED DATA

Flotation Feed

Flow Rate: 100 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	38.20	38.34	44.60	44.52	28.00	28.01
150	0.40	0.40	38.20	38.64	44.60	44.83	28.00	27.51
106	1.50	1.54	38.20	38.03	44.60	44.19	28.00	28.53
75	9.30	9.36	50.10	49.81	53.60	53.28	16.18	16.95
53	16.10	16.19	60.70	60.89	62.50	62.64	8.11	8.23
38	11.70	11.65	64.30	64.47	65.60	65.62	5.59	5.57
25	20.80	20.78	66.30	66.66	67.00	67.37	4.04	3.84
10	40.10	39.98	67.30	68.27	67.60	68.59	3.96	2.93
	Head Chemistry		**63.50**	**63.95**	**64.66**	**65.09**	**6.45**	**6.11**

Rougher Cell 1 Tails

Flow Rate: 4.5 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.02	15.90	15.41	21.90	21.35	65.90	67.02
150	0.20	0.09	15.90	14.90	21.90	20.81	65.90	67.34
106	2.60	2.39	15.90	14.97	21.90	20.68	65.90	68.19
75	13.20	11.94	19.30	20.85	25.40	27.51	60.32	59.94
53	14.00	13.84	24.70	26.67	31.70	34.60	49.95	49.26
38	8.60	9.75	27.40	29.91	36.60	40.22	43.63	41.17
25	20.50	20.26	34.00	37.15	43.40	47.54	31.59	26.78
10	40.80	41.72	59.00	56.75	63.20	60.03	8.29	10.68
	Head Chemistry		**39.87**	**40.67**	**46.26**	**47.19**	**30.48**	**29.57**

Rougher Cell 2 Tails

Flow Rate: 1.0 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.30	0.30	17.00	15.18	24.00	21.91	64.40	68.15
150	0.70	0.69	17.00	15.03	24.00	21.80	64.40	67.14
106	3.30	3.22	17.00	16.65	24.00	23.51	64.40	65.20
75	13.50	13.19	23.70	24.21	30.70	31.39	54.10	53.94
53	17.50	17.44	29.70	30.33	37.70	38.65	42.19	42.10
38	7.80	8.02	37.00	37.54	45.70	46.41	29.88	29.63
25	14.20	14.26	34.20	34.41	45.20	45.84	30.04	29.45
10	42.70	42.88	54.40	53.53	59.60	58.56	11.07	12.05
	Head Chemistry		**40.10**	**40.04**	**47.21**	**47.22**	**28.78**	**28.96**

Rougher Cell 3 Tails

Flow Rate: 1.1 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.30	0.30	17.40	15.27	23.50	21.12	65.00	69.20
150	0.40	0.40	17.40	16.08	23.50	22.06	65.00	66.78
106	2.10	2.06	17.40	17.13	23.50	23.14	65.00	65.58
75	9.70	9.49	20.60	20.90	28.40	28.88	55.95	55.94
53	11.30	11.22	26.50	26.87	35.30	35.92	45.31	45.26
38	6.50	6.64	36.00	36.48	43.50	44.02	32.00	31.90
25	14.30	14.33	38.00	38.31	48.00	48.93	27.50	26.62
10	55.40	55.55	51.70	49.89	58.30	56.50	14.50	16.42
	Head Chemistry		**41.90**	**41.09**	**49.40**	**48.72**	**26.41**	**27.27**

Rougher Cell 4 Tails

Flow Rate: 1.2 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.08	16.10	15.56	23.90	23.23	65.80	66.89
150	0.20	0.17	16.10	15.60	23.90	23.31	65.80	66.51
106	2.90	2.83	16.10	15.76	23.90	23.32	65.80	66.63
75	16.60	15.98	22.50	23.05	30.20	31.02	54.19	54.22
53	11.50	11.40	27.60	28.01	37.30	37.98	43.51	43.43
38	3.10	3.12	33.00	33.28	41.10	41.32	30.00	30.01
25	10.80	10.88	36.00	36.02	48.90	49.92	25.00	24.13
10	54.80	55.54	48.40	46.48	56.60	55.58	14.76	16.02
	Head Chemistry		**38.86**	**38.14**	**47.64**	**47.60**	**27.82**	**28.12**

Rougher Cell 1 Con.

Flow Rate: 99.2 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	37.90	38.55	43.60	44.73	30.00	27.65
150	0.40	0.40	37.90	38.77	43.60	44.97	30.00	27.30
106	1.50	1.48	37.90	39.49	43.60	45.71	30.00	26.02
75	8.80	8.98	50.70	51.35	54.10	54.66	16.58	14.63
53	16.00	15.79	62.10	62.10	63.60	63.65	8.13	6.72
38	12.40	11.63	63.80	65.27	64.80	66.27	5.34	4.57
25	20.80	20.67	67.30	67.71	67.70	68.06	3.63	2.95
10	40.00	40.95	67.60	68.53	69.10	68.81	2.67	2.67
	Head Chemistry		**64.11**	**64.85**	**65.57**	**65.82**	**5.85**	**5.13**

Rougher Cell 2 Con.

Flow Rate: 98.2 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	38.90	39.27	44.50	45.44	25.70	26.40
150	0.40	0.40	38.90	39.19	44.50	45.38	25.70	26.59
106	1.50	1.46	38.90	40.01	44.50	46.21	25.70	25.13
75	9.10	8.94	52.10	51.76	55.30	55.01	15.43	14.03
53	17.40	15.78	63.00	62.46	64.40	63.94	6.32	6.32
38	12.70	11.67	64.50	65.47	65.30	66.41	4.94	4.39
25	21.10	20.74	69.20	67.95	69.50	68.23	2.44	2.76
10	37.70	40.93	69.20	68.69	70.50	68.92	2.01	2.57
	Head Chemistry		**65.36**	**65.10**	**66.66**	**66.00**	**4.92**	**4.89**

Rougher Cell 3 Con.

Flow Rate: 97.0 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	39.50	40.13	45.00	46.31	25.00	24.87
150	0.40	0.40	39.50	39.46	45.00	45.65	25.00	26.13
106	1.50	1.45	39.50	40.39	45.00	46.60	25.00	24.46
75	9.60	8.93	52.30	52.15	55.30	55.34	15.00	13.52
53	16.00	15.83	63.80	62.76	65.10	64.17	6.00	6.00
38	11.40	11.72	66.80	65.66	67.50	66.56	4.16	4.21
25	23.70	20.81	69.30	68.19	69.50	68.38	2.31	2.57
10	37.30	40.76	69.30	68.99	70.40	69.12	1.71	2.35
	Head Chemistry		**65.91**	**65.38**	**67.05**	**66.21**	**4.56**	**4.63**

Rougher Cell 4 Con.

Flow Rate: 95.8 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	42.60	40.39	48.00	46.55	24.04	24.43
150	0.40	0.40	42.60	39.58	48.00	45.77	24.04	25.92
106	1.40	1.44	42.60	40.98	48.00	47.15	24.04	23.44
75	8.60	8.85	52.40	52.79	55.30	55.87	13.85	12.61
53	16.10	15.88	64.20	63.06	65.40	64.40	5.72	5.67
38	12.30	11.83	67.00	65.77	67.60	66.64	3.90	4.12
25	24.30	20.93	69.40	68.39	69.50	68.49	2.26	2.43
10	36.80	40.58	69.40	69.37	69.90	69.35	1.65	2.12
	Head Chemistry		**66.30**	**65.72**	**67.13**	**66.44**	**4.21**	**4.34**

Combined Rougher Tails

Flow Rate: 7.8 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.10	0.11	15.00	15.29	22.00	21.68	66.00	68.30
150	0.20	0.22	15.00	15.33	22.00	21.80	66.00	67.02
106	2.20	2.52	15.00	15.64	22.00	21.89	66.00	67.12
75	13.50	12.36	22.00	21.75	28.80	28.88	56.79	57.54
53	15.50	13.56	26.60	27.47	34.30	35.86	48.43	46.84
38	9.00	8.07	34.00	31.88	42.40	41.54	37.00	37.92
25	15.50	17.20	38.00	36.89	48.50	47.76	24.00	26.80
10	44.00	45.97	52.90	53.27	58.00	58.41	13.62	12.83
	Head Chemistry		**39.69**	**40.26**	**46.60**	**47.47**	**29.87**	**28.94**

Dewatering Magnetic Separator Tails

Flow Rate: 0.4 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.20	0.22	9.80	9.90	19.50	20.24	66.30	63.81
150	0.50	0.52	9.80	9.91	19.50	20.21	66.30	64.88
106	1.10	1.12	9.80	9.79	19.50	19.67	66.30	65.95
75	5.10	5.23	4.70	4.70	14.00	13.91	65.00	64.77
53	6.40	6.52	6.30	6.29	19.30	19.04	64.50	64.68
38	5.00	5.01	8.90	8.91	31.50	31.32	48.90	49.01
25	20.00	22.67	12.00	12.06	36.00	34.53	37.00	37.68
10	61.70	58.70	13.00	13.34	36.00	28.42	36.00	42.20
	Head Chemistry		**11.69**	**11.85**	**33.29**	**28.42**	**40.69**	**44.59**

Dewatering Magnetic Separator Concentrate

Flow Rate: 7.4 %

Size	**% Weight**		**Satmagan Iron (%)**		**Total Iron (%)**		**Silica (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.10	0.10	15.50	15.88	21.10	21.84	66.70	68.79
150	0.20	0.21	15.50	16.02	21.10	22.01	66.70	67.29
106	2.40	2.59	15.50	15.77	21.10	21.94	66.70	67.14
75	14.00	12.72	23.20	22.11	29.40	29.20	56.34	57.39
53	15.50	13.91	28.30	27.98	35.70	36.27	46.30	46.42
38	9.20	8.23	32.90	32.58	40.50	41.85	38.18	37.58
25	13.20	16.92	35.20	38.57	44.90	48.65	31.23	26.06
10	45.40	45.33	54.70	55.90	58.80	60.39	12.39	10.90
	Head Chemistry		**40.56**	**41.70**	**46.57**	**48.44**	**30.12**	**28.14**

Froth Thickener O/F

Flow Rate: 0.4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	13.80	13.80	20.80	20.80	67.00	67.00
150	0.20	0.20	13.80	13.80	20.80	20.80	67.00	66.86
106	1.20	1.21	13.80	13.79	20.80	20.79	67.00	66.93
75	6.70	6.83	16.30	16.32	23.20	23.17	65.94	65.92
53	10.00	10.24	19.30	19.27	27.50	27.38	60.22	60.30
38	7.80	7.79	21.00	21.03	31.30	31.15	54.27	54.38
25	23.50	24.75	19.00	18.83	32.10	31.67	51.32	51.82
10	50.50	48.88	34.50	34.34	46.40	45.48	30.38	31.39
	Head Chemistry		**26.75**	**26.38**	**38.03**	**37.20**	**43.08**	**44.10**

Froth Thickener U/F

Flow Rate: 7.0 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.10	0.10	16.00	16.00	21.90	21.90	68.90	68.90
150	0.30	0.21	16.00	16.14	21.90	22.07	68.90	67.32
106	2.10	2.67	16.00	15.82	21.90	21.97	68.90	67.15
75	10.70	13.06	19.90	22.29	28.10	29.39	60.60	57.13
53	12.20	14.13	27.10	28.35	36.50	36.64	48.00	45.82
38	8.10	8.25	30.70	33.22	43.10	42.44	37.68	36.65
25	16.30	16.46	42.10	40.31	51.60	50.15	23.33	23.78
10	50.20	45.12	56.70	57.27	61.70	61.34	9.28	9.60
	Head Chemistry		**43.65**	**42.60**	**50.89**	**49.10**	**25.58**	**27.21**

Regrind Ball Mill Discharge

Flow Rate: 7.0 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.10	16.70	20.64	24.10	27.78	64.04	57.04
106	0.70	1.02	16.70	17.64	24.10	24.98	64.04	62.46
75	4.60	5.62	16.70	17.88	24.10	25.38	64.04	61.23
53	8.00	9.07	22.90	23.16	33.40	30.62	50.86	54.64
38	7.00	9.69	26.90	32.18	39.30	41.66	42.74	37.54
25	22.90	21.97	37.20	36.27	46.40	44.42	29.85	32.80
10	56.60	52.52	54.00	53.71	60.20	58.68	12.76	13.84
	Head Chemistry		**43.72**	**42.60**	**51.45**	**49.10**	**24.64**	**27.21**

Scavenger Cell 1 Tails

Flow Rate: 2.3 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.11	15.00	14.97	22.80	21.63	65.00	64.92
106	2.00	1.28	15.00	9.22	22.80	16.51	65.00	76.54
75	8.70	8.26	15.00	14.40	22.80	21.92	65.00	66.74
53	18.00	17.46	19.65	19.99	25.65	26.47	62.12	60.73
38	10.90	10.80	22.60	19.52	33.00	29.90	50.10	55.06
25	29.20	30.58	21.10	21.99	31.40	32.12	51.81	50.64
10	31.10	31.50	31.00	31.91	43.50	43.99	36.24	35.43
	Head Chemistry		**23.42**	**23.70**	**33.37**	**33.58**	**50.06**	**49.77**

Scavenger Cell 2 Tails

Flow Rate: 0.8 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.11	17.00	14.12	25.00	21.87	62.00	67.06
106	1.00	1.01	17.00	13.74	25.00	21.54	62.00	68.13
75	13.50	11.34	17.00	15.84	25.00	23.54	62.00	64.80
53	19.50	13.02	22.60	22.52	30.60	30.99	56.72	56.35
38	9.90	11.00	23.40	21.12	33.70	31.62	52.31	55.07
25	19.50	22.49	20.00	19.89	34.90	35.66	46.24	45.83
10	36.50	41.04	32.90	33.20	43.80	43.41	29.86	30.15
	Head Chemistry		**25.11**	**25.30**	**35.74**	**36.25**	**45.21**	**44.18**

Scavenger Cell 3 Tails

Flow Rate: 0.3 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.10	19.00	17.82	26.80	25.55	58.00	59.69
106	1.50	1.58	19.00	16.76	26.80	24.50	58.00	61.81
75	13.00	12.07	19.00	18.57	26.80	26.27	58.00	58.98
53	16.90	14.52	22.60	22.88	31.80	32.33	51.08	50.34
38	10.00	10.25	24.50	23.86	35.60	35.04	43.64	44.56
25	14.20	15.47	20.80	20.51	35.80	36.48	43.94	43.67
10	44.30	46.00	30.70	30.69	42.70	42.74	31.07	31.12
	Head Chemistry		**25.60**	**25.59**	**36.85**	**37.18**	**41.47**	**41.11**

Scavenger Combined Tails

Flow Rate: 3.4 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.11	15.00	15.00	22.00	22.00	65.00	65.00
106	2.00	1.24	15.00	10.93	22.00	18.37	65.00	73.28
75	11.00	9.32	18.10	15.29	25.10	22.88	60.72	65.31
53	12.80	16.15	19.20	20.70	27.40	27.80	59.49	59.08
38	11.00	10.80	20.42	20.27	30.32	30.75	53.56	54.19
25	27.00	27.34	17.80	21.51	37.20	33.03	50.78	49.36
10	36.10	35.04	30.50	32.13	43.90	43.69	33.48	33.47
	Head Chemistry		**22.83**	**24.25**	**35.96**	**34.53**	**47.35**	**47.68**

Scavenger Cell 1 Con.
Flow Rate: 4.7 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.10	18.90	23.68	26.10	31.07	60.60	52.80
106	1.00	0.89	18.90	23.50	26.10	30.87	60.64	52.66
75	3.30	4.34	18.90	21.08	26.10	28.56	60.64	56.15
53	3.50	5.01	28.00	28.51	38.00	37.62	44.70	44.38
38	10.90	9.16	33.00	39.41	43.40	48.37	33.51	27.54
25	19.30	17.81	47.50	48.13	55.50	54.63	19.09	17.98
10	61.90	62.69	59.10	59.01	62.00	62.25	9.17	8.59
	Head Chemistry		**51.16**	**51.75**	**56.30**	**56.61**	**17.25**	**16.29**

Scavenger Cell 2 Con.
Flow Rate: 3.9 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.10	25.60	25.80	32.90	33.11	47.76	49.63
106	1.00	0.87	25.60	25.84	32.90	33.11	47.76	48.96
75	3.10	2.90	25.60	25.28	32.90	32.58	47.76	49.22
53	3.30	3.37	34.40	33.27	43.90	42.88	33.07	34.87
38	11.10	8.78	44.90	44.11	53.20	52.67	19.62	20.45
25	16.90	16.85	55.10	55.87	61.10	59.83	11.24	10.35
10	64.50	67.14	62.90	62.25	65.70	64.61	5.92	5.89
	Head Chemistry		**57.08**	**57.18**	**61.44**	**60.79**	**10.99**	**10.57**

Scavenger Cell 3 Con.
Flow Rate: 3.6 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.10	27.70	26.47	34.90	33.75	45.16	48.79
106	1.00	0.81	27.70	27.29	34.90	34.48	45.16	46.91
75	2.80	2.16	27.70	28.34	34.90	35.46	45.16	44.77
53	3.20	2.46	35.90	38.27	45.40	47.96	29.80	27.42
38	11.20	8.66	48.90	46.06	56.70	54.37	16.20	18.12
25	16.60	16.96	56.00	58.50	58.70	61.56	8.00	7.87
10	65.10	68.86	63.00	63.96	64.50	65.79	5.00	4.51
	Head Chemistry		**58.01**	**59.75**	**60.89**	**62.71**	**9.11**	**8.08**

Scavenger Concentrate

Flow Rate: 3.6 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.10	0.10	29.00	26.47	36.20	33.75	42.36	48.79
106	1.00	0.81	29.00	27.29	36.20	34.48	42.36	46.91
75	2.80	2.16	29.00	28.34	36.20	35.46	42.36	44.77
53	2.60	2.46	39.10	38.27	48.60	47.96	26.95	27.42
38	11.00	8.66	46.80	46.06	55.30	54.37	16.48	18.12
25	16.90	16.96	58.40	58.50	61.30	61.56	7.41	7.87
10	65.60	68.86	63.10	63.96	65.30	65.79	4.42	4.51
	Head Chemistry		**58.56**	**59.75**	**61.96**	**62.71**	**8.32**	**8.08**

Combined Flotation Tails

Flow Rate: 10.0 %

Size	% Weight		Satmagan Iron (%)		Total Iron (%)		Silica (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.70	0.70	13.70	13.70	21.10	21.10	67.76	67.76
150	0.20	0.20	13.70	13.70	21.10	21.10	67.76	67.76
106	1.40	1.40	13.70	13.70	21.10	21.10	67.76	67.76
75	5.20	5.20	14.00	14.00	19.20	19.20	73.62	73.62
53	5.40	5.40	17.10	17.10	24.00	24.00	66.66	66.66
38	9.90	9.90	17.50	17.50	25.80	25.80	61.04	61.04
25	20.00	20.00	24.70	24.70	36.20	36.20	47.08	47.08
10	57.20	57.20	24.70	24.70	36.20	36.20	47.08	47.08
	Head Chemistry		**22.77**	**22.77**	**33.28**	**33.28**	**51.38**	**51.38**

APPENDIX E

PRELIMINARY VALIDATION SAMPLING

RAW AND MASS BALANCED DATA

FOR LINE 1 AND LINE 3

Rod Mill Feed

Size	Weight %			
	Line 1		Line 3	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
26500	1.17	1.17	1.63	1.63
19000	14.33	14.33	21.59	21.59
13200	17.97	17.97	21.31	21.31
9500	18.47	18.47	21.75	21.75
6700	8.76	8.76	7.76	7.76
4750	7.74	7.74	6.08	6.08
3350	5.35	5.35	4.07	4.07
2360	4.61	4.61	2.97	2.97
1700	1.66	3.16	1.07	2.07
1180	4.26	2.76	2.39	1.39
850	2.13	2.13	1.24	1.24
600	1.85	1.85	1.09	1.09
425	1.59	1.59	0.91	0.91
300	1.14	1.14	0.65	0.65
212	1.12	1.12	0.66	0.66
150	1.10	1.10	0.68	0.68
106	0.97	0.97	0.59	0.59
75	0.99	0.99	0.58	0.58
53	0.84	0.84	0.52	0.52
38	0.73	0.73	0.46	0.46
25	3.21	3.22	2.00	2.00

Rod Mill Discharge

Size	Weight %			
	Line 1		Line 3	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	4.82	4.70	2.47	1.94
3350	8.33	7.55	5.71	4.28
2360	5.31	8.39	4.09	7.37
1700	15.20	12.31	14.56	10.79
1180	19.12	14.44	20.46	15.59
850	9.97	9.53	11.42	11.05
600	8.09	8.04	9.13	9.44
425	5.80	6.03	6.37	7.14
300	3.35	3.77	3.71	4.47
212	2.86	3.39	3.14	4.08
150	2.45	3.03	2.76	3.56
106	1.88	2.42	2.09	2.78
75	1.63	2.21	1.90	2.50
53	1.55	1.98	1.71	2.20
38	1.55	1.95	1.90	2.24
25	8.09	10.26	8.56	10.57

Cobber Concentrate

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
4750	5.47	5.48	2.04	2.08
3350	8.58	8.66	4.50	4.61
2360	5.29	9.55	3.99	8.10
1700	13.96	13.31	12.49	11.61
1180	18.80	15.80	19.37	16.77
850	10.13	10.16	11.55	11.75
600	8.30	8.29	9.69	9.70
425	6.02	5.98	7.22	7.13
300	3.56	3.50	4.33	4.22
212	3.10	3.03	3.91	3.75
150	2.74	2.65	3.48	3.34
106	2.19	2.10	2.72	2.59
75	2.01	1.91	2.46	2.35
53	1.64	1.58	2.04	1.96
38	1.55	1.50	1.95	1.91
25	6.66	6.48	8.24	8.11

Cobber Tails

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
4750	2.59	2.59	1.55	1.56
3350	4.53	4.54	3.39	3.42
2360	2.05	5.27	2.44	5.48
1700	9.92	9.59	9.59	8.67
1180	12.73	10.77	14.39	12.58
850	7.77	7.80	9.15	9.25
600	7.34	7.35	8.71	8.76
425	6.15	6.15	7.16	7.16
300	4.53	4.50	5.17	5.13
212	4.42	4.37	5.02	4.93
150	4.10	4.03	4.21	4.14
106	3.34	3.27	3.32	3.25
75	3.13	3.04	2.95	2.89
53	3.13	3.06	2.88	2.82
38	3.24	3.17	3.10	3.07
25	21.04	20.50	16.97	16.87

Ball Mill Discharge

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
4750	0.48	0.35	0.00	0.00
3350	0.58	0.40	0.09	0.08
2360	0.39	0.34	0.19	0.09
1700	1.35	1.02	0.47	0.41
1180	2.90	2.65	1.69	1.59
850	2.90	2.80	2.62	2.30
600	5.50	5.24	4.96	4.61
425	7.72	7.42	6.55	6.12
300	6.85	6.88	5.90	5.96
212	8.78	8.80	8.24	8.52
150	12.26	12.25	12.36	12.65
106	12.84	12.94	13.39	13.89
75	11.87	11.54	13.01	12.63
53	7.34	7.53	8.33	8.26
38	4.73	4.93	4.96	5.51
25	13.51	14.91	17.23	17.38

Rougher Concentrate

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
3350	0.83	0.81	0.10	0.09
2360	0.36	0.36	0.10	0.09
1700	0.95	1.08	0.40	0.43
1180	2.60	2.82	1.60	1.69
850	2.84	2.96	2.31	2.44
600	5.21	5.53	4.71	4.88
425	7.69	7.79	6.32	6.41
300	7.22	7.09	6.12	6.13
212	8.88	8.86	8.63	8.61
150	12.43	12.40	12.84	12.89
106	13.37	13.24	14.44	14.27
75	11.72	11.85	12.84	12.98
53	7.57	7.49	8.02	8.27
38	4.73	4.62	5.82	5.24
25	13.61	13.09	15.75	15.58

Rougher Tails

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
3350	0.11	0.11	0.03	0.03
2360	0.11	0.11	0.06	0.06
1700	0.33	0.38	0.14	0.14
1180	0.88	0.94	0.56	0.56
850	1.21	1.22	0.83	0.83
600	2.32	2.33	1.81	1.81
425	3.75	3.76	3.20	3.21
300	4.75	4.76	4.31	4.31
212	8.17	8.20	7.65	7.64
150	10.60	10.65	10.30	10.29
106	9.93	9.97	10.02	10.01
75	8.39	8.44	9.05	9.08
53	7.95	7.96	8.21	8.22
38	8.06	8.03	8.35	8.22
25	33.44	33.15	35.49	35.58

Cyclone U/F

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
3350	0.77	0.98	0.00	0.11
2360	0.44	0.44	0.12	0.11
1700	1.54	1.30	0.60	0.55
1180	3.86	3.39	2.28	2.13
850	3.75	3.55	3.13	3.08
600	7.28	6.64	6.13	6.09
425	9.15	9.32	7.69	7.96
300	8.16	8.46	7.57	7.54
212	10.36	10.47	10.70	10.52
150	13.78	14.02	15.26	15.07
106	14.00	14.33	15.75	15.83
75	12.02	12.18	13.46	13.69
53	6.17	6.20	6.85	6.64
38	2.87	2.89	3.13	3.25
25	5.84	5.84	7.33	7.42

Cyclone O/F

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
600	0.00	0.00	0.51	0.26
425	0.13	0.10	1.01	0.49
300	0.38	0.22	1.27	0.72
212	1.02	0.83	1.90	1.34
150	4.32	4.31	4.69	4.58
106	7.62	7.75	8.11	8.33
75	11.94	10.21	10.52	10.27
53	13.98	13.94	15.08	14.46
38	13.72	13.32	12.42	12.85
25	46.89	49.31	44.49	46.71

Hydroseparator O/F

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
212	0.05	0.05	0.28	0.30
150	0.10	0.10	0.17	0.17
106	0.25	0.25	0.17	0.17
75	1.27	1.28	1.93	1.93
53	6.84	6.84	9.91	9.92
38	13.68	13.72	15.14	15.15
25	77.80	77.76	72.41	72.36

Hydroseparator U/F

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
600	0.00	0.00	0.31	0.27
425	0.12	0.11	0.52	0.52
300	0.23	0.24	0.73	0.76
212	0.82	0.89	1.35	1.39
150	4.57	4.61	4.67	4.82
106	7.96	8.28	8.61	8.77
75	10.30	10.83	10.68	10.72
53	14.40	14.43	14.94	14.70
38	13.23	13.30	12.34	12.73
25	48.36	47.32	45.85	45.32

Fine Screen O/S

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
600	0.13	0.00	0.62	0.62
425	0.13	0.36	0.99	1.00
300	0.81	0.79	1.48	1.47
212	2.42	2.29	2.59	2.66
150	13.84	13.77	9.99	9.67
106	16.53	15.73	15.41	14.78
75	10.75	10.87	11.96	12.14
53	10.89	10.96	12.08	12.39
38	10.08	10.19	10.73	10.55
25	34.41	35.05	34.16	34.71

Fine Screen U/S

Size (micron)	Weight % Line 1 Raw Data	Line 1 Mass Bal.	Line 3 Raw Data	Line 3 Mass Bal.
425	0.00	0.00	0.14	0.15
300	0.11	0.01	0.27	0.21
212	0.32	0.30	0.41	0.42
150	0.76	0.76	1.09	1.08
106	5.39	5.15	4.22	4.15
75	10.68	10.82	9.54	9.64
53	15.86	15.89	15.94	16.48
38	14.35	14.60	14.99	14.40
25	52.54	52.48	53.41	53.47

APPENDIX F

BLEND 1 FINAL VALIDATION SAMPLING

MAGNETIC CIRCUIT

RAW AND MASS BALANCED DATA

Rod Mill Feed

Flow Rate: **360** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
26500	2.90	2.90	24.17	24.21
19000	18.40	18.39	24.17	24.46
13200	19.30	19.31	25.43	25.76
9500	18.70	18.70	24.78	25.09
6700	8.20	8.20	24.78	24.92
4750	7.20	7.20	25.31	25.43
3350	4.60	4.60	25.31	25.39
2360	3.90	3.90	25.23	25.30
1700	2.70	2.70	24.42	24.46
1180	2.20	2.20	24.42	24.46
850	1.90	1.90	24.42	24.45
600	1.40	1.40	24.42	24.44
425	1.30	1.30	24.42	24.44
300	1.00	1.00	25.37	25.38
212	0.80	0.80	25.37	25.38
150	0.70	0.70	32.33	32.34
106	0.80	0.80	32.33	32.34
75	0.60	0.60	32.33	32.34
53	0.60	0.60	32.33	32.34
38	0.50	0.50	32.33	32.34
25	2.30	2.30	21.85	21.88
	Head Chemistry		**25.01**	**25.22**

Rod Mill Discharge 1

Flow Rate: **360** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	1.90	2.01	22.33	23.83
3350	3.40	3.64	22.33	24.32
2360	3.90	4.67	23.89	25.10
1700	13.80	15.91	23.89	24.73
1180	10.10	11.59	23.19	24.46
850	10.20	10.32	23.19	24.26
600	8.30	8.07	23.63	25.22
425	7.50	6.88	23.63	24.44
300	5.60	4.88	25.10	26.16
212	4.20	3.68	25.10	25.21
150	3.80	3.17	28.35	28.21
106	3.60	3.26	31.58	32.75
75	3.30	2.65	33.08	30.04
53	3.00	2.74	32.68	31.77
38	3.00	2.86	32.34	31.55
25	14.40	13.65	21.80	21.59
	Head Chemistry		**24.71**	**25.22**

Rod Mill Discharge 2

Flow Rate:	**360**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
4750	2.90	2.01	23.19	23.83
3350	4.50	3.64	23.19	24.32
2360	4.80	4.67	25.23	25.10
1700	18.00	15.91	25.23	24.73
1180	10.90	11.59	25.31	24.46
850	10.80	10.32	25.31	24.26
600	8.50	8.07	25.16	25.22
425	7.20	6.88	25.16	24.44
300	5.40	4.88	26.96	26.16
212	3.70	3.68	26.96	25.21
150	3.40	3.17	31.40	28.21
106	3.20	3.26	34.77	32.75
75	2.50	2.65	36.79	30.04
53	2.20	2.74	37.27	31.77
38	2.30	2.86	38.56	31.55
25	9.70	13.65	28.77	21.59
	Head Chemistry		**26.96**	**25.22**

Cobber Concentrate

Flow Rate:	**252.7**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
4750	2.30	2.27	29.58	29.09
3350	4.30	4.24	29.58	28.88
2360	5.80	5.53	29.97	29.59
1700	18.70	18.53	29.97	29.57
1180	13.80	13.47	29.93	29.48
850	11.70	11.84	29.93	29.57
600	8.90	9.02	32.23	31.69
425	7.20	7.36	32.23	31.98
300	4.70	4.82	37.51	37.25
212	3.40	3.48	37.51	37.53
150	2.70	2.78	45.05	45.15
106	2.90	2.93	51.31	51.22
75	1.90	1.98	56.02	56.25
53	2.10	2.13	57.40	57.50
38	2.10	2.13	59.73	59.81
25	7.50	7.50	54.40	54.39
	Head Chemistry		**35.46**	**35.23**

Cobber Tails

Flow Rate: **107.3** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	1.40	1.41	4.12	3.94
3350	2.20	2.23	4.12	3.94
2360	2.70	2.65	3.05	3.00
1700	9.90	9.75	3.05	3.00
1180	7.20	7.16	2.31	2.25
850	6.60	6.73	2.31	2.25
600	5.60	5.84	1.64	1.64
425	5.50	5.73	1.64	1.64
300	4.70	5.04	1.13	1.17
212	4.10	4.17	1.13	1.02
150	4.00	4.10	1.11	1.20
106	3.90	4.04	1.15	1.17
75	4.30	4.23	1.11	1.12
53	4.30	4.19	1.13	0.96
38	5.00	4.60	1.03	0.80
25	28.60	28.13	1.02	0.98
	Head Chemistry		**1.66**	**1.62**

Classifier Sands

Flow Rate: **54.9** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
4750	2.80	2.76	3.84	3.94
3350	4.40	4.35	3.84	3.94
2360	5.30	5.17	2.97	3.00
1700	18.20	19.05	2.97	3.00
1180	14.20	13.97	2.21	2.25
850	13.10	13.14	2.21	2.25
600	11.70	11.40	1.64	1.64
425	11.30	11.19	1.64	1.64
300	8.90	8.51	1.20	1.15
212	4.90	5.24	1.20	1.28
150	2.20	2.20	2.59	2.46
106	1.10	1.10	4.62	4.56
75	0.50	0.50	7.66	7.66
53	0.20	0.21	10.99	11.41
38	0.10	0.10	12.58	12.98
25	1.10	1.11	10.46	10.55
	Head Chemistry		**2.42**	**2.45**

Classifier Fines

Flow Rate: **52.3** **LTPH**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
300	1.40	1.39	1.32	1.31
212	3.00	3.05	0.52	0.53
150	5.60	6.10	0.75	0.72
106	6.80	7.13	0.63	0.62
75	8.30	8.15	0.70	0.70
53	9.30	8.37	0.63	0.68
38	9.20	9.32	0.58	0.65
25	56.40	56.49	0.76	0.78
	Head Chemistry		**0.72**	**0.74**

Ball Mill Discharge

Flow Rate: **1240.0** **LTPH**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	0.60	0.43	18.88	19.82
1700	1.30	1.32	21.05	20.39
1180	1.70	1.75	24.37	24.62
850	2.60	2.63	24.59	24.73
600	3.50	3.92	32.46	33.88
425	6.00	6.55	32.46	33.87
300	6.70	6.72	34.99	35.46
212	7.10	6.84	34.99	35.12
150	9.40	9.28	39.00	39.71
106	13.40	13.83	48.80	48.22
75	11.90	11.37	56.82	57.11
53	8.80	8.82	58.82	58.49
38	6.10	6.07	57.12	57.13
25	20.90	20.48	54.10	54.69
	Head Chemistry		**46.29**	**46.44**

Rougher Concentrate

Flow Rate: **1133.0** **LTPH**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	0.70	0.44	19.96	20.79
1700	1.50	1.37	19.96	21.16
1180	2.00	1.83	25.24	25.58
850	2.90	2.77	25.24	25.58
600	4.20	4.11	35.77	35.23
425	6.90	6.88	35.77	35.20
300	7.30	6.94	41.86	37.35
212	6.90	6.96	41.86	37.48
150	9.20	9.47	45.17	42.47
106	13.60	14.20	51.15	51.30
75	11.80	11.65	61.17	60.80
53	8.60	8.80	64.50	64.05
38	6.10	5.84	64.95	64.81
25	18.30	18.75	65.48	65.13
	Head Chemistry		**51.41**	**50.64**

Combined Rougher Concentrate

Flow Rate:	1133.0	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	1.10	0.44	21.32	20.79
1700	1.60	1.37	21.32	21.16
1180	1.90	1.83	26.16	25.58
850	2.80	2.77	26.16	25.58
600	4.20	4.11	36.82	35.23
425	7.20	6.88	36.82	35.20
300	6.80	6.94	37.28	37.35
212	6.90	6.96	37.28	37.48
150	9.60	9.47	41.34	42.47
106	14.20	14.20	51.31	51.30
75	10.80	11.65	61.43	60.80
53	8.40	8.80	63.13	64.05
38	5.20	5.84	64.31	64.81
25	19.30	18.75	64.34	65.13
	Head Chemistry		**50.07**	**50.64**

Rougher Tails

Flow Rate:	106.7	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	0.30	0.29	4.16	4.15
1700	0.70	0.69	4.16	4.17
1180	0.90	0.89	3.65	3.65
850	1.20	1.20	3.65	3.65
600	1.90	1.90	2.75	2.75
425	3.10	3.10	2.75	2.75
300	4.40	4.39	3.78	3.78
212	5.60	5.58	3.78	3.79
150	7.30	7.30	1.66	1.66
106	10.10	9.97	1.60	1.60
75	8.30	8.33	2.32	2.32
53	9.20	9.07	1.20	1.20
38	8.70	8.51	1.13	1.13
25	38.30	38.79	1.06	1.06
	Head Chemistry		**1.72**	**1.72**

Hydrocyclone U/F

Flow Rate: **856.9** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	0.80	0.58	21.80	20.79
1700	1.60	1.82	21.80	21.16
1180	2.40	2.42	25.02	25.58
850	3.40	3.66	25.02	25.58
600	4.70	5.43	34.70	35.23
425	8.30	8.93	34.70	35.31
300	9.00	8.95	33.93	37.56
212	8.80	8.79	33.93	37.87
150	11.40	11.68	43.37	44.08
106	16.00	15.97	55.52	55.80
75	12.90	12.24	64.80	65.07
53	7.70	6.97	67.39	67.36
38	3.50	3.05	66.71	66.67
25	9.50	9.52	67.26	67.17
	Head Chemistry		**48.63**	**48.96**

Hydrocyclone O/F

Flow Rate: **276.5** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.40	0.52	31.90	29.07
300	0.80	0.71	31.90	29.08
212	1.80	1.29	31.90	29.19
150	3.70	2.63	21.33	20.33
106	8.80	8.70	26.14	25.70
75	10.10	9.84	46.63	44.36
53	15.30	14.49	59.48	59.10
38	13.60	14.47	63.64	63.59
25	45.50	47.35	64.06	63.86
	Head Chemistry		**55.66**	**55.88**

Hydroseparator O/F

Flow Rate: **8.6** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	0.40	0.40	18.40	18.40
75	1.70	1.70	18.40	18.44
53	9.90	9.87	2.53	2.53
38	16.10	16.08	3.63	3.63
25	71.90	71.95	1.58	1.58
	Head Chemistry		**2.36**	**2.36**

Hydroseparator U/F

Flow Rate:	267.9	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
425	0.60	0.53	29.80	29.07
300	0.80	0.73	29.80	29.08
212	1.30	1.33	29.80	29.19
150	2.50	2.72	20.26	20.33
106	8.60	8.97	25.53	25.70
75	9.90	10.10	43.89	44.50
53	14.70	14.63	59.98	60.33
38	14.90	14.42	65.48	65.73
25	46.70	46.56	67.05	66.95
	Head Chemistry		**57.74**	**57.59**

Fine Screen O/S

Flow Rate:	130.5	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
425	1.00	1.10	25.54	29.07
300	1.30	1.50	25.54	29.08
212	2.60	2.60	25.54	28.73
150	6.30	5.34	18.72	19.39
106	16.20	15.16	24.21	24.35
75	12.20	11.85	40.45	41.72
53	12.40	12.67	58.90	58.66
38	11.20	11.43	64.80	64.54
25	36.80	38.36	66.67	66.73
	Head Chemistry		**50.38**	**51.58**

Fine Screen U/S

Flow Rate:	137.5	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.10	0.12	37.04	38.17
150	0.20	0.23	37.04	40.91
106	3.20	3.10	31.34	31.98
75	8.80	8.44	47.99	48.20
53	16.40	16.49	61.17	61.54
38	17.00	17.26	66.55	66.49
25	54.30	54.35	66.48	67.09
	Head Chemistry		**62.78**	**63.29**

Finisher Concentrate

Flow Rate:	**132.4**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.20	0.10	45.26	44.66
150	0.30	0.23	45.26	42.27
106	2.90	2.93	35.17	34.63
75	8.10	8.26	50.23	50.73
53	16.60	16.61	63.43	63.09
38	17.80	17.60	67.45	67.32
25	54.10	54.27	69.40	69.28
	Head Chemistry		**65.40**	**65.28**

Finisher Tails

Flow Rate:	**5.0**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	1.10	0.71	13.77	13.56
150	0.30	0.30	13.84	13.64
106	7.60	7.59	5.05	5.04
75	13.60	13.14	6.17	6.18
53	13.50	13.53	11.58	11.51
38	8.30	8.31	19.79	19.67
25	55.60	56.42	11.72	11.45
	Head Chemistry		**11.14**	**10.98**

APPENDIX G

BLEND 1 FINAL VALIDATION SAMPLING

FLOTATION CIRCUIT

RAW AND MASS BALANCED DATA

Flotation Feed

Flow Rate: **100** **%**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.83	1.07	44.01	49.57
150	1.28	1.34	44.01	46.70
106	5.79	6.01	43.14	43.78
75	13.52	14.08	54.36	54.56
53	16.92	18.09	61.80	62.47
38	11.13	11.49	64.71	65.41
25	27.27	22.01	67.21	67.33
10	23.26	25.92	66.13	66.54
	Head Chemistry		**62.14**	**62.35**

Combined Flotation Feed

Flow Rate: **113.1** **%**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.88	0.95	46.83	49.44
150	1.30	1.22	46.83	45.86
106	6.26	5.54	43.59	42.91
75	13.52	13.19	52.85	53.17
53	18.27	17.18	60.32	60.90
38	12.04	11.33	63.37	63.54
25	23.08	22.75	65.87	66.07
10	24.65	27.83	64.53	65.94
	Head Chemistry		**60.65**	**61.47**

Rougher Tails

Flow Rate: **19.8** **%**

Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.20	0.15	17.61	16.69
150	1.05	1.02	17.61	17.18
106	6.44	5.30	19.36	18.58
75	11.88	11.73	25.37	24.03
53	13.03	13.02	32.65	32.11
38	8.41	9.15	35.74	35.99
25	22.78	23.42	50.73	50.43
10	36.21	36.20	60.40	60.19
	Head Chemistry		**45.17**	**45.08**

Rougher Concentrate

Flow Rate:	**93.3**	**%**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	1.33	1.12	50.88	50.38
150	1.26	1.27	50.88	50.79
106	5.32	5.59	47.76	47.80
75	13.68	13.51	58.54	58.53
53	18.26	18.06	65.44	65.30
38	11.54	11.80	68.19	68.08
25	21.43	22.61	69.46	69.51
10	27.18	26.05	67.82	67.63
	Head Chemistry		**65.00**	**64.94**

Dewatering Mag. Sep. Tails

Flow Rate:	**0.7**	**%**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	5.05	1.68	15.79	15.71
150	1.31	1.25	15.79	15.68
106	5.05	5.90	13.18	13.18
75	9.17	9.29	17.08	17.06
53	10.98	11.11	21.04	20.97
38	7.56	7.56	21.28	21.23
25	20.68	21.55	28.86	28.63
10	40.20	41.66	36.45	35.81
	Head Chemistry		**27.78**	**27.84**

Dewatering Mag. Sep. Concentrate

Flow Rate:	**19.1**	**%**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.15	0.10	17.50	17.29
150	0.95	1.02	17.50	17.24
106	6.02	5.27	18.64	18.79
75	11.66	11.81	24.10	24.22
53	13.14	13.09	32.54	32.44
38	8.77	9.21	36.63	36.42
25	21.86	23.49	51.61	51.15
10	37.45	36.01	62.02	61.20
	Head Chemistry		**46.12**	**45.69**

Froth Thickener O/F

Flow Rate:	0.2	%		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
150	0.98	0.96	13.86	13.85
106	3.73	3.75	11.63	11.62
75	8.45	8.46	11.95	11.92
53	11.59	11.61	11.63	11.59
38	10.22	10.19	10.48	10.45
25	33.86	35.19	9.22	9.13
10	31.17	29.84	24.01	23.55
	Head Chemistry		**14.60**	**14.23**

Froth Thickener U/F

Flow Rate:	18.9	%		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.05	0.10	16.14	17.29
150	0.90	1.02	16.14	17.27
106	4.34	5.29	18.55	18.83
75	11.68	11.84	22.51	24.30
53	12.85	13.10	31.19	32.60
38	10.86	9.20	36.57	36.66
25	23.81	23.39	49.94	51.67
10	35.51	36.06	61.07	61.46
	Head Chemistry		**45.14**	**45.96**

Regrind Ball Mill Discharge

Flow Rate:	18.9	%		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.05	0.02	18.72	20.48
150	0.41	0.29	18.72	20.13
106	1.98	1.64	19.88	20.56
75	6.59	5.87	24.22	26.14
53	10.76	10.17	31.13	32.97
38	11.65	11.27	34.77	36.98
25	31.74	29.90	44.28	45.70
10	36.82	40.83	53.86	55.93
	Head Chemistry		**43.36**	**45.96**

Scavenger Concentrate
Flow Rate: **13.1** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.03	0.04	23.06	20.48
150	0.33	0.35	23.06	21.36
106	1.89	1.94	22.25	22.21
75	6.01	6.44	30.08	29.94
53	9.83	10.22	39.66	39.54
38	9.95	10.16	47.49	47.38
25	27.76	28.41	58.73	58.61
10	44.20	42.45	63.26	63.12
	Head Chemistry		**55.20**	**54.74**

Scavenger Tails
Flow Rate: **5.9** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.13	0.15	14.08	13.85
106	0.96	0.99	13.44	13.37
75	4.52	4.63	14.47	14.42
53	9.91	10.04	18.18	18.11
38	13.57	13.72	19.99	19.90
25	32.21	33.22	21.24	21.21
10	38.70	37.25	37.87	37.74
	Head Chemistry		**26.81**	**26.47**

Combined Flotation Tails
Flow Rate: **6.7** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.03	0.17	11.35	15.71
150	0.24	0.28	11.35	14.67
106	1.52	1.55	12.74	13.20
75	5.09	5.19	13.95	14.80
53	9.11	10.18	16.45	18.25
38	11.97	13.02	18.08	19.80
25	35.52	32.09	20.26	21.40
10	36.52	37.52	31.64	37.26
	Head Chemistry		**23.35**	**26.32**

APPENDIX H

BLEND 2 FINAL VALIDATION SAMPLING

MAGNETIC CIRCUIT

RAW AND MASS BALANCED DATA

Rod Mill Feed

Flow Rate:	360	LTPH		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
26500	0.63	0.63	23.37	23.39
19000	20.16	20.18	23.37	24.01
13200	19.05	19.06	22.93	23.52
9500	11.11	11.10	21.94	22.26
6700	11.89	11.88	21.94	22.28
4750	7.95	7.95	21.94	22.17
3350	5.52	5.52	22.94	23.11
2360	4.98	4.98	22.94	23.09
1700	3.14	3.14	21.77	21.86
1180	2.79	2.79	21.77	21.85
850	1.93	1.93	21.77	21.82
600	1.90	1.90	21.77	21.82
425	0.87	0.87	21.77	21.79
300	1.05	1.05	21.78	21.81
212	0.81	0.81	21.78	21.80
150	0.80	0.80	25.49	25.52
106	0.58	0.58	28.64	28.67
75	0.62	0.62	28.53	28.56
53	0.66	0.66	31.56	31.59
38	0.42	0.42	32.08	32.10
25	3.14	3.14	20.26	20.34
	Head Chemistry		**22.67**	**23.04**

Rod Mill Discharge

Flow Rate:	360	LTPH		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	1.43	0.85	22.30	22.35
6700	5.04	4.07	22.30	22.55
4750	8.70	8.33	22.30	22.52
3350	9.32	9.45	22.30	22.28
2360	7.12	7.06	22.79	22.47
1700	18.16	18.10	22.79	22.76
1180	9.81	9.99	21.94	21.88
850	7.75	7.95	21.94	21.78
600	5.88	6.07	21.85	21.95
425	4.64	4.82	21.85	21.59
300	3.40	3.53	23.29	23.21
212	2.55	2.64	23.29	23.12
150	2.36	2.42	26.97	27.00
106	1.60	1.65	30.02	30.48
75	1.61	1.65	31.54	32.28
53	1.63	1.74	34.02	34.39
38	1.05	1.15	31.56	31.51
25	7.95	8.53	21.19	21.94
	Head Chemistry		**22.95**	**23.04**

Old Cobber Feed

Flow Rate:	204.9	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
9500	1.00	1.19	22.00	22.27
6700	7.00	4.76	22.00	22.37
4750	9.05	8.54	22.00	22.01
3350	8.66	8.69	22.00	21.17
2360	7.04	6.89	22.66	21.56
1700	17.90	17.93	22.66	21.71
1180	9.54	9.85	21.80	21.13
850	7.44	7.78	21.80	21.07
600	5.49	5.79	21.71	21.19
425	4.52	4.83	21.71	20.95
300	3.30	3.55	23.31	22.53
212	2.40	2.54	23.31	22.51
150	2.27	2.39	27.12	26.63
106	1.52	1.61	30.04	30.38
75	1.57	1.68	31.30	32.18
53	1.60	1.73	33.25	33.97
38	1.02	1.15	31.13	31.19
25	8.68	9.09	19.39	20.88
	Head Chemistry		**22.61**	**22.27**

New Cobber Feed

Flow Rate:	155.1	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
9500	0.30	0.39	22.91	22.71
6700	3.11	3.15	22.91	22.93
4750	8.01	8.04	22.91	23.25
3350	10.64	10.45	22.91	23.50
2360	7.28	7.30	23.04	23.60
1700	18.67	18.32	23.04	24.11
1180	10.34	10.18	22.22	22.83
850	8.38	8.18	22.22	22.67
600	6.65	6.44	22.12	22.85
425	4.87	4.81	22.12	22.45
300	3.61	3.49	23.24	24.11
212	2.86	2.79	23.24	23.84
150	2.54	2.46	26.67	27.47
106	1.76	1.70	29.98	30.60
75	1.68	1.62	32.02	32.41
53	1.68	1.75	35.56	34.95
38	1.10	1.15	32.42	31.93
25	6.52	7.79	24.81	23.58
	Head Chemistry		**23.56**	**24.04**

Old Cobber Con

Flow Rate: **136.8** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	2.00	1.38	28.16	27.78
6700	5.00	5.59	28.16	27.47
4750	9.49	9.67	28.16	27.90
3350	8.75	9.01	28.16	28.95
2360	7.14	7.27	28.00	29.22
1700	19.21	19.39	28.00	28.80
1180	10.49	10.49	27.90	28.55
850	8.22	8.21	27.90	28.70
600	5.93	5.89	29.58	30.05
425	4.78	4.76	29.58	30.54
300	3.37	3.35	33.46	34.34
212	2.39	2.39	33.46	34.44
150	2.19	2.18	41.70	42.18
106	1.48	1.45	49.24	48.63
75	1.51	1.46	54.87	53.72
53	1.48	1.43	59.93	59.27
38	0.88	0.86	59.87	59.83
25	5.69	5.23	53.73	51.08
	Head Chemistry		**31.74**	**31.92**

New Cobber Con

Flow Rate: **133.9** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	2.48	0.37	23.11	27.49
6700	4.00	3.30	23.11	25.13
4750	10.00	8.85	23.11	24.35
3350	9.85	11.67	23.11	24.28
2360	7.80	8.07	24.03	24.65
1700	14.43	19.84	24.03	25.66
1180	10.48	10.90	24.57	24.58
850	7.50	8.66	24.57	24.67
600	6.26	6.72	25.69	25.21
425	5.72	4.82	25.69	25.75
300	4.20	3.38	29.46	28.68
212	3.23	2.63	29.46	29.03
150	2.88	2.16	36.68	35.93
106	2.54	1.40	43.53	42.80
75	1.64	1.20	50.67	50.16
53	1.87	1.28	54.24	54.76
38	0.87	0.72	57.41	57.88
25	4.25	4.04	50.13	51.48
	Head Chemistry		**27.75**	**27.66**

Old Cobber Tail

Flow Rate:	68.1	LTPH		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	1.00	0.82	3.67	3.76
6700	3.00	3.08	3.67	3.77
4750	5.46	6.27	3.67	3.74
3350	7.79	8.07	3.67	3.74
2360	6.49	6.13	3.27	3.32
1700	17.27	15.02	3.27	3.35
1180	9.84	8.58	2.85	2.93
850	7.61	6.93	2.85	2.95
600	5.77	5.58	2.45	2.42
425	4.87	4.96	2.45	2.44
300	3.64	3.94	2.30	2.37
212	2.70	2.83	2.30	2.28
150	2.60	2.82	2.36	2.49
106	1.80	1.92	2.77	2.77
75	1.90	2.14	2.70	2.70
53	2.15	2.35	3.20	3.09
38	1.82	1.74	2.98	2.88
25	14.29	16.83	2.13	2.03
	Head Chemistry		**2.90**	**2.91**

New Cobber Tail

Flow Rate:	21.2	LTPH		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	1.00	0.55	2.44	2.45
6700	2.00	2.24	2.44	2.45
4750	2.63	2.97	2.44	2.44
3350	2.66	2.73	2.44	2.44
2360	2.39	2.44	1.83	1.83
1700	8.27	8.76	1.83	1.83
1180	5.43	5.64	1.48	1.48
850	4.97	5.16	1.48	1.48
600	4.42	4.65	1.27	1.27
425	4.47	4.73	1.27	1.27
300	3.89	4.22	1.01	1.01
212	3.49	3.78	1.01	1.01
150	3.99	4.33	0.76	0.79
106	3.34	3.59	0.68	0.68
75	3.94	4.24	0.75	0.75
53	4.62	4.71	0.89	0.86
38	3.77	3.83	1.02	1.01
25	34.72	31.44	0.97	0.95
	Head Chemistry		**1.24**	**1.24**

Classifier Sands

Flow Rate: **61.1** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
9500	1.00	1.11	3.66	3.54
6700	4.00	4.21	3.66	3.52
4750	7.92	8.02	3.66	3.57
3350	10.01	9.95	3.66	3.62
2360	7.68	7.68	3.18	3.16
1700	19.35	19.80	3.18	3.12
1180	11.38	11.53	2.76	2.69
850	9.49	9.53	2.76	2.67
600	7.87	7.84	2.15	2.18
425	7.35	7.18	2.15	2.17
300	5.81	5.61	2.04	1.98
212	3.80	3.37	2.04	2.07
150	2.19	2.05	3.03	2.90
106	0.72	0.57	5.43	5.42
75	0.45	0.39	7.19	7.16
53	0.27	0.30	11.58	11.71
38	0.12	0.14	17.01	17.20
25	0.59	0.72	14.11	14.17
	Head Chemistry		**3.07**	**3.05**

Classifier Fines

Flow Rate: **28.3** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
300	0.81	0.56	3.14	3.13
212	2.48	2.37	1.40	1.40
150	5.70	5.61	1.22	1.19
106	6.16	6.10	1.32	1.32
75	7.55	7.49	1.38	1.37
53	8.77	8.54	1.49	1.52
38	7.07	6.77	1.43	1.47
25	61.46	62.57	1.31	1.33
	Head Chemistry		**1.35**	**1.36**

Ball Mill Discharge

Flow Rate:	1189.4	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	2.53	2.88	21.69	21.80
1700	2.55	2.83	21.69	21.61
1180	2.55	2.70	21.69	21.64
850	3.30	3.36	21.69	21.77
600	4.43	4.46	30.38	31.07
425	6.23	6.23	30.38	31.00
300	6.61	6.66	31.69	32.12
212	6.98	7.43	31.69	31.97
150	11.14	11.08	36.48	36.48
106	10.49	10.97	44.42	45.96
75	10.86	10.12	51.12	51.97
53	7.03	7.05	53.95	53.36
38	4.23	3.91	53.68	52.30
25	21.07	20.32	49.36	48.33
	Head Chemistry		**40.65**	**40.36**

Rougher Concentrate

Flow Rate:	1057.7	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	3.46	3.10	23.28	22.60
1700	3.63	3.00	23.28	22.66
1180	3.13	2.86	23.28	22.65
850	3.78	3.61	23.28	22.61
600	4.80	4.77	32.24	32.52
425	6.61	6.64	32.24	32.56
300	6.97	7.02	34.25	34.14
212	7.91	7.77	34.25	34.22
150	11.29	11.60	39.07	39.06
106	11.29	11.43	51.84	49.48
75	9.70	10.29	58.59	57.35
53	6.57	6.85	61.37	61.56
38	3.25	3.58	62.92	63.95
25	17.61	17.47	62.56	62.87
	Head Chemistry		**45.07**	**45.20**

Combined Rougher Concentrate

Flow Rate:	1057.7	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	4.03	3.10	22.72	22.60
1700	3.02	3.00	22.72	22.66
1180	2.69	2.86	22.72	22.65
850	3.32	3.61	22.72	22.61
600	4.50	4.77	33.46	32.52
425	6.54	6.64	33.46	32.56
300	6.99	7.02	34.48	34.14
212	7.93	7.77	34.48	34.22
150	11.37	11.60	38.87	39.06
106	11.70	11.43	53.41	49.48
75	9.99	10.29	58.49	57.35
53	6.79	6.85	60.03	61.56
38	3.53	3.58	62.87	63.95
25	17.60	17.47	61.94	62.87
	Head Chemistry		**45.51**	**45.20**

Rougher Tails

Flow Rate:	131.7	LTPH		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
2360	1.41	1.14	4.47	4.47
1700	1.51	1.47	4.47	4.47
1180	1.36	1.35	4.47	4.47
850	1.41	1.41	4.47	4.47
600	1.94	1.96	2.64	2.64
425	2.90	2.94	2.64	2.64
300	3.73	3.77	2.04	2.04
212	4.69	4.67	2.04	2.04
150	6.78	6.91	1.64	1.64
106	6.78	7.24	1.28	1.28
75	8.04	8.78	1.28	1.28
53	8.92	8.62	1.04	1.04
38	7.39	6.54	1.05	1.05
25	43.14	43.19	1.07	1.07
	Head Chemistry		**1.49**	**1.48**

Hydrocyclone U/F

Flow Rate: **820.1** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
2360	4.29	4.00	21.81	22.60
1700	3.38	3.87	21.81	22.66
1180	3.51	3.69	21.81	22.65
850	4.42	4.65	21.81	22.61
600	6.16	6.15	32.88	32.52
425	8.49	8.56	32.88	32.56
300	8.71	8.91	34.11	34.19
212	9.65	9.70	34.11	34.22
150	13.72	13.63	41.53	40.99
106	12.48	12.22	52.13	53.76
75	9.85	9.43	61.43	60.37
53	4.52	4.38	64.32	64.59
38	1.77	1.63	65.93	67.99
25	9.05	9.19	65.73	67.86
	Head Chemistry		**42.76**	**42.84**

Hydrocyclone O/F

Flow Rate: **237.6** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.02	0.02	32.74	30.89
300	0.49	0.49	32.74	30.89
212	1.93	1.11	32.74	34.23
150	5.36	4.59	24.00	19.28
106	9.04	8.72	31.08	28.76
75	13.41	13.28	49.64	49.96
53	16.83	15.38	60.03	58.57
38	7.60	10.34	60.13	61.76
25	45.32	46.07	59.83	59.44
	Head Chemistry		**53.34**	**53.34**

Hydroseparator O/F

Flow Rate: **8.2** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	10.16	9.34	4.24	4.25
75	1.88	1.88	7.48	7.48
53	5.00	5.00	4.08	4.08
38	7.50	7.38	2.70	2.70
25	75.46	76.40	1.42	1.43
	Head Chemistry		**2.05**	**2.03**

Hydroseparator U/F

Flow Rate: **229.4** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.03	0.02	36.03	30.89
300	0.66	0.51	36.03	30.89
212	1.16	1.15	36.03	34.23
150	4.59	4.75	18.49	19.28
106	8.70	8.69	29.63	29.70
75	13.99	13.68	52.42	50.16
53	15.76	15.75	59.16	59.19
38	10.89	10.44	63.11	63.25
25	44.22	44.99	62.90	62.94
	Head Chemistry		**55.44**	**55.16**

Fine Screen O/S

Flow Rate: **98.6** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
425	0.05	0.05	28.67	30.89
300	1.13	1.19	28.67	30.89
212	2.01	2.02	28.67	28.92
150	10.73	10.27	16.72	16.96
106	16.10	16.18	27.69	27.94
75	14.84	15.07	46.64	48.56
53	12.79	12.82	57.97	58.03
38	8.27	8.11	62.98	63.07
25	34.08	34.29	62.81	62.89
	Head Chemistry		**48.12**	**48.67**

Fine Screen U/S

Flow Rate: **130.8** **LTPH**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
212	0.50	0.50	51.15	50.55
150	0.85	0.60	51.15	49.45
106	2.96	3.05	36.07	36.71
75	12.48	12.64	50.26	51.60
53	17.80	17.96	60.03	59.81
38	12.20	12.20	63.22	63.34
25	53.21	53.06	63.03	62.96
	Head Chemistry		**59.97**	**60.06**

Fnisher Concentrate

Flow Rate:	**122.9**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.50	0.50	52.24	52.74
150	0.50	0.58	52.24	53.31
106	3.09	3.00	40.09	39.50
75	12.62	12.75	53.65	54.35
53	18.46	18.35	62.05	62.25
38	13.02	12.51	65.69	65.68
25	51.81	52.30	67.85	67.82
	Head Chemistry		**63.69**	**63.80**

Finisher Tails

Flow Rate:	**7.9**	**LTPH**		
Size	**% Weight**		**Satmagan Iron (%)**	
(micron)	**Raw Data**	**Mass Bal.**	**Raw Data**	**Mass Bal.**
212	0.38	0.38	5.80	5.80
150	0.76	0.80	5.80	5.81
106	3.73	3.72	1.92	1.92
75	10.90	10.85	1.73	1.73
53	12.05	12.01	2.12	2.12
38	7.55	7.50	2.82	2.82
25	64.63	64.74	2.22	2.22
	Head Chemistry		**2.23**	**2.23**

APPENDIX I

BLEND 2 FINAL VALIDATION SAMPLING

FLOTATION CIRCUIT

RAW AND MASS BALANCED DATA

Flotation Feed

Flow Rate:	100	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.90	0.86	52.36	49.88
106	3.20	3.21	31.81	32.32
75	7.50	7.68	48.75	48.73
53	15.10	15.37	62.24	63.60
38	17.60	17.44	66.92	67.40
25	25.90	25.56	70.05	70.06
10	29.80	29.89	69.33	68.82
	Head Chemistry		**65.12**	**65.21**

Combined Flotation Feed

Flow Rate:	110.4	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.40	0.78	49.23	49.88
106	2.90	3.13	29.67	31.19
75	7.10	7.48	48.08	46.92
53	14.90	14.72	61.94	62.00
38	17.60	16.84	67.44	66.36
25	24.00	25.52	70.08	69.67
10	33.10	31.54	68.73	68.75
	Head Chemistry		**65.14**	**64.63**

Rougher Tails

Flow Rate:	17.0	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.30	0.28	13.24	14.49
106	5.80	5.47	15.47	15.06
75	10.40	10.23	20.58	19.99
53	11.70	11.96	28.02	27.31
38	10.90	11.44	39.30	38.52
25	19.20	18.65	57.39	56.84
10	41.70	41.98	64.19	64.32
	Head Chemistry		**48.43**	**48.18**

Rougher Con

Flow Rate:	93.5	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.60	0.87	49.72	51.93
106	3.00	2.71	38.00	37.11
75	7.20	6.98	53.86	54.09
53	15.50	15.22	67.98	66.95
38	17.50	17.82	69.79	69.60
25	26.80	26.77	71.23	71.30
10	29.40	29.64	69.43	69.89
	Head Chemistry		**67.57**	**67.62**

Dewatering Mag. Sep. Tails

Flow Rate: **0.5** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	2.90	2.86	16.76	14.38
106	6.20	6.29	9.98	9.99
75	9.60	9.60	9.57	9.57
53	10.60	10.59	12.52	12.53
38	9.30	9.28	18.16	18.17
25	15.80	15.80	28.69	28.74
10	45.60	45.58	33.19	33.26
	Head Chemistry		**24.71**	**24.67**

Dewatering Mag. Sep. Concentrate

Flow Rate: **16.5** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.20	15.51	14.54
106	5.40	5.44	15.51	15.23
75	10.00	10.24	20.33	20.29
53	11.80	12.00	28.07	27.70
38	11.40	11.50	39.52	39.02
25	18.80	18.74	58.14	57.55
10	42.40	41.87	65.53	65.33
	Head Chemistry		**49.43**	**48.89**

Froth Thickener O/F

Flow Rate: **0.4** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	2.10	2.10	12.33	12.34
75	5.60	5.60	13.99	14.00
53	10.00	9.98	17.46	17.49
38	13.40	13.34	22.83	22.89
25	25.30	25.30	38.83	39.05
10	43.60	43.68	52.99	53.29
	Head Chemistry		**38.78**	**39.00**

Froth Thickener U/F

Flow Rate: **16.0** **%**

Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.21	14.73	14.54
106	5.30	5.54	14.73	15.26
75	10.50	10.37	19.84	20.38
53	12.40	12.05	27.15	27.94
38	12.10	11.45	38.52	39.54
25	18.00	18.56	57.40	58.25
10	41.50	41.82	65.93	65.68
	Head Chemistry		**48.61**	**49.16**

Regrind Ball Mill Discharge

Flow Rate:	16.0	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	2.00	2.11	14.72	15.87
75	5.60	5.63	19.42	20.15
53	10.00	9.85	26.75	27.20
38	13.10	13.04	37.03	37.38
25	23.10	23.15	52.41	53.26
10	46.20	46.22	62.37	60.16
	Head Chemistry		**49.83**	**49.16**

Scavenger Concentrate

Flow Rate:	10.4	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	2.50	2.38	17.75	16.56
75	5.60	5.56	23.61	22.96
53	8.50	8.52	34.64	34.39
38	11.10	11.06	50.75	50.66
25	25.40	25.13	66.10	65.83
10	46.90	47.35	66.90	68.35
	Head Chemistry		**58.51**	**59.11**

Scavenger Tail

Flow Rate:	5.6	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
106	1.60	1.59	14.21	13.96
75	5.70	5.75	15.27	15.11
53	12.20	12.32	17.95	17.95
38	16.80	16.73	20.96	21.05
25	19.40	19.48	22.91	23.08
10	44.30	44.12	42.49	43.81
	Head Chemistry		**30.08**	**30.65**

Combined Flotation Tails

Flow Rate:	6.5	%		
Size	% Weight		Satmagan Iron (%)	
(micron)	Raw Data	Mass Bal.	Raw Data	Mass Bal.
150	0.20	0.22	14.18	14.38
106	4.00	1.98	14.18	12.89
75	8.40	6.03	14.42	14.37
53	11.70	12.03	21.06	17.57
38	12.90	15.94	27.39	21.03
25	18.30	19.60	42.03	24.83
10	44.50	44.20	55.34	43.63
	Head Chemistry		**40.12**	**30.77**