Optimization of Comminution Circuit Throughput and Product Size Distribution by Simulation and Control

Quarterly Technical Process Report

Report Period Start Date:	October 01, 2001
Report Period End Date:	December 31, 2001
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Date of Issue:	January 2002
DOE Award Number:	DE-FC26-01NT41062

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Abstract

The goal of this project is to improve energy efficiency of industrial crushing and grinding operations (comminution). Mathematical models of the comminution process are being used to study methods for optimizing he product size distribution, so that the amount of excessively fine material produced can be minimized. This will save energy by reducing the amount of material that is ground below the target size, and will also reduce the quantity of materials wasted as "slimes" that are too fine to be useful. This will be accomplished by: (1) modeling alternative circuit arrangements to determine methods for minimizing overgrinding, and (2) determining whether new technologies, such as high-pressure roll crushing, can be used to alter particle breakage behavior to minimize fines production.

In the fourth quarter of this project, plant studies were continued at the plants operated by the industrial co-sponsors of this project to provide data for model validation. This time the studies were concentrated on analyzing data collected from sampling campaigns carried out at critical parts of the comminution circuits. Samples were collected from two different grinding circuits. The first sample was analyzed for chemical composition and specific gravity through the whole size distribution in order to locate areas where the degree of overgrinding can be controlled. The second sample has been recently gathered and the same analysis will be run. Samples have also been collected to run experimental work at the University facilities to help determine the effect of percent of solids and density in the classification circuit and evaluate how this affects overgrinding comminution.

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Introduction

While crushing and grinding (comminution) of various feedstocks is a critical operation in mining, as well as in a range of other industries, it is both energy-intensive and expensive, with tremendous room for improvement. A neglected route in optimizing the comminution process is the minimizing of overgrinding. Since grinding particles to finer than the target size both wastes energy and produces unusable product, such overgrinding must be minimized in order to improve energy efficiency.

Optimization of full-scale comminution processes by direct experimental work is difficult and expensive because of the cost associated with modifying and operating the circuits to conduct these experiments. Mathematical simulation of the process is therefore necessary to make a preliminary determination of the most promising routes for optimizing the processes. The research needed to develop the models will also determine what effects can be used to alter not just breakage rate, but also the manner in which breakage occurs, and to use this information to improve control over product size.

Executive Summary

The goal of this project is to use comminution modeling to study methods for optimizing the product size distribution, so that the amount of excessively fine material produced can be minimized. This will be accomplished by (1) modeling alternative circuit arrangements to determine methods for minimizing overgrinding, and (2) determining whether new technologies, such as high-pressure roll crushing, can be used to alter particle breakage behavior to minimize fines production.

In the previous quarter, the first sampling campaign was successfully completed. Samples were taken from a grinding – classification circuit, and analyzed using the in-house facilities at Cleveland Cliff’s research lab. A mass balance of the different streams was also performed to help gain a better understanding of the process. A second sample was then analyzed at Michigan Tech for iron content and specific gravity to determine efficiency curves.

The investigators also receive valuable information from meetings held with professionals from the industrial partners, especially Cleveland Cliffs Iron Co, who also provided assistance with samples preparation and analysis.
Validation work is currently being carried out using the results obtained from this first sample campaign.

A second extensive sample series weighting 93 pounds total has been collected to carry out experimental work at the research laboratories of the University to help establish the effect of percent of solids and density in the classification efficiency and their relationship with fines generation.
A third sample was collected from a second grinding circuit at a different plant and will be analyzed at Michigan Tech, this sample will help with the models validation, and to ensure that the results from this project will be generally applicable.

Experimental

Project personnel traveled to an Iron ore concentrator to provide support in a sampling campaign. Samples were taken from the different streams of the grinding-classification circuit as shown in figure 1. The samples were then analyzed using the facilities of the industrial partner. A mass balance was performed to help establish baseline information for the models, and to provide initial information for the validation work.

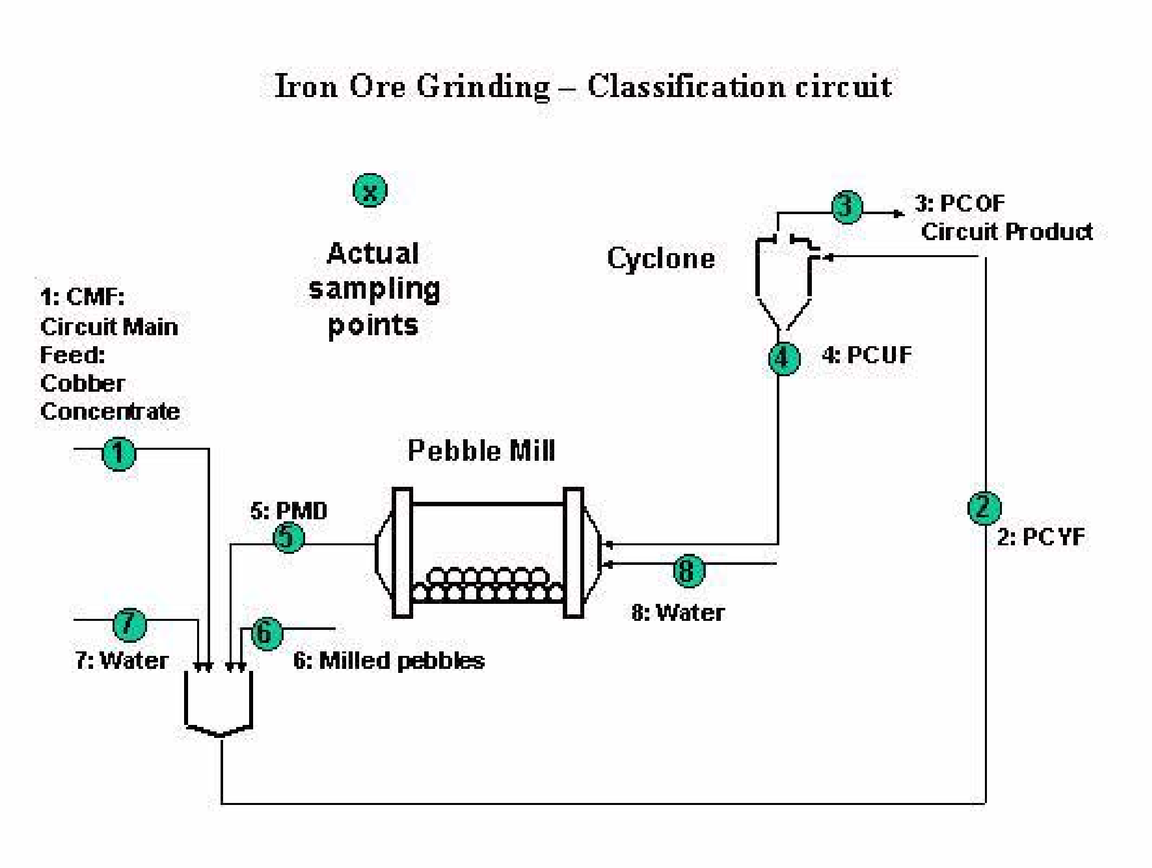

Figure 1: Flow diagram of the grinding-classification circuit at an Iron ore concentrator showing the sampling points.

A second visit took place to gather information and resulted in new samples that were brought to the research laboratories at Michigan Tech for analysis. These samples come from the classification part of the circuit and were gathered to prepare efficiency curves. The collected samples corresponded to the hydrocyclone feed, formed from approximately three parts cobber concentrate (CON_CN) and one part pebble mill discharge (PMD), hydro cyclone underflow (PCUF) and overflow (PCOF).

The bulk samples were split into representative sub-samples using a rotary splitter. The samples were later screened to determine size distributions. Once the size distribution was completed, iron content and specific gravity for each size fraction was determined. Figure 2 shows the samples after the analysis were completed.

Figure 2: Iron ore samples divided into the different particle sizes after the iron assays and specific gravity was completed.

The iron content was determined using titration methods and the specific gravity was determined using Gay-Lussac specific gravity bottles.

A bulk sample was also collected from the Iron ore mill, specifically from the cyclones in order to carry out experimental work at Michigan Tech. The work will be focused on determining efficiency curves for the classification equipment (hydrocyclones) that would allow us to complete the models for the classification equipment and include them in the overall model for the grinding-classification section.

A third sample has been collected from a copper concentrator after project personnel visited the mine site. The samples will be analyzed for copper content and specific gravity and mass balances will be completed. It is expected that this partner will provide experimental values for the Breakage and Selection functions that would help with the modeling process. The sample collected is currently on its way to Michigan Tech.

This sample was collected from the grinding section as shown in figure 3. Historical data, including mass balances for the circuit operating under various operating conditions, was also provided.

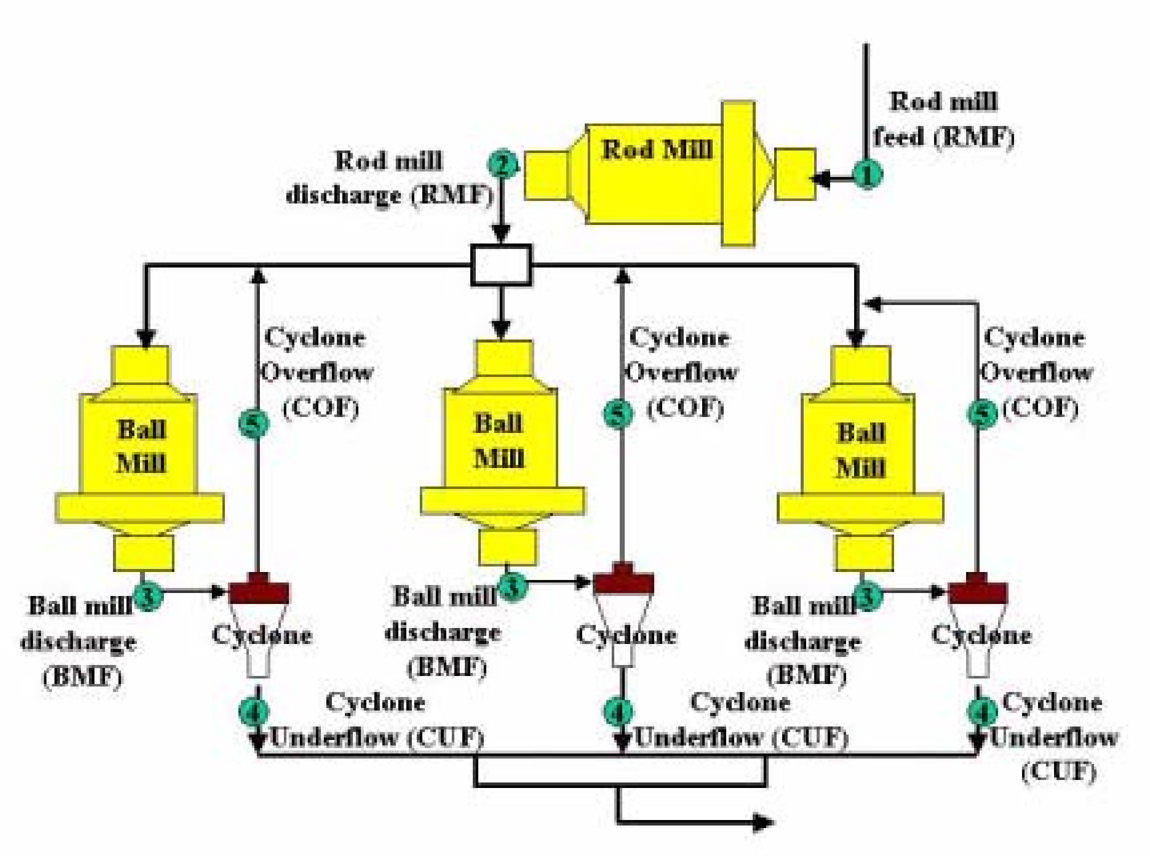

Figure 3: Flow diagram of the grinding-classification circuit at a Copper ore concentrator showing the sampling points.

Results and Discussion

The collection of historical data has been continued. This information will be analyzed to determine what factors affect the production of fines and how to represent them in the models. Work will then focus on allowing the models to respond to changes in operating conditions, and provide and accurate predicted product. This is extremely important to have a valid simulation model.

The mass balance from the primary crushing – magnetic separation circuit is shown in figure 4. It shows the losses occurring in the magnetic separation section were approximately 50 percent of the total feed. This stream is rejected as tails that are sent to the tailing dam. The iron content of this stream averages 19 percent. These losses are mainly due to an inadequate grinding that is not able to completely liberate the iron units and entrainment associated with the process. A better control of the grinding product has the potential to reduce these losses, increasing the overall plant recovery.

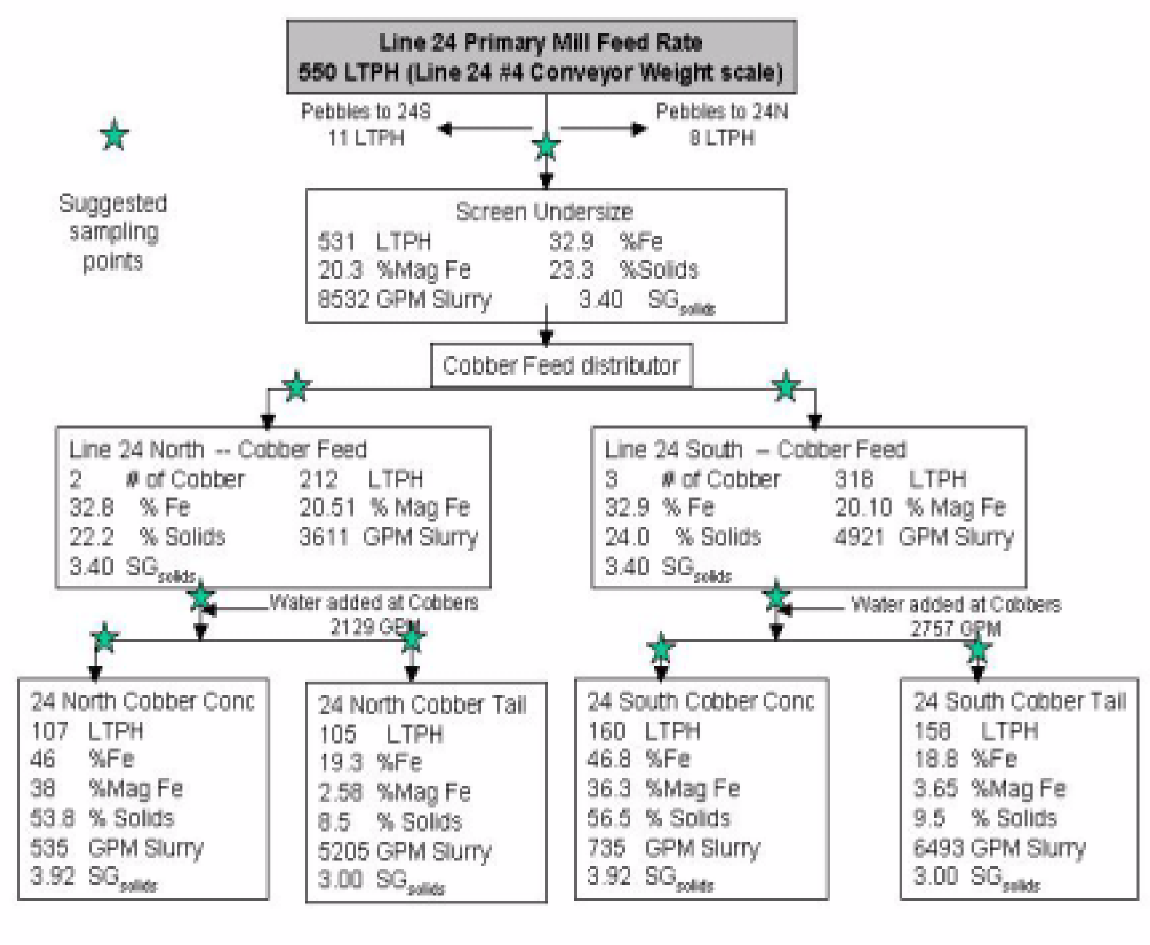

Figure 4: Mass balance for the primary grinding – magnetic separation section at an iron ore processing plant.

The size distribution as well as the iron content and specific gravity for the samples of the different streams in the iron ore mill grinding section that were analyzed at Michigan Tech are shown in the following tables. The target grind size at the iron ore mill is 80% minus 500 mesh. From the analysis performed, a noticeable increase in iron content and specific gravity is achieved in the last two finer sizes.

From these results it is possible to observe that as the particles gets finer, there is a slight change in the iron content and specific gravity, this is noted specially in the last two sizes.

The Cobber concentrate does not have enough iron content to meet commercial requirements. The grade has to be further increased. This is achieved by further reducing the particle size to obtain a better liberation, which is followed by another concentration stage.

There is less increase in iron content and specific gravity for the cyclone overflow sample that is the final product from the grinding circuit.

Table 1: Pebble Mill discharge sample analysis, including size distribution, iron content and specific gravity for each particle size.

Size		Individual		Cumulative		Iron Content		Spec. Grav.	
Mesh	Microns	Weight (g)	Ind %	% Pass	% Retained	Avg	Stdev	Avg	Stdev
+6#	3327	2	0.21	0.21	99.79	19.80	0.06	2.76	0.23
-6#..+8#	2362	3	0.32	0.53	99.47	29.72	0.10	2.84	0.30
-8#..+10#	1651	2.3	0.24	0.77	99.23	30.42	0.12	2.95	0.54
-10#..+14#	1168	1.9	0.20	0.97	99.03	32.01	0.08	2.91	0.13
-14#..+20#	833	2.9	0.31	1.28	98.72	35.09	4.14	3.04	0.02
-20#..+28#	589	3.1	0.33	1.60	98.40	32.71	0.38	3.36	0.27
-28#..+35#	417	1.7	0.18	1.78	98.22	NA	NA	3.04	0.14
-35#..+48#	295	6	0.63	2.41	97.59	32.80	0.41	2.99	0.17
-48#..+65#	208	6.3	0.66	3.08	96.92	33.03	0.11	3.00	0.19
-65#..+100#	147	11.6	1.22	4.30	95.70	33.48	0.14	3.15	0.09
-100#..+150#	104	17.4	1.83	6.14	93.86	33.41	0.27	3.32	0.12
-150#..+200#	74	38.6	4.07	10.21	89.79	33.96	0.27	2.97	0.12
-200#..+270#	52	53.7	5.66	15.87	84.13	33.66	0.54	3.01	0.39
-270#..+325#	44	53.5	5.64	21.51	78.49	37.14	0.20	2.68	1.13
-325#..+500#	25	225.6	23.79	45.30	54.70	45.15	0.25	3.87	0.25
-500#		518.7	54.70	100.00	0.00	46.31	11.11	3.60	0.26

Table 2: Cobber Concentrate sample analysis, including size distribution, iron content and specific gravity for each particle size.

Size		Individual		Cumulative		Iron Content		Spec. Grav.	
Mesh	Microns	Weight (g)	Ind %	% Pass	% Retained	Avg	Stdev	Avg	Stdev
+6#	3327	0.00	0.00	0.00	100.00	NA	NA	NA	NA
-6#..+8#	2362	0.00	0.00	0.00	100.00	NA	NA	NA	NA
-8#..+10#	1651	1.50	0.08	0.08	99.92	37.31	2.10	2.82	1.78
-10#..+14#	1168	32.40	1.77	1.85	98.15	33.72	0.61	3.31	0.64
-14#..+20#	833	117.60	6.42	8.27	91.73	34.37	0.21	3.26	0.49
-20#..+28#	589	147.00	8.02	16.29	83.71	34.77	0.30	3.18	0.35
-28#..+35#	417	147.10	8.03	24.32	75.68	34.29	1.07	3.08	0.30
-35#..+48#	295	156.10	8.52	32.83	67.17	35.69	0.26	3.30	0.35
-48#..+65#	208	158.10	8.63	41.46	58.54	36.09	0.22	3.27	0.11
-65#..+100#	147	118.10	6.44	47.91	52.09	36.65	0.19	3.12	0.30
-100#..+150#	104	127.50	6.96	54.86	45.14	37.24	0.19	3.23	0.16
-150#..+200#	74	110.40	6.02	60.89	39.11	38.79	0.48	3.20	0.14
-200#..+270#	52	46.10	2.52	63.41	36.59	39.40	0.61	3.65	0.50
-270#..+325#	44	36.80	2.01	65.41	34.59	42.16	1.24	3.63	0.05
-325#..+500#	25	136.70	7.46	72.87	27.13	49.92	1.59	3.81	0.17
-500#		497.10	27.13	100.00	0.00	63.45	0.27	4.47	0.13

Table 3: Cyclone Underflow sample analysis, including size distribution, iron content and specific gravity for each particle size.

Size		Individual		Cumulative		Iron Content		Spec. Grav.	
Mesh	Microns	Weight (g)	Ind %	% Pass	% Retained	Avg	Stdev	Avg	Stdev
+6#	3327	3.90	0.16	0.16	99.84	25.59	5.83	2.88	0.46
-6#..+8#	2362	7.10	0.29	0.44	99.56	29.38	1.02	2.94	0.27
-8#..+10#	1651	7.00	0.28	0.72	99.28	29.94	0.60	3.11	0.24
-10#..+14#	1168	22.60	0.91	1.63	98.37	17.10	17.61	3.26	0.24
-14#..+20#	833	74.00	2.97	4.60	95.40	33.86	0.53	2.69	0.83
-20#..+28#	589	91.60	3.68	8.28	91.72	34.36	0.52	3.16	0.15
-28#..+35#	417	99.90	4.01	12.29	87.71	34.62	0.50	3.20	0.16
-35#..+48#	295	100.10	4.02	16.31	83.69	35.22	0.16	2.97	0.25
-48#..+65#	208	106.50	4.28	20.59	79.41	35.18	0.32	2.88	0.38
-65#..+100#	147	88.70	3.56	24.15	75.85	35.79	0.41	3.54	0.90
-100#..+150#	104	122.20	4.91	29.05	70.95	35.02	0.56	3.52	0.07
-150#..+200#	74	168.00	6.75	35.80	64.20	35.06	0.72	3.56	0.19
-200#..+270#	52	120.90	4.85	40.65	59.35	34.18	1.24	3.04	0.86
-270#..+325#	44	106.00	4.26	44.91	55.09	37.16	0.92	3.45	0.18
-325#..+500#	25	604.10	24.26	69.16	30.84	51.63	1.02	3.83	0.39
-500#		768.00	30.84	100.00	0.00	67.50	0.70	4.26	0.06

Table 4: Cyclone Overflow sample analysis, including size distribution, iron content and specific gravity for each particle size.

Size		Individual		Cumulative		Iron Content		Spec. Grav.	
Mesh	Microns	Weight (g)	Ind %	% Pass	% Retained	Avg	Stdev	Avg	Stdev
+6#	3327	0.00	0.00	0.00	100.00	NA	NA	NA	NA
-6#..+8#	2362	0.10	0.01	0.01	99.99	NA	NA	NA	NA
-8#..+10#	1651	0.20	0.02	0.03	99.97	NA	NA	NA	NA
-10#..+14#	1168	0.20	0.02	0.05	99.95	NA	NA	NA	NA
-14#..+20#	833	0.20	0.02	0.07	99.93	NA	NA	NA	NA
-20#..+28#	589	0.20	0.02	0.10	99.90	NA	NA	NA	NA
-28#..+35#	417	0.20	0.02	0.12	99.88	NA	NA	NA	NA
-35#..+48#	295	0.20	0.02	0.14	99.86	NA	NA	NA	NA
-48#..+65#	208	0.30	0.03	0.17	99.83	NA	NA	NA	NA
-65#..+100#	147	0.20	0.02	0.19	99.81	NA	NA	NA	NA
-100#..+150#	104	0.80	0.09	0.28	99.72	NA	NA	NA	NA
-150#..+200#	74	4.00	0.43	0.70	99.30	25.53	0.03	3.26	0.24
-200#..+270#	52	5.40	0.58	1.28	98.72	27.09	0.14	3.14	0.07
-270#..+325#	44	8.90	0.95	2.23	97.77	27.47	0.15	3.19	0.05
-325#..+500#	25	97.10	10.34	12.57	87.43	33.33	0.42	3.28	0.05
-500#		821.00	87.43	100.00	0.00	43.16	0.63	3.58	0.23

The screen analysis from the Pebble mill discharge shows that approximately 55% of the particles had been ground to minus 500 mesh. The Pebble mill discharge stream is later combined with the cobber concentrate stream (27% minus 500 mesh) and fed to the hydrocyclones in order to: (1) Remove the gangue from the valuable based on a difference in density between iron ore and silica, and (2) Separate the coarse material that needs further grinding from the material that has achieved the target size. Studying the overflow size distribution we can observe that approximately 12.5% of coarse materials has reported to the overflow, and will be rejected, and improvement in the efficiency of the classifier will produce a cleaner product. It has to be noted also that approximately 31% of fine material (-500 mesh) is reporting to the underflow and going back to the pebble mill were it is subject to further grinding. This results in a reduction of the circuit capacity and the unnecessary use of energy to continue grinding material that has already been ground.

With the new samples from the iron ore mill we expect to be able to carry out experimental work using a laboratory scale hydrocyclone to determine the effect of factors such as percent solids, density and pressure. Then this information will be used to further refine the overall circuit model.

The samples from the copper mill will be analyzed in a similar way to those from the iron ore mill. We expect by this to gain a better understanding of the process, and most important, to be able to determine what properties from the material have a critical effect in fines generation, and how to attack this problem.

Conclusions

Plant sampling has been carried which has allowed gathering important operational information that provides a basis for the better understanding of the process and it's variables.

Improving the classification that takes place in the hydrocyclones should result in an important improvement of the comminution process.

The experimental information together with the historical information gathered, will be used to validate the models currently under development.

References

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