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

## Quarterly Technical Process Report

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Authors: S. K. Kawatra – Principal Investigator
T. C. Eisele – Engineer Scientist
H.J. Walqui – Graduate Student



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Submitting Organization


Department of Mining and Materials Processing Engineering
Michigan Technological University
1400 Townsend Drive
Houghton, Mi 49931 - 1295

**DISCLAIMER:**

## 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 fifth quarter of this project, work was centered on analyzing the considerable plant data gathered during the first year of the project. An irregularity in the efficiency curve was detected, which is believed to be due to specific gravity effects and has a large influence on overgrinding and slimes production. In order to understand this phenomenon, laboratory test work has been planned and will be carried out. Work will be focused on studying the effect of specific gravity on the cyclone efficiency curves.

A breakage function has been developed from historical data that was used to calculate selection functions for different percent solids fed to the mill.

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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. This project is currently trying to prepare adequate models to simulate grinding and classification while understanding which factors affect fines generation so that they can be addressed by the models.

## 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.

During this quarter, work has been focused on analyzing the considerable quantity of plant data collected to date and using it to validate the process models. Several mass balances have been completed for the iron ore grinding – classification circuit, under different operating conditions and arrangements. The additional analyses of the samples brought to Michigan Tech during the fourth quarter are being used to examine into the classification efficiency curves.

Cyclone efficiency curves have been prepared for different circuit operating conditions. A "hump" has been observed in these curves at the finer particle size. It is believed that this hump is the result of a combination of density differences and mechanical interlocking effects. A work plan is being prepared to run laboratory experiments in order to confirm this hypothesis.

Development of breakage and selection functions based on historic data continued. From previous experimental work, it was possible to determine a breakage function for the pebble mill used at the iron ore mill. Based on this breakage function, and plant data, the changes in the selection function with varying percent solids were calculated. An equation for representing the changes in percent solids was also prepared so that the selection function could respond to variations in the operating conditions.

## Experimental

Work during this quarter was focused on analyzing available data. It was focused on two major areas: (1) Evaluating different grinding – classification circuit operating conditions, and (2) Studying historical data to develop suitable breakage and selection functions for the iron ore pebble mills.

Four different mass balances were completed for the grinding-classification circuit. The available information for calculating the mass balances is shown at table 1, this information was available from the second sampling campaign:

**Table 1:** Available information to perform mass balance (water and solids). An entry of "X" signifies that the data was available from direct measurements, and an entry of "NA" indicates that the values needed to be calculated in the course of the mass balance.

| Stream | Dry LT/hour | % Solids |
|---|---|---|
| Cobber Concentrate (Cobb Conc) | **X** | **X** |
| Pebble mill discharge (PMD) | **NA** | **X** |
| Chips (C) | **X** | **X** |
| Pebbles (P) | **X** | **X** |
| Cyclone feed (CyF) | **NA** | **NA** |
| Cyclone overflow (COF) | **X** | **X** |
| Cyclone underflow (CUF) | **X** | **X** |
| Make-up water 1 (W1) | **NA** | **NA** |
| Make-up water 2 (W2) | **NA** | **NA** |

The mass balances were necessary to provide a baseline between the different operating conditions of the circuit, and for completing cyclone efficiency curves.

An important factor that also had to be considered was classification occurring within the grinding circuit. In order to evaluate this, cyclone efficiency and corrected efficiency curves were plotted. Table 2 presents a summary of the different operating conditions that were studied

From the iron assays carried out during the previous quarter, it was possible to estimate the relative proportions of magnetite and silica in the overflow, underflow, and feed to the cyclones. Work is currently underway to have this data incorporated into the cyclone efficiency curves.

From historical data it has been possible to prepare an estimated breakage function for the magnetite ore under study. Once a breakage function was available it was possible to back calculate individual selection functions for specific operating conditions where feed and product size distributions were known. A summary of the operating conditions for the available plant data is presented in Table 3. Based on careful consideration of the process and on past experience, the mill feedrate and the feed% solids were chosen as the variables most likely to have an effect on the selection function values in the pebble mills.

**Table 2:** Operating conditions used to calculate Cyclone efficiency curves

| | **Diameter** | **No cyclones** | **LTPHr** | **% Solids** |
|---|---|---|---|---|
| Circuit 1 | | | | |
| North | 15 in. | 14 | 2964.2 | 14.5 |
| South | 15 in. | 14 | 3260.7 | 13.1 |
| Circuit 2 | | | | |
| North 1 | 15 in. | 14 | 3097.3 | 13.9 |
| North 2 | 26 in. | 3 | 1691.9 | 18.2 |
| South 1 | 15 in. | 14 | 3217.9 | 13.95 |
| South 2 | 26 in. | 3 | 2157.3 | 15.1 |
| | | | | |

**Table 3:** Summary of operating conditions used to calculate theoretical Selection functions based on the Breakage function determined from historical data.

| | **North 1** | **South 1** | **North 2** | **South 2** |
|---|---|---|---|---|
| LTPHr | 368.1 | 222.7 | 481.2 | 424.3 |
| % Solids | 65.1 | 76.8 | 69.0 | 70.6 |

Once the selection functions had been determined for each of the available data sets, each element of the functions were fitted to the feedrate and percent solids values using a simple linear equation of the form shown in Equation 1:

$$\mathbf{Y=ax_1+bx_2+c} \qquad \text{Equation 1}$$

Where:

Y: value of selection function element.
$X_1$: percent solids of feed to pebble mill (Cyclone underflow)
$X_2$: Mass flowrate of pebble mill feed in LTPH
a, b & c: constants

Statistical analysis of the results showed that the feed rate had no statistically significant effect on the values of any of the selection function elements, and so the simple linear equation was replaced by Equation 2, using only percent solids as a variable.

$$\mathbf{Y=ax^2+bx+c} \qquad \text{Equation 2}$$

Where:

Y: value of selection function element.
X: percent solids of feed to pebble mill (Cyclone underflow)
a, b & c: constants

## Results and Discussion

### Mass Balances

Four mass balances for the same circuit, each with individual and unique operating condition were completed based on samples that personnel from the project collected with the assistance of plant personnel. Additionally, six more mass balances have been completed from previous sampling and analysis campaigns carried out by one of the industrial partners. An example of one of the mass balances is presented in Figure 1.

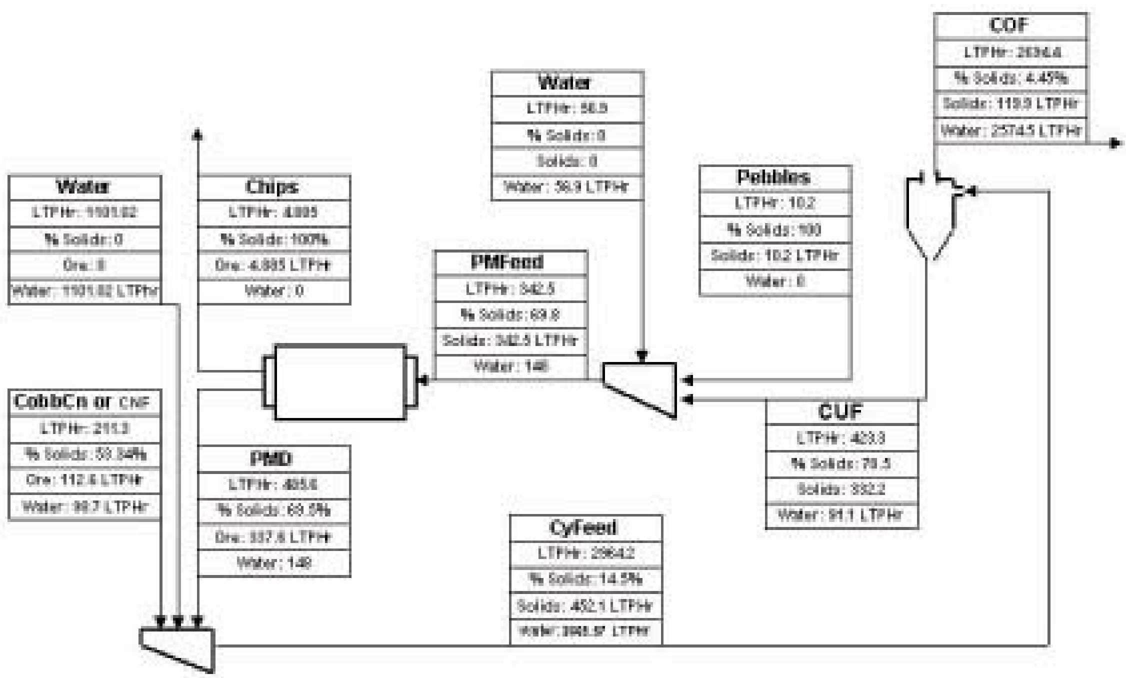


Figure 1: Mass balance for Iron ore grinding – classification circuit, Circuit 1 North.

### Classification efficiency curves

Cyclone efficiency curves were calculated based on the size distributions of the cyclone overflows and underflows. While analyzing the resulting efficiency curves it was observed that a pronounced "hump" forms in all of the curves. This is shown in figures 2 and 3. Since this is seen in all of the efficiency curves for this plant, the "hump" is a real feature of the curves and not an analytical error.

The shape of these efficiency curves differs from the expected shape for a cyclone efficiency curve for feed particles of uniform density, which would be a smooth "S" shape. After examination of the data, it was hypothesized that the deviation from an ideal "S" shape is due to the fact that particles of greatly differing densities are present in the cyclone feed slurry.

In order to corroborate this, experimental work using a 4" Krebs cyclone will be carried out focused on one specific area: specific gravity of the solids. Magnetite and silica have very different specific gravities (Magnetite: 7.87; Silica 2.65), and as the percent of magnetite changes in the ore, the specific gravity is also affected. By studying how the efficiency curves change when the specific gravity of the ore changes, a mathematical model to address the effect of specific gravity will result from this experimental work.

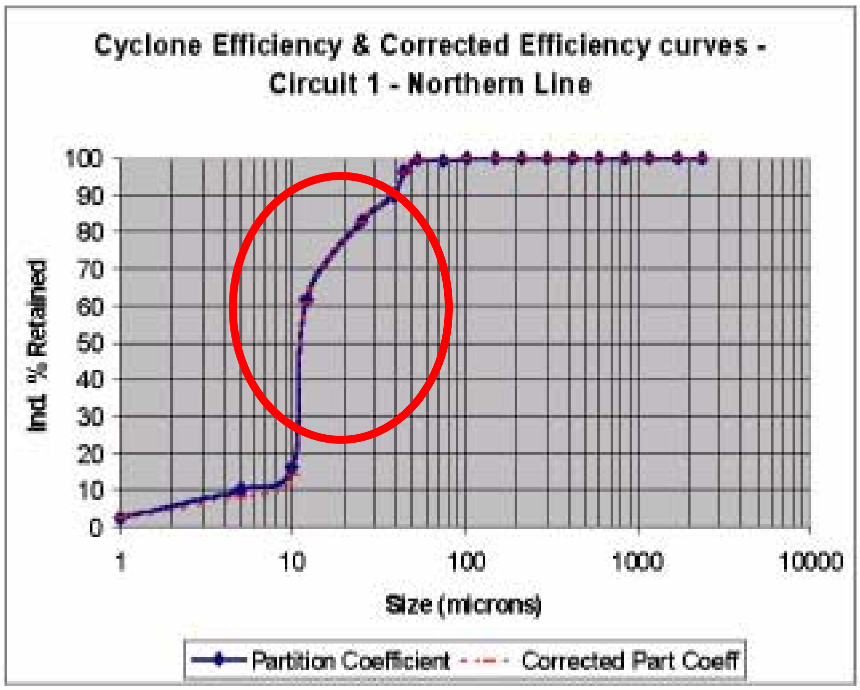


Figure 2: Cyclone efficiency curve for Circuit 1 – North Line. The "hump" is circled, and represents a considerable deviation from the smooth "S" shaped efficiency curve normally encountered when cyclones are processing feeds of uniform density.

**Breakage and selection functions**

Access to previous studies allowed the development of a breakage function for the iron ore under study. This was then used to calculate selection functions for the pebble mill under different operating conditions where data was available for the feed and product size distributions.

At the present time, evaluation is underway to determine the validity of the relationships calculated between feedrate, feed percent solids, and the selection function elements.

The breakage function that is currently being used is shown in table 4. A key point that has to be taken into consideration while developing the mathematical models is pebble addition and chips removal. At this point it is being determined whether the pebbles added share the breakage function of the mill feed, or if a different matrix should be calculated for the pebble chips. If this is the case, the cyclone underflow and the pebble ships will

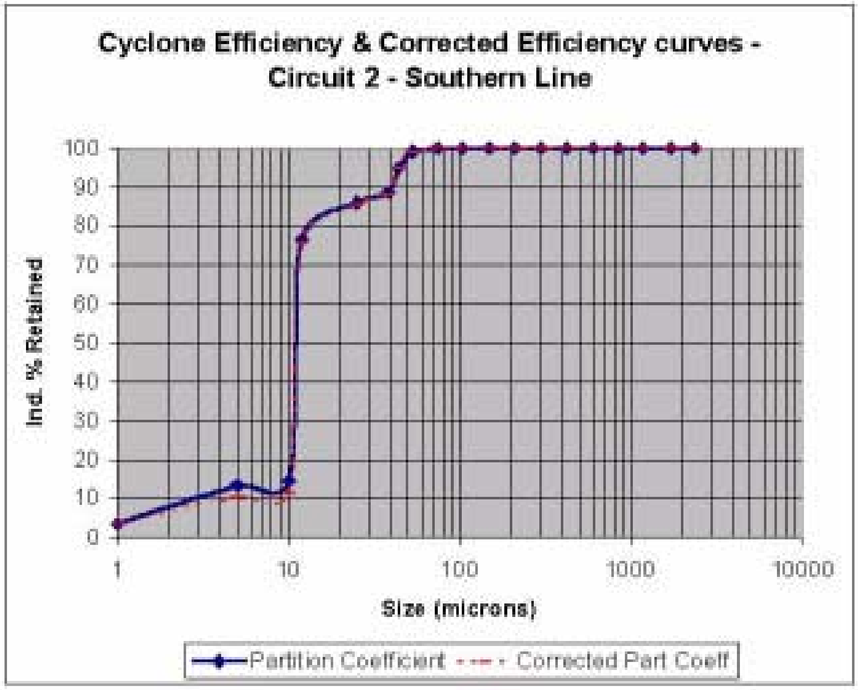


Figure 3: Cyclone efficiency curve for Circuit 2 – South Line. Deviation from theoretical efficient curves observed. This curve also shows a "hump" similar to that seen in Figure 2, indicating that this is a regular feature of cyclone efficiency curves for this feed.

need to be treated as two separate feed streams whose grinding behavior will have to be calculated separately and then combined.

## Conclusions

Several mass balances for different operating condition and arrangements have been finished, this mass balanced provided the baseline for model validation work, as well as performance evaluation.

A hump in the cyclone efficiency curves has been observed which is present for all operating conditions. This represents a deviation from theoretical curves that would be expected for feeds of uniform density. This deviation appears to be related to entrainment occurring due to interlocking of magnetite and silica particles, which affects the separation between them and increases overgrinding. Experimental work will be conducted to study this effect so that it can be properly accounted for by the models.

Initial breakage and selection functions for the pebble mill model have been completed and are currently under evaluation. The selection function is being fitted to the plant data so that it will respond to changes in operating conditions.

**Table 4:** Breakage function matrix calculated from previous studies and used to determine selection function matrices for different operating conditions.

| Microns | Breakage Function Matrix | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1700 | **0.206** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 850 | **0.388** | **0.206** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 425 | **0.184** | **0.388** | **0.206** | 0 | 0 | 0 | 0 | 0 | 0 |
| 212 | **0.103** | **0.184** | **0.388** | **0.206** | 0 | 0 | 0 | 0 | 0 |
| 103 | **0.041** | **0.103** | **0.184** | **0.388** | **0.206** | 0 | 0 | 0 | 0 |
| 53 | **0.019** | **0.041** | **0.103** | **0.184** | **0.388** | **0.206** | 0 | 0 | 0 |
| 38 | **0.015** | **0.019** | **0.041** | **0.103** | **0.184** | **0.388** | **0.206** | 0 | 0 |
| 15 | **0.025** | **0.015** | **0.019** | **0.041** | **0.103** | **0.184** | **0.388** | **0.206** | 0 |
| -15 | **0.020** | **0.025** | **0.015** | **0.019** | **0.041** | **0.103** | **0.184** | **0.388** | **0.206** |

## References


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