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 Chemical Engineering
Michigan Technological University
1400 Townsend Drive
Houghton, Mi 49931 - 1295

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 sixth quarter of this project, work was centered on analyzing the considerable plant data gathered during the first year of the project. Modeling is being carried out of the hydrocyclone portion of the grinding circuit, since this has been identified as the primary source of overgrinding and inefficiency.

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Introduction

When grinding iron ore to liberation size, many of the iron oxide particles are ground beyond the size where they are liberated from the silicate grains. This overgrinding of the mineral grains is a significant waste of energy. In order to increase the energy efficiency, this excess grinding must be prevented. The objective of this project is therefore to sample and simulate a full-scale iron ore processing plant to determine methods for increasing grinding circuit energy efficiency by minimizing overgrinding.

This report is based on the information received corresponding to a circuit survey carried out in an operating iron ore processing plant. An analysis of the received information, followed by mass balances and determination of cyclone efficiency curves are presented together with the observations and conclusions resulting from the analysis.

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, plant data and laboratory analyses of plant samples were used to evaluate the performance of the hydrocyclone in the grinding circuit. It had previously been determined that the hydrocyclone was responsible for much of the overgrinding that was occurring, because a disproportionate quantity of the magnetite in the ore was reporting to the coarse hydrocyclone product. As a result, fine liberated material that should have reported to the overflow instead reported to the underflow and was reground. This is a major source of energy inefficiency in the grinding process.

If the magnetite rich fine fraction of the underflow could be recovered before reaching the pebble mill, it would not be overground. The benefits of this would be improved energy efficiency due to reduction in the amount of energy wasted on grinding liberated particles, and increased circuit capacity proportional to the reduction of the amount of material overground.

Experimental

The reports included a large amount of data corresponding to the survey's rough data. Data was transferred into an electronic format (Microsoft ® Excel 2000 *.XLS file format was used on Microsoft ® Windows XP platforms) so that it could be analyzed. After sorting the data, a mass balance was completed, using the average of the two sets of samples available. Then cyclone efficiency curves were calculated for the ore, and then separately for the principal components (silica and magnetite).

Background

Closed grinding circuits are used when a single stage comminution process will not efficiently produce the desired product size. Several cycles of breakage are then required to achieve the specified product, which is achieved by re-circulating the coarse cyclone product. The goal of the cyclone is to quickly remove particles that have reached the target size before any more energy is expended on grinding them, while returning the coarser particles for additional grinding. Therefore, the sizing device strongly influences the comminution circuits' performance, by determining the re-circulating loads, circuit capacity and eventually, the final product size (T.J. Napier Munn et.al., 1996).

Hydrocyclones work on the principle of fluid dynamic classification, which takes advantage of the difference in rate of travel of particles in a fluid due to the difference in the particle size and density. Figure 1 shows a schematic of a typical cyclone, with coarse/heavy particles going toward the wall and the fine/lighter particles moving inward and in an opposite direction of the coarse particles.

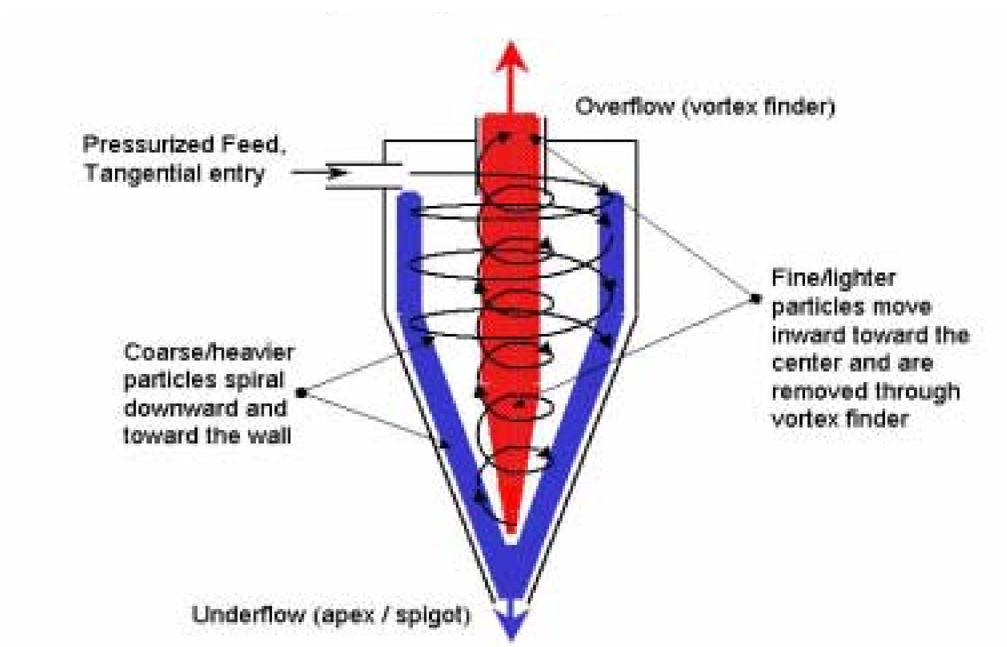

Figure 1: Schematic showing the different paths followed by fine/light and coarse/heavy particles inside a typical Hydrocyclone.

The separation action results from the feed slurry entering tangentially to the body of the cyclone where it is constrained to move into a circular path. This rotation of the fluid generates high centrifugal forces that cause the coarser (heavier) particles to go towards the wall where they will continue flowing down to the underflow exit (apex or spigot) together with some of the water. Simultaneously, fine (lighter) particles together with the bulk of the water are forced to the axis principally due to a higher drag effect of the fluid on smaller particles that causes slower movement of particles with respect to fluid. When these fine particles reach the bottom they reverse direction at the tapered end of the cyclone, and flow upward through the center of the cyclone until they reach the vortex finder and exit through it. (L.G. Austin et.al., 1984; T.J. Napier Munn et.al., 1996; A.R. Laplante and J.A. Finch, 1983)

An important factor, usually not considered, is the effect of the difference in density between the components of the ore. If the ore components have a large density difference, the hydrocyclone behavior tends to also do a separation based on particle density simultaneously with the separation based on particle size. Typical magnetite ores are mostly composed of silica and magnetite, with a substantial difference in specific gravities. This difference can result in fine magnetite particles having a similar behavior as coarser silica particles that the cyclone is unable to properly separate. The result is that, in order to ensure that quartz particles are all ground to a fine enough size to fully liberate the magnetite, the cyclone must also return a large fraction of the already-liberated magnetite particles. This overgrinding of the magnetite is a major source of energy inefficiency in the grinding operation.

In order to determine the degree of overgrinding in the circuit, a plant sampling campaign was carried out at an operating iron ore concentrator. Data was then provided to Michigan Technological University so that an independent analysis could be carried out. The data was entered into an MS Excel format electronic spreadsheet.

After sorting the data, a mass balance was completed using the individual percent retained at the minus 500 mesh as the analysis value, together with the measured flow of the Circuit New Feed, Pebbles Added, and Pebble Chips Removed, to determine solids flow and water balance (Figure 2).

Two sets of data were available that included percent solids calculations, size distributions (including micro sieves), specific gravities and iron assays. In order to determine cyclone efficiency curves, the average of the two data sets was used, as each corresponded to subsamples taken simultaneously to ensure sample quality and reproducibility. Once the mass balance was completed, overall cyclone efficiency curves and overall corrected efficiency curves were plotted for the averaged sample, and later, for the individual ore components (magnetite and silica). In order to calculate the individual magnetite and silica efficiency curves, it was assumed that complete liberation had occurred, that the ore was composed exclusively of silica and magnetite, and that the water split was the same for each component.

A very sharp separation occurred in the cyclone, as shown by the steep, nearly vertical slope of the efficiency curve. However, the critical size fraction between 10 to 30 microns encountered a discontinuity in the overall efficiency curve, where the slope becomes very

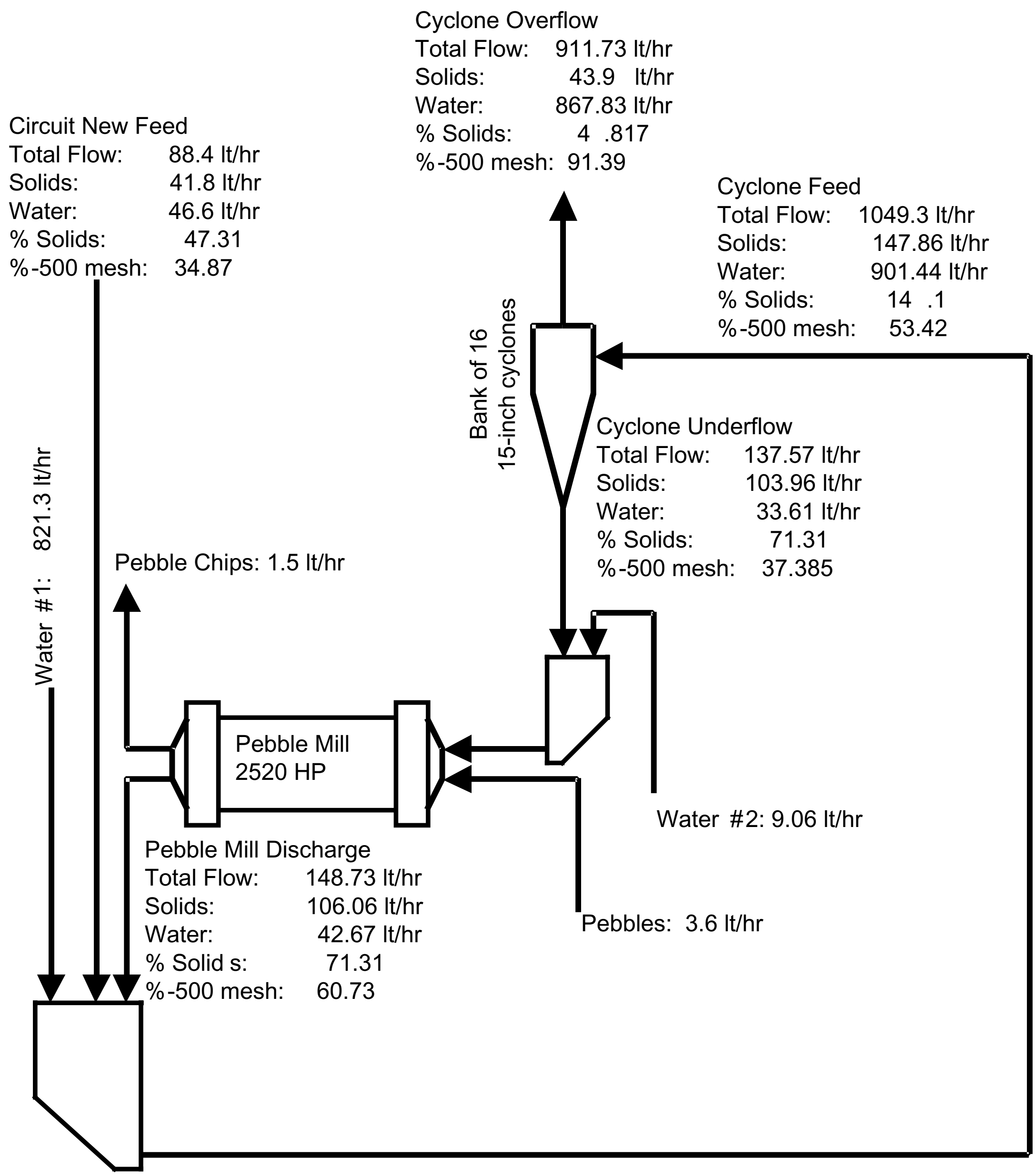

Figure 2: Circuit Mass Balance based on percent –500 mesh. All flows are in long tons per hour.

shallow approaching the horizontal ("Fish Hook"). This resulted in poor cyclone performance at that size range.

The most likely explanation for this "fish hook" curve is that the fine magnetite that should have reported to the overflow based on its size, instead reported to the underflow due to its high specific gravity making it behave like the coarser quartz particles. This effect reduced circuit capacity by retaining fine magnetite for regrinding even though it had already been liberated. In addition, this magnetite was also overground, which both reduces energy efficiency and creates fines that are difficult to deal with.

Results and Discussion

This work focused on analyzing the classification section that was identified as most likely to be responsible for excessive fines generation. The first step was to observe the performance of the cyclone. Figure 3 shows the mass balance for the cyclone, considering only the -400 mesh fraction, and the iron assay for the –400 mesh/+500 mesh sample.

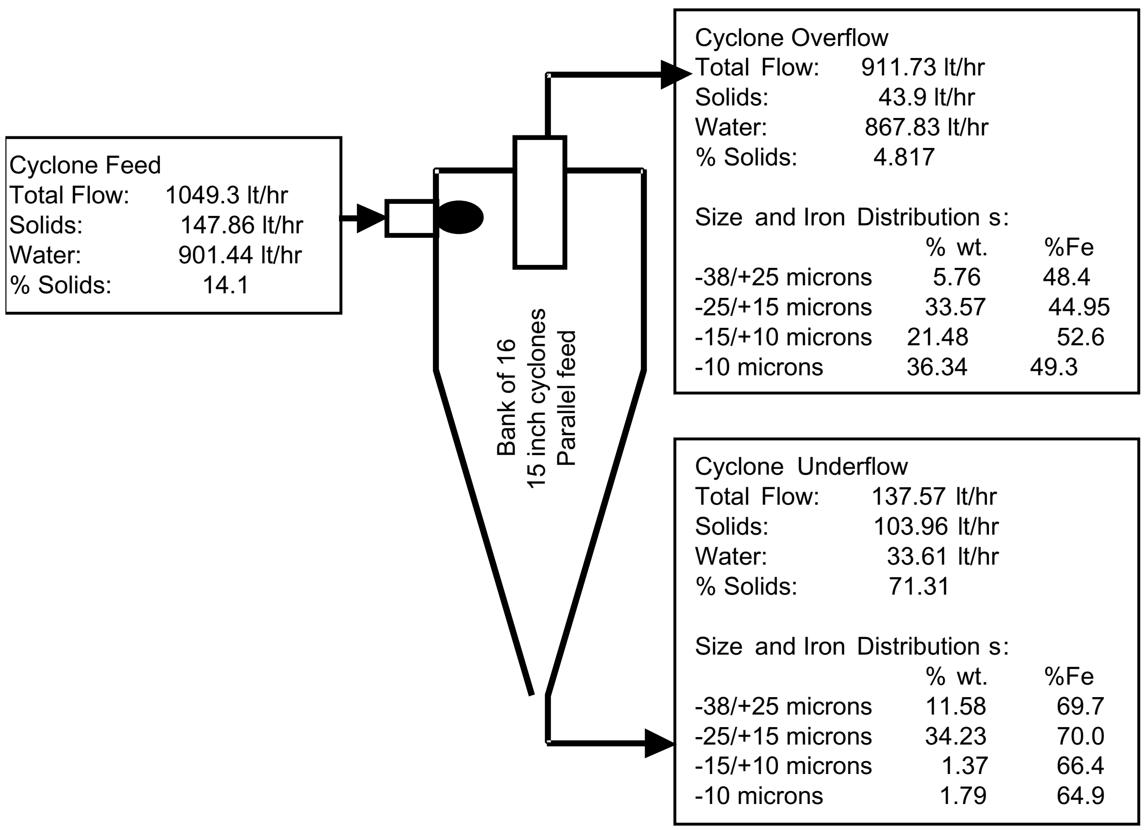

Figure 3: Simplified version of the mass balance, including size distribution and iron content for minus 400 mesh particles.

The following facts were noted from the cyclone mass balance, when the iron assays and size distributions for only the fine fraction are considered:

- A large fraction of the overflow (97.2%) was finer than 400 mesh, and the overflow had a relatively low iron content (48.8% Fe) when compared to the underflow.
- Approximately 49% of the underflow was finer than 400 mesh; however, the iron content of this fine fraction was approximately 30% higher (67.8% Fe) in the underflow than the overflow, showing that the cyclone was preferentially returning fine magnetite for regrinding, which correspondingly wastes energy.

Magnetite was locked to silica in the coarser fraction, but was mainly liberated below 400 mesh. However, corresponding to the very fine fraction, the high iron content represented liberated magnetite. Ideally, the fine liberated magnetite should have left the circuit, but instead was re-circulated to the pebble mill for further grinding.

Therefore, the two main components of the ore behaved differently in the hydrocyclone. Separation was not occurring by size differences only, but also by density differences between magnetite and silica. To further analyze this, cyclone efficiency curves were calculated based on the percent solids and size distributions of the hydrocyclone overflow and underflow.

The overall cyclone efficiency curves for all components combined (Figure 4), showed a high degree of efficiency of the classification circuit. However, a "fish hook" effect was found between 10 microns and 30 microns.

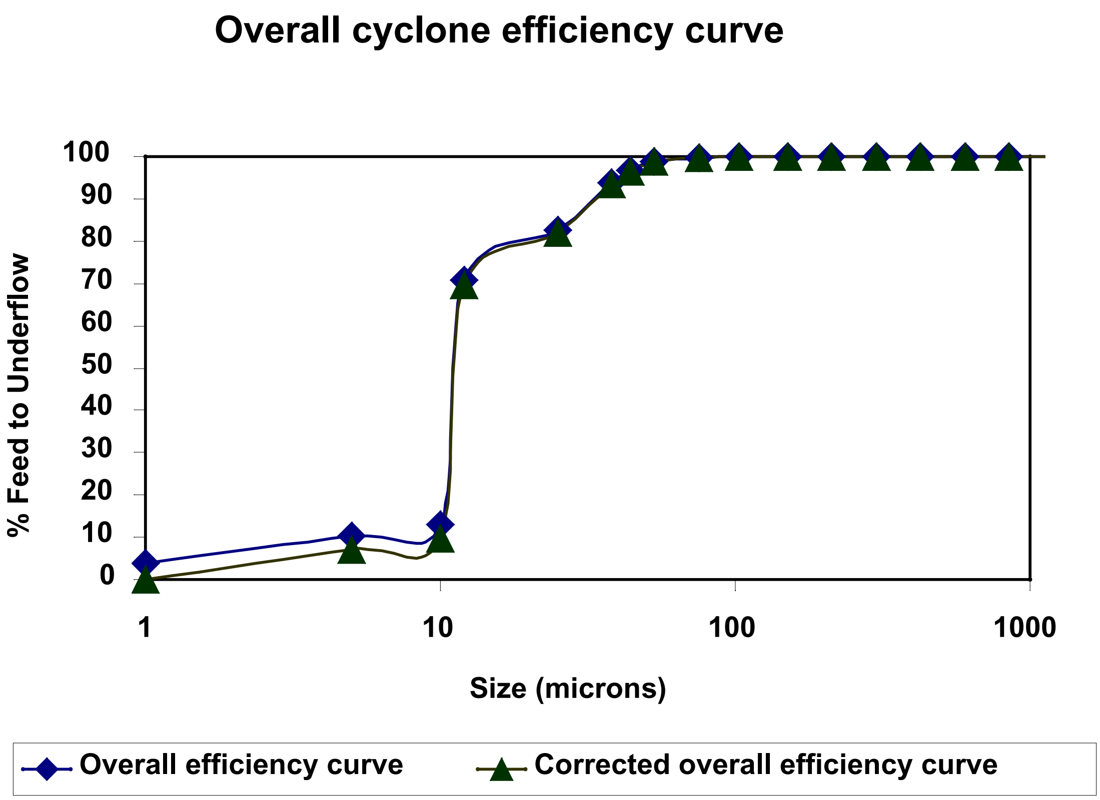

Figure 4: Cyclone Efficiency curve showing "Fish Hook" effect between 10 to 30 microns. The small by-pass fraction causes the corrected efficiency curve to be very similar to the corrected efficiency curve.

Specific gravity differences between silica and magnetite caused the magnetite particles of the same relative size to behave as if they were as coarse as the silica particles. This resulted in a large fraction of fine magnetite reporting to the underflow. In the 10 - 30 micron size interval the cyclone separation depended on the particle weight rather than particle size. As previously mentioned, magnetite has a higher specific gravity (5.2) than silica (2.6) (Weiss 1985), so fine magnetite that should have reported to the overflow because of its size, reported to the underflow because of its weight, resulting in the Fish Hook. A relevant study shown in the literature for three different massive copper sulfides, showed a phenomenon similar to the one observed in the plant surveyed (A.R. Laplante and J.A Finch, 1983).

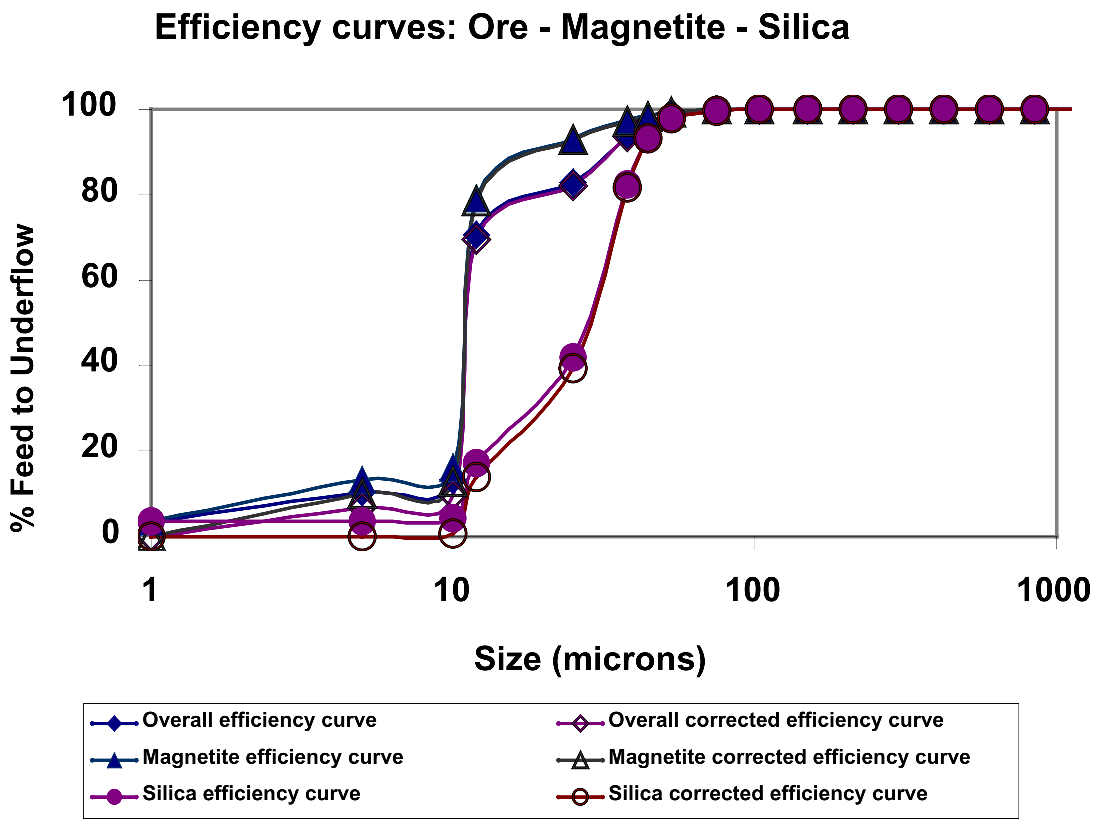

Figure 5: Efficiency curve showing Magnetite and Silica components. Silica behaved different from Magnetite between approximately 10 and 30 microns. The small by-pass fraction causes the corrected efficiency curves to be very similar to the uncorrected efficiency curves.

The influence of the specific gravity can be better appreciated when the efficiency curves for both the magnetite and silica are plotted as shown in Figure 5. In order to calculate these curves, it was assumed that the magnetite was completely liberated from the silica, that the ore was constituted only of silica and magnetite, and that the by-pass fraction was constant for the two components. It was understood that complete liberation could not have been achieved at this stage, but by dividing the streams into this two components, the efficiency curves for each component could be calculated.

It could be observed that between 10 and 30 microns, each component had a distinct behavior, resulting in the cyclone having and overall d_{50} of 14.9 microns, while the silica

d_{50} was 29.2 microns. Particles coarser than the d_{50} would report to the underflow and the finer particles would report to the overflow.

This difference in d_{50} values suggests that coarser lighter silica particles left the cyclone through the overflow, while finer (but more massive) magnetite particles were carried to the underflow (Table 1). This seems to be explained mainly by the large difference in specific gravity between magnetite (5.2) and silica (2.6).

Table 1: Summary of D_{50} and D_{50c} values, including water split.

	Overall	**Magnetite**	Silica
D_{50} (microns)	14.9	13.7	29.2
D_{50C} (microns)	15.9	14.0	30.1
Rf (percent)	3.73	3.73	3.73

It can clearly be seen from Table 1 that, as the specific gravity changes, the overall efficiency curve also moves to either finer or coarser sizes depending on the direction of the specific gravity change.

Circuit Simulation

Circuit simulation studies are being carried out to determine whether the fine, liberated magnetite in the cyclone underflow can be separated from the stream returning to the pebble mill. Two circuits are being examined: a two-stage cyclone circuit, and a cyclone/screen circuit. These circuits are shown in Figures 6 and 7.

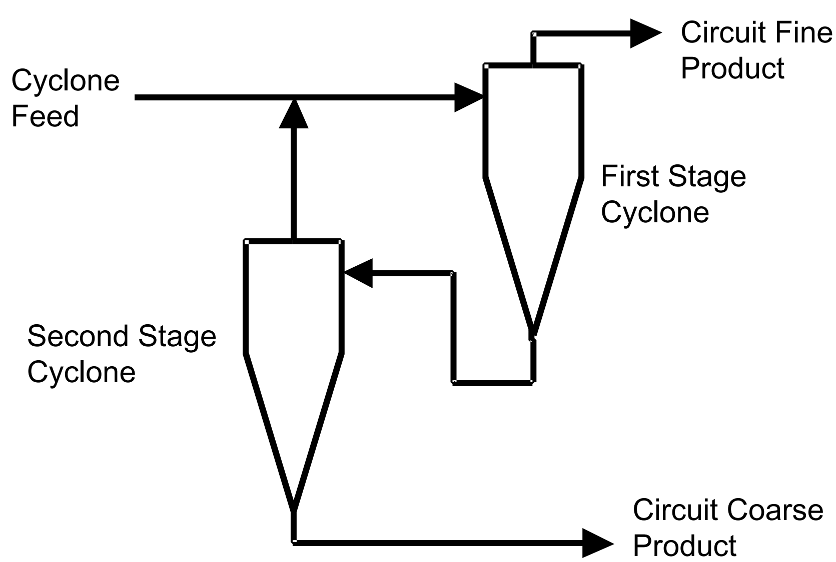

Figure 6: Two-stage cyclone circuit being examined in simulation studies

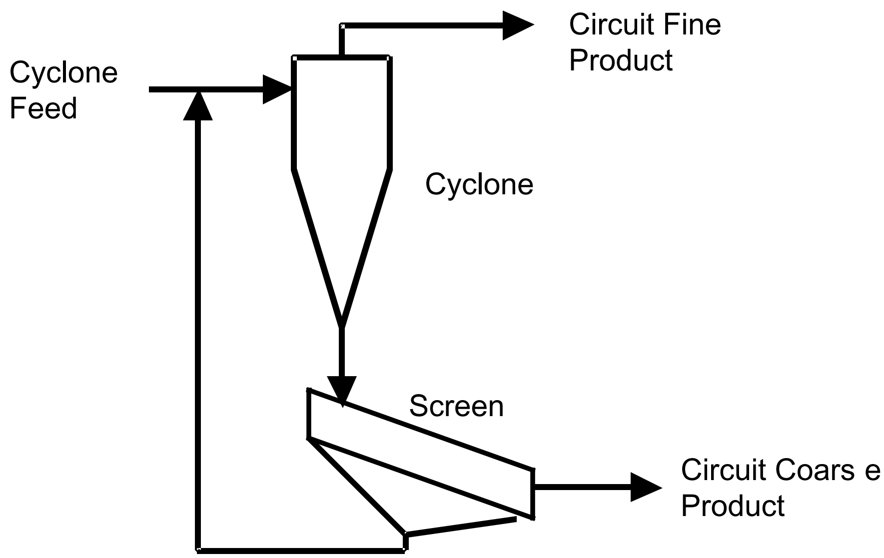

Figure 7: Cyclone/screen circuit being examined in simulation studies.

Conclusions

Fine liberated material that should have reported to the overflow instead reported to the underflow and was reground. This is a major source of energy inefficiency in the grinding process.

If the magnetite rich fine fraction of the underflow could be recovered before reaching the pebble mill, it would not be overground. The benefits of this would be improved energy efficiency due to reduction in the amount of energy wasted on grinding liberated particles, and increased circuit capacity proportional to the reduction of the amount of material overground.

The overall cyclone efficiency curve was separated into individual efficiency curves for magnetite and silica, that were calculated based on the iron assays and the cyclone efficiency curve:

The D_{50} for the magnetite curve (13.7 microns) was finer than the D_{50} for the silica curve (29.2 microns), resulting a region of poor separation shown as the “fish hook” on the efficiency curve.

In this region the cyclone is unable to separate coarse silica from fine magnetite, because they have the same settling rates and both report to the underflow. This reduces the magnetite recovery.

Large specific gravity differences between magnetite and silica caused the shift of the efficiency curve to a coarser size. Since the silica specific gravity was only half that of the magnetite, the resulting difference in efficiency curves between the two minerals was very large.

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