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

Quarterly Technical Progress Report

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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 the product size distribution, so that the amount of excessively fine material produced can be minimized. The goal is to save energy by reducing the amount of material that is ground below the target size, while simultaneously reducing the quantity of materials wasted as "slimes" that are too fine to be useful. This is being accomplished by mathematical modeling of the grinding circuits to determine how to correct this problem. The approaches taken included (1) Modeling of the circuit to determine process bottlenecks that restrict flowrates in one area while forcing other parts of the circuit to overgrind the material; (2) Modeling of hydrocyclones to determine the mechanisms responsible for retaining fine, high-density particles in the circuit until they are overground, and improving existing models to accurately account for this behavior; and (3) Evaluation of advanced technologies to improve comminution efficiency and produce sharper product size distributions with less overgrinding.

Table of Contents

Introduction	5
Executive Summary	5
Experimental	7
Results and Discussion	8
Conclusions	12
References	12

List of Tables and Graphical Materials

Figure 1. Novel comminution circuit developed and simulated in this project.	6
Figure 2: Original, unmodified fine comminution circuit.	7
Figure 3: Existing flowsheet of a second iron ore concentrator being examined (Plant B) 8	8
Figure 4: Cyclone before ball mill, to remove fine particles before they can be overground. The screen is expected to remove and recycle locked particles.	9
Figure 5: Cyclone before ball mill, screens eliminated	10
Figure 6: Removal of liberated gangue before sizing operation	10
Figure 7: Intermediate gangue removal with single screen included for size control.	11
Figure 8: Intermediate gangue removal with screens eliminated.	11
Figure 9: 2-stage open circuit grinding, no circulating load.	11

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. 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.

Plant sampling and analysis has demonstrated that the largest single source of overgrinding in the industrial process is the return of high-density material to the grinding process by hydrocyclones. Simulations of the comminution circuit indicate that substantial reductions of the circulating load can be achieved, resulting in an increase in throughput of approximately 50% while using the same number of grinding mills, with a corresponding increase in energy efficiency. A grindinding circuit in a second plant is being analyzed to determine the degree to which it can benefit from similar circuit modifications.

The final project report is being prepared for submission at the end of this project in June 2005.

Executive Summary

The goal of a comminution circuit is to grind particles to their liberation size, so that the valuable minerals are completely broken free from the gangue minerals. For the best grinding efficiency, all particles should ideally be ground only to the liberation size, and no finer. In order to accomplish this, the circuit should have the following characteristics:

1. Material should be removed from the circuit as soon as it is sufficiently fine, otherwise particles retained in the circuit have the opportunity to break further.

2. Breakage at the coarser sizes should be maximized, as a coarse particle breaking does not produce as many extremely fine particles as a finer particle breaking will produce.

3. All particles of the target size should have equal probability of being removed by the classification system, regardless of factors such as particle density.

An additional characteristic has been identified in this project: it is important that particles that are already near the desired target size be ground just sufficiently to reach the specified size. This means that the near-size particles should be subjected to at most one breakage event, and then removed from the circuit.

To accomplish this, the circuit shown in Figure 1 was devised based on the body of data generated earlier in this project.

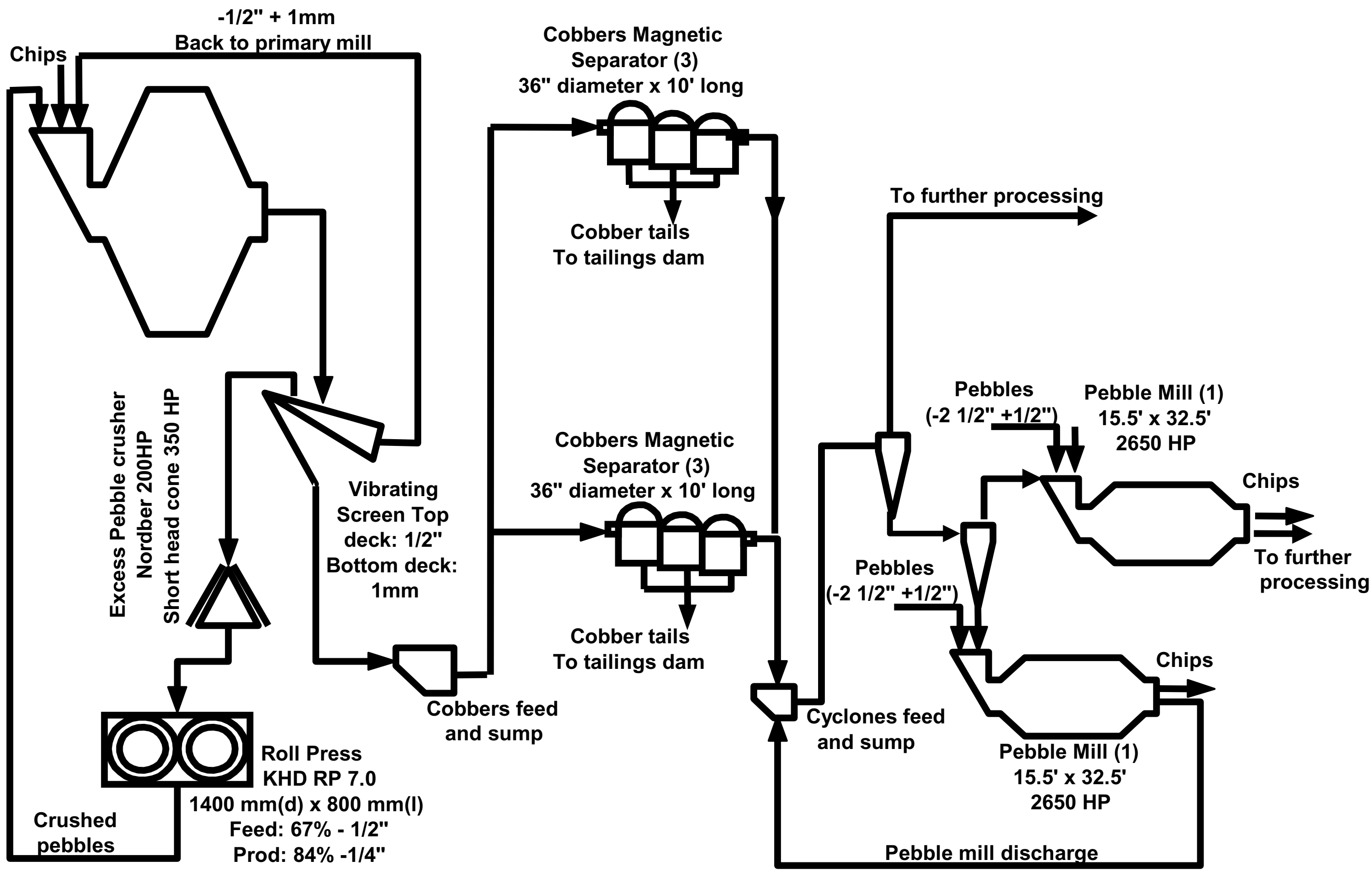

Figure 1. Novel comminution circuit developed and simulated in this project.

The key features of this novel circuit are:

1. It uses a pair of hydrocyclones to separate the particles which are just slightly coarser than the target size into a separate stream, which consists of very nearly monosized particles.

2. This stream of intermediate size particles, instead of recirculating to a closed-circuit mill, is diverted to a mill operating in open circuit. The particles going through the open circuit mill are subjected to only a very limited number of breakage events, and so the probability of a particle being broken more than once, and overground as a result, is minimal. Since the particles are nearly monosized, the product from the open circuit mill remains very narrow.

As a result of the novel features of this flowsheet, the intermediate-sized particles that would normally make up a large fraction of the circulating load (and would therefore both tend to be overground, and would tend to decrease the mill capacity by increasing its circulating load) is prevented from interfering with the grinding of the coarser fraction.

Simulations of this circuit indicated that this new configuration would have roughly 50% greater throughput than a conventional circuit using the same number of mills, and that the energy consumption per ton of material ground would be reduced accordingly. This gain is primarily due to a great reduction in the circulating load to the closed-circuit mill.

These results have been presented to plant personnel, who are currently deciding which plant would be most appropriate for a plant-scale test of this circuit configuration.

Experimental

Simulation models were prepared using data previously collected from a plant operated by one of the industrial partners on this project (referred to as Plant A). The original, unmodified circuit was as shown below in Figure 2. Hydrocyclone and grinding mill model parameters used were described in previous progress reports.

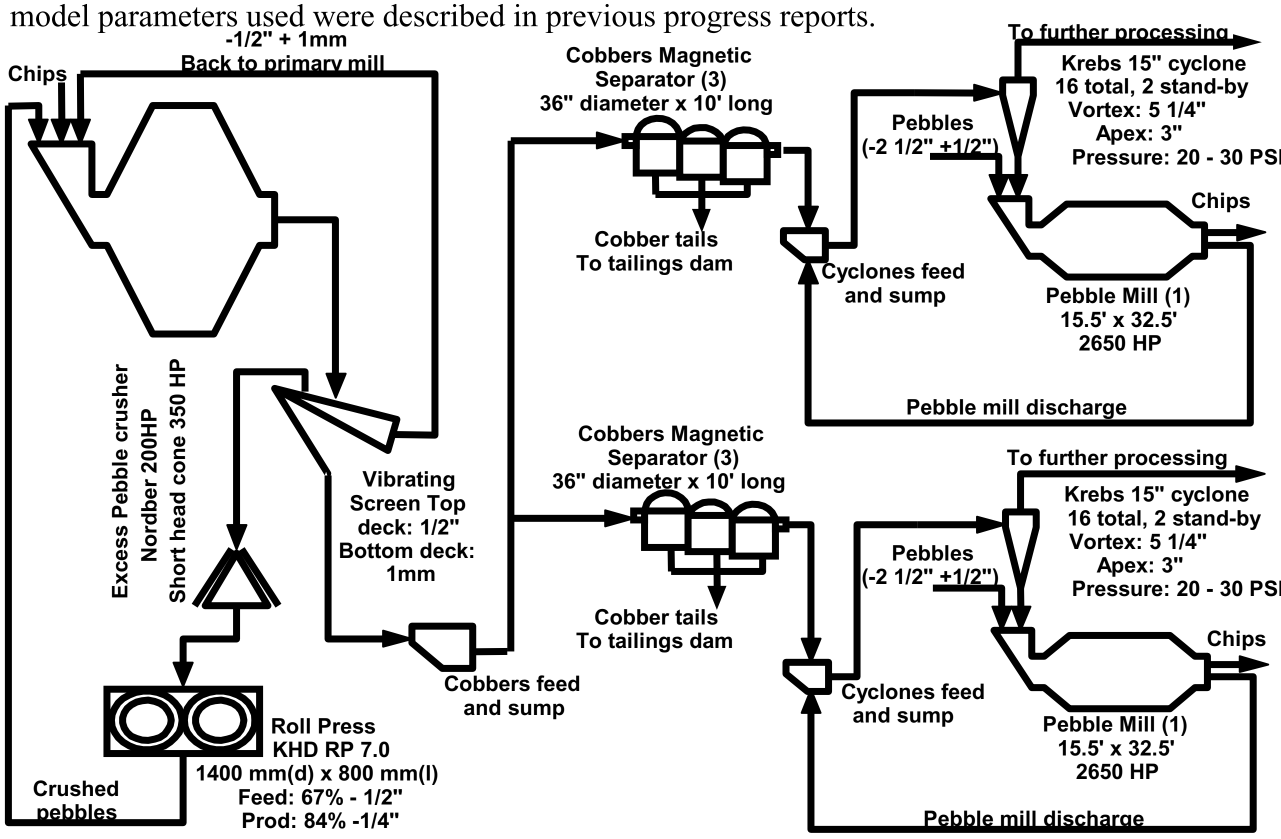

Figure 2: Original, unmodified fine comminution circuit. Plant sampling and analysis demonstrated that this circuit, which operated with approximately 250% recirculating load in the pebble mill discharge streams, tended to significantly overgrind the high-density magnetite particles.

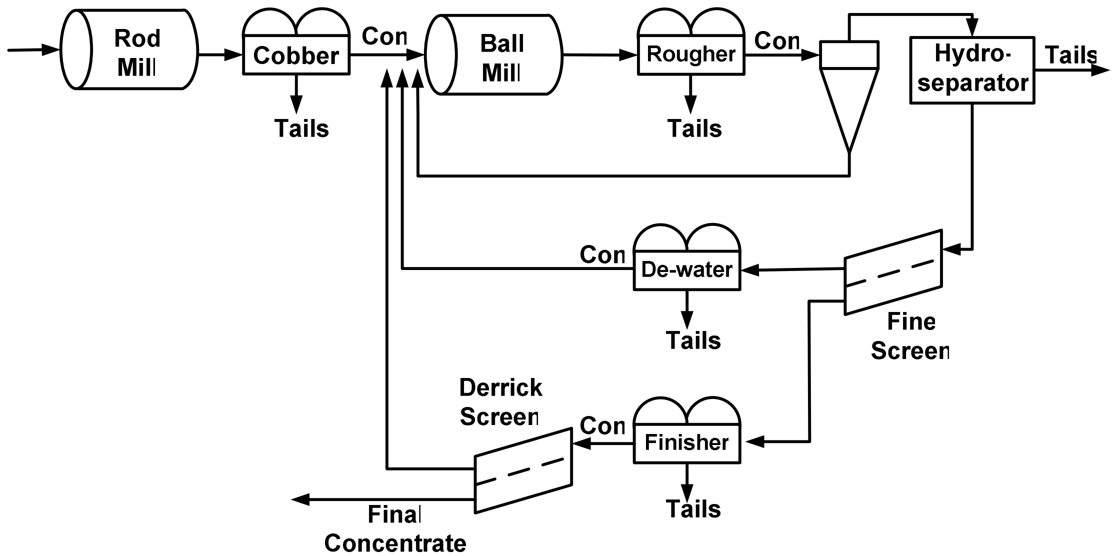

Figure 3: Existing flowsheet of a second iron ore concentrator being examined (Plant B)

After modeling this base circuit, the circuit was reconfigured as shown in Figure 1, to reduce the tendency for overgrinding of intermediate-sized particles. The modified circuit, with two grinding mills, was directly compared to a pair of mills operating in parallel circuits of the type shown in Figure 2.

Based on successful simulations of modifications for the circuit shown in Figure 2, models were also created for the circuit of a second iron ore concentrator (Plant B), as shown in Figure 3. In this circuit, the problems were somewhat different in that the bulk of the overgrinding that occurred was a result of inefficiencies with the screens. The screens were also more difficult to operate and maintain than hydrocyclones, and so there was interest in determining whether the number of screens could be reduced without causing the hydrocyclones to retain fine magnetite in the circuit as occurred in Plant A. A number of potential modified circuits are being examined.

Results and Discussion

When the Plant A simulation was modified to use 2-stage cycloning with combined open-circuit and closed-circuit grinding as shown in Figure 1, it was determined that there was a substantial decrease in circulating load in the two-stage circuit, at only 42.5% as compared with 250% for the unmodified circuit. As a result of this reduction in circulating load, a considerable amount of grinding capacity was made available for grinding fresh feed, to the extent that the overall circuit capacity was increased by approximately 50%. This represents a major improvement in operation. Since for both circuits the mills are operating with the same quantity of material filling them, they require approximately the same quantity of energy to turn regardless of whether they are in the single-stage configuration or the two-stage configuration. However, the large increase in throughput means that the quantity of energy to grind a ton of ore will be decreased comparably, by approximately 50%.

These results indicate a significant breakthrough in preventing the overgrinding problem and the accompanying waste of energy. The plant personnel are keenly interested in implementing this new configuration, as even a fraction of this efficiency increase would be worth millions of dollars in operating cost reductions.

The circuit for Plant B has been successfully simulated, and it was determined that the situation was different from Pland A due to the use of screens. Instead of the cyclones being the primary cause of overgrinding, in Plant B the main issue is inefficiency of the screens. Due to the fine particle size, the screen efficiency is limited, resulting in a considerable amount of fines being retained in the screen oversize products. In addition, screens are more expensive to operate and maintain than hydrocyclones, and so a reconfiguration of the circuit to reduce the dependence on screens is expected to be of considerable benefit. Studies of modified circuits are currently underway to determine whether the screens can be reduced in importance, or eliminated, without impairing the performance of the circuit and while minimizing the quantity of overgrinding that occurs.

Several candidate circuits for Plant B that are under examination are shown in figures 5-9.

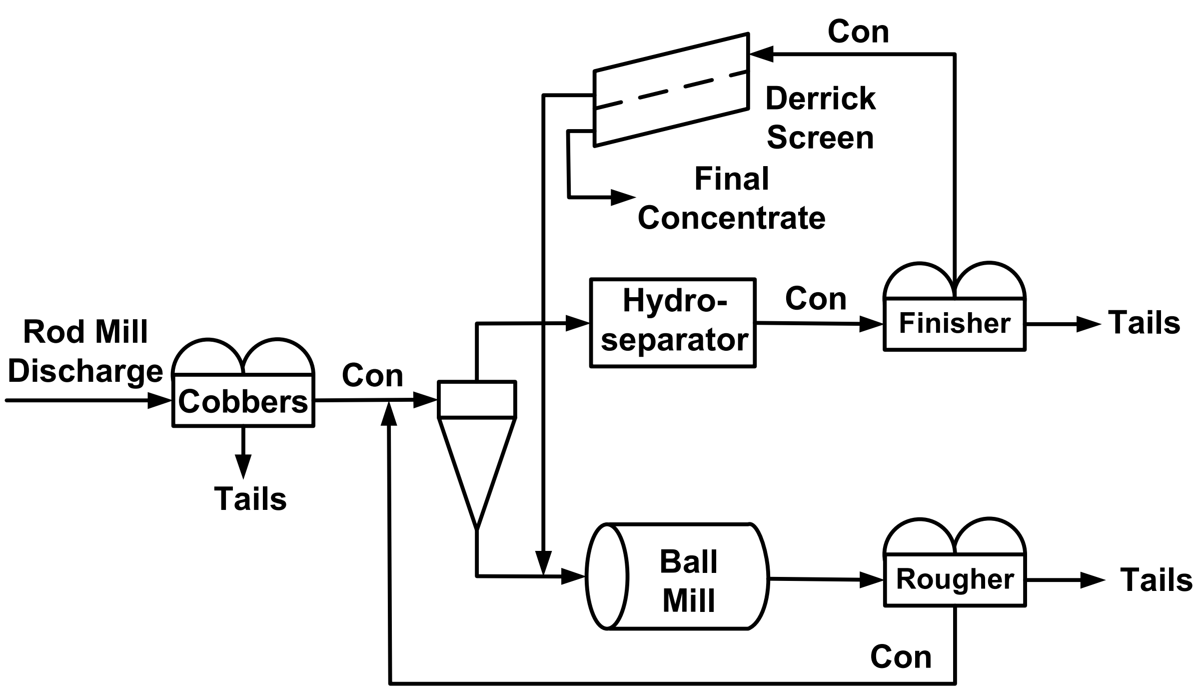

Figure 4: Cyclone before ball mill, to remove fine particles before they can be overground. The screen is expected to remove and recycle locked particles.

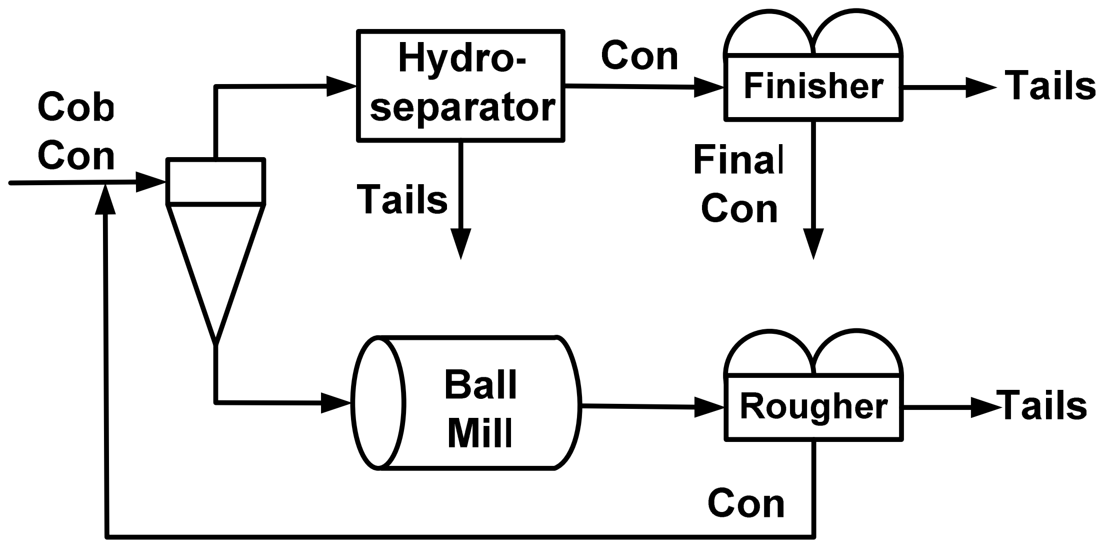

Figure 5: Cyclone before ball mill, screens eliminated

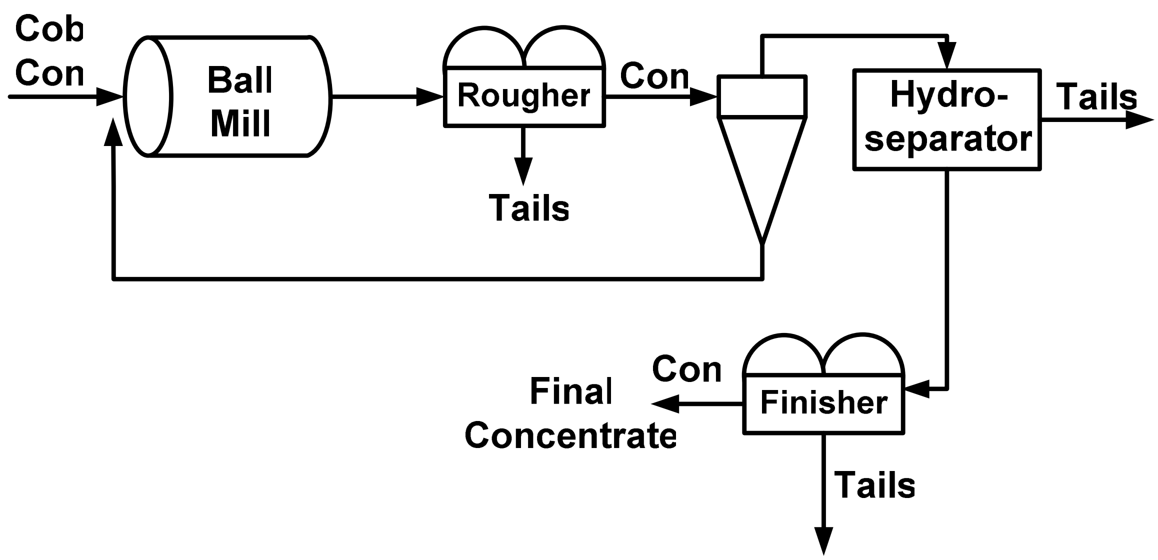

Figure 6: Removal of liberated gangue before sizing operation

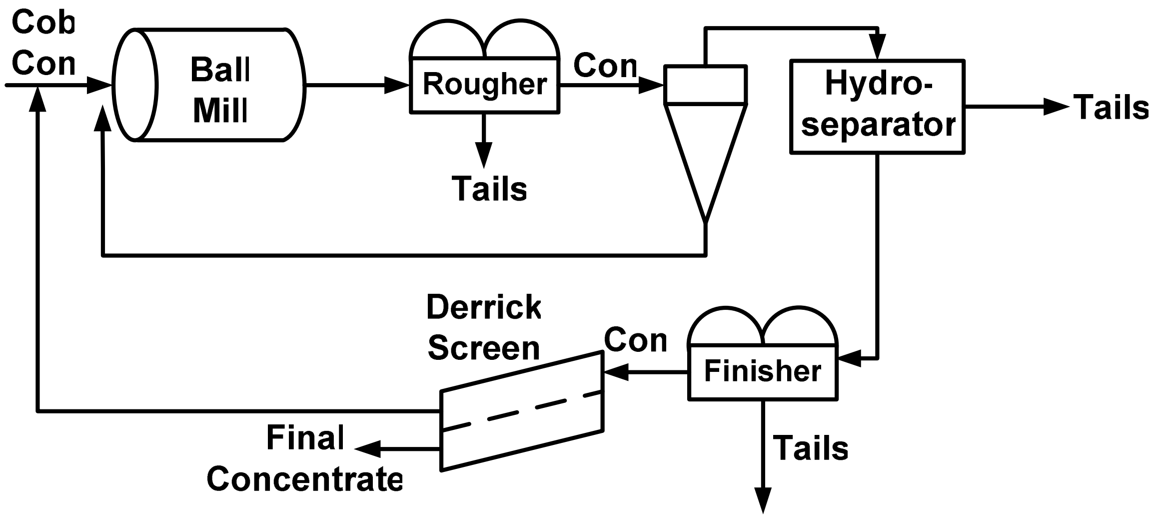

Figure 7: Intermediate gangue removal with single screen included for size control.

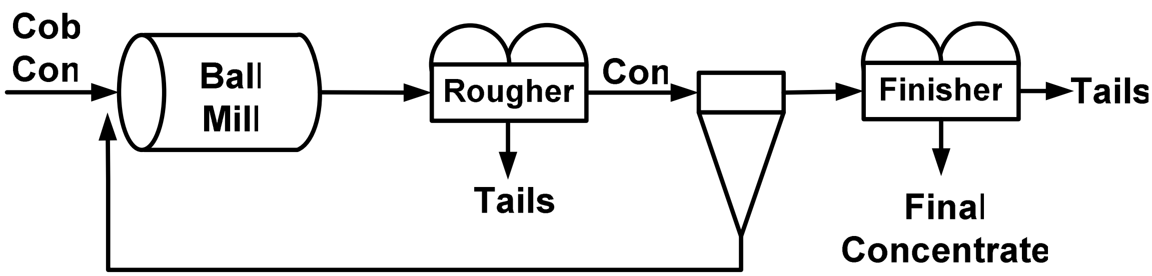

Figure 8: Intermediate gangue removal with screens eliminated.

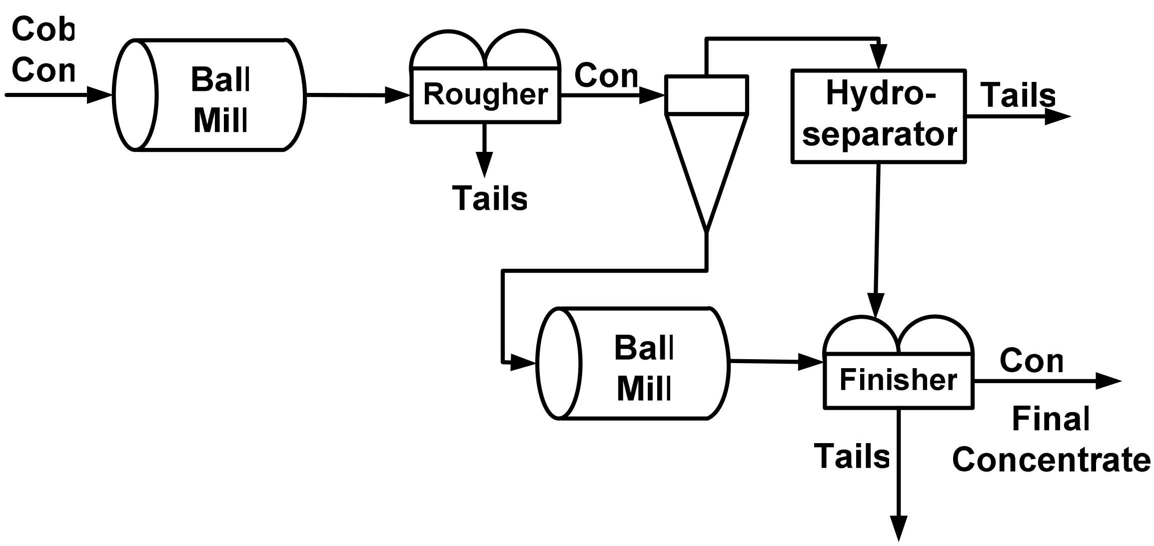

Figure 9: 2-stage open circuit grinding, no circulating load.

Simulations of these and other alternative circuits for Plant B will be completed and included in the final project report, which is currently being prepared.

Conclusions

Simulations of novel grinding circuit configurations have indicated an extremely promising potential arrangement for boosting grinding efficiency by as much as 50% in iron ore grinding circuits, by greatly reducing the overgrinding of high-density iron oxide minerals. Development of this circuit required the use of comminution models based on actual plant data, as without such models it would not have been possible to prove the benefits of this configuration without excessive plant modification costs.

Using the experience with the first plant (Plant A), it was possible to much more rapidly develop a model for a second plant (Plant B), which was successfully simulated. Work is underway to determine new circuit configurations that will improve the energy efficiency for Plant B.

The final project report is currently being prepared.

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