

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

Quarterly Technical Progress Report

Report Period Start Date: **April 01, 2003**

Report Period End Date: **June 30, 2003**

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

Date of Issue: July 2003

DOE Award Number: DE-FC26-01NT41062

Submitting Organization

Department of Chemical Engineering
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931 - 1295

DISCLAIMER:

This report was prepared as an account work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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 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.

Table of Contents

Introduction5
Executive Summary5
Experimental6
Results and Discussion9
Conclusions10
References.....10

List of Tables and Graphical Materials

Figure 1: Hydrocyclone test rig assembled for the laboratory hydrocyclone validation experiments6
Figure 2: Apparatus for precise, simultaneous sampling of the overflow and underflow products from the hydrocyclone. This simultaneous sampling is critical for properly measuring the hydrocyclone performance.....7
Figure 3: Davis Magnetic Tube apparatus. This device quantitatively separates magnetic material from non-magnetic material. Use of this device makes it possible to cleanly separate the hydrocyclone products into a high-density magnetite fraction and a low-density quartz fraction, so that the hydrocyclone efficiency curves for each density class can be precisely calculated.:9

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.

Executive Summary

Inefficiency in the operation of the hydrocyclone classifier was identified as a major cause of poor energy efficiency in the grinding circuit. In order for the comminution process to reach the liberation size for the entire ore, the hydrocyclone is set so that the low-density particles do not escape from the circuit until they are finer than the liberation size. In the process, the high-density particles are classified by the hydrocyclone to an even finer size. As a result, the high-density particles are recycled by the hydrocyclone and overground.

Previous hydrocyclone models could not adequately deal with mixed-density particles, and they did not predict the “fish-hook” behavior seen in the plant. The term “fish-hook” refers to an inflection in the hydrocyclone efficiency curve, where some of the finer particles are more likely to report to the hydrocyclone oversize product than are coarser particles. The inability of hydrocyclone models to account for this behavior appears to be due to the fact that the overall hydrocyclone efficiency curve is not simply the sum of the efficiency curves of the individual particle classes. The effects of other parameters, particularly specific gravity and viscosity, appear to be contributing factors.

A new hydrocyclone model has been coded that is expected to be able to account for the fish-hook in the efficiency curve is being tuned and validated. To provide validation data, laboratory hydrocyclone experiments are needed that can produce performance data under precisely controlled conditions that are comparable to the conditions seen in the plant. In the past quarter, a hydrocyclone test rig and testing procedure has been developed that will be used to produce the necessary validation data.

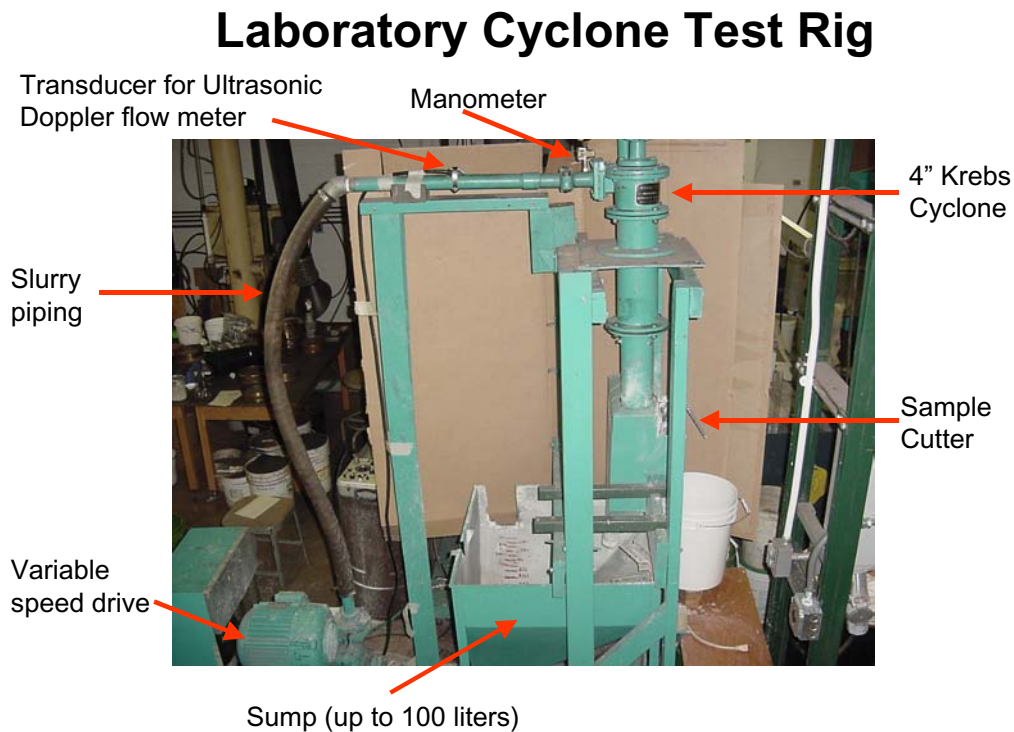
It is also necessary to be able to separate the overall hydrocyclone efficiency curve into two components: a curve for the silica component (low density), and a curve for the magnetite (high density). A procedure was developed for this purpose using a Davis Magnetic Tube apparatus, which quantitatively separates the magnetic iron oxides from the non-magnetic quartz. This makes it possible to separately measure the quartz and magnetite particle size distributions in each of the hydrocyclone products, and calculate the individual efficiency curves for each type of material.

Experimental

Hydrocyclone test rig

A hydrocyclone test rig was constructed to conduct the laboratory experiments needed to tune and validate the hydrocyclone model. This was needed because it is impractical to collect sufficiently accurate samples from hydrocyclones in the plant, or to fully monitor and control the hydrocyclone performance over the desired range without interfering with the plant operations.

The test rig, which is shown in Figure 1, includes a 100 liter sump with variable-speed pump that allows continuous recirculation of slurry sample. This makes it possible to exactly control the composition and percent solids of the hydrocyclone feed slurry, and to feed it to the hydrocyclone at a wide range of pressures and flowrates.



14

Figure 1: Hydrocyclone test rig assembled for the laboratory hydrocyclone validation experiments.

The key part of the test rig is the sampling arrangement, consisting of a moving gate and sample splitter that allows collection of precise, simultaneous samples from overflow and underflow. Simultaneous sampling of both streams is particularly critical, because it ensures that (a) samples can be collected without altering the composition of the slurry recirculating in the feed sump, so the hydrocyclone performance is unaffected by sampling, and (b) the two samples can be directly compared to determine relative flowrates to

the hydrocyclone overflow and underflow, which is crucial information for accurately calculating hydrocyclone efficiency curves.

The instrumentation on the hydrocyclone feed consists of an Ultrasonic Doppler flow meter to directly measure feed flow rate, and a pressure gauge to measure feed pressure. Both measurements are needed in order to determine both the total flowrate of slurry, and the pressure drop across the cyclone that was available for providing energy to drive the hydrocyclone operation.

The hydrocyclone installed on the test rig was a Krebs cyclone, and is shown in Figure 2. The hydrocyclone was equipped with a range of replaceable vortex finder and apex inserts so that it could be adjusted to closely match the performance of the hydrocyclones in use in the plant. The dimensions of the hydrocyclone were as follows:

- Body diameter: 4 in. (10.2 cm)
- Apex diameter: 0.5 in. (1.27 cm)
- Vortex finder diameter: 1 in. (2.54 cm)
- Cyclone height: 24 in. (61 cm)

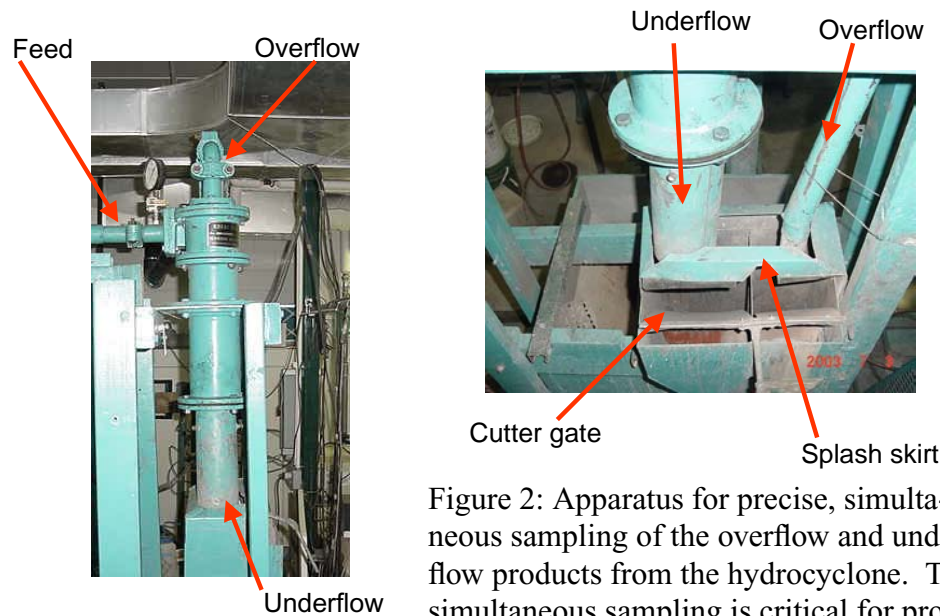


Figure 2: Apparatus for precise, simultaneous sampling of the overflow and underflow products from the hydrocyclone. This simultaneous sampling is critical for properly measuring the hydrocyclone performance.

Davis Magnetic Tube Separator

The Davis Magnetic Tube Separator, shown in Figure 3, is used to quantitatively separate magnetic iron minerals from non-magnetic minerals. A strong magnetic field traps the magnetic particles within an oscillating glass tube, while non magnetic particles are washed out by an steady stream of water. The oscillation of the tube continuously agitates the trapped particles so that entrained non-magnetic particles are released.

The size distributions of both the magnetic and the non-magnetic products can then be determined using the Microtrac particle size analyzer. Since the Davis Magnetic Tube can quantitatively separate magnetic and non-magnetic particles down to a particle size of approximately one micrometer, this is the most effective method available for determining the exact ratios of magnetite and quartz as a function of particle size.

The procedure for operating the Davis Magnetic Tube and carrying out Microtrac size analysis of the products is as follows:

- Thoroughly blend sample, and weigh out two samples of 30.0000 grams using an analytical balance.
- Set the Davis Tube as follows:
 - Wash water flowrate at 380 ml/minute (6.02 gal/hr)
 - Tube reciprocation at 84-86 cycles per minute. Record the rheostat setting needed to reach this value.
 - Magnetic coils at 2 amps
- Clamp off tube outlet, and fill tube with water to above the magnetic poles.
- Turn on magnet
- Carefully pour in the 30.0000 gram sample, and gently wash down any material that adheres to the wall of the tube
- Put stopper into inlet end of tube, and turn on water at proper rate.
- Place container under the tube outlet to capture the non-magnetic fraction
- Open outlet clamp (the stopper will maintain a seal at the top of the tube, so that the water will run out at the same speed as the fresh water runs in)
- Turn on agitation, run for 10 minutes while collecting the non-magnetic fraction
- At the end of the test, turn off the reciprocation, put a pan under the outlet, turn off the magnet, and wash the magnetic fraction into a pan.
- Dry and weigh the magnetic and non-magnetic fractions.
- Disperse each fraction for microtrac analysis by suspending the appropriate amount of material (0.1-0.3 grams) in 5 ml of a 1% solution of sodium silicate, and agitating in an ultrasonic bath for 2 minutes.
- Place the dispersed material into the Microtrac recirculation chamber. For the non-magnetic (silica) fraction, dilute to the necessary volume with water adjusted to pH-8.5 with sodium carbonate. For the magnetic fraction, dilute in distilled water.
- Average three 45-second measurements in the Microtrac to determine the size distribution.



Figure 3: Davis Magnetic Tube apparatus. This device quantitatively separates magnetic material from non-magnetic material. Use of this device makes it possible to cleanly separate the hydrocyclone products into a high-density magnetite fraction and a low-density quartz fraction, so that the hydrocyclone efficiency curves for each density class can be precisely calculated.

Results and Discussion

The hydrocyclone test rig was constructed and tested in the past quarter of the project, and the procedures have been developed for using the Davis Magnetic Tube in conjunction with a Microtrac particle size analyzer to determine the separate magnetite and quartz hydrocyclone efficiency curves. The following experiments are currently underway with this apparatus:

- Determination of the efficiency curves for pure magnetite, pure quartz, and mixtures of the two as a function of feed solids loading and hydrocyclone pressure.
- Laboratory testing of actual hydrocyclone feed collected from the plant, under precisely controlled conditions, with separation of the magnetite and quartz fractions.

These experiments are critical for proper validation of the hydrocyclone model that has been coded for this project, as it is not practical to carry out experiments in the plant with the degree of instrumentation and sampling accuracy that can be achieved with the laboratory test rig.

Once the hydrocyclone experiments and model verification are completed, in-plant studies will be carried out to determine whether the predictions made using the model accurately reflect the performance of the actual plant comminution circuit.

Conclusions

Modeling of the plant comminution circuit has been complicated by the difficulty of accurately modeling the hydrocyclones when there are large amounts of material with two different densities. Due to the difficulty of fully instrumenting, controlling the inputs to, and sampling from hydrocyclones in the plant, a highly-instrumented hydrocyclone test rig was set up in the laboratory that would be ideally suited for validating hydrocyclone models. A procedure was also developed for quantitatively separating the high-density magnetite fraction from the low-density quartz fraction, so that each type of material could have its size distribution measured separately. This has made it possible to determine not only the overall efficiency curve for the hydrocyclone, but also to separately determine the efficiency curves for the magnetite and quartz fractions. It is not possible to determine how well the models can predict the performance of multiple density components in the hydrocyclone.

References

- L.G. Austin, R.R. Klimpel, P.T. Luckie. 1984. Process Engineering of Size Reduction: Ball Milling. Society of Mining Engineering, AIME. New York
- A.R. Laplante and J.A. Finch, 1984. The Origin of Unusual Cyclone Performance Curves. International Journal of Mineral Processing, Volume 13, p 1 – p 11.
- T.J. Napier-Munn, S. Morrel, R.D. Morrison, T. Kojovis. 1006. Mineral Comminution Circuits, Their Operation and Optimization. JKMRRC Monograph Series in Mining and Mineral Processing 2. Australia.
- N.L. Weiss, 1985. SME Mineral Processing Handbook. American Institute of Mining, Metallurgical and Petroleum Engineers. Volume 1, Section 2, p2-10 to p2-14.
- H.J. Walqui, Mathematical Modeling of Coal Pulverizers using Population Balance Models, M.S. Thesis, Michigan Technological University, submitted August 2001.
- H.J. Walqui, T.C. Eisele, and S.K. Kawatra, Development of Mathematical Models for Coal Pulverization, To be presented at the SME Annual Meeting, Phoenix, AZ, Feb. 25-27, 2002