IMPLEMENTING STRATEGIES TO IMPROVE MILL CAPACITY AND EFFICIENCY THROUGH CLASSIFICATION BY PARTICLE SIZE ONLY, WITH CASE STUDIES

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Abstract

Recent advances in fine screening technology allow for the efficient classification of mill products by means of particle size separation only, the advantages are numerous, including improved throughput, reduced power consumption, coarser grind and reduced reagent consumption. The paper will review the history of fine screening from early 20th Century to modern day technology and will detail the economic benefit obtained through modern day fine classification techniques by means of the patented Stack Sizer^{TM} technology.

Introduction

The purpose of this paper is to present an analysis of the typical grinding circuits used in the processing of base metals with emphasis on classification. This paper shall present historical references to past classification practices, practices used presently and the most up to date technology available. The overall intention is to provide end users the means to increase production capacity while realizing other benefits such as improved flotation recovery and reduced chemical consumption, improved filtration, better control of circuit product size distribution, etc.

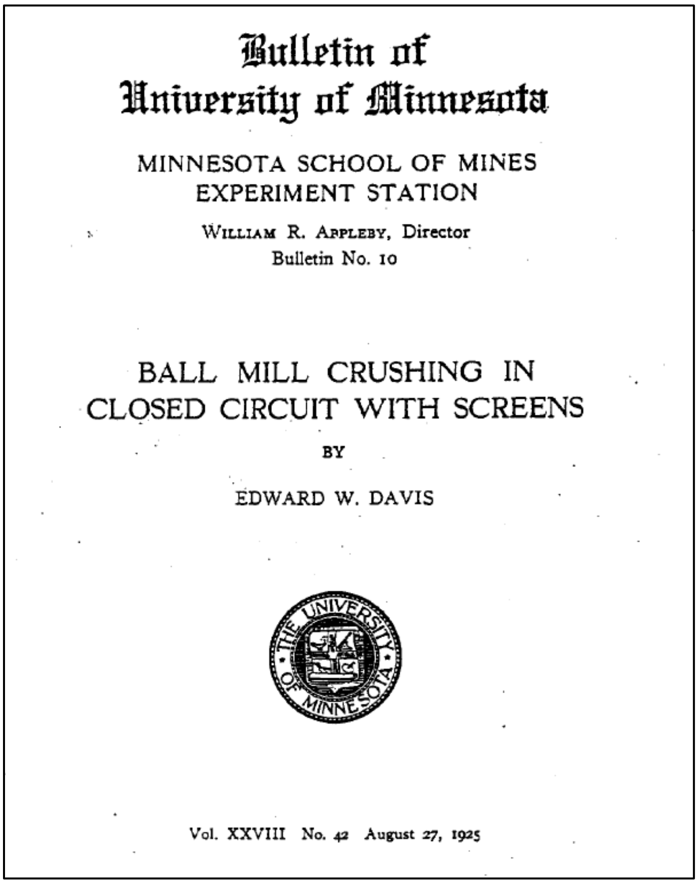
Early mineral processing techniques employed the use of grinding mills as the first phases of liberating and isolating desirable minerals from gangue. In the early phases it was also recognized that some form of size classification associated with the grinding mill would allow for more efficient operation of these grinding mills. We will look at these classification technologies as they've evolved through the years with attention paid to physical and economical limitations of the technologies. Accuracy of the classification is paramount in efficient grinding circuit operation; however accuracy comes at a price. Of course we all recognize that economic considerations must ultimately rule in selecting appropriate technologies.

History

Traditionally the classification systems used in closed grinding circuits comprised of rake classifiers, spiral classifiers, hydrocyclones, sedimentation cones, and in some cases rudimentary commodity style vibratory screening machines with steel wire surfaces.

The classification of particles in rakes, spirals, cyclones, and sedimentation cones is based on settling rate velocities which take into account both particle size and density. Vibratory screening machines utilize particle size only in the classification process. It is this fundamental difference between hydraulic classifiers and vibratory screens which created the potential for increased capacity in closed grinding circuits.

In 1925 E.W. Davis, see Figure 1, conducted tests which compared rake classifiers, spiral classifiers and vibratory screens in the closing of grinding circuits. He concluded that vibratory screens provided higher capacity and better control over grind size than either rake or spiral classifiers. Grinding mills at the time were comparatively small, therefore some attempts were made to utilize vibratory screens in full scale operations based on this testing. Due to limitations in the weaving of stainless steel wire at the time and the inherent problems with wire cloth relating to blinding, high wear rates and replacement costs these full scale operations proved impractical and uneconomical. In addition the screening machines produced at the time had extremely low capacity, requiring huge amounts of floor space. This floor space requirement increased installed costs tremendously, thus making vibratory screens impractical.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BALL MILL CRUSHING IN
CLOSED CIRCUIT WITH SCREENS

BY

EDWARD W. DAVIS

Vol. XXVIII No. 42 August 27, 1925

Figure 1. Title page of article published in 1925

After WWII, hydrocyclones became the norm in the closing of grinding circuits. As mill sizes increased, rake and spiral classifiers became less economically viable due to their large footprint requirements and capital costs. The hydrocyclone on the other hand required very little space, provided high capacity with relatively low capital costs. For these reasons and the increased demand for refined minerals, processing plant designs started catering for greater tonnages. With these larger processing facilities becoming the norm, hydrocyclones became the standard device for closing of grinding circuits.

Operational experiences have indicated that the separation efficiencies of hydrocyclones fall between 45% and 65%. Throughout the years, cyclone manufacturers made a series of modifications in the design including geometry, materials of construction, cone angles, vortex finder penetration and diameter, etc. These changes were made in efforts to improve performance, and in some cases provided marginal improvements but most processing plants never surpassed the 60% separation efficiency level. (Refer Appendix 1 for efficiency calculations). The end result of closing grinding circuits with this relatively low separation efficiency device is that most mills in the base metals industry operate with circulating loads in excess of 200%.

Other studies concluded with statements such as “lower grinding costs are possible with screen circuits” (Albert 1945) and “the master key for great improvements in capacity and in energy consumption in closed grinding circuits is in improved sharpness of classification” (Hukki and Eland 1965). A recent presentation on flow sheet development for the planned Essar steel iron ore concentrator project in Minnesota, USA which included results from pilot scale tests and simulation work, demonstrated a significant coarsening of the grind/grade relationship through the use of screens instead of cyclones (Murr, Wennen and Nordstrom 2009).

Stack Sizer Screening Machine

In 2000, Derrick Corporation designed and introduced the Stack Sizer™ multiple deck fine wet screening machine as illustrated in Figure 2. In review of Figure 2 we see that a single feed is

introduced to the screening machine at five separate feed points by means of a standard flow divider. This is done in order to take advantage of the well known fact that width of screen surface is the most important factor in determining the capacity and efficiency of wet screening machines vs. length or area. It is understood that once free water leaves the mineral slurry on a screen surface - sizing ceases to occur, therefore feeding thin uniform layers of slurry across the entire width of each of the five feed points provide maximum separation efficiencies and tonnage rates. A linear high frequency vibratory motion is supplied to all five screen decks uniformly throughout the entire length and width of each screen deck by means of a pair of TENV (Totally Enclosed Non Ventilated) vibratory motors with a sealed for life bearing design. This vibratory motion induces fluid and undersize solids throughput while also extending the effective fluidized zone for sizing. The vibratory motion is also extremely effective in conveying oversize material to the end of each screen deck making way for the new oncoming feed. A unique hopper and launder assembly allows all undersize to discharge from one outlet and the oversize to discharge from another single outlet.

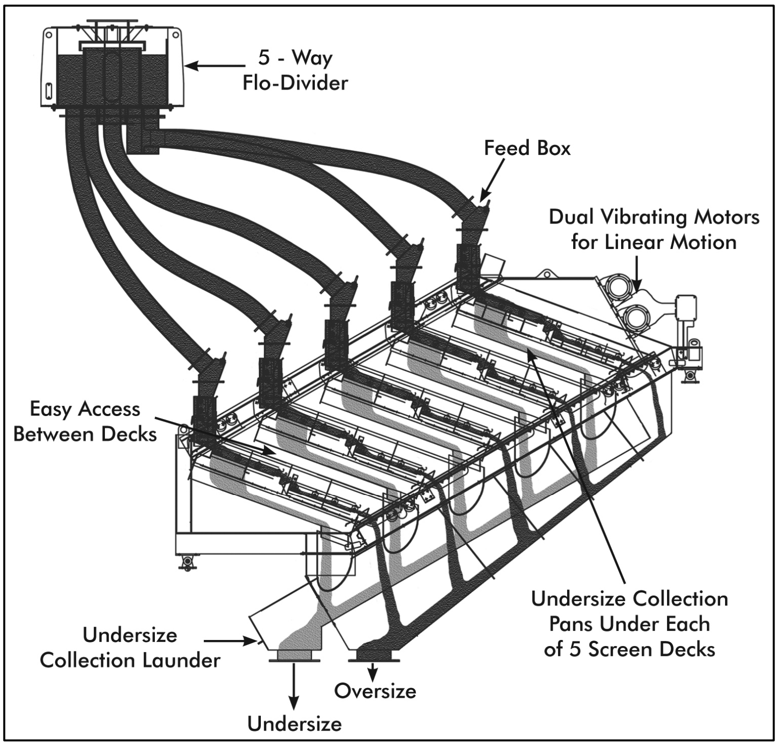


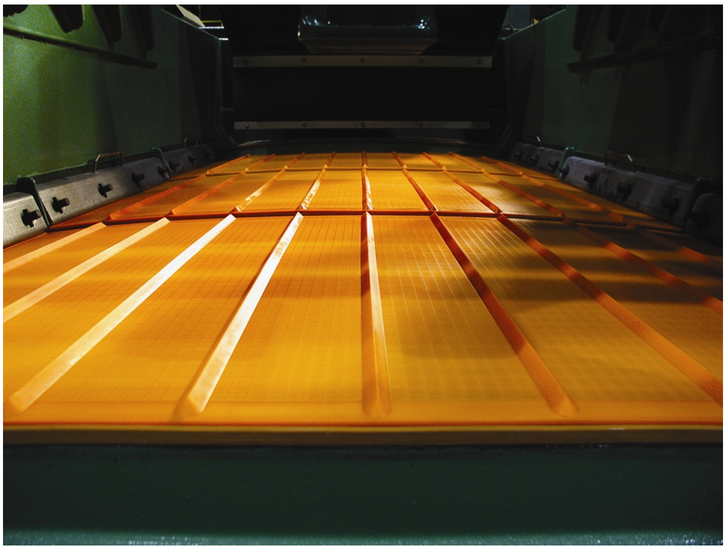
Figure 2. Schematic Diagram of 5 Deck Stack Sizer

The introduction of the Stack Sizer provided end users with an exceptionally high tonnage, wet screening system which was previously not available. The Stack Sizer in combination with the high open area urethane screen surfaces basically eliminates all of the prior concerns about the applicability

of fine screening technology in closed circuit grinding. The high tonnage rate capabilities reduce footprint requirements dramatically while the patented urethane screen surfaces eliminate wear and blinding issues. It is this combination of technologies from Derrick Corporation that makes screening a viable option particularly in closing grinding circuits for base metal applications. At this point it should also be mentioned that this is not experimental technology as over 600 stack sizers have been produced and delivered around the world.

Polyurethane Screen Surfaces

The availability of high open area, long wearing polyurethane screen surfaces with openings as fine as 75 microns (200 mesh) has made fine wet screening more feasible than previously thought possible. The open area of urethane screen surfaces has traditionally been one of their biggest draw backs, particularly when dealing with the finer end of the screening spectrum. The conventional 305 X 305 pin and sleeve panel, typically has a relative open area of about 10% for a 500 micron aperture panel. In contrast the total open area of Derrick urethane panels range from 35 to 45%, similar to conventional woven wire screen panels, resulting in significantly higher capacities or smaller, lighter equipment being required. Remarkably, these urethane screen surfaces typically last 4 to 12 months, depending upon the abrasiveness of the material and the panel opening. Moreover, the slotted openings are designed with a tapered relief angle to minimize blinding. Picture 1 shows how the urethane panels are side-tensioned over a slightly crowned deck.



Picture 1. Typical Crowned Deck Configuration

Grinding Circuits

Grinding is the process of reducing the size of a mineral ore to a point where the desirable mineral is liberated and then presented to further process technologies for efficient separation from the undesirable gangue material. The mills themselves have evolved in size, power draw and durability for over a century but the technology has remained basically the same. It is in the classification stages that technology has evolved into functionally different forms in recent years. We identify the following four basic types of grinding circuits, commonly used in base metals (Barrios 2006):

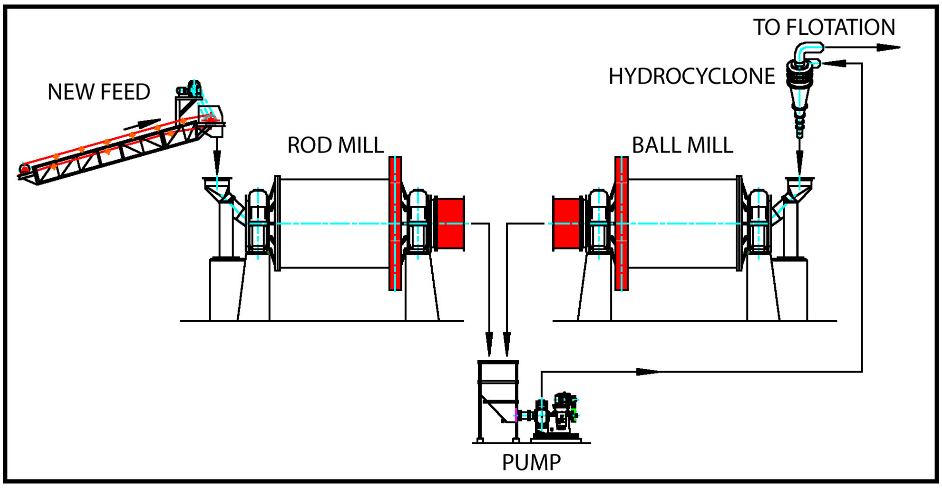


Figure 3. Primary Rod Mill followed by Secondary Ball Mill

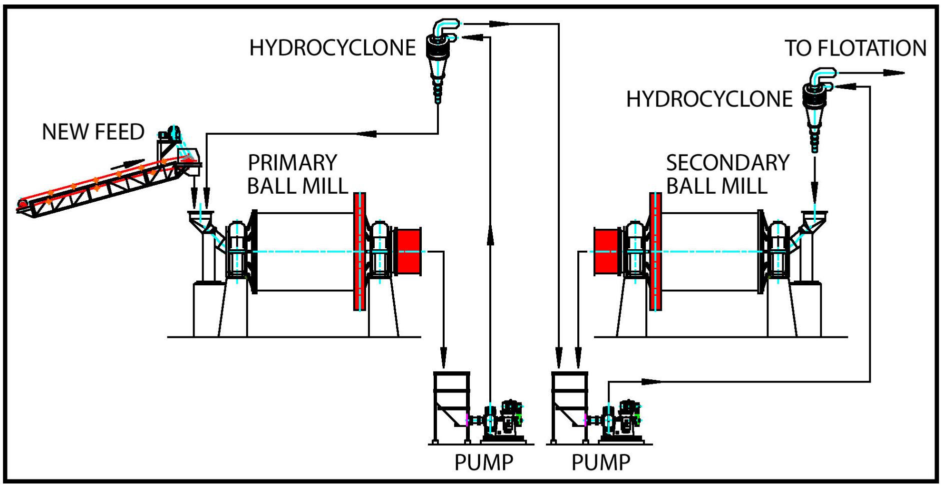


Figure 4. Two Ball Mills in Series

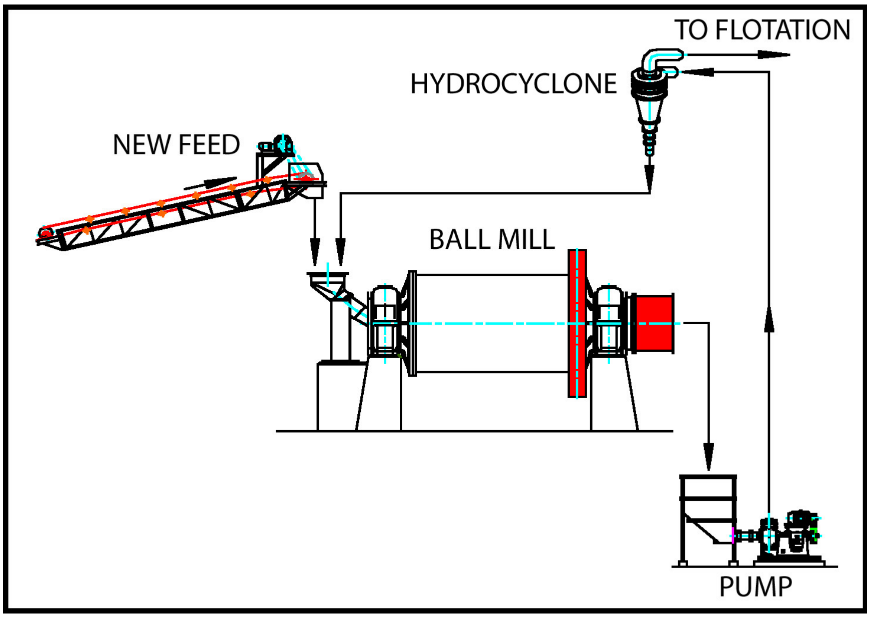


Figure 5. Single Ball Mill

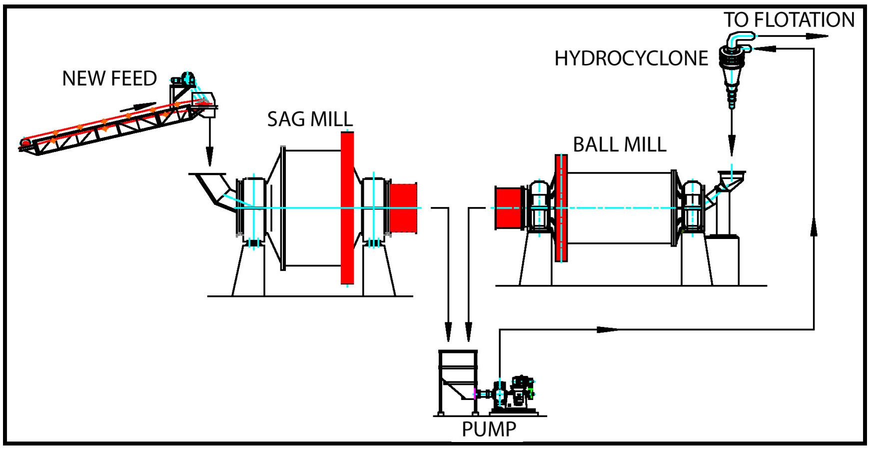


Figure 6. SAG Mill (semi-autogenous) followed by Secondary Ball Mill

Until recently, the majority of classifiers used in the closing of base metals grinding circuits have been hydrocyclones of varying models and installation methods. These include vertical, horizontal and inclined installations, with varying materials of construction and a myriad of geometrical adaptations. Irrespective of the mode and designs applied, the separation efficiency seldom surpasses 60%. The end result is that most grinding circuits closed by hydro cyclones operate with high circulating loads that range between 230 – 450%. (See figures 3, 4, 5 and 6 for circuit types).

The grinding operation in a mineral processing facility typically consumes the majority of the energy used. In addition to energy these mills consume special steel rods or balls as well as the steel mill linings. Combining all of these factors we see why grinding is one of the highest costs involved in mineral processing. Keeping these costs in mind it is extremely important that the mills carry out their operation in an efficient manner. Basically we want to ensure that once a particle has been ground to its designated liberation size, it is effectively removed from the milling process as soon as possible by an efficient classification method. In other words let's consume energy, rods, balls and linings only on the particles which need to be ground further and remove liberated particles for down stream separation and refining.

Classification, Cyclone versus Stack Sizer™

The main objective of a classifier in the closing of a grinding circuit is to remove liberated mineral particles from the mill as coarse as possible in order for them to be recovered via mineral concentrating method, such as flotation, spirals, etc. A liberation point for any ore is defined by a specific particle size; therefore a classification system which makes the most efficient size separation will be the one that most efficiently reaches the objective of getting liberated particles on their way for recovery. We mentioned earlier that cyclones typically operate with separation efficiencies in the range of 45% to 65%. The Stack Sizer on the other hand typically operates with separation efficiencies in the range of 85% to 99%. The difference between the two technologies does not end at size separation efficiency. Cyclones make their separations based on differences in settling rate velocities, particle size and mass while screening machines ignore all other variables with the exception of particle size. Complications with cyclones in grinding circuits are further exacerbated when there are large specific gravity differentials between the desirable mineral and the gangue material. The heavier fine, liberated minerals report to the underflow and of course back to the grinding mill while lighter, middling particles report to overflow and on for concentration without the liberation of the desirable mineral. The screen on the other hand recognizes the particle size only and allows for accurate determination of liberation. Below is a listing of the main economic advantages of screens versus cyclones in grinding circuits.

- Typically require less water for operation
- Reduction in slimes generation allows for reduced reagent consumption in flotation
- Reduced energy consumption due to reduced circulating loads
- Increased production rates (typically between 10 to 30%)
- Reduces grinding media consumption
- Reduced mill maintenance costs
- Increased efficiency in down stream classification devices such as spirals, flotation cells and jigs as they process a narrower size range of particles more efficiently
- Increased mineral recovery rates
- Reduced concentrate dewatering costs due to coarser liberation and reduction of slimes

Efficiency Calculations

Many different efficiency calculations exist, the formulae employed in this paper is a simple one, as defined below.

The *Oversize Efficiency* is the amount of coarse in the oversize divided by the amount of coarse material in the feed.

The *Undersize Efficiency* is the amount of fines in the undersize divided by the amount of fine material in the feed.

The *Overall Efficiency* is the total amount of correctly placed material, coarse in the overs plus the fines in the unders divided by the total amount of material in the feed.

We define (all values expressed as percentage %)

Measured values	Calculated values
A = Oversize in Feed	R = Fraction of feed in unders
B = Undersize in Feed	O = Fraction of feed in overs
C = Coarse in Oversize	Eo = Oversize Efficiency
D = Fines in Undersize	Eu = Undersize Efficiency
	E = Overall Efficiency

Considering that:
A + B always equals 100
R + O always equals 100

We calculate R by writing a material balance around the coarse fraction . The coarse in the feed equals the coarse in the oversize plus the coarse in the undersize.

$100\ (A) = O \times C + R\ (100 – D)$, therefore
$100\ (A) = (100 – R) \times C + R\ (100 – D)$, from this follows
$R = 100((C – A) / (C + D – 100))$

Therefore:
$Eo = O \times C / A$
$Eu = R \times D / B$
$E = (O \times C + R \times D) / 100$

Case Studies

Mina Colquijirca – Sociedad Minera El Brocal S.A.A.

The plant is located at Tinyahuarco, Pasco Province Peru, high up in the Andes mountain range, it produces lead, zinc, copper and gold (Aquino and Vizcarra 2007). As shown in Figure 7, the concentrator flow sheet originally consisted of three rod mills operating in parallel and in open circuit followed by three ball mills operating in parallel in closed circuit with a bank of 10 inch cyclones. The rod mill discharge and ball mill discharge are combined in the same sump and pumped to the cyclones. The circulating load is about 350% and over grinding of the high specific gravity minerals such as galena results in significant slime losses before flotation.

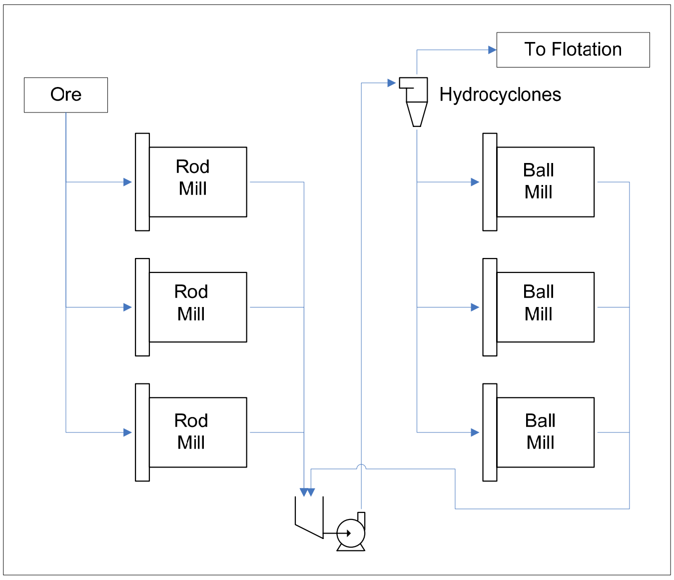


Figure 7. Original Brocal grinding circuit with hydrocyclones

Brocal wished to increase capacity and was considering the addition of a fourth ball mill. As an alternative they considered ways to improve grinding efficiency and conducted full scale Stack Sizer tests. Encouraging results led to the installation of two 5 deck Stack Sizer screens fitted with 0.50 mm urethane panels in place of the 10 inch cyclones. The effect was immediate as production increased significantly by 11% and lead recovery increased by 9%. The circulating load decreased to about 60% and Brocal shut down two of the three operating ball mills with significant savings in operating costs.

Subsequent to the initial screen installation and to take advantage of the increased grinding capacity, Brocal added additional crushing, flotation and filtration capacity, as well as three additional Stack Sizers. The current grinding circuit with screen classification is shown in Figure 8. One of the two ball mills originally shut down was put back into operation and rod mill rotational speed was increased. Production increased from 138 tph with the cyclone circuit to 245 tph with the screen circuit, an increase of over 75% with less total grinding energy. The circulating load was maintained at about 60% and over grinding has been minimized, the slime content (particles less than 10 microns) in the flotation feed reduced from 18% to 10%, resulting in significant increases in metal recovery.

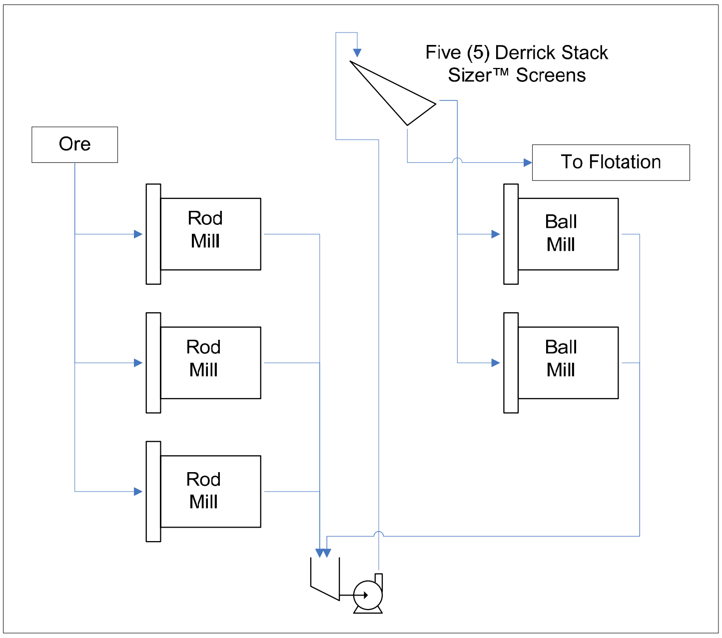


Figure 8. Current Brocal grinding circuit with screens

OJSC KMAruda

KMAruda operates an iron ore mine in Russia and run of mine ore contains about 34% total iron (Pelevin and Lazebnaya 2009). The primary grinding circuit consists of two ball mills in parallel operating in closed circuit with spiral classifiers. Similarly, the secondary circuit has two ball mills in parallel in closed circuit with hydrocyclones. Product is fed to multiple stage magnetic separators.

Two Stack Sizer screens fitted with 100 micron urethane panels were fitted in place of the cyclones on one concentrator production line. The circulating load in the screen circuit was reduced and significantly coarser. While the goal was to maintain the same final product grade, the final concentrate from the screen circuit was also coarser and they experienced reduced iron losses in the magnetic separation stages..

Minera Cerro Lindo

Minera Cerro Lindo is located southwest of Lima Peru and produces copper, lead and zinc concentrates (Ticse 2009). The grinding circuit consists of ball mill operating in closed circuit with a bank of 26 inch cyclones, with circulating load of about 260%.

Following the success of screen classification at Brocal and other polymetallic mining operations in Peru, Cerro Lindo initiated a program to improve concentrator performance. Following full scale testing, four Stack Sizer screens were installed in place of the 26 inch cyclones, fitted with 0.23mm and
0.18 mm aperture panels. As per the previous case studies, the circulating load decreased to 108% and line capacity increased by some 14%. The P_{80} was coarser in

the screen circuit at 160 microns compared to 141 microns with the cyclone circuit. Steel consumption per kwh decreased and tailings filtration capacity increased as the tailings are now coarser and more homogeneous.

Ongopolo Tsumeb

Ongopolo Tsumeb is located in northern Namibia, adjacent to the world famous Etosha Game Reserve. The company produces primarily copper with lesser quantities of gold, zinc and silver. They conducted tests on a Stack Sizer screen to split the mill feed sample into two products with the specific requirement of achieving a screen undersize specification of 80% less than 115 micron.

The objective was achieved with 125 micron panels, resulting in a recovery of 97.2% of plus 125 micron in the oversize at an overall efficiency of 91.7%.

Ongopolo was delighted with the results, unfortunately the world economic crisis intervened and they placed the plant on care and maintenance at the end of 2008.

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