Multiple Concentrator Survey of Real-Time Individual Cyclone Particle Size Tracking (PST)

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ABSTRACT

Proper grind control has been limited by the inability to track the particle sizes in the overflow in real-time and on an individual cyclone basis. Instruments based on older technology, such as those using ultrasonics, laser diffraction, or mechanical calipers, do not perform real-time measurements, having typical update rates of three to nine minutes. In addition, they require samplers, typically have low uptime rates, and cannot cost effectively monitor individual cyclones. These limitations have been overcome with the advent of a new technology, acoustic impact based particle size tracking (PST). This new measurement has enabled higher level control of the particle size through control of the grind circuit and individual cyclones.

The first commercial implementation of acoustic impact based particle size tracking has resulted in a system that monitors the overflow of every cyclone in a cluster with real-time four-second updates. This paper details the calibration and resulting accuracy of this technology under different cyclone overflow pipe orientations, different ore types, particularly with varying specific gravities, and different size fractions. The results from seven different concentrators will be presented. The dry solids specific gravities ranged from 2.7 to 4.1. The overflow pipe orientations ranged from vertical to horizontal. The size fractions varied from a P80 of 75 to 200 microns. The total measurement accuracies obtained were within 5 percentage points for one standard deviation. These accuracies were measured under plant operating conditions as referenced to samples obtained from the overflow pipes and sieved using both wet and dry sieving procedures.

INTRODUCTION

The value of a real-time particle size measurement is that it allows for both a determination of the impact of changing operating conditions on particle size and more importantly, the effective implementation of a control system that has demonstrated increased economic value to a concentrator (Cirulis et al., 2015). The value of such a measurement on each cyclone overflow pipe is that it allows for the monitoring of the performance of each cyclone, which can vary substantially between cyclones in the same cluster. The value of a non-sampling particle size measurement system is that it requires minimal maintenance and has a very high availability rate or uptime.

PRINCIPLE OF OPERATION

Acoustic impact based particle size tracking is a unique method for measuring and tracking particle sizes in cyclone overflow lines. The implementation of this technology is centered upon a probe that is inserted into the slurry stream via a two inch (50 mm) hole in the overflow pipe as seen in Figure 1. Particles within the slurry stream impact the surface of the probe generating traveling stress waves within the probe. A sensor converts these traveling stress waves into an electrical signal and proprietary signal processing techniques translate these signals into a particle size measurement that is output every four seconds. The sensor effectively samples a few percent or more of the slurry stream, which is orders of magnitude more than is sampled by other traditional technologies that utilize online samplers and that do not sample individual hydrocyclones. Also, because of the location of the sensor downstream of the hydrocyclone and the presence of an air core at that point, the sensor produces no change in the back pressure seen by the hydrocyclone.

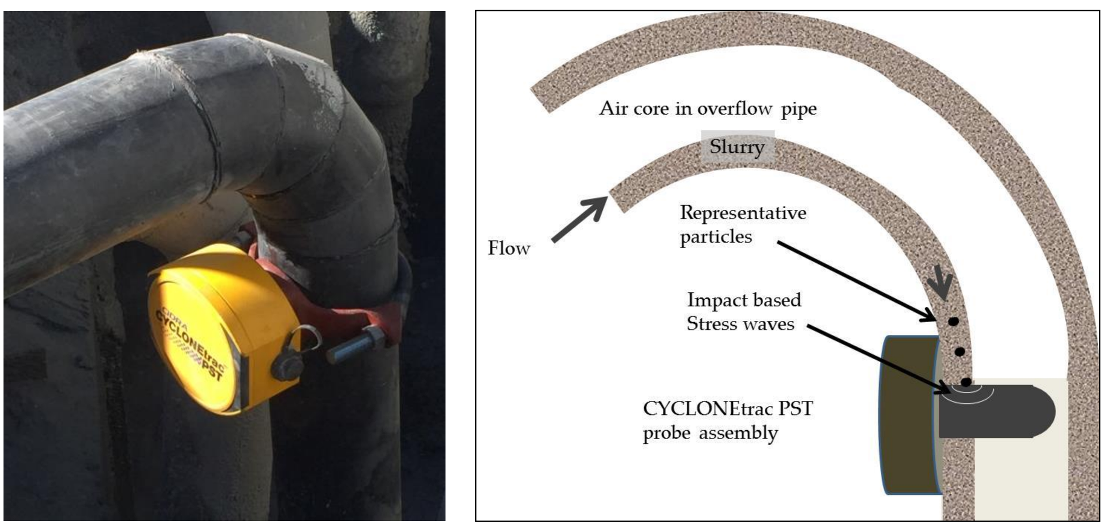

Figure 1 CYCLONEtrac PST - Installed on overflow pipe (left); illustration of principle of operation (right).

On-line cyclone overflow sizing methods, whether laser diffraction, ultrasonic, caliber or impact based, require calibration by correlating their signals to reference particles or to samples that are correspondingly analyzed with laboratory screens (Outotec, 2009). The impact based CYCLONEtrac PST also requires calibration to compensate for influences from cyclone type, ore type, and sensor installation location. To ensure a good composite calibration that can be applied across all the cyclones in a cluster, calibration samples must be taken from the overflow of each cyclone in a cluster. Once such calibration takes place, it does not have to be performed again even if the probe is replaced. In addition, samples must be taken beyond the expected operating range of the cyclones to ensure accurate measurements when the cyclone is operating outside its normal operating range including but not limited to roping events, startups, shutdowns, and grindouts. This avoids the measurement uncertainty that occurs when calibration models are used to extrapolate measurements beyond their calibrated range.

TYPICAL TESTING METHODOLOGY

The tests were grouped into two categories: full cyclone cluster/plant tests or single cyclone tests. In every case, 2 inch (50 mm) holes were drilled into the cyclone overflow pipes and a PST probe assembly was installed. For full cyclone cluster/plant tests, the PST probes were wired to a central processing computer; whereas, for the single cyclone tests the PST probe was connected to a standalone AC/battery powered data logger. While recording data, samples were taken from the cyclone overflow typically via a variety of samplers. These samples were either dry stack sieved, single screen wet sieved, or multiple screen (stack) wet sieved using a variety of different procedures depending on the the metallurgical laboratory protocol or if it was done by CiDRA personnel. The time at which the sample was taken was recorded, and the sample results were used in conjunction with the recorded data to generate calibration coefficients. During a full cyclone cluster or plant sampling campaign, the sample results were split between calibration samples and validation samples.

SITE LOCATION #1 (USA): COPPER, MOLYBDENUM IN PORPHYRY ORE

This concentrator processes 168 kt/d of copper porphyry ore with a typical copper head grade of 0.2 to 0.5%. In addition the ore body contains molybdenum with a grade from 0 to 0.1%, as well as gold and silver. After crushing, the ore is sent through four parallel primary grind lines each consisting of a SAG mill and pebble crushing circuit followed by two parallel ball mills each operating in reverse closed circuit with a dedicated cluster of 10 to 14 cyclones. The overflow is sent for flotation to either Wemco mechanically agitated cells or Outotec forced air cells. Particle size measurements are performed through 12 hour composite shift samples.

PST systems were installed on each cyclone cluster for a total of 92 PST probes. Over a period of several months, over 1000 samples were taken from the cyclone overflows and processed through either stack dry sieves or wet sieved through 100 mesh (150 micron) screens. These samples were used to either generate the calibration coefficients or to validate the calibrated PST measurements. The parameter used in the control system is %+100 mesh. The operating range for the %+100 mesh typically ranges from 20 to 35% with the desired size set to maximize economic value of the production. The control system uses the PST measurement to set and hold the desired particle size. During the course of collecting the calibration and validation samples, the particle sizes ranged from 6.7 to 34.6 %+100 mesh with some samples collected at much higher ranges during roping events. When the calibrated PST measurements over the non-roping range were compared to the samples gathered for calibration and validation, the coefficient of determination or R^2 of 0.803 was obtained. In terms of the difference between the PST measurements and the sample results, a standard deviation of 4.45 percentage points or 4.45 %+100 mesh was calculated. Cyclone to cyclone and cluster to cluster variations in the calibration are captured in this standard deviation since the same calibration coefficients were applied to all cyclones in the plant. A comparison of the calibrated PST measurements to the sample results, along with lines indicating a deviation of two standard deviations from the ideal correlation are shown in Figure 2.

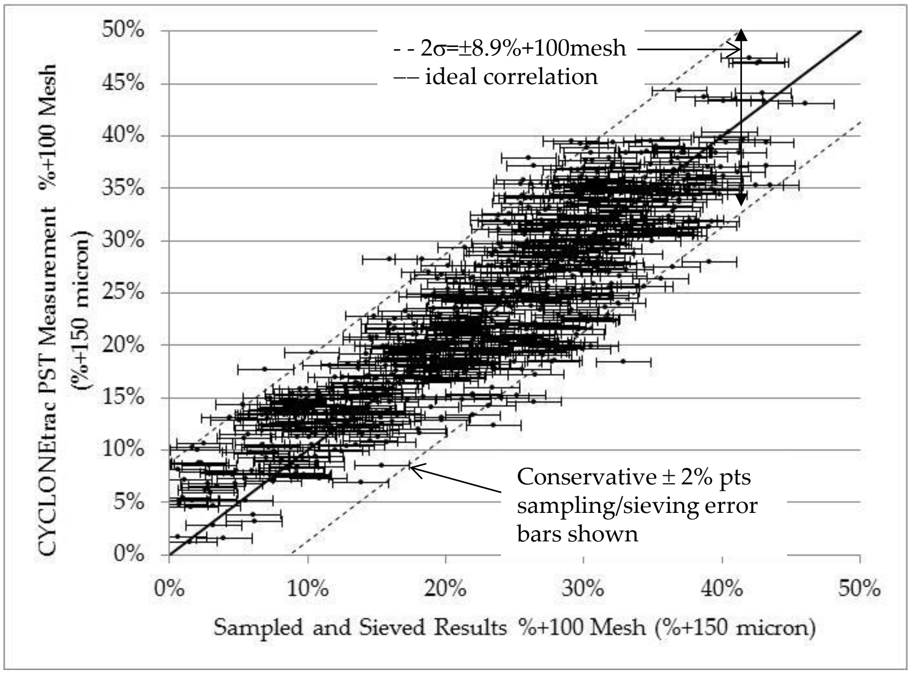

Figure 2 CYCLONEtrac PST 150 micron measurements compared to the sieved samples for a copper/molydenum concentrator processing copper porphyry ore

SITE LOCATION #2 (MEXICO): COPPER, GOLD AND SILVER IN PORPHYRY ORE

This concentrator processes 8,000 t/d of ore containing 0.9 – 1.1% copper, 48-53 g/t of silver, and 1.5 – 1.9 g/t of gold. It has six open circuit ball mills in its primary grinding stage, followed by cyclone classification with one 15 inch cyclone per ball mill such that the overflow reports to flotation and the underflow reports to secondary grinding. In secondary grinding the slurry passes through two ball mills that are in closed circuit with two cyclone clusters of 20 inch cyclones. Particle size measurements are currently performed via manual sampling and sieving.

A PST probe was installed on the cyclone associated with ball mill #5 in the primary grinding stage. During the course of 5 days in a one week period, 42 samples were taken and dry stack sieved with mesh sizes of 60, 100, 150 and 200 mesh. Calibration coefficients were generated for the percentage by weight of solids greater than 200 mesh (%+200 mesh). This was the size of interest with a nominal operating level of 40% +200 mesh with an operating range of 20-60% +200 mesh. By varying the solids feed rate and water addition, a variety of particle sizes in the overflow were created ranging from 11.3 to 40.9 %+200 mesh for non-roping conditions and 68.4 and 68.8 %+200 mesh during roping events. When the calibrated PST measurements were compared to the sampled and sieved results, an R^2 of 0.964 was obtained. In terms of the difference between the PST measurements and the sample results, a standard deviation of 2.19 percentage points or 2.19%+200 mesh was calculated. A comparison of the calibrated PST measurements to the sample results, along with lines indicating a deviation of two standard deviations from the ideal correlation are shown in Figure 3.

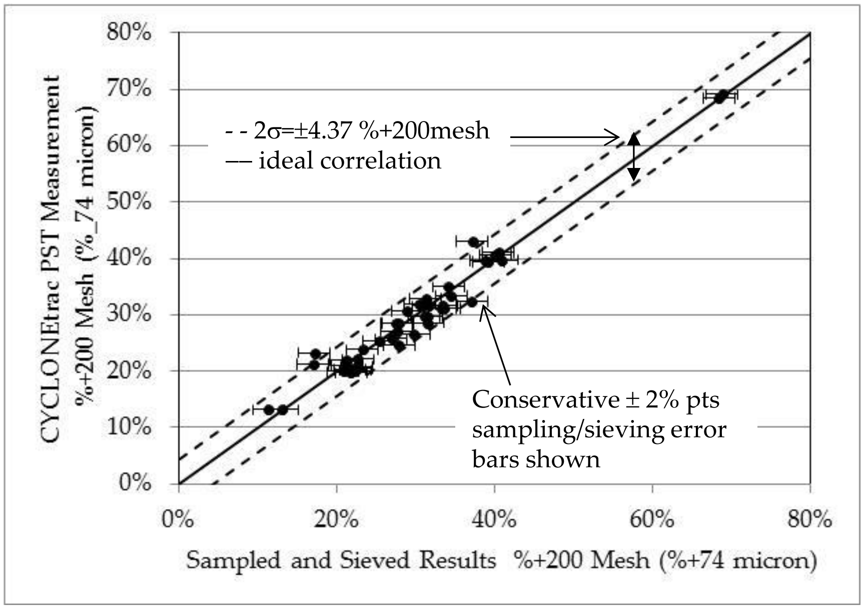

Figure 3 CYCLONEtrac PST 74 micron measurements compared to the sieved samples for a copper, silver and gold plant dominated by silica and feldspar in the ore

SITE LOCATION #3 (CHILE): COPPER IN PORPHYRY ORE

This concentrator processes approximately 100,000 t/d of ore containing typical porphyry deposit minerology consisting of chalcocite, pyrite, chalcopyrite, bornite and covelite with a copper grade of over 0.5%. The remainder of the ore consists primarily of silica. The grind circuit consists of a SAG mill followed by multiple ball mills operating in reverse closed circuit with a cluster of 33 inch cyclones with more than 10 cyclones per ball mill. The overflow from the cyclones report to flotation. The control parameter of interest is the percentage of material retained by 100 mesh (150 micron) screens. The typical range of operation is 15 to 20 %+100 mesh (%+150 micron).

An entire cluster of 10+ hydrocyclones was instrumented with a PST system, with individual PST probes on each cyclone overflow. Due to a very short vertical downflow section, the PST probes were installed on a long horizontal section of the overflow pipe. Over a period of several weeks, 268 samples were taken and wet sieved with CiDRA's rapid wet sieving equipment and procedure at 100 mesh (150 micron). Between natural variations in the process, deliberate manipulations of the pressure via cyclone openings and closings, as well as the particle size differences between cyclones, a range of particle sizes was captured. The range extended from 6.8 to 40.5% +100 mesh. Calibration coefficients were generated and applied to the PST system in order to compare the PST measurements with the sampled results. This comparison yielded an R^2 of 0.86 and a standard deviation of 2.7 percentage points for the difference between the PST measurements and the sample results. A comparison of the calibrated PST measurements to the sample results, along with lines indicating a deviation of two standard deviations from the ideal correlation are shown in Figure 4.

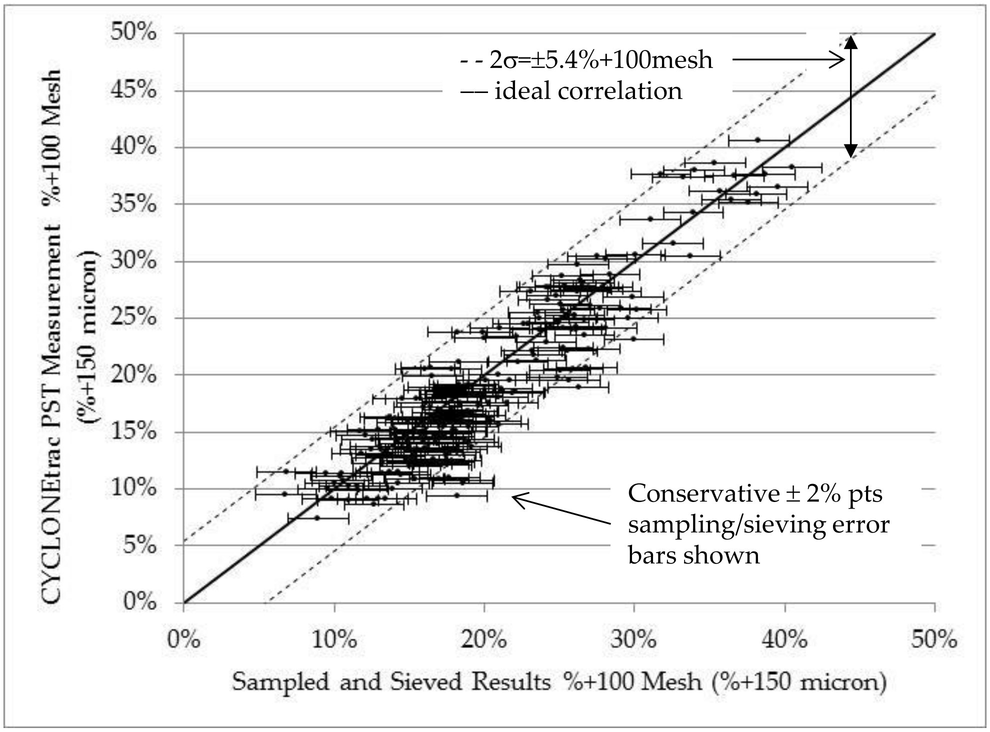

Figure 4 CYCLONEtrac PST 150 micron measurements compared to the sieved samples for a large copper concentrator

SITE LOCATION #4 (BRAZIL): IRON IN ITABIRITE IRON ORE

This concentrator in Brazil is expected to produce over 15 Mt of iron in 2016. The grind circuit consists of several stages of crushing, followed by HPGR grinding and then two parallel ball mills. Each ball mill operates in direct closed circuit with a cluster of 33 inch cyclones. The overflow of the cyclones passes through desliming cyclones to reverse flotation. The control parameter of interest is the percentage of material passing 150 mesh (106 micron). Currently, the particle size is measured via manual sampling and sieving.

A single cyclone was instrumented with a PST probe, and over a single day 15 samples were taken over a range of five operating conditions. Operating conditions were varied by opening and closing cyclones to vary the pressure and by changing the water addition to the pump box feeding the cyclone cluster pump. The samples were wet stack sieved by the metallurgical laboratory with mesh sizes of 325, 200, 150 and 100 mesh. Calibration coefficients were generated for the percentage of solids passed by the 150 mesh (106 micron) screen. For the purposes of this paper, the results were converted from the percent of solids passed to the percent of solids retained. When the calibrated PST measurements were compared to the sampled and sieved results, the R^2 value of 0.968 was obtained. A comparison of the difference between the CYCLONEtrac PST results and the sieved samples resulted in a standard deviation of 0.5 %+150 mesh as shown in Figure 5.

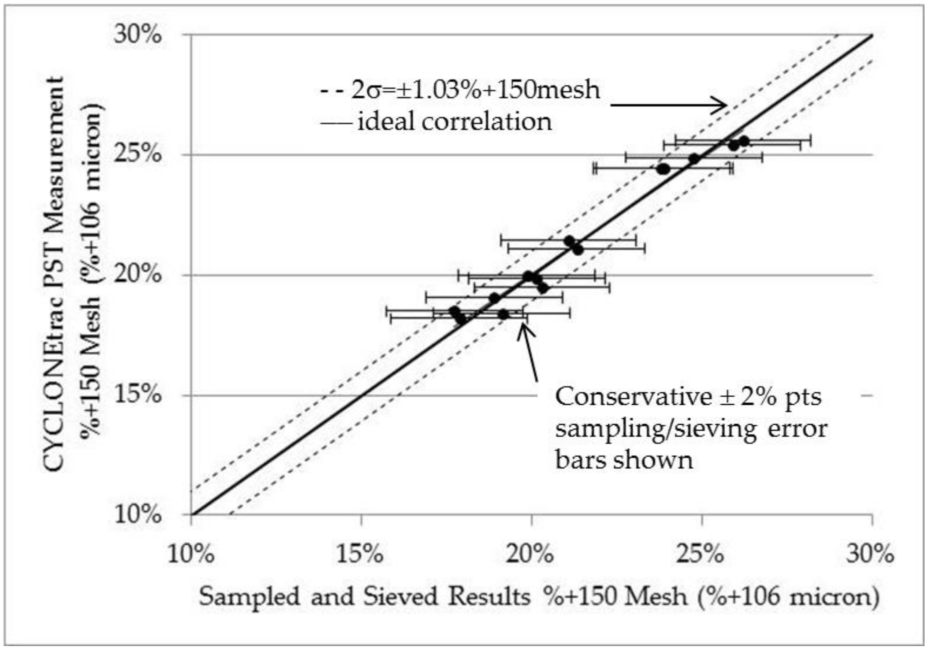

Figure 5 CYCLONEtrac PST 74 micron measurements compared to the sieved samples for an iron ore concentrator

SITE LOCATION #5 (USA): COPPER IN PORPHYRY ORE

This mill processes over 50,000 t/d of copper ore containing less than 0.4% copper and less than 0.1% molybdenum. The comminution circuit consists of three stages of crushing followed by parallel lines of ball mills each operating in direct closed circuit with a dedicated cyclone cluster of 33 inch inclined cyclones. The particle size parameter of interest is +65 mesh (%+210 micron) with a typical operating range of 15 to 14 %+65 mesh.

The horizontal section of the overflow from a single cyclone was instrumented with a PST probe, and over three days 29 samples were taken over a range of operating conditions. Operating conditions were varied by changing the solids feed rate to the ball mill and changing the water addition to the cyclone cluster pump box. The samples were dry stack sieved by the metallurgical laboratory with mesh sizes of 48, 65, 100, 150 and 200. Calibration coefficients were generated for the percentage of solids passed by the 65 mesh (210 micron) screen. For the purposes of this paper, the results were converted from the percent of solids passed to the percent of solids retained. When the calibrated PST measurements were compared to the sampled and sieved results, the R^2 value of 0.93 was obtained. A comparison of the difference between the CYCLONEtrac PST results and the sieved samples resulted in a standard deviation of 1.97 %+65 mesh as shown in Figure 6.

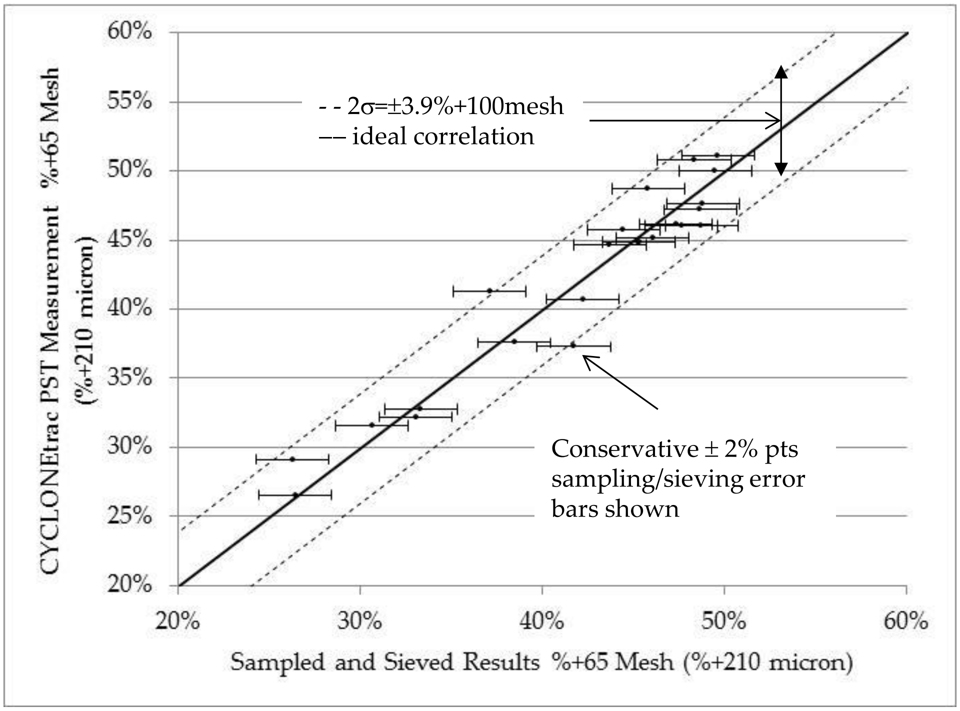

Figure 6 CYCLONEtrac PST 210 micron measurements compared to the sieved samples for a coppery/molybdenum plant.

SITE LOCATION #6 (BRAZIL): PHOSPHATE IN ORE WITH SILICA, MICA, MAGNETITE

This is a phosphate rock plant with a complex ore mineralogy that includes phosphate, magnetite, mica, and silicates. Comminution contains a reverse closed circuit ball mill with cyclone classification. The cyclone cluster associated with each ball mill has 26 inch cyclones. The particle size of interest is 100 mesh.

A single CYCLONEtrac PST probe was installed and over the course of four days, 39 samples were gathered and wet stack sieved with screens of 48, 65, 100, 150, and 200 mesh. Calibration coefficients were generated for the %+100 mesh (%+150 microns). When the calibrated PST measurements were compared to the sampled and sieved results, the R^2 value of 0.89 was obtained. A comparison of the difference between the CYCLONEtrac PST results and the sieved samples resulted in a standard deviation of 1.73 %+100 mesh as shown in Figure 7.

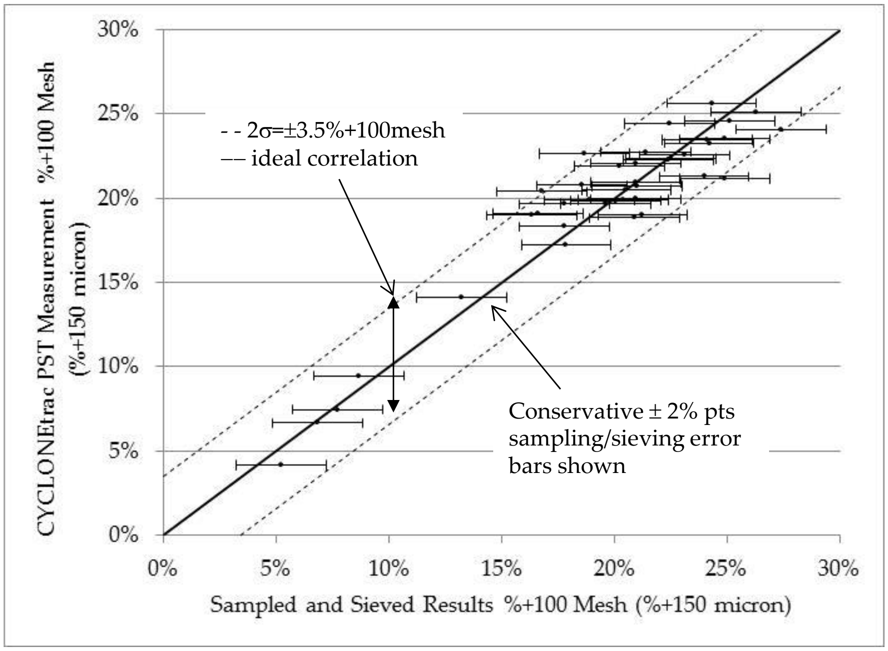

Figure 7 Comparison of CYCLONEtrac PST results and sieved samples

SITE LOCATION #7 (BRAZIL): GOLD IN ORE WITH VARYING MINERALOGY INCLUDING QUARTZ

This is a gold leach concentrator processing over 1 Mt/y of ore containing 3 g/t of gold along with a complex minerology containing quartz, sulphides, and carbonaceous metapelite. The grind circuit consists of crushers followed by two parallel ball mills, each operating in closed circuit with a cyclone cluster. The overflow from the cyclones feeds a leach circuit. The particle size of interest is 150 mesh (106 microns).

A single CYCLONEtrac PST probe was installed on the one operating cyclone in a two cyclone cluster, and over the course of three days, 54 samples were gathered and wet stack sieved with screens of 100, 150, and 200 mesh. Operating conditions were changed by varying solids feed rate and water addition to the cyclone cluster pump box. Calibration coefficients were generated for the %+150 mesh (%+106 microns) which ranged from 6 to 30.7 %+150 mesh. When the calibrated PST measurements were compared to the sampled and sieved results, the R^2 value of 0.87 was obtained. A comparison of the difference between the CYCLONEtrac PST results and the sieved samples resulted in a standard deviation of 2.36 %+100 mesh as shown in Figure 8.

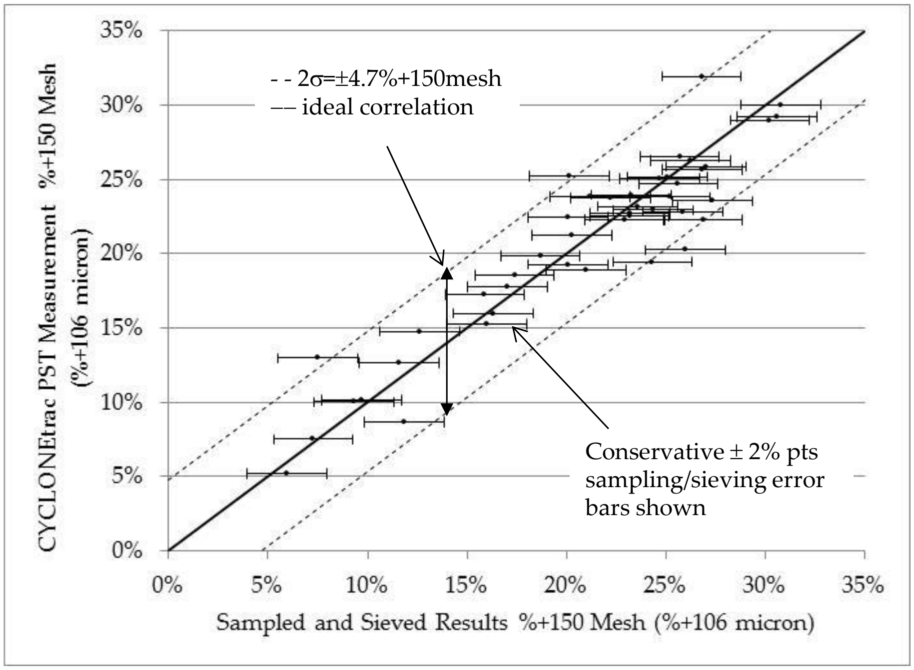

Figure 8 CYCLONEtrac PST 106 micron measurements compared to the sieved samples for a gold concentrator

RESULTS AND DISCUSSION

A summary of the results from applying the acoustic impacted based particle sizing technology at seven sites is given in Table 1. A literature search for similar in-plant testing of other particle size measurement technologies was unsuccessful; therefore, a critical review or comparison was not possible.

Table 1 Acoustic impact based PST particle size measurement results including differences from sampled and sieved results. Note: sampling and sieving uncertainties were not determined but can be a significant source of the differences between the PST and the sample measurements.

					Under plant operating conditions. Includes sampling and sieving errors which can be significant	
Site Type and Ore	Measurement of interest	Test particle size range (excluding roping events)	Cyclone orientation	Overflow pipe orientation	PST vs Sampled R^2	(PST-Sampled) Standard deviation
Copper/Molybdenum in Porphyry	%+100# (% +150 microns)	6.7 to 34.6 %+100#	Vertical	Vertical	0.803	4.45
Copper, Gold, Silver in porphyry	%+200# (%+74 microns)	11.3 to 40.9 %+200#	Vertical	Vertical	0.964	2.19
Copper in porphyry	%100# (%+150 microns)	6.8 to 40.5 %+100#	Inclined	Horizontal	0.860	2.70
Iron ore with silica	%+150# (%+106 microns)	17.7to 26.2 %+150#	Vertical	Vertical	0.968	0.50
Copper in porphyry	%+100# (%+150 microns)	26.3 to 49.7 %+100#	Inclined	Horizontal	0.930	1.97
Phosphate with silica, mica and magnetite	%+100# (%+150 microns)	5.2 to 27.4 %+100#	Slightly off vertical	Vertical	0.890	1.73
Gold in quartz, metasedimentary, metavolcaniclastic rocks, and metabasalts	%+150# (%+106 microns)	6.0 to 30.7 %+150#	Vertical	Vertical	0.870	2.36

CONCLUSION

The acoustic impact based particle sizing technology implemented in the CYCLONEtrac PST has demonstrated excellent performance when compared to the sampled and sieved data for a variety of ore types, cyclone types and orientations, overflow pipe configurations, and particle sizes. When properly installed and calibrated, the output of the instrument is driven by particle size and the impact from other influences, such as from ore density, could not be detected due to the level of uncertainties typically found in sampling and sieving. Differences between the PST measurements and the sieved samples are quite low and are due to both measurement noise and sampling/sieving uncertainty. These low differences between measured and reference data indicate good measurement accuracy as evidenced by high R^2 values of 0.8 and above.

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