Ultrasonic extinction for full concentration, real time particle size analysis in the mining industry

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ABSTRACT

Particle size control is vital for effective performance in many aspects of mining and mineral processing and fast feedback of particle size would be the ideal for control and optimisation of many processes. Most online analysis techniques for slurry analysis require extensive sample preparation such as dilution and deaeration and are susceptible to small amounts of contamination which ultimately makes implementation complex and unreliable.

The OPUS ultrasonic extinction system from Sympatec monitors the particle size distribution as well as the solid concentration in opaque and highly concentrated ore and mineral slurries on-line in real time *e.g.* behind mills or cyclones applying 31 ultrasonic frequencies for high resolution. The technique is also highly suited to the analysis of emulsions as may be encountered during solvent extraction processes.

Ultrasonic extinction overcomes limitations known from optical and mechanical systems for example, contamination, blockage and wear. OPUS measures slurries in their original state without any dilution, hence no extensive sampling procedure or sample conditioning is required. The sensor covers particle size distributions from 0.01 to 3,000.00 µm and solid concentrations up to 70 % by volume and can be easily adapted to monitor a number of production lines simultaneously.

Entrained air is often found in process streams, this is detected as an erroneous signal and dealt with through the use of suitable algorithms, entrained air bubbles do not influence the quality of analysis.

INTRODUCTION

For efficient processing of ore slurries the particle size distribution behind the milling and cyclone stage is of decisive importance. Slurries with excessively coarse particle size cannot be efficiently pulped mechanically or require extensive and expensive reagents for chemical pulping, flotation processes also require tight control of particle size for optimum performance. In order to avoid over sized particles, an extended grinding time or lower feed rates are applied which requires higher energy consumption per unit and smaller throughputs. Alternatively slurries which are too fine affect the handling of the pulps and increase the effort required for drying.

A more efficient process can be obtained by controlling the particle size distribution behind the mill and the additional distribution information allows the design of ideal control parameters rather than relying upon single point measurements such as sieve data.
Off-line methods are not suitable for providing the required size information due to the time lag needed to obtain the sample and perform the analysis. On-line instruments on the other hand, are

mostly based on optical and mechanical methods, which by principle only can operate in highly diluted suspensions and thus demand an extensive sampling and dilution effort that might affect the accuracy of the results. Dilution of broadly distributed particle sizes often leads to a non representative sample and thus do not represent the real PSD in the product flow. Some optical techniques can operate at higher concentrations without dilution, but require infinitesimally small path lengths giving virtually a monolayer of particles for analysis. The use of optically based instruments in mineral processing is often difficult due to even small amounts of contamination rendering the measurement useless and the extreme dilutions or thin path lengths potentially give highly non representative results.

Ultrasonic extinction (USE) applies sound waves instead of light and therefore overcomes the limitations of optical instruments since the ultrasonic waves are able to propagate through relatively wide films of concentrated suspension. As long as the density contrast between the suspension media and the solid particles shows a difference, USE can be applied. This density contrast is normally achieved in mineral processing applications. USE operates in totally opaque media with solids concentrations up to 70 per cent vol. and allows robust instrument designs specifically made for harsh industrial environments.

The following article describes the Ultrasonic Extinction based OPUS sensor and its successful on-line application for opaque pulp slurries such as iron ore, fluorspar, copper, alumina or quartz sand.

ULTRASONIC EXTINCTION

The fundaments for OPUS (On-line Particle size analyses using Ultrasonic **S**pectroscopy) were laid in 1988 at the University of Karlsruhe, Germany. In the early 1990^s Sympatec GmbH developed the OPUS sensor as a robust industrial instrument.

Principle

The design of an instrument for the determination of frequency dependent Ultrasonic Extinction (USE) is schematically presented in Figure 1. An electrical high frequency generator is connected to a piezoelectric ultrasonic transducer which transmits ultrasonic waves into the suspension to interact with the suspended particles. In simple terms particles which are very much smaller than the wavelength of the ultrasonic wave are entrained and do not attenuate the signal whereas particles larger than the wavelength scatter and attenuate the signal. After passing the measuring zone the ultrasonic waves are received by an ultrasonic detector and converted into an electrical signal. The extinction of the ultrasonic waves is calculated from the ratio of the signal amplitudes on the generator and detector side, the frequency of the ultrasonic wave may be varied between 100 KHz and 200 MHz.

The Ultrasonic Extinction of a suspension of mono-disperse particles can be described by the Lambert-Beer law according to Riebel [1].

$$-\ln\left(\frac{I}{I_0}\right)_{f_i} = \Delta l \cdot C_{PF} \cdot K\left(f_i, x\right) \tag{1}$$

The extinction $-\ln(I/I_0)$ at a given frequency f_i is linearly dependent on the thickness of the suspension layer Δl, the projection area-concentration c_{PF} and the extinction coefficient K.

In a poly-disperse system the extinction of single particles overlay:

$$-\ln\left(\frac{I}{I_0}\right)_{f_i} = \Delta l \cdot C_{PF} \cdot \int_{x_{\min}}^{x_{\max}} K(f_i, x) \cdot q_2(x)dx \tag{2}$$

The integral in Equation 2 can be substituted by a sum as a first approach and the projection area concentration can be substituted by the particle concentration and the 1st momentum of the q2(x_j) distribution:

$$-\ln\left(\frac{I}{I_0}\right)_{f_i} \cong \Delta l \cdot 1.5 \cdot c_V \cdot \frac{1}{M_{1,2}} \sum_j K(f_i, x_j) \cdot q_2(x_j)\Delta x \tag{3}$$

If now extinction measurements are performed at various frequencies, this results in a linear equation system:

$$\begin{pmatrix} m(f_1) \\ \vdots \\ m(f_j) \end{pmatrix} = \Delta l \cdot 1.5 \cdot \frac{1}{M_{1,2}} \cdot c_V \cdot \begin{pmatrix} K_{1,1} & \cdots & K_{1,j} \\ \vdots & \ddots & \vdots \\ K_{i,1} & \cdots & K_{i,j} \end{pmatrix} \cdot \begin{pmatrix} q_{21} \cdot \Delta x_1 \\ \vdots \\ q_{2i} \cdot \Delta x_i \end{pmatrix} \tag{4}$$

The extinction function *K(f_i,x_i)* is a product parameter independent from particle size or concentration. The extinction function can be considered as a constant product specific calibration curve determined by a semi-empirical one-time calibration procedure obtained during off-line preliminary tests or on site during installation. Figure 2 shows the extinction function of copper ore.

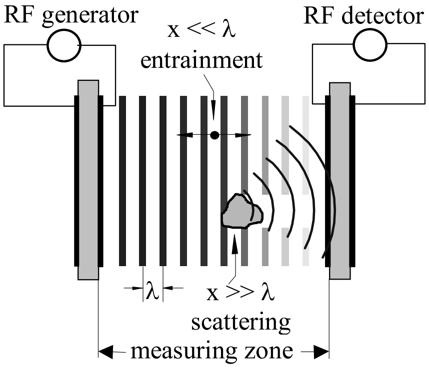

Figure 1 Instrument schematic

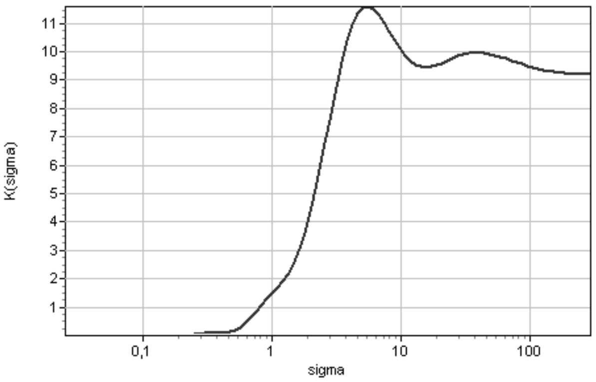

Figure 2 Extinction function

OPUS system

In order to obtain a particle size distribution with 31 classes, the attenuation at 31 frequencies is recorded as one measurement lasting 60 seconds (typically) which leads to an attenuation spectrum. With the knowledge of the acoustic properties represented by the extinction function as shown in Figure 2, the particle size distribution and solid concentration is calculated from the effective signal.

The entire measuring range of OPUS covers 0.01 to 3,000um, however in practice the ratio between lower and upper size ranges should not exceed a factor of 1000 (*i.e.* 1-1000um for ore applications).

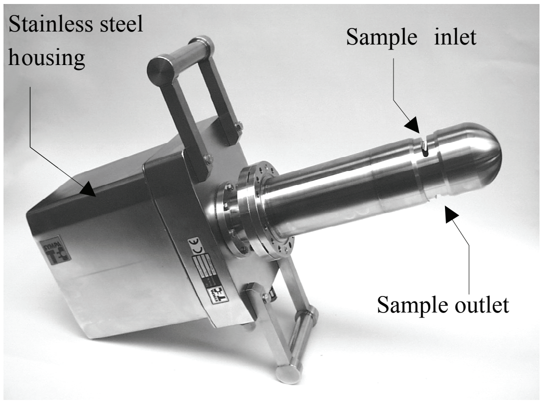

Figure 3 OPUS Sensor

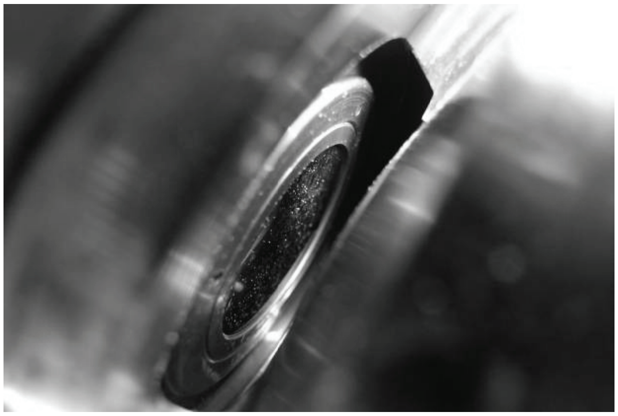

Figure 4 OPUS measuring zone

Figure 3 presents the Sympatec OPUS System. The instrument is designed as probe and can be adapted to nearly all kinds of process pipes (> DN200) or vessels using a DN 100 flange or process adapters for smaller pipe diameters (DN10 – DN50). OPUS is designed for fully automatic real-time particle size analysis in process environment, protection class is IP65 or ATEX rated.

Parts in contact with the slurry are constructed from massive stainless steel (DIN/ISO 1.4571, SS316) and SIGRADUR® (high density carbon) to withstand mechanical and chemical attacks without exhibiting significant wear even after extended periods of operation. The OPUS system is designed to have product contact parts replaced in the field.

Since no sample treatment is required and the analytical principle does not require any moving parts inside the sensor, the entire probe operates without any movement as static probe. Nevertheless, the gap distance inside the measuring zone can be opened and closed automatically if needed *e.g.* to assist cleaning if water flushing cycles are demanded (Figure 4).

Evaluation and noise compensation

OPUS raw data are processed and transformed into particle size distributions applying the extinction theories as described previously. The algorithms implemented in the WINDOX software include compensation for temperature and fouling effects but in addition provide a powerful gas bubble correction model for the reliable reduction of gas bubble evoked noise which is present in nearly every production process. The correction of gas bubble signals becomes possible due to significantly different extinction behaviour of gas bubbles compared to particles [2, 3]. Optical methods misinterpret gas bubbles as particles since these instruments cannot distinguish between particles and bubbles. Due to the powerful gas bubble correction functionality of OPUS no sample preparation equipment such as de-aeration tanks are generally needed.

Data Presentations

The initial output and presentation of 31 particle size classes may be displayed in a wide variety of formats; typical outputs will be shown later. The data are available as numerical reports, graphical distribution diagrams, statistical and trend diagrams.

All data presentations can be customised according to customer's needs and the output data may be reduced to provide simple outputs for process control, it should be noted that the complete data set is always preserved for later evaluation.

Varying components in the ore body

Since USE employs a material specific extinction function, the question regarding possible influence of changing ore body composition in terms of mineralogical components may arise. In order to judge this influence, different kinds of materials have been analysed using a uniform extinction function. The resulting PSD from this USE measurement were compared to results obtained by laser diffraction. Deciding to use laser diffraction as reference method excludes possible mistakes which would occur on sieve analysis whenever significant variations of the material raw density of the tested minerals emerge. Laser diffraction also provides data of a similar interval to the USE output which is ideal for comparison of the complete distribution.

Figure 5 shows six PSD – three USE analyses and three analyses performed with laser diffraction (HELOS) on a sample of platinum ore which has been separated using sieves. The three samples clearly can be identified a being "Fine", "Coarse" and "Mixed" quality. While the Fine sample consists mainly of sand (SiO_2), the Coarse sample mainly consists of chrome oxide. The mean size sample is an inhomogeneous mixture of both minerals. Even though a single extinction function for both materials was applied, an excellent agreement to the reference method could be obtained. Blending both fractions, the quality of agreement between USE and laser diffraction is not degraded.

More than ten years of experience indicates that for most Coarse minerals above 1 µm, a single model of extinction function is very reliable and robust without any significant dependency on thee mineralogical habit of the ore.

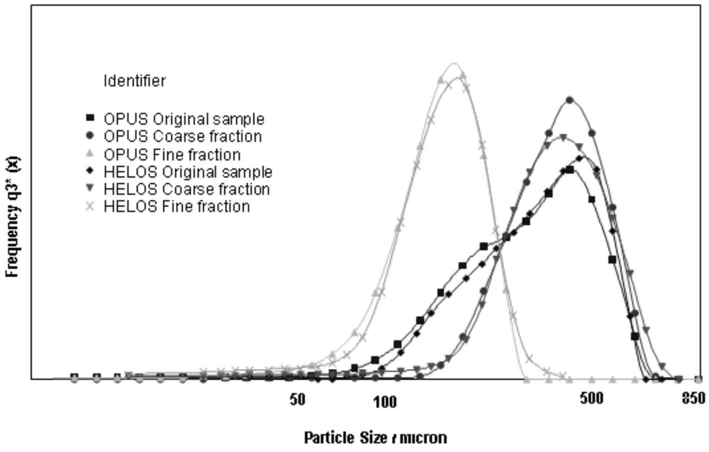

Figure 5 Effect of varying ore components

APPLICATION

In order to obtain rapid feedback of PSD information from the grinding process stage without lag times, OPUS is usually installed behind the mill or cyclone outlet. Control of particle size entering a flotation process is another usual application for OPUS due to the ability to deal with streams of varying concentration containing moderate levels of entrained air.

The sensor is designed to be installed directly in the main process flow, however, to ensure a long lifetime of the sensor it is recommended to separate the sensor from the main product flow (with flow speeds of typically several m/s) and supply OPUS with product via a bypass line with sample flow of lower flow speed. The minimum required sample flow depends on the sedimentation velocity of the particles and thus on the particle size and physical density, it should be noted that the results of the OPUS system are not flow dependent. Typically only 0.1–1 m/s are necessary to ensure a reliable and homogeneous sample flow. Various system adaptations are possible.

Copper dressing – multiplex installation

A typical multiplexed OPUS installation is shown in Figures 6 and 7. Here the sensor is installed in a copper dressing plant and connected to three milling lines. It receives the product through 50mm pipes directly behind the first cyclone stage after the mill. The product is taken from the main product lines (Ø = 400mm) on the second floor via an electrical valve and linked to the OPUS sensor located in a cabin in the basement. While passing through the instrument for two to three minutes the slurry is fed back to the process. Closing the main valves and activating a tap water flushing sequence, the instrument and pipes are cleaned and cross contamination as well as pipe blockage is prevented. By alternately switching from one line to the other, each of the three lines is analysed approx. every ten minutes.

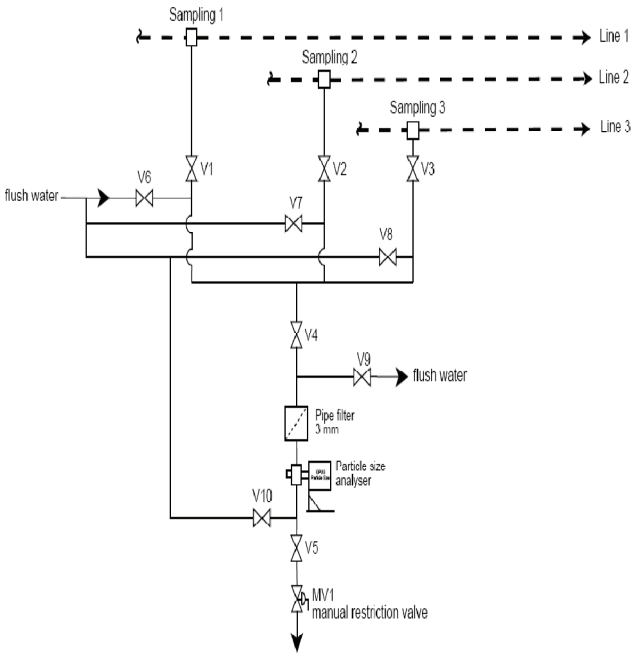

Figure 6 Flow chart of OPUS installation

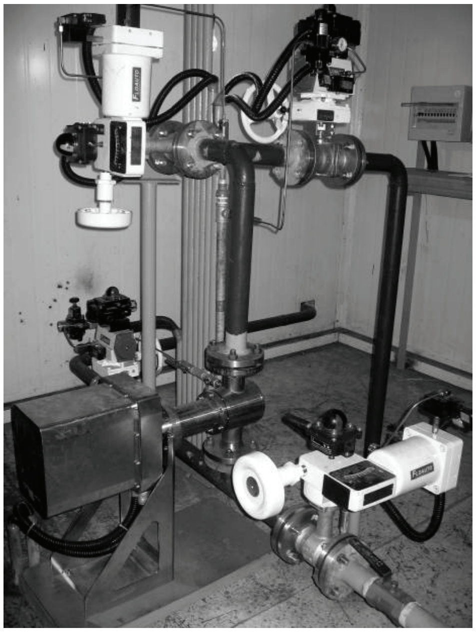

Figure 7 System setup

Control of all valves in the sampling system is facilitated by the sensor software via PLC. Results in terms of graphical, numerical PSD and trend diagrams of customer specific values (Figure 9) are presented on the system PC as well as forwarded to the process control system via PROFIBUS.
The data presented in Figure 8 shows that the concentration occasionally drops from a normal content of around 40% to 15%, this was due to operators manually opening a water flush valve on the main system. The interesting point to note is that the particle size data is unaffected by the change in concentration demonstrating the robustness of the technique to process fluctuations. The system has demonstrated reliable operation without intervention for periods in excess of 12 months due to the simple water flush system and the insensitivity of the instrument to contamination.

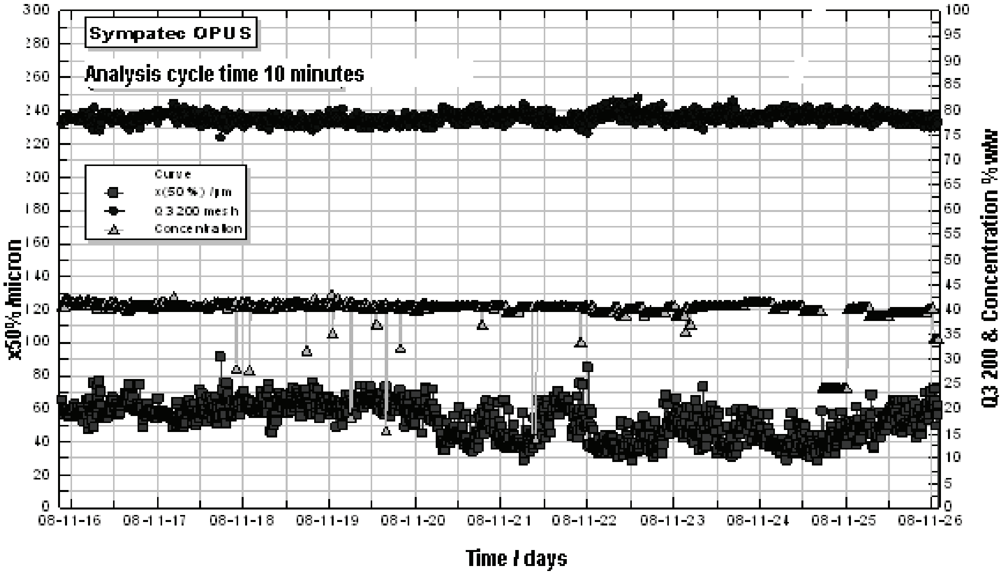

Figure 8 Trend data from single process line

Fluorspar dressing – hybrid measuring station

Occasionally the concentration of the sample stream is too high for OPUS and a rough dilution of the stream is required. The setup outlined in Figures 9 and 10 allows for samples to be accepted and diluted from two process streams in combination with a manual sample operation option. A sample of 5-50l suspension is taken automatically or introduced manually and released into the sample circulation loop, the initial OPUS signal is evaluated and if necessary dilution water is added until the signals come within range, at this point the analysis commences. It should be noted that the OPUS measurement is generally very robust to concentration effects and the dilution is performed in a very rough fashion. This setup allows OPUS to be applied as a central measuring station to several product lines as well as the analysis of manually fed samples of widely varying concentrations the dilution and stirring also permits analysis of samples with large amounts of entrained air *e.g.* from flotation streams.

Here, OPUS is adapted to the sample loop using the FT25-Adapter (25mm flow through). The sampling loop is equipped with tap water line to flush and clean the loop after each sample automatically. The control of the valves is via a PLC in combination with the WINDOX application program software thus, the entire sampling and analysis system runs fully automatically. Manual samples can be analysed by simply pressing a local sample button which halts automated operation and prepares the system for the addition of a manual sample. Figure 11 shows the outputs from both the coarse rougher feed stream and from the finer flotation deslime overflow.

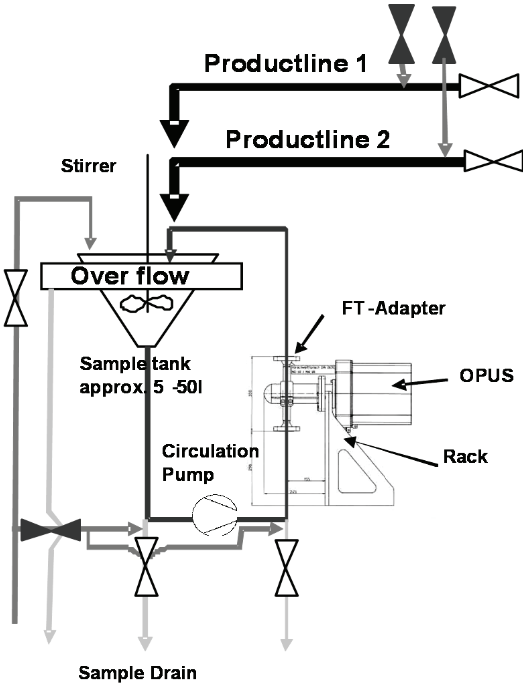

Figure 9 Schematic

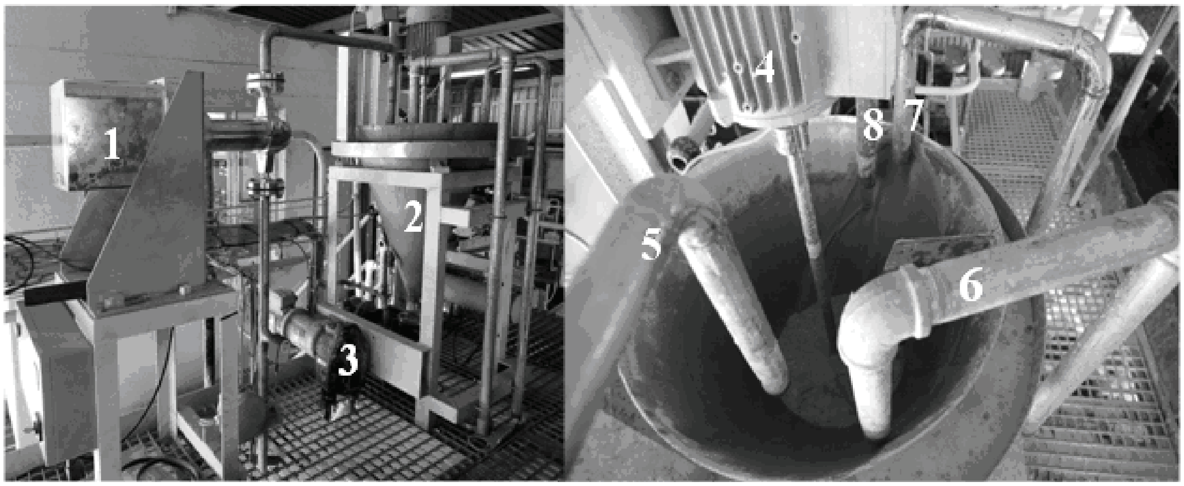

Figure 10 Setup as measuring station for on-line and off-line operation. 1) OPUS 2) Sample reservoir 3) Pump 4) Stirrer 5) Sample loop 6) Sample line 1 7) Sample line 2 8) water line (flushing)

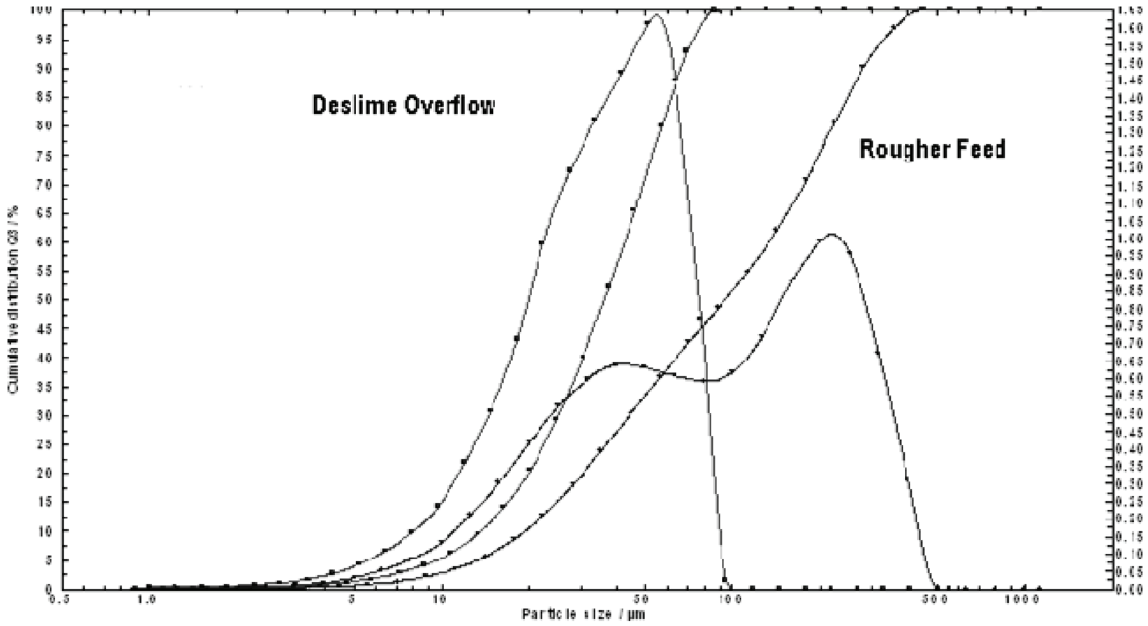

Figure 11 Outputs of rougher feed and deslime overflow streams

CONCLUSIONS

The established and presented installations clearly indicate the feasibility of the ultrasonic extinction based OPUS system for the on-line particle size analysis of various ore or mineral slurries. The applications presented have demonstrated reliable, maintenance free operation over extended periods of time.

The analytical method allows for operation in the harsh environment of mining and exploitation plants and is capable of handling mineral slurries in their original state without preliminary conditioning. The measurement technique is generally unaffected by concentration variation and is able to provide feedback of solids concentration.

The OPUS is highly robust to mechanical wear and chemical attack and does not require optical standards of cleanness to be maintained. The high resolution particle size distribution provides a wide variety of data for process and product control.

NOMENCLATURE

I	Intensity of the received sound wave	$[J\ m^2\ s^{-1}]$
I_0	Intensity of the introduce sound wave	$[J\ m^2 s^{-1}]$
f	frequency	[Hz]
Δl	thickness of suspension layer	[m]
C_{PF}	projection area-concentration	$[m^{-1}]$
Cv	Particle Volume concentration	[per cent]
K	Extinction coefficient	[-]
x	particle size diameter	[m]

q_2	projection area density distribution	[m^{-1}]
m	measured extinction	[-]
R	residue value of PSD	[per cent]
q_3*	density distribution value of volume based log PSD	[per cent]
Q	Cumulative value of PSD	[per cent]

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