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Inline Characterization of Mining Slurries by Ultrasonic Velocity Profile Technique (UVP)

William Montes-Q[1]*, Pamela Garrido[1], and César Moscoso[1]
Investigation Centre CI-JRI, Chile

ABSTRACT

It has been determined, after a technical feasibility study, that ultrasonic is the best alternative to characterize slurry flows in tailings flumes, by using the "Ultrasonic Velocity Profile" (UVP) technique, which among its many advantages it has shown not to be invasive, to have a high sample frequency, to have the ability to make measurements in opaque means, to have portability, and also that its implementation in existing structures is not complex, nor that it requires special permissions like other technologies do (based on radiation).

In the Investigation Centre JRI (CI-JRI), two measurement UVP's prototypes have been designed, built and set up in transport systems of flumes on a laboratory scale. These prototypes have also been able to perform ultrasonic measurements that have got to a correct estimation of the velocity profile, together with an *ad hoc* post-processing methodology, outcomes that allow projecting applications at an industrial level and that would generate meaningful benefits in the operation.

The future challenges aim to higher scale tests and the development of a given post-processing methodology that would let determine inline, and with a precision over 1%, associated values to the concentration of solids in the fluid, the velocity profile of the fluid in the flume and rheological parameters, all essential to a correct controlling of stages in the transportation of tailing slurries with high concentration.

INTRODUCTION

The two-phase solid-liquid suspensions, commonly known as tailings and concentrate slurries in the metallurgical process, are transported in variable operating conditions as a result of changes in mineralogy, chemistry, pH, reagents flocculants, solids concentration and particle properties (such as particle size distribution, shape and solids density). These variations alter de behavior of the system that results in changes in the flow behavior, shear rates, flow regime and settling properties of the slurry.

Particularly, tailing transport accounts for the major process flow by volume, therefore, it is necessary to permanently monitor flow rates, solids concentrations, and rheological parameters, to achieve operational control, identifying bottlenecks, confirming material mass balances sheets and optimizing processes.

The higher majority of tailings in Chile are transported in gravity flow flumes (open channel launders) and as the solids concentration of the tailings increases (so that a higher quantity of water can be retrieved) the flow behavior becomes increasingly complex and laminar flow may occur with the potential for particles to settle in the flume. In order to avoid these problems, it is important to have accurate and continuous measurement of critical parameters. This is currently done using sensors (superficial velocity, opacity, among other variables of lesser relevance), or manually characterizing physically obtained specific samples. The latter method has a low frequency, and although it provides critical information, it is historical data-based and not a reflection of current conditions, hindering the operational decision making.

After a technical feasibility research developed, in the CORFO 17CH8393-2 project, it has been determined that the best tool to characterize mining slurry flows, in tailings flumes, is an ultrasonic method called "Ultrasonic Velocity Profile" technique (UVP), which shows many advantages mentioned above in the abstract. In the CI-JRI, there has been designed and built two measurement prototypes with the UVP method, whose main result is that both prototypes have allowed obtaining the velocity profile of flows in a measurement line.

The results collected so far are promising and validate the current technique. It is estimated that eventually, the next version of the device will help to solve the problem of lack of inline operational information, for the transport of fluids in flumes management. The inline data generated with this technique will not only allow measuring velocity profiles, but it will also provide information related to a concentrate of solids. The applications of this inline information can be used to: facilitate the confirmation of material mass balance sheets, determine the wear of the flume and, prevent instabilities during the transportation to final deposition sites.

Specifically, in the case of the characterization of rheological properties, the measuring is made through trials, with samples (steady-state operation), these results can cover up properties that vary under a transient operation mode (such as thixotropic) and not necessarily represent the rheological behavior of the sample in situ.

The former predicament, it is not only seen in mining but also generalized to other industries whose processes have been involved in work with suspensions, which has led to the emergence of different inline measurement methods, each of them with advantages and limitations. For example, due the opacity of this suspensions, the laser Doppler anemometry (LDA) [3] is discarded, operationally invasive methods are also discarded, such as Hotwire anemometry (HFA) [4], tomography by electrical resistance (ERT), mapping by magnetic resonance (MRI) and x-ray radiography [5]. On the other hand, the ultrasonic method has none of these restrictions and is possible to estimate the rheological parameters from the velocity profile of a fluid [2]

METHODOLOGY

The technique of velocity profile determination by ultrasonic pulses was originally developed in medical engineering to measure the blood flow in the human body [6]. The ultrasonic pulse is reflected in the surface of the present particles in the blood and by the Doppler Effect relation we have:

$$f_d = f_0\left(\frac{v_{r1} + v_{r2}}{C - v_{r2}}\right) \tag{1}$$

Where:

v_{r1}, v_{r2} correspond to the radial velocity reflected by the particles 1 and 2 namely,

C is the speed of sound in the middle,

f_0 is the frequency in a zero position,

f_d the frequency in a d position or Doppler.

It is possible to determine the speed distribution along a flow path. In a schematic and general way, the system to determine the velocity profile of fluids/suspensions can be seen in Figure 1. It is also worth mentioning that this method can be used in both a fully flowing circular pipeline configuration (Fig 1-a), as well as in a free surface configuration (Fig1-b).

After a reasonable assumption, making, as $v_{r2} << C$ (considering a configuration like echo pulse, where the transmitter would be the receiver) we can assume that $v_{r1} = v_{r2} = v_r$, obtaining:

$$f_d = f_0\left(\frac{2v_r}{C}\right) \tag{2}$$

Solving for v_r we have that:

$$v_r = \frac{C f_d}{2 f_0} \tag{3}$$

Experimental set-up

The equation (3), when using a radial type of velocity, shows us that the source (and receiver), should be an ultrasonic transducer with a narrow approach that produces a conical sound beam with a small opening angle [5] that will not affect the spectral coherence of the results. The signal received by this type of transductor contains information about the ultrasonic pulses generated, reflections, scattering, sound, among others: all as a function of time.

Figure 2 shows, schematically, the correspondence between the measuring line and the generated signal. Immediately after the ultrasonic pulse emission, the acoustic wave travels through a fluid and it is reflected by particles that also travel inside it; generating the echo in a lesser range present in the signal, drawn schematically in the low section of Figure 2. Then it is possible to relate x position in the measuring line with time t of the signal according to [7].

$$x = \frac{Ct}{2} \tag{4}$$

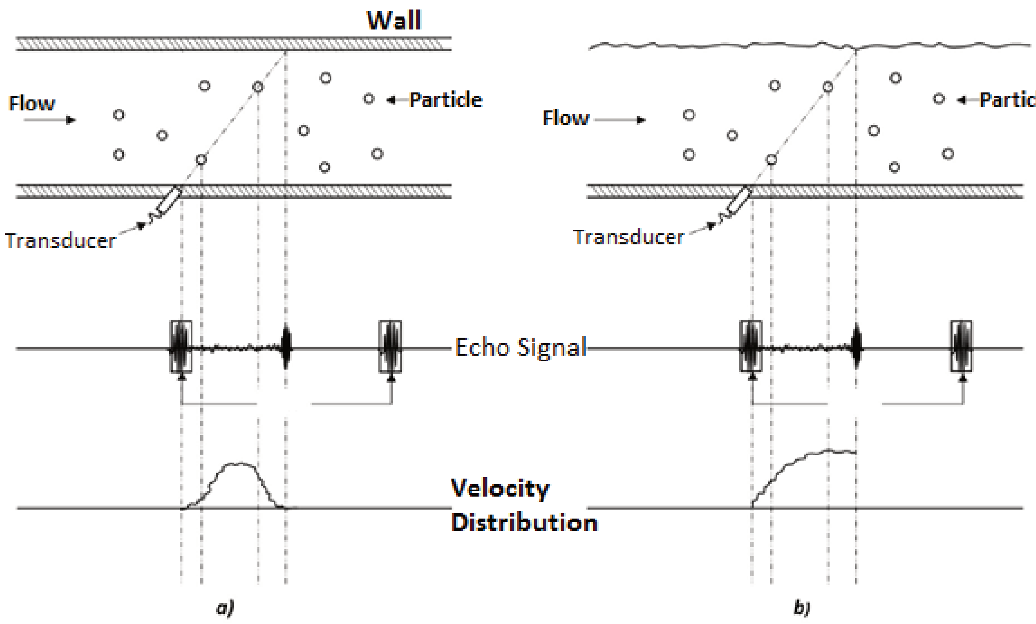

Figure 1 Diagram of the system to determine the velocity profile of a fluid/suspension; where a) corresponds to a system applied in circular piping and b) applied to a flume [6].

Related to this, for each point x in the measurement line, it is possible to determine a Doppler frequency offset*f_d which has a radial velocity v_r, this allows us to generate a velocity profile with a given amount of determined points [7]. We use this strategy to mount our two prototypes, the first corresponds to a flume with a square cross-section of 80 cm^2, arranged with a variable angle inclination, while the second one is a flume of a semi-circular section of 8 cm inner diameter also with a variable angle inclination (Figure 3). In both cases, ultrasound sensors are placed in the last quarter of the opposite side in the supply area of the flow, we also use two types of sensors: a "pill" of one MHz (SMD10TR11wl) and a two MHz of a conventional type, where the main difference between them is that the pill type does not count with backing and it can only stand lower voltages. In both cases, different types of fluids are assessed: water, a suspension of water-oil to 20 [v/v] and bentonite samples in different solids concentrations by mass (15%, 25% y 50%)

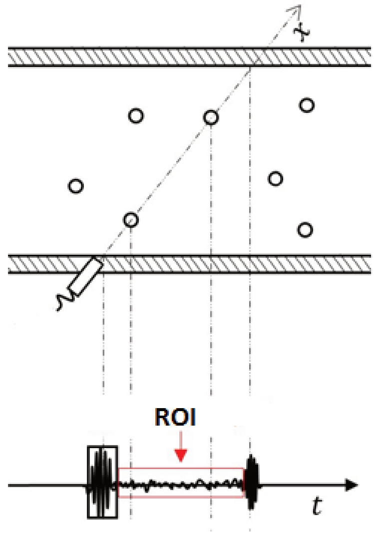

Figure 2 Ultrasound signal diagram generated by the transducer. The "Region of interest" (ROI) zone indicates the echo generated by suspended particles in the fluid, with a velocity other than zero. Adapted from Takeda [8]

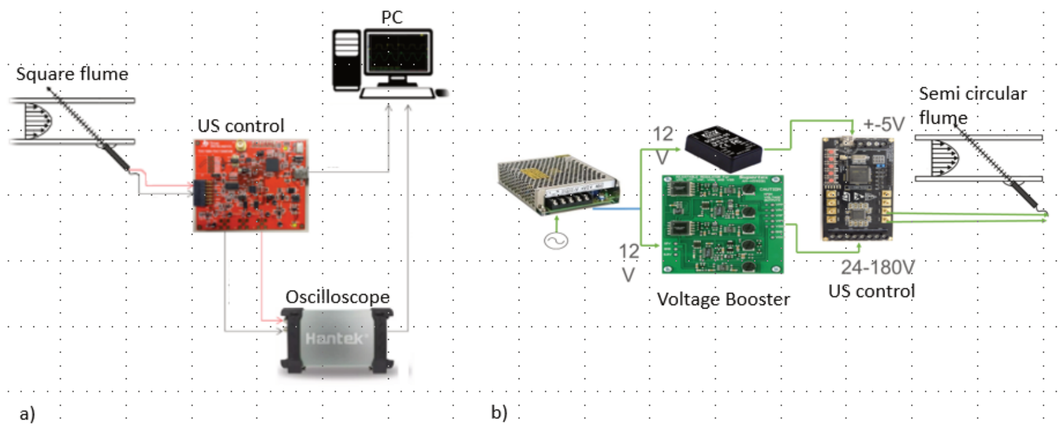

Figure 3 The ultrasonic control for the two prototypes, a) square cross-section, where the input voltage is given by a USB port (3.3 V), b) semi-circular section, where the input voltage is given by a voltage booster (from 1 to 150 V).

RESULTS AND DISCUSSION

Ultrasound signals were acquired with a high-speed sampling rate and up to 12 bits of vertical resolution, since it is necessary to analyze a fraction of the signal, which are not generally used for nondestructive test (NDT), in Figure 4, it can be observed the appearance of a typical ultrasound signal for UVP processing acquired by one of the developed prototypes.

Once the signal is acquired, two tasks must be carried out: first, it must be identified the temporal portion to which the area of interest corresponds (Figure 5) and second, it must be determined the methodology to be used for the signal processing. In this case, we have studied two signal analysis procedures. The sinusoidal curve adjustment method and the IQ demodulation method [10].

It's worth mention that, this signal can be also used to make another type of measurement, the estimation of the percentages of dissolved solids (we carry out tests from 0% to 50% in solids concentration), according to the methodology of variations in density used in [11] were they show that is it possible to make a calibration curve (empirical) for the water and oil content assessment in test samples

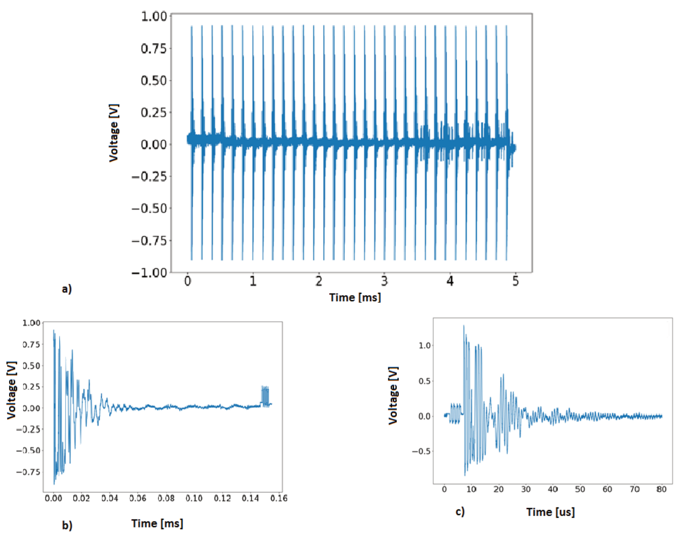

Figure 4 Screenshot of signals a) Full ultrasonic signal flow, b) ultrasonic signal until the start reference signal (or ultrasonic pulse), and c) start reference signal until the ultrasonic signal

In figure 6 it is shown, as an example, an ultrasonic signal processed to obtain the velocity profile of fluids with a concentration of solids of 25% and 50% solids by weight, as is suggested in [2] [3].

Finally, it is important to point out that the calculations of the velocity profile processing are performed as a post-processing activity, which is one of the future challenges to automate this methodology so it would be "inline".

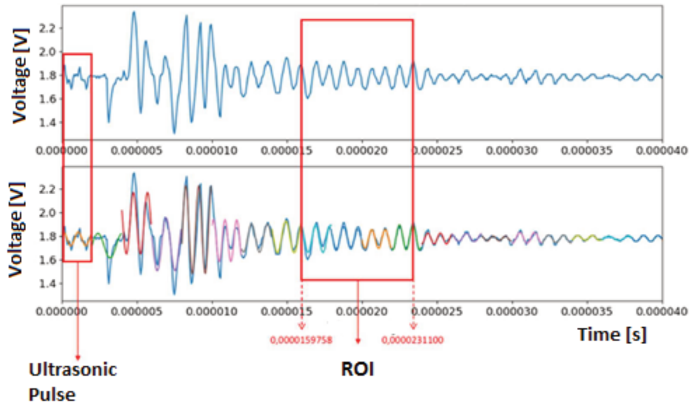

Figure 5 Ultrasonic signal obtained with an average resolution (above), and the processed signal (bellow) using a sinusoidal curve adjustment method

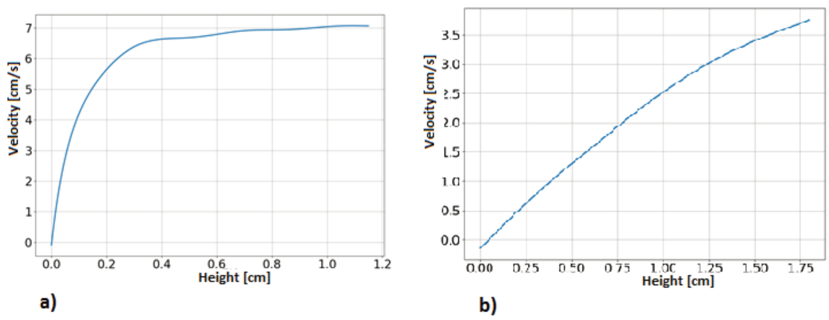

Figure 6 Two velocity profiles of a bentonite sample with a concentration of solid of a) 50% and b) at 25%

CONCLUSION

There were two experimental assemblies made to perform ultrasonic measures in a vertical line of measurement, in a transport system at a laboratory, with promising results of velocity profile, that would allow projecting applications at an industrial level.

The strategies of recovering signals allow defining a post-processing methodology for the right estimation of velocity profiles.

The future challenges associated with larger-scale tests and the development of an automatic? post-processing methodology that would allow to determine inline and with a precision greater than 1% associated values to the concentration of solids in the fluid and rheological parameters, being both essential to a correct control of the stages in the transport of high concentration of tailing slurries, from the discharge of thickeners to the final disposition places.

NOMENCLATURE

v_{ri} radial velocity reflected by particle i
C speed of sound in the middle
f_0 frequency in zero position
f_d frequency in "d" position

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