APPLICATIONS OF NON-INTRUSIVE SONAR TECHNOLOGY IN HYDROTRANSPORT

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ABSTRACT

In this presentation, CiDRA's patented technology platform and its applications will be described. CiDRA's non-invasive, passive sonar array-based flow meter technology provides the volumetric flow rate of single or multiphase fluids by measuring the speed at which naturally occurring structures such as turbulent eddies or density variations convect with the flow past an axial array of sensors. These sensors are incorporated in a band that is wrapped around the outside of the pipe, resulting in no process downtimes for installation and unprecedented reliability. This technology has resulted in a unique ability to measure the flow rate of most fluids – clean liquids, high solids content slurries, pastes, and liquids and slurries with entrained air. Unique and difficult minerals processing and hydrotransport flow measurement problems and their solutions will be described, such as high solids content slurries, pastes, and liquids and slurries with entrained air.

Recent developments in extending this technology to solve other unique hydrotransport measurement problems will also be presented. Applications to be discussed include non-invasive slurry velocity profiling, and sanding detection which make use of the unique ability to measure localized velocities within a slurry pipe. Additionally, applications such as valve movement detection make use of the unique ability to measure overall frequency selectable sound levels within a process pipe to provide acoustic condition monitoring.

INTRODUCTION

Flow measurements in the mineral processing industry suffer from the limitations placed by previously available flowmeters including the commonly used instruments such as ultrasonic meters, magmeters, turbine meters, orifice plate meters, vortex flow meters, Coriolis flow meters, and venturi meters. The desire or requirement to make a non-contact measurement that is accurate and robust, and can be performed on practically any type of fluid within practically any type of pipe has driven the creation of a new class of flowmeters. This new class of flowmeter technology utilizes sonar-based processing algorithms and an array of passive sensors to measure not only flow, but also fluid composition.

The sonar-based flowmeter technology is truly unique. “To the best of my knowledge, there has not been a completely new industrial flowmetering principle produced since the invention of the Coriolis mass flowmeter....Finally, I’ve seen a new one.....Enter the CiDRA Corporation (www.CiDRA.com). They’ve produced just such an instrument,” (Boyes 2003)

PRINCIPLE OF OPERATION

Sonar-based flowmeters are ideal for tracking and measuring the mean velocities of disturbances traveling in the axial direction of a pipe. These disturbances generally will convect with the flow, propagate in the pipe walls, or propagate in the fluid or slurry. First let us focus on the disturbances that convect with the flow. The disturbances that convect with the flow can be density variations, temperature variations or turbulent eddies. The overwhelming majority of industrial flows will have turbulent eddies convecting with the flow, thus providing an excellent means of measuring the flow rate as described below.

Turbulent Eddies and Flow Velocity

Turbulent flow is composed of eddies, also known as vortices or turbulent eddies, which meander and swirl in a random fashion within the pipe but with an overall mean velocity equal to the flow, that is they convect with the flow. An illustration of these turbulent eddies is shown in Figure 1. The vortices in a pipe have a broad range of sizes, whose sizes are bracketed by the diameter of the pipe on the largest vortices and by viscous forces on the smallest vortices. On the average, these vortices are distributed throughout the cross section of the pipe and therefore across the flow profile. Thus if one tracks the average axial velocities of the entire collection of vortices, one can obtain a measurement that is close to the average velocity of the fluid flow.

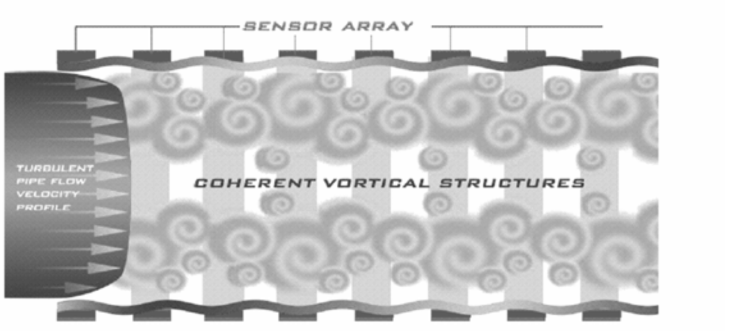


Figure 1 Diagram of Pipe with Turbulent Flow Showing Fully Developed Flow Profile and Turbulent Eddies As Well as Non-Contact Passive Sensors Wrapped Around Exterior of Pipe

Array Measurement of Flow Velocity

Through the combination of an array of passive sensors and the sonar array processing algorithms, the average axial velocities of a collection of vortices is obtained. The sequence of events to perform this measurement is as follows:

- The movement of the turbulent eddies creates a small pressure change on the inside of the pipe wall
- This small pressure changes results in a dynamic strain of the pipe wall itself (Figure 1 exaggerates)
- The mechanical dynamic strain signal is converted to an electrical signal through a passive sensor wrapped partially or fully around the pipe – no couplant gels or liquids are required
- This electrical signal is interpreted as a characteristic signature of the frequency and phase components of the turbulent eddies under the sensor.
- This characteristic signature is detected by each element of the array of sensors. These sensors are spaced a precisely set distance from each other along the axial direction of the pipe.
- An array processing algorithm combines the phase and frequency information of the sensor array elements to calculate the velocity of the characteristic signature as it convects under the array of sensors.

The challenges of performing this measurement in a practical manner are many. These include the challenges of operating in an environment with large pumps, flow generated acoustics, and vibrations all of which can cause large dynamic straining of the pipe. The impact of these effects is that the dynamic strain due to the passive turbulent eddies is usually much smaller than the dynamic strain arising from pipe vibrations and acoustic waves propagating in the fluid. The strength in the array processing algorithm is its ability to isolate and measure the velocities of these different components, including the weak signal from the convecting turbulent eddies, and the strong signals from the acoustic waves and vibrations.

Typically flowmeters do not provide an indication of the quality of the measurement. Conversely, in the sonar processing algorithm such a quality factor can be generated by comparing the strength of the velocity measurement against background energy levels. A quality factor ranging from 0 to 1.0 is generated, with any flow measurement providing a quality factor above 0.1 to 0.2 (depending on the application) having the confidence as being a good measurement.

Currently this technology can report the volume flow rate on liquids and slurries with flow velocities extending from 3 to several hundred ft/sec. The technology lends itself to measurement on practically any pipe size, as long as the flow is turbulent, and for some non-Newtonian fluids, even without turbulence. The pipe must be full but it can have entrained air in the form of well mixed bubbles.

Calibration and its maintenance

The volume flow measurement provided by tracking the turbulent eddies does require some adjustment or calibration. In practice the calibration adjusts the reported output by only a few percent, depending on the Reynolds number. After applying a correction factor, the offset is brought to within +/- 0.5% under these reference conditions as seen in Figure 2. In the field, without in-line calibration, our accuracy specification is +/1.0%.

Since the flow measurement and hence calibration is not dependent on the absolute values of any analog signals, it will not drift with time or temperature. Maintenance of the calibration from meter to meter and from temperature effects and aging is dependent on maintaining the spacing between the sensor elements and maintaining the stability of the clock used in the digitizer. The spacing between the sensors is set in the factory where they are bonded to a stainless steel sheet and cannot be adjusted by the customer. The clock stability is better than 0.01% and thus is 50 times better than the technology's typical accuracy of +/- 1% in the field; and +/- 0.5% under reference conditions or after in-field supplemental calibration. As a result the impact of clock stability can be neglected. In Figure 2 one can see the results from applying the same calibration coefficients to six flowmeters, all of the 6-inch variety and all tested on the same pipe. As can be seen, the meter to meter variation is quite low and will not change with time.

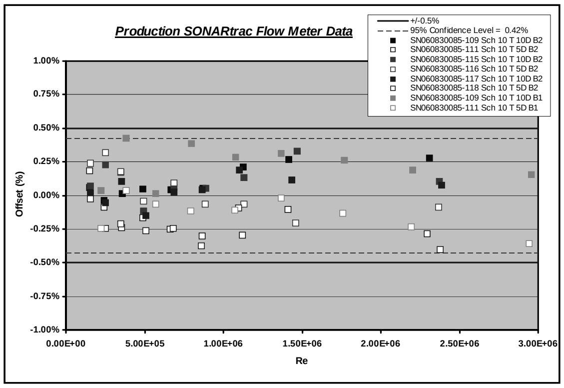


Figure 2 Illustration of Calibration Consistency from Meter to Meter. All Meters Have Same Calibration Coefficients.

Array Measurement of Acoustic Waves

As mentioned earlier, the same sensors and algorithm can be used to measure the velocity of naturally occurring acoustic waves that are traveling in the fluid. This fluid can be multiphase, or multicomponent single phase. In a single phase fluid, the acoustic velocity is a function of the ratio and acoustic properties of the two fluids, thus this measurement can be used to determine mixture ratios through application of the simple mixing rule (volume average of velocity). In multiphase fluids that consist of a gas mixed with a liquid or slurry, the acoustic velocity can be used to determine the amount of entrained gas (gas void fraction) when the gas is in the form of bubbles that are well mixed within the liquid or slurry.

These acoustic waves are generated naturally from a variety of sources, including pumps, flow-through devices, and flow-through pipe geometry changes. These acoustic waves are low frequency (in the audible range), and travel in the pipe's axial direction, and have wavelengths much longer than the entrained gas bubbles. An illustration of these acoustic waves in a pipe is shown in Figure 3 and as can been seen in the figure they can propagate in either direction down the pipe or in both directions. Since acoustic waves are pressure waves, they will dynamically strain the pipe during the cycling from compression to rarefaction and back. This dynamic strain is then captured by the sensors, and converted to an acoustic velocity measurement.

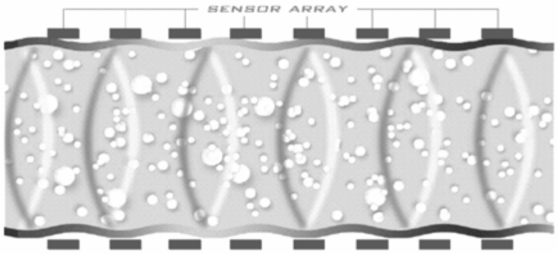


Figure 3 Illustration of Naturally Occurring Acoustic Waves Propagating in Pipe under the Sonar Array Sensors

Since the wavelengths of the acoustic waves are much larger than the bubble size, a complex interaction takes place that sets the acoustic velocity to be a strong function of the gas void fraction. An example of the resulting relationship is shown in Figure 4.

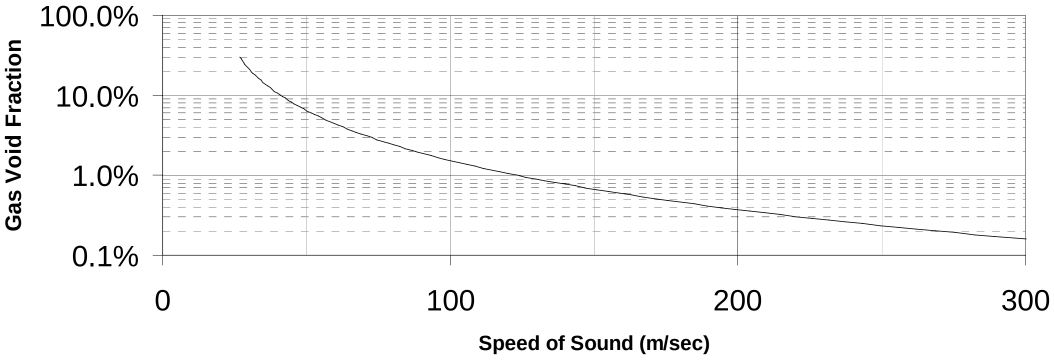


Figure 4 Example of Relationship between Gas Void Fraction and Speed of Sound

The gas void fraction measurement is used in a variety of different fields and applications. Within mineral processing, it is used for nuclear density gauge correction, flowmeter correction to provide true volume flow, and air injection applications. It has been successfully used for entrained air applications ranging from 0.01% to 20% gas void fractions with an accuracy of 5% of the reading.

VOLUMETRIC FLOW APPLICATIONS

Sonar-based flow instruments have been installed in over eleven countries and have proven themselves in grinding/classification, refining, leaching, hydrotransport and smelting operations. These include hydrocyclone feed lines, hydrocyclone overflow lines, hydrocyclone underflow lines, water feed and recovery lines, SAG mill discharge lines, ball mill discharge lines, thickener underflow lines, tailings lines, final concentrate lines, red mud and green liquor bauxite lines, pregnant leach solution lines, raffinate lines, organic lines, acid lines, multi-batch long and short distance hydrotransport and scrubber water lines. A few examples of these applications are outlined in this section.

Scale Build up on Interior Pipe Walls

A common situation in hard water lines, scrubber lines, bauxite lines, and lines carrying lime, is the buildup of scale on the interior of the pipe walls. This scale buildup can vary from a thin layer to several inches thick, depending on the pipe material and lining, the fluid composition, the flow rate and the time intervals between maintenance actions performed to remove the scale. The impact of this scale build up on most flowmeters varies from small such as an increase in noise, to large such as a drift in the reported flow measurement, or a complete failure of the flowmeter to report any flow. No flowmeter is truly immune to the effects of scale buildup but flowmeters commonly used in mineral processing such as magmeters and ultrasonic flowmeters are particularly sensitive to scale. In ultrasonic flowmeters, the scale will most likely attenuate the signal and change its angle of propagation in the fluid, thus producing an erroneous flow reading. In magmeters, the scale buildup on the electrodes serves to electrically isolate the electrodes preventing the flowmeter from measuring the flow induced voltage. The only recourse is to stop the process or divert the flow, remove the magmeter and remove the scale.

Impact of Scale Buildup on Sonar Array Flowmeter

The passive sonar array technology does not rely on the contact of any electrodes with the fluid, nor does it rely on the injection and retrieval of a signal into the fluid. The turbulent eddy induced pressure signals simply strain the scale which in turn strains the pipe wall and then the sensors. The impact of scale buildup is that the effective stiffness of the pipe may increase which will reduce the magnitude of the strain. Since the absolute magnitude is not used in the flow calculation, there is no change in the measurement of the flow velocity.

This technology has been proved on a variety of pipes with scale buildup from scrubber water, bauxite green liquor, and lime. An example of the ability to operate in the presence of scale is shown in Figure 5. Here a sonar based flowmeter is operating on an 18-inch pipe which is feeding water to a ball mill. In this case, based on previous magmeter cleanings, the pipe is estimated to have about two inches (5cm) of lime scale. Downstream of the meter is a magmeter that is cleaned out every few months to remove the scale from the electrodes and allow the magmeter to function again. This operation is labor intensive, it results in the loss of flow measurements and it relies on a bypass system to prevent a process shut down. Unfortunately, the valve used to divert the flow is developing problems from the same scale build up and the bypass system has a limited life. As can be seen in the figure, both flowmeters have similar noise levels, flow rate change responses, and outputs. The difference is in the maintenance requirements, and the flow measurement downtime.

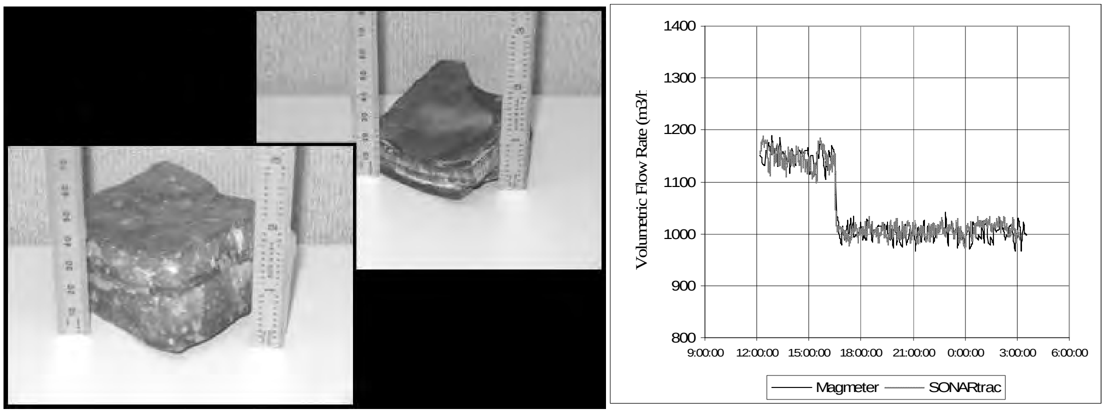


Figure 5 Examples of Scale Buildup and Sonar- Based Flowmeter Operation in Water Pipe with Five Centimeters of Scale Buildup. Comparison to Recently Cleaned Magmeter is Shown.

Lined Pipes

The sonar based flow monitoring system operates in the presence of practically any type of pipe lining for the same reason as it operates in the presence of scale. As long as the lining provides good mechanical contact with the pipe wall in order to transfer the strain from the lining into the pipe, the passive sonar array system will work. *SONARtrac* technology has been used successfully on rubber lined, teflon lined, cement lined, and urethane lined pipes. As an example, in teflon lined pipes carrying acid used in a leaching operation, the sonar based flowmeter was used to replace frequently leaking magmeters. The teflon lining is not attached to the interior of the pipe, but when filled with the acid under temperature and pressure, it makes intimate mechanical contact with the pipe wall. The mechanical contact transfers the strain from the passing vorticals or turbulent eddies to the pipe wall, leading to a solid measurement of the flow.

High Density Polyethylene Pipe (HDPE)

High density polyethylene pipe (HDPE pipe) is a thick-walled, low modulus, inexpensive pipe that is well suited for carrying pregnant leach solutions and raffinate. A picture of a cross section is shown in Figure 6. HDPE is a semicrystalline material, which is it has both crystalline and amorphous structure; it exhibits both elastic and ductile properties. Coupled with its high coefficient of thermal expansion (CTE), which is about 200 parts per million per deg C or 10 times more than steel, it presents challenges in mating to and maintaining leak free seals at metallic structures such as magmeters. The thick wall and ultrasonic attenuation in the wall make it difficult to obtain reliable ultrasonic flowmeter measurements. In contrast, the strain signals pass readily through the low modulus material, resulting in a superb signal for the sonar array measurement method.

Figure 6 provides an example of the results of a sonar based flowmeter installed on a 30-inch HDPE pipe with 2.25 inch thick walls. In this case the pipe is carrying a raffinate solution in an environment that exhibits large temperature variations. The volumetric flow measurement was verified through a tank draw down test and found to be very accurate, and as can be seen in the figure, the quality factor is very close to the theoretical maximum of 1.0, indicating a robust measurement.

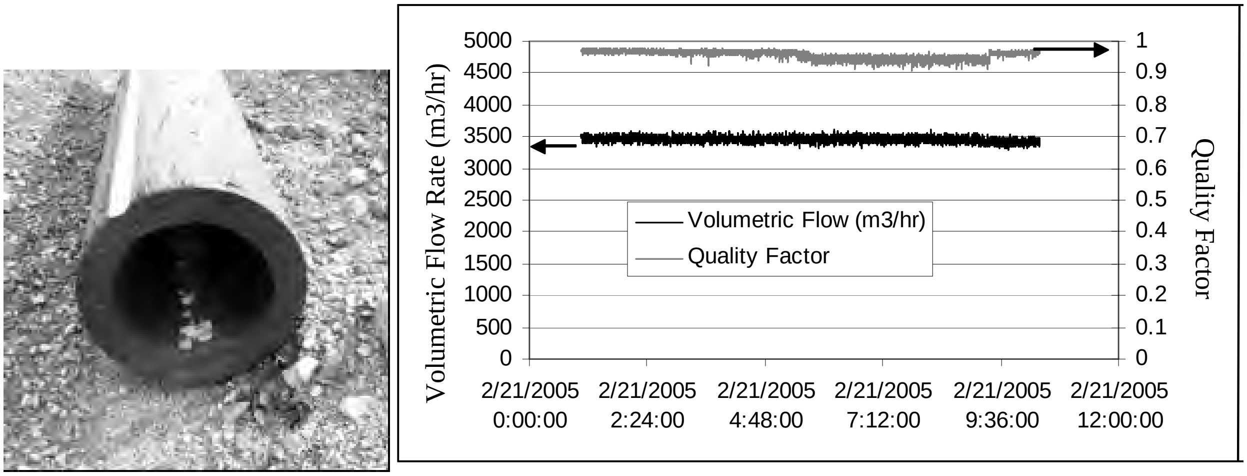
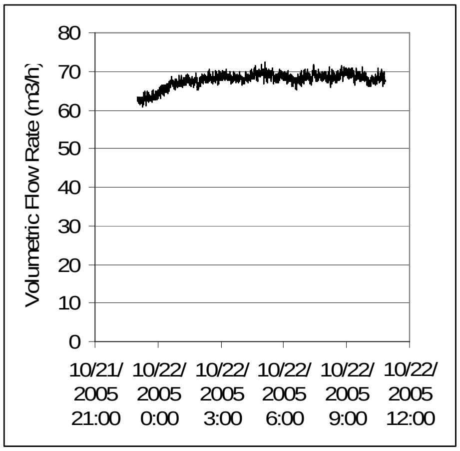


Figure 6 Flow Measurements of Raffinate in a 30 inch High Density Polyethylene Pipe. Wall Thickness is 22.25 inches (5.6cm)

Magnetite

Magnetite in a slurry line, whether intentional in an iron ore mill or whether unintentional in mills concentrating other metals, poses a potential problem for magmeter flow measurements. Quite a few locations mining copper, gold or other non-ferrous metals have magnetite in or near their ore body. The magnetite, even in small quantities, changes the magnetic field within the magmeter and can cause the magmeter to register a higher flow rate than the actual flow rate, or introduce a high quantity of noise in the flow rate output. Magmeter manufacturers have attempted to circumvent the impact of magnetite with a third coil, with magnetic field measurements, and with manual offset adjustments based on laboratory samples of the typical slurry. These methods have resulted in mixed results in which many times, the calibration or offset changes depending on the quantity of magnetite present.

A better solution is to use a flowmeter technology that is not impacted by the presence of magnetite. Since the passive array technology used in the sonar based flow monitoring system does not rely on the use of any magnetic fields, it is totally impervious to the effects of magnetite. An example of this is illustrated in Figure 7 in which a sonar-based flowmeter was placed on a line in which ultrasonic doppler flowmeters and several magnetite compensated magmeters had failed. In Table 1, one can see the readings provided by the sonar based flowmeter and whose accuracy was verified with tank fill tests.



Pump Speed	Test 1 – Flow Rate	Test 2 – Flow Rate	Difference
100%	313.72	313.93	0.07%
88%	263.16	262.84	0.12%

Figure 8 Flow Reading in Magnetite Slurry Table 1 Flow Measurement Reproducibility Results

Reproducibility and flow reading noise tests on both a 4-inch final concentrate line and a 24-inch tailings line were performed to ascertain the performance of the sonar based flowmeter. Noise and repeatability were well within 1%.

Monitoring of Acoustics for Operational Events and Conditions

A unique feature of the sonar-based flow meter is its ability to measure the overall sound pressure level (SPL) in the process pipe, which can be correlated to specific operational events and conditions. Figure 9 shows an example of the sonar detection of actuation of a valve used to control flow in a choke station of a 24” diameter, 56 km long hydrotransport slurry pipeline operated by Anglo Chile’s Los Bronces Division. The graph clearly shows significant increases in SPL during valve actuation, and distinct SPL differences between the two operating states; valve closed (flow through the loop), and valve open (flow bypassing the loop). Thus, the sonar detection capability can be used to detect proper valve actuation. Similarly, the sonar detection can be used to detect other events that produce significant acoustic signatures such as detachment of inner rubber pipe liner which then becomes stuck in valves or chokes, producing high local turbulence which can rapidly cause leaks due to high line pressure. The non-invasive nature and insensitivity to pressure of the sonar-based flowmeter allowed installation at this high-pressure location (~1,000 psi) without stopping the process.

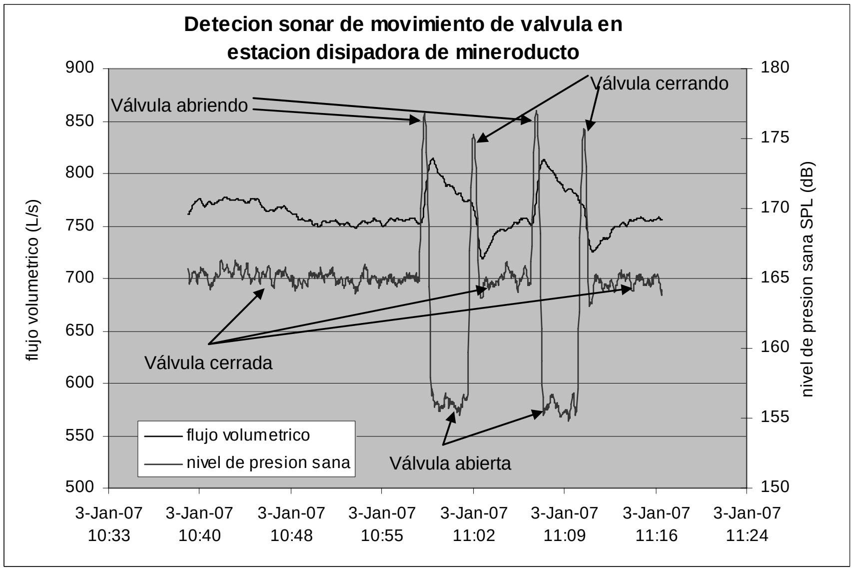


Figure 9 Measurement of Acoustic Levels Used to Confirm Valve Movement and Status

Pipeline Leak Detection

The sonar-based flowmeter is well suited for leak detection in long distance hydrotransport pipelines. Figure 10 shows the performance of two meters installed on a 24", 56 km long slurry pipeline operated by Anglo Chile, Div. Los Bronces. One meter is installed at each end of the pipeline. The graph shows good agreement between the two meters, with an average difference within approximately +/-1%. The non-invasive nature of the meter allowed both meters to be installed without stopping operation of the pipeline. The complete insensitivity to line pressure allowed the LT meter to be installed at the input to the last choke station, where the line pressure is approximately 1,000 psi. Invasive flowmeters for such high-pressure lines are expensive, and pose a risk for high pressure leaks which cause significant operational costs and environmental damage. Additionally, the non-invasive nature of the sonar-based meter eliminates abrasive wear which can cause degradation of performance and eventual failure of invasive flowmeters.

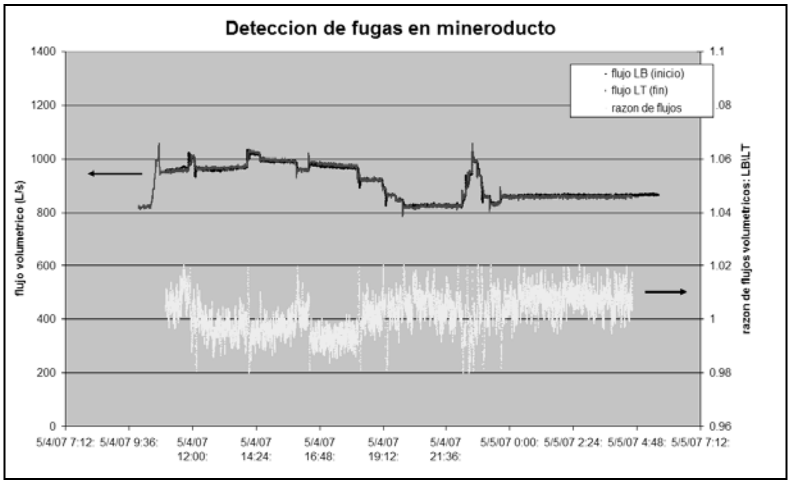


Figure 10 Pipeline Leak Monitoring Using Two Flowmeters Showing Excellent Tracking of Flowmeters in the Absence of Leak

Batch Tracking Using Real-time Speed of Sound Measurement

A unique ability of the sonar-based flowmeter is its ability to measure the real-time speed of sound in process piping. Figure 11 shows simultaneous measurements of volumetric flow and speed of sound from two sonar-based flowmeters located 26 km apart on a hydrotransport slurry pipeline. At the start and end of a multi-hour batch run, and sometimes during the batch, water is typically introduced for a short time. The graph shows a clear change in speed of sound between the water and slurry, enabling detection of the water batch at the two meters which have a transit time between them of approximately three hours. The non-invasive nature and insensitivity to pressure of the sonar-based flowmeter allowed installation of one meter at a high-pressure location (~1,000 psi), at the discharge of a large positive displacement pump, without stopping the process.

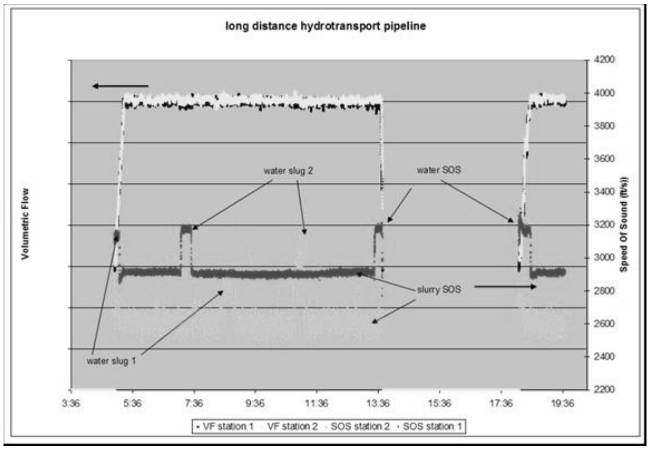


Figure 11 Detection of Water Slugs Separating Batches of Concentrate in Hydrotransport Pipeline at Two Different Locations on Pipeline

Insensitivity to Density Changes

The sonar-based flowmeter is well suited to measuring aggressive slurry flows with variable solids content. Figure 12 shows a volumetric flow measurement during a transition from water to heavy slurry (s.g. = 2), while the positive displacement pump maintained a constant speed. During this transition period, the standard deviation of the volumetric flowrate was less than 1% of the average flowrate, thus showing very good insensitivity to large density changes.

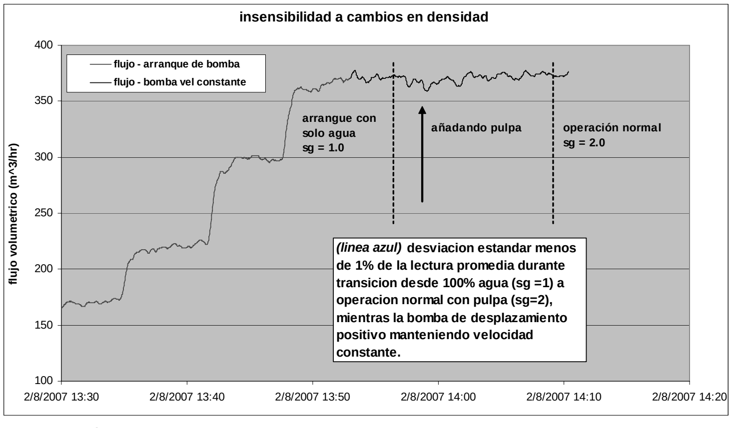


Figure12 Measurement of Both Water and Slurry with Same Meter and with Same Calibration Coefficients Show No Change in Measured Flow. Use of a Positive Displacement Pump Keeps Flow Rate the Same

MEASUREMENT OF FLOW STRATIFICATION AND DETECTION OF SANDING (SOLIDS DEPOSITION) – NEW PRODUCT DEVELOPMENT

An obvious concern in hydrotransport of solids in horizontal pipes is avoiding the deposition of solids on the bottom of the pipe, commonly known as "sanding" in some industries. Sanding can cause problems ranging from high abrasion due to elevated velocities, to complete plugging of the pipe and its associated high costs. Theoretical and experimental work combined with operational experience has produced a knowledge base that is used to predict operational conditions that avoid sanding. However, accurately predicting sanding is a very complex and inexact process, because the specific conditions that lead to sanding depend on many factors, which include; solids loading, particle size and shape, particle and fluid density, particle-particle interaction (e.g. agglomeration), and degree of turbulence.[i] At this time, a robust and non-invasive system for monitoring conditions leading to sanding does not exist. At the same time, industry conditions are putting increasing pressure on operators to reduce water usage through such techniques as use of thickened tailings, paste, etc., which increase the challenges to operate such hydrotransport lines with higher solids content while avoiding sanding conditions. The sonar flowmeter described here possesses unique capabilities that allow it to provide a measurement which can be used to predict and detect such undesirable sanding conditions.

Two approaches have been developed and have undergone laboratory testing and limited field testing. These systems are described below, and results are presented.

In addition to measuring a spatially averaged velocity within the pipe, the sonar flowmeter possesses the ability to measure a spatially localized velocity as well. This is accomplished by using specially shaped sensors located in strategic locations at various heights around the circumference of a horizontally orientated pipe. This unique ability enables the sonar meter to function as a stratification monitor in two ways.

First, by measuring a localized velocity (e.g. at the top of the pipe) and comparing it with the average velocity in the pipe at a reference location where the slurry is well mixed (e.g. near a pump discharge and/or at a vertical location). This approach is called the Stratification Metric technique.

Second, by measuring the velocity at various heights around the circumference of the horizontal pipe with a single meter installed at a location where sanding is a concern. This approach is called Velocity Profiling.

These two approaches will be discussed below.

Physics of Sonar flowmeter in Stratified flow

The flow behavior of slurries or suspensions can be classified into three general categories: homogeneous, heterogeneous, and saltation ("sanding"). There are no sharp boundaries between these categories; however the figure below provides some understanding.

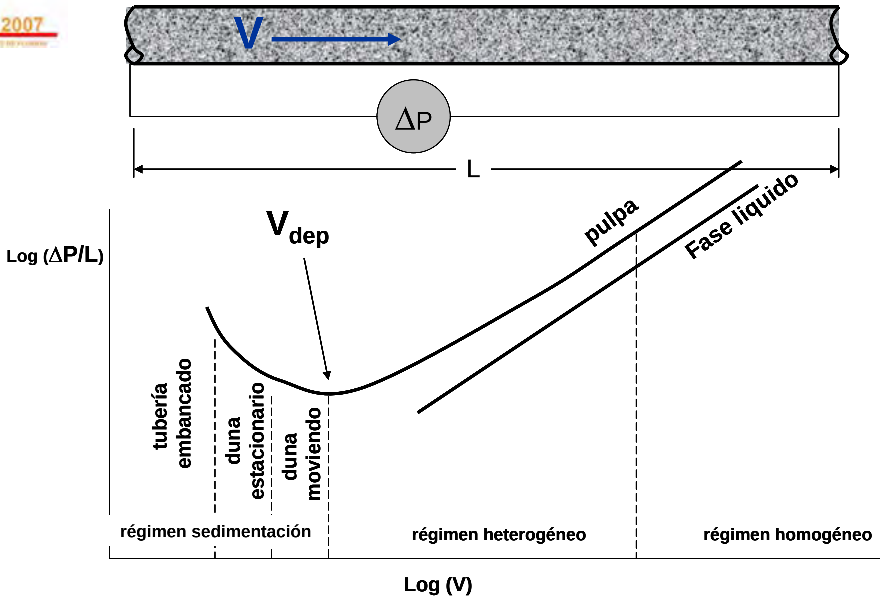


Figure 8 Pressure gradient vs velocity for various flow regimes

The figure above shows that the deposition velocity (Vdep) at which solids begin to settle on the bottom of the pipe is identified by a minimum in the pressure drop. The theoretical prediction of this critical velocity is very difficult, and a robust and non-invasive measurement system that can predict Vdep should be of significant value.

As slurry flow becomes more stratified due to higher solids loading, reduced turbulence, etc., the flow profile in the pipe changes as shown in the figures below, from homogeneous to heterogeneous.

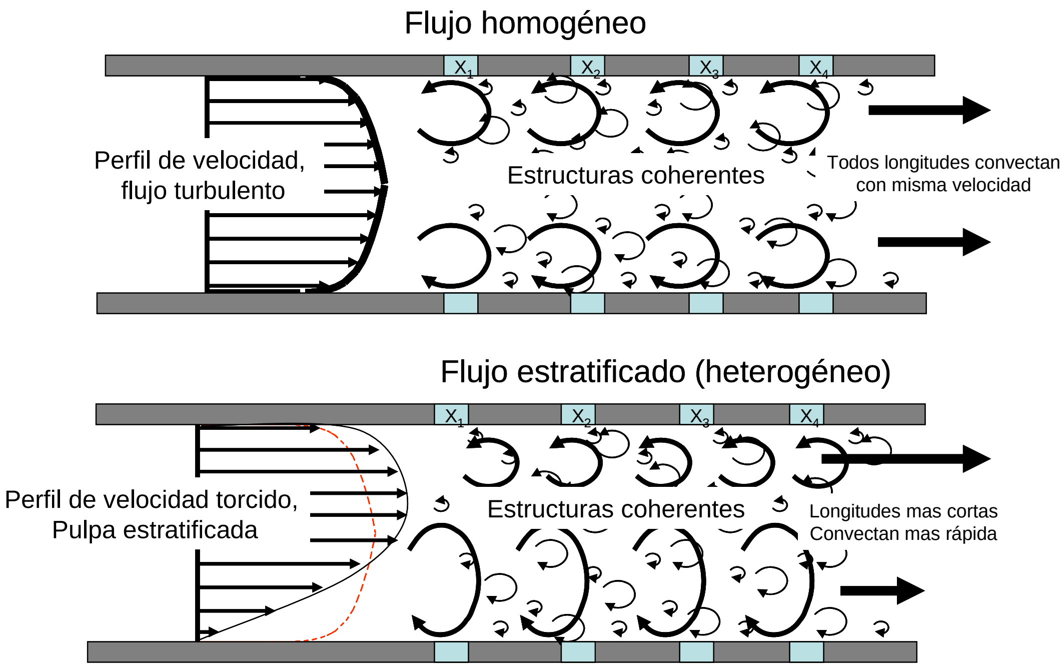


Figure 9 Flujometro sonar en flujos estratificados

As shown above, for the homogeneous flow regime (top figure), the various size vorticle structures are uniformly distributed about a vertical section of the pipe, and the velocity profile is also uniform, being symmetric about a horizontal plane. However for the heterogeneous flow regime (bottom figure), the shorter length-scale faster-moving vorticle structures are predominantly located in the top region of the pipe, while the long length-scale slower-moving vorticle structures are predominantly located in the bottom section of the pipe. Thus, the velocity profile is no longer uniform as for the homogeneous flow regime. Therefore, the sonar flowmeter with properly shaped and located sensors can measure these distinct velocities and thus quantify the degree of heterogeneity or stratification in the flow, even before sanding occurs.

In addition to the obvious advantage of simply avoiding costly plugging conditions, an important value of such measurements could be the ability to operate hydrotransport lines at higher solids levels while avoiding plugging problems, and thus significantly reducing water consumption. An example would be the operation of thickened tailings lines in water scarce areas of Latin America such as Chile and Peru.

Stratification Metric approach to monitoring stratification and predicting sanding

This first approach involves a reference flowmeter and a separate stratification flowmeter. The reference meter is ideally installed at a location where stratification and sanding are very unlikely, such as a short distance after a pump discharge where the slurry is well mixed, or in a vertical section where gravitational effects insure an axisymmetric flow profile, i.e. no stratification. Alternately, the meter can be installed at another location where it will also measure the average velocity across the mid-section of the pipe in a horizontal plane as shown below. The stratification flowmeter is installed at a location where measurement of stratification or sanding detection is desired, and will measure the velocity across the top section of the pipe as shown below. As stratification occurs and increases, the velocities in the top section of the pipe will increase with respect to the average velocity across the mid section. These two velocities can be combined using the simple relationship shown below, which essentially is a ratio of the difference in velocities normalized by the average velocity. The resulting value is a number which is called the Stratification Metric, with higher values indicating increasing stratification which is a precursor of sanding.

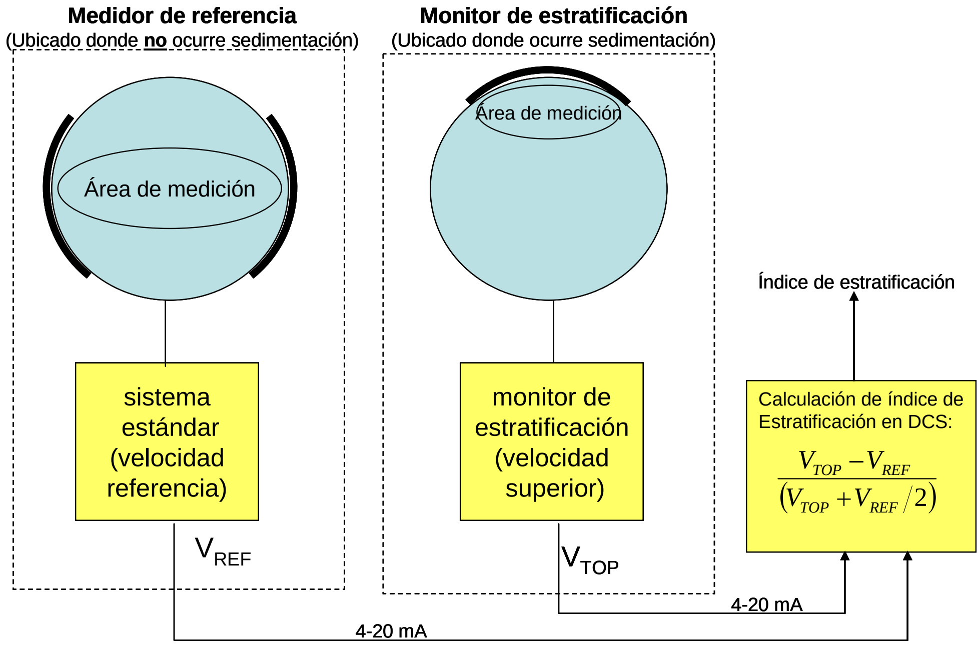


Figure 10 Implementacion #1, Medicion de Indice de Estratification

A test of this Stratification Metric approach was recently performed in a slurry test loop shown below at the Saskatchewan Research Center (SRC) in western Canada.

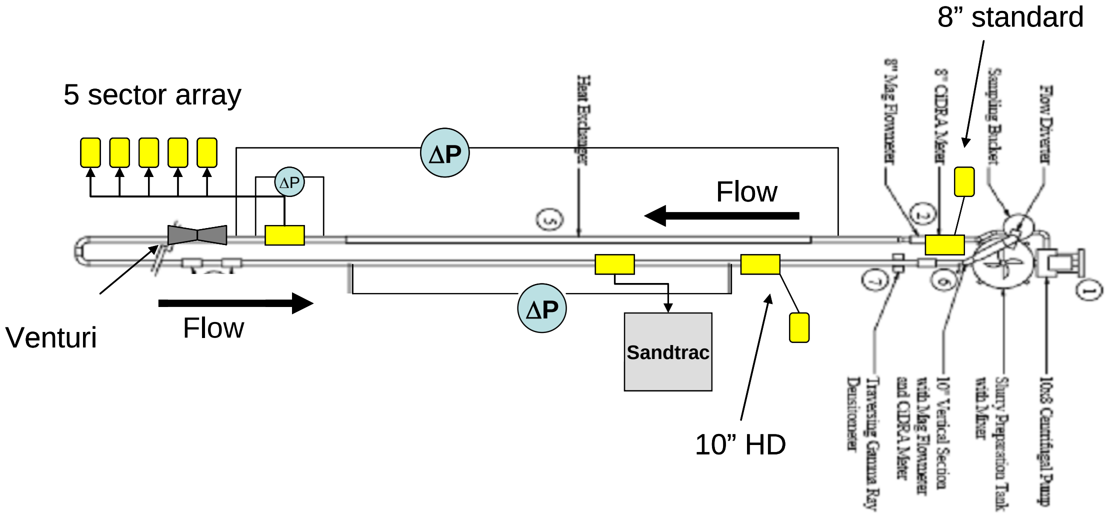


Figure 11. Loop de Prueba en Canada

A slurry of silica sand was used with the properties show in the graph below. As shown, as the reference velocity decreased, the Stratification Metric increased, with sanding occurring shortly thereafter. The occurrence of sanding was verified in the test loop by measurements of pressure drop and density change.

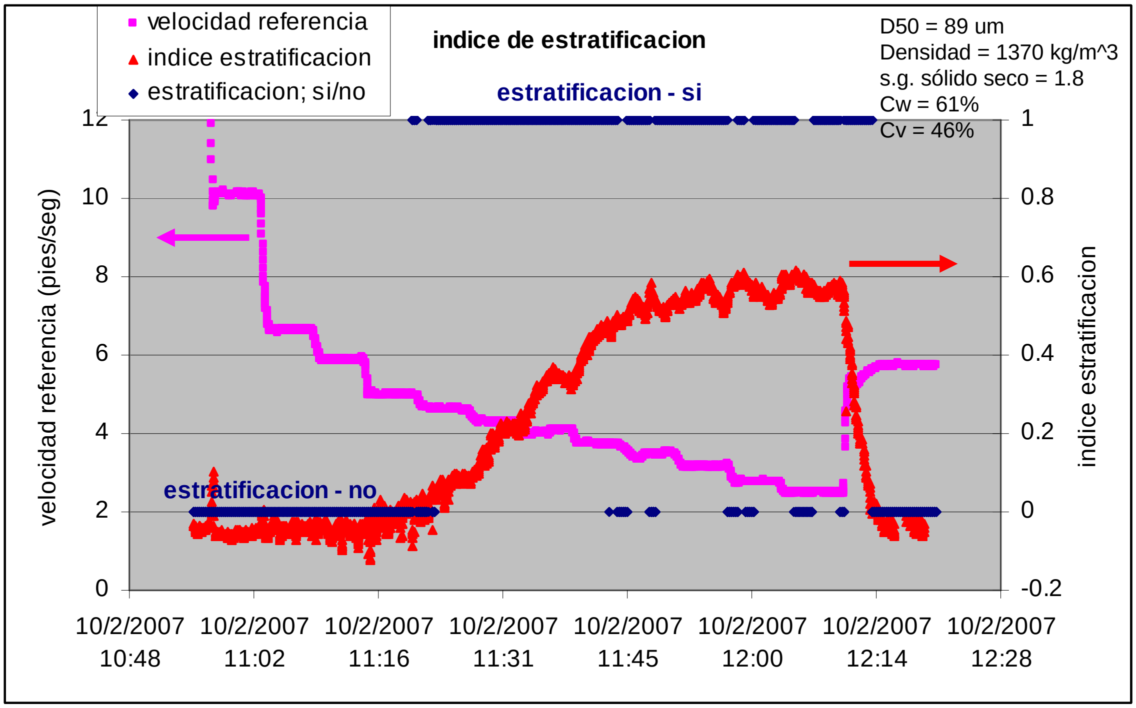
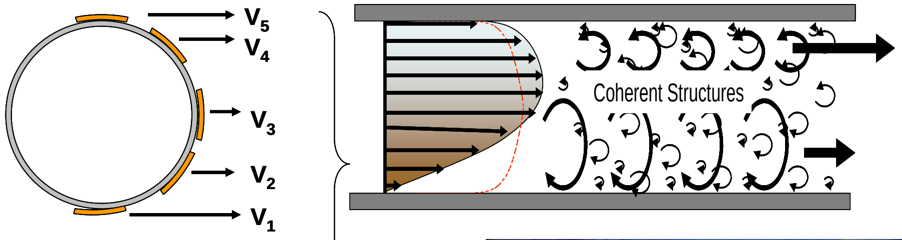
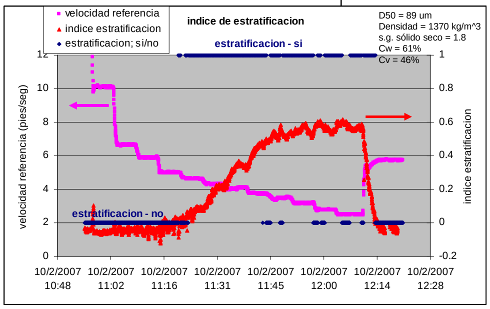


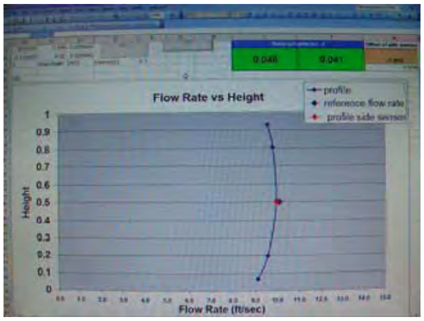
Figure 12. Resultados; Indice de Estratificacion

Velocity Profile approach to monitoring stratification and predicting sanding

This approach involves the mounting of small sensor arrays at various heights around the circumference of pipe as shown below. The results have been processed to produce a dynamic graph of the five velocities vs time as shown below. In this approach, a good indicator of sanding was seen when the bottom velocity (V1) suddenly became greater than the velocity just above it (V2). This phenomenon was called “roll under” due to its visual appearance. The “roll under” affect correlated very well with the other sanding indicators available in the test loop, such as pressure drop increase and density decrease.







Summar: Measurement of Stratification and Sanding Detection

Both approaches detected stratification increases and the occurrence of sanding. The two approaches offer slightly different advantages and limitations with respect to mounting locations and operation of the Hydrotransport line. Hardware is now available for additional field testing with customers. A goal is to install three systems in Latin America in appropriate locations such as northern Chile and Peru.

SONARtrac™ Scalable Architecture and Platform

SONARtrac™ technology is based on a scalable architecture, and its functions and performance can be expanded and enhanced through algorithm development and hardware configuration. This scalability enables the addition of new and innovative measurement features that can enhance current measurements, enable new functionality and insight into the dynamics of process flows. Some of these new functionalities can include rock detection, velocity profiling, machine diagnostics, and valve actuation monitoring.

SUMMARY

SONAR-based flow and entrained air measurement instruments are a new class of industrial flow and compositional analyzers leveraging over 60 years of SONAR development and utilization. SONAR-based flow meters are installed worldwide in many industrial applications and are ideally suited for a wide range of minerals processing applications and provide new measurement insight and quantifiable value to operators.

Table 2 Comparison of Conventional and Sonar-Based Mineral Processing FlowMeter Technologies

Feature	***SONARtrac* Flow Technology**	**Electromagnetic Meter**	**Ultrasonic**	**Orifice Plate/Venturi**
Measurement Principle	Passive SONAR-Array Processing	Faraday's Law	Ultrasonic Transit Time or Doppler	Differential Pressure
Clamp-on Installation – No Process Downtime	**Yes**	No	**Yes**	No
Broad Applicability to Abrasive/Corrosive Materials	**Yes**	No	Limited	No
Direct Measurement of Velocity	**Yes**	**Yes**	**Yes**	No
Impervious to Degradation due to Wear	**Yes**	No	**Yes**	No
Reduced Maintenance Requirements	**Yes**	No	No	No
Measurement of Entrained Air in Slurry or Fluid	**Yes**	No	No	No
Operates with Lined Pipes or Scale Buildup	**Yes**	Degrades with scale	No	Degrades with scale

SONAR-based, clamp-on *SONARtrac* technology is a scalable platform that is more than just a flow technology. It has the ability and capability to provide several other value added measurements and information such as speed of sound, entrained air/gas, gas hold-up, velocity profile, and other process conditions.

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[i] Cheremisinoff, N.P.; "Encyclopedia of Fluid Mechanics, Vol. 5, Slurry Flow Technology"; Golf Pub. Co, 1986.