APPLICATION OF NON-INTRUSIVE SONAR ARRAY-BASED TECHNOLOGY TO SOLVE UNIQUE AND DIFFICULT MEASUREMENT SITUATIONS

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Key Words: Flowmeter, gas holdup, gas void fraction, entrained air, slurries, magnetite, arsenopyrite, pyrrhotite, acid, flow rate, scale, high pressure, hydrocyclones, clamp-on, non-invasive

ABSTRACT

Unique and difficult minerals processing measurement situations will be described and the application of passive array-based technology for performing these measurements will be illustrated. Examples of these situations include volume flow measurements in froth lines and flotation feed lines with entrained air, slurry lines with magnetite and other magnetic ore, slurry lines with abrasive or corrosive materials, high pressure lines, and slurry and non-slurry lines exhibiting scale buildup. Other situations include measurement of entrained air levels in pipes and in flotation columns. These measurements are achieved through CiDRA's patented passive sonar array-based technology. This technology performs two independent measurements – flow rate and entrained air amounts. Two hardware implementations of this technology have resulted in a non-intrusive flow and entrained air meter which easily is installed on the outside of the pipe, and a submersible version for entrained air or gas holdup measurements which is used in flotation processes. Recent developments in extending this technology to solve other unique measurement problems such as valve movement confirmation will be covered.

INTRODUCTION

The minerals processing industry faces many unique and challenging process control conditions and environments. In terms of flow measurements, many of these situations are not being properly served by traditional flowmeters such as ultrasonic meters, magmeters, turbine meters, orifice plate meters, vortex flow meters, Coriolis flow meters, and venturi meters. A new class of flowmeters has been developed that solves these unique situations and flow measurement problems. 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. It does so accurately, reliably and without making contact with the fluid. These measurements are performed on practically any type of fluid within virtually any type of pipe.

PRINCIPLE OF OPERATION

Sonar array-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

In most mineral processing and oil sands processes, the flow in a pipe is turbulent. 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 Figure1. These eddies are being continuously created, and then breaking down into smaller and smaller vortices, until they become small enough that through viscous effects they dissipate as heat. For several pipe diameters downstream, these vortices remain coherent retaining their structure and size before breaking down into smaller vortices. The vortices in a pipe have a broad range of sizes, that 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. The flow profile itself is a time-averaged axial velocity of the flow that is a function of the radial position in the pipe with zero flow at the pipe wall and the maximum flow at the center as seen in Figure 1. In turbulent flow, the axial velocity increases rapidly when moving in the radial direction away from the wall, and quickly enters a region with a slowly varying time-averaged axial velocity 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.

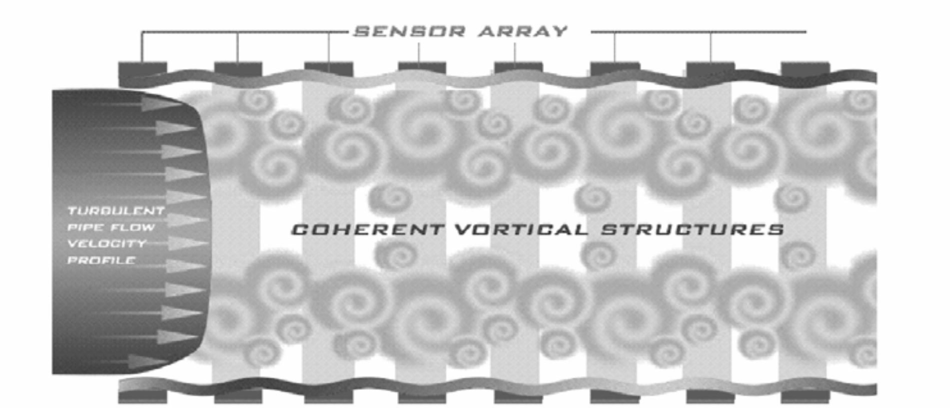

Figure 1 Diagram of Pipe with Turbulent Flow Showing Fully Developed Flow Profile and Turbulent Eddies

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 that occur to make this measurement possible is as follows:

- The movement of the turbulent eddies creates a small pressure change on the inside of the pipe wall
- This small pressure change 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.

The technology lends itself to the generation of a measurement robustness indicator otherwise known as a quality factor. Most other 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 signal from the flow 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 (0.9 m/s) 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 to give an accurate volumetric flow rate 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.

Since the flow measurement and hence calibration are not dependent on the absolute values of any analog signals, they will not drift with time or temperature. Maintenance of the calibration from meter to meter as well as 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. Pictures of the lightweight sensor band are shown in Figure 2.

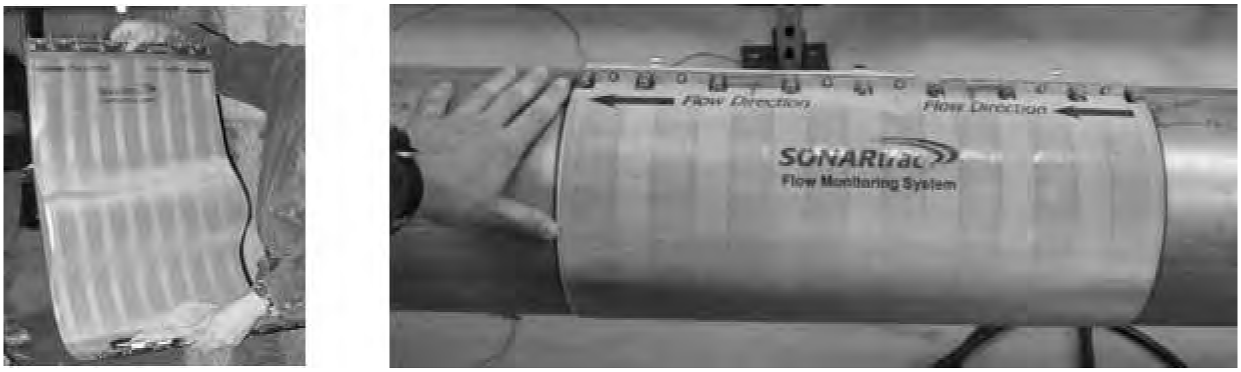

Figure 2 Pictures of the Sensor Band with Drift-Free Sensor Elements

The clock stability is better than 0.01% and thus is 50 times better than needed to maintain the flowmeter'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 3 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.

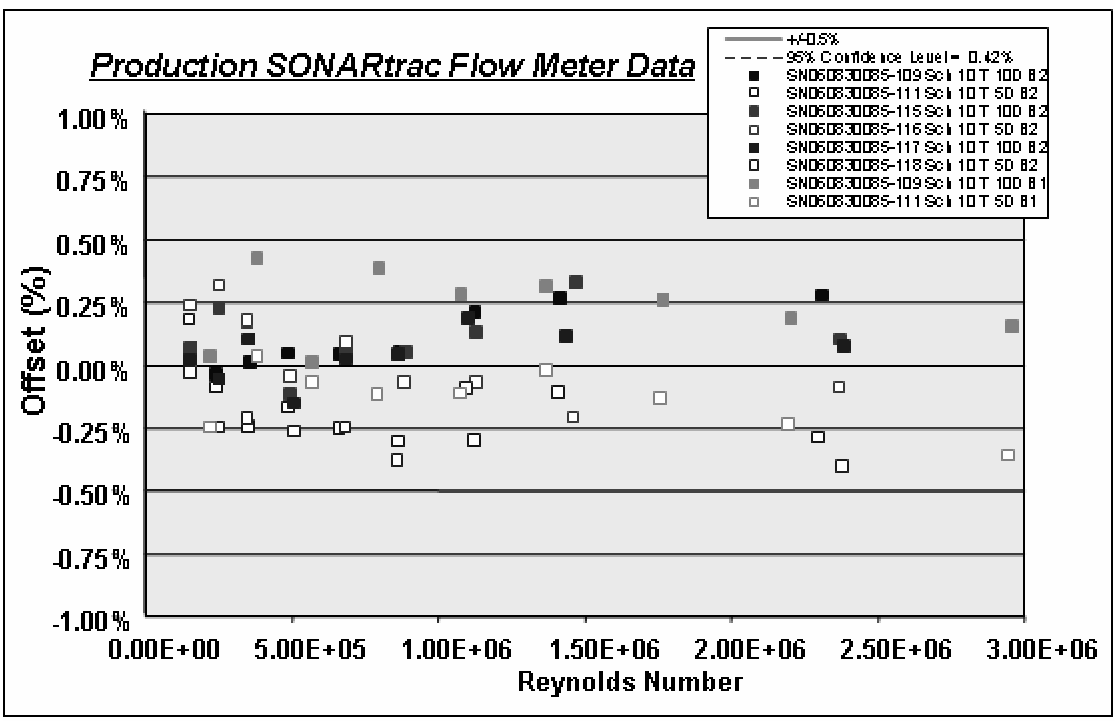

Figure 3 Illustration of Calibration Consistency from Meter to Meter. All Meters Have Same Calibration Coefficients

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 multicomponent 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). The resulting acoustic velocity c_M can be given by:

$$c_M = \phi_1 c_1 + \phi_2 c_2 \qquad \text{(Wang and Nur 1991)}$$

where $\phi_{1,2}$ are the phase volume fractions
$c_{1,2}$ are the acoustic velocities of the phases

Using $\phi_2=1-\phi_1$ this can be rearranged to give:

$$\phi_1 = \frac{c_M - c_2}{c_1 - c_2}$$

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, with wavelengths much longer than the entrained gas bubbles. An illustration of these acoustic waves in a pipe is shown in Figure 4 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 and to rarefaction and back. This dynamic strain is then captured by the sensors, and converted to an acoustic velocity measurement.

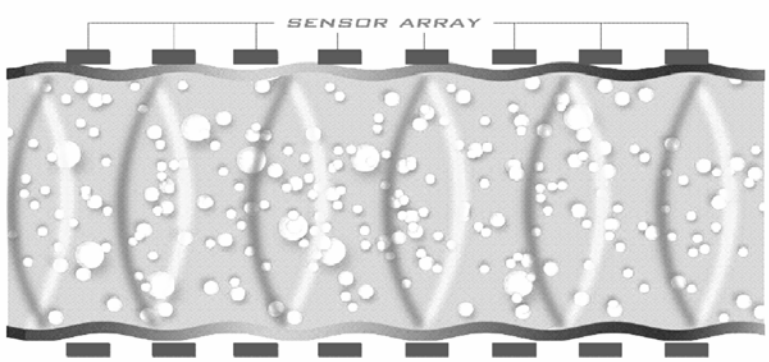

Figure 4 Illustration of Naturally Occurring Acoustic Waves Propagating in Pipe under the Sonar Array Sensors

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. The speed of sound is proportional to the square root of the ratio of the compressibility and the density, both of which are heavily influenced by air content. An example of the resulting relationship is shown in Figure 5.

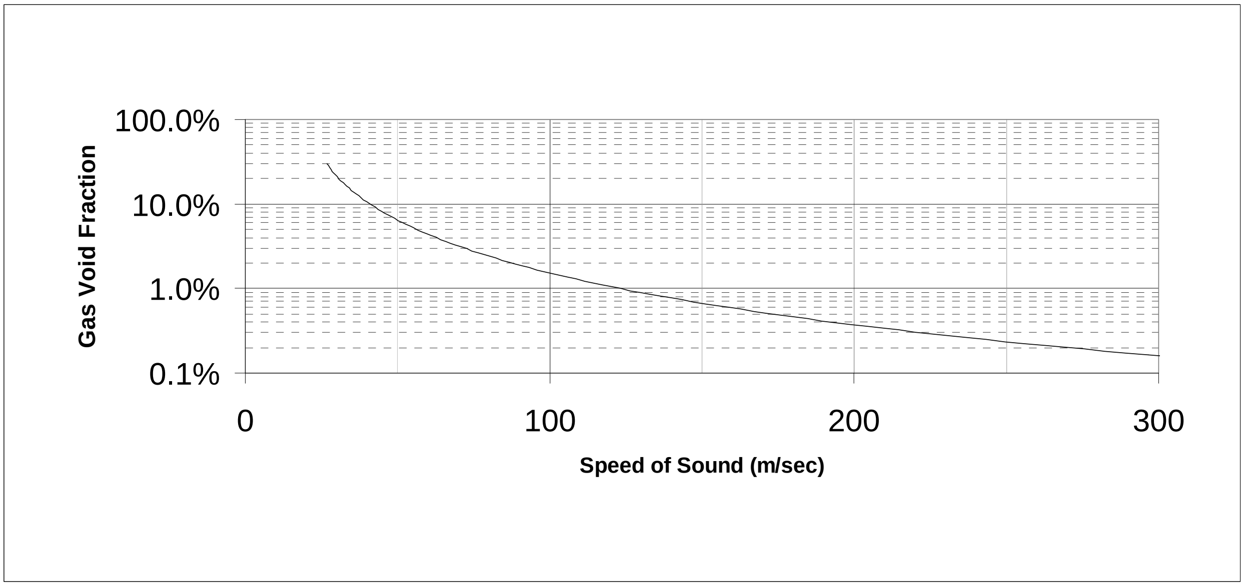

Figure 5 Example of Relationship between Gas Void Fraction and Speed of Sound

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, diagnosis of pumping issues, detection of flashing, and air injection applications. It is being successfully used for entrained air applications ranging from 0.01% to 20% gas void fractions with an accuracy of 5% of the reading.

APPLICATION OF ARRAY-BASED TECHNOLOGY TO SOLVE VOLUMETRIC FLOW MEASUREMENT PROBLEMS

CiDRA's array-based flow instruments have been installed in over fourteen countries and have proven themselves in grinding/classification, refining, slurry hydrotransport, leaching 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, and scrubber water lines. A few examples of these applications are outlined in this section.

Accurate Non-Invasive Flow Measurements for High Pressure Applications

Due to its non-invasive nature and easy installation, the sonar array-based flowmeter is ideally suited for abrasive and/or high pressure applications. As an example, there was a need to have a reliable flowmeter to measure flow at the beginning and end of a >50 km pipeline. The requirement was to accurately measure flow in order to detect any leaks, as well as monitor the load out rate. The challenge for the plant was to do so without breaking into the pipe due to the high pressures (>1000 psi, >70bar) seen on the second flowmeter site. A picture of the high pressure installation (Figure 6) shows how the external nature of the flowmeter makes for a quick and safe installation, as well as a safe operation.

Figure 6 Safety in High Pressure Lines (>1000 psi, >70 bar)

The resulting flow measurements seen in Figure 7 clearly show the two flowmeter signals (dark lines) lying on top of each other. The only way to see the small differences between the two readings is by looking at the ratio of the two outputs (light line). Except where transitions cause a difference in flow between the top and bottom meters due to the transit time of the flow change in the pipeline, the averaged ratio is within approximately +/- 1%, which is within the specifications of the meters and the requirements of the plant.

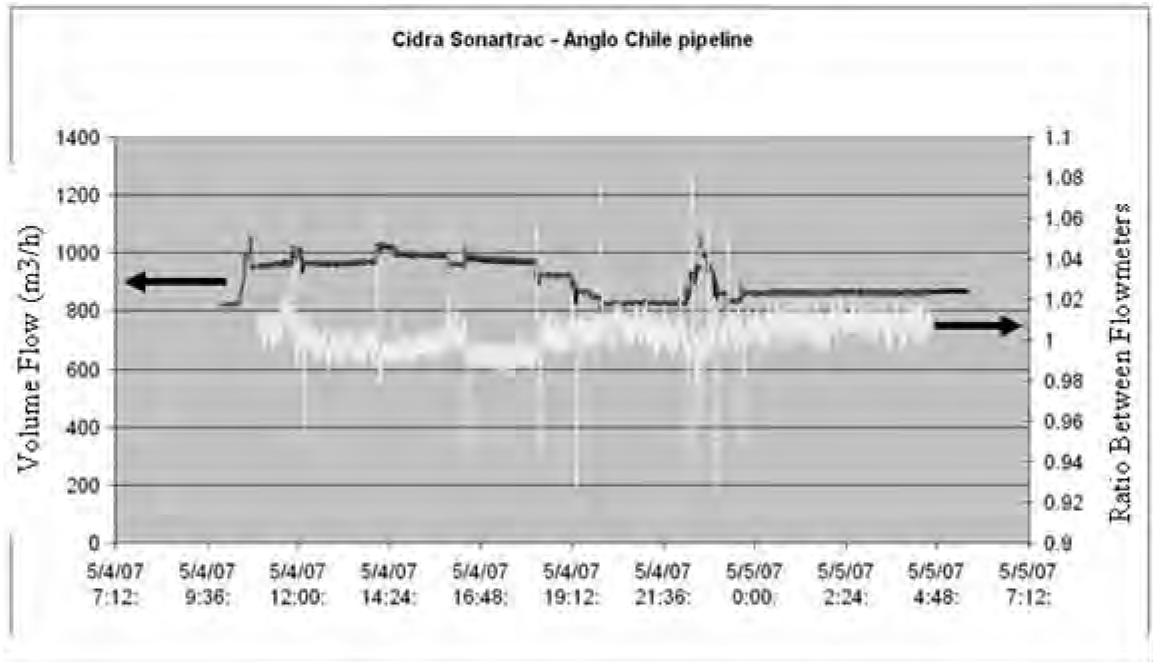

Figure 7 Leak Detection using Sonar Array-Based Flowmeters. Overlapping Dark Lines are Flowmeter Outputs. Light Line is Ratio Between the Two Outputs

Accurate Flow Measurement without Drift

There are many cases where the measurements provided by flowmeters cannot be verified through an accurate gold standard test such as a tank fill or draw down calibration. Most flowmeters will drift with time and/or temperature resulting in a change in the signal that is not noticed or cannot be verified. As an example, magmeters rely on the stability of analog electronics that can drift with time and temperature, the absence of magnetic particles in the ore, and/or clean electrodes to accurately report flow. When any of these conditions are not met, which happens frequently, the operator is not even aware that an error has taken place unless the magmeter is compared to another meter, or is recalibrated via a gold standard test.

As an example data is shown in Figure 8 from two magmeters placed in series in close proximity to each other at a gold and copper mill. In that figure the two dark lines are the magmeter outputs, while the light line between the two dark lines is the sonar array-based flowmeter. The sonar array-based flowmeter was configured using the universal calibration coefficients used for this meter.

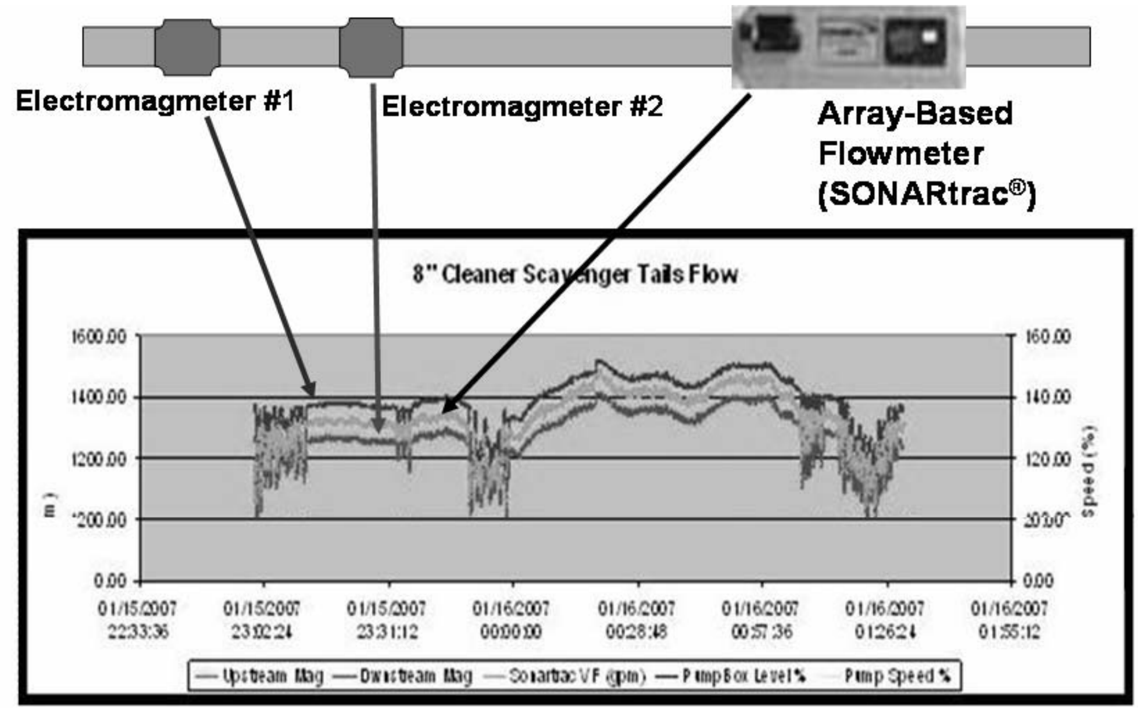

Figure 8 Two Magmeters in Series with Array-Based Flowmeter

Here the two magmeters differ on the average by over 12%. The data from an sonar array-based flowmeter is seen to provide a flow reading that is approximately an average of the two magmeters, but with the confidence that it will not drift with time.

Flow Measurement with Build-up of Scale 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.

Impact of Scale Buildup on Ultrasonic and Electromagnetic Flowmeters

In transit time ultrasonic flowmeters, an ultrasonic wave injected into the fluid has to travel between two transducers using known bending or refraction of the ultrasonic wave at the pipe to fluid interface. The impact of scale on such a meter involves three effects: 1) attenuation of the ultrasonic signal in the scale, 2) scattering of the ultrasonic signal at the scale to fluid interface, and 3) change in the refraction angle at the scale to fluid interface.

Ultrasonic Doppler Flowmeters operate on a different principle than transit time flowmeters and their transducer arrangement differs as well, but they do suffer from similar problems induced by scale. Whereas the change in refraction angle may not necessarily cause the ultrasonic signal from one transducer to miss the second transducer, it certainly will change the reported flow. The conversion of the Doppler frequency shift to a flow reading requires that the instrument know the angle between the ultrasonic wave propagation direction and the axial direction of the pipe. Scale will change this angle thus producing an erroneous flow reading.

Magmeters operate by using the interaction of a magnetic field with a flowing conductive fluid to create an electric field within the fluid. The electric field is in turn detected and measured by a pair of electrodes placed on opposite sides of the interior of the pipe. 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. Like most velocity meters, the sonar array-based flowmeter uses the effective inner cross-sectional area of the pipe to convert the velocity to a volumetric flow. Scale buildup will decrease this inner cross-section area thus requiring some adjustment of the inner diameter entered into the transmitter. The difference is that, unlike older generation flowmeters such as magmeters, ultrasonic meters, differential pressure based meters, etc., the sonar array-based flowmeter will continue to operate thus eliminating periods of time in which the operator is "operating blindly" at those measurement points.

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 9. 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 changes responses, and outputs. The difference is in the maintenance requirements, and the flow measurement downtime.

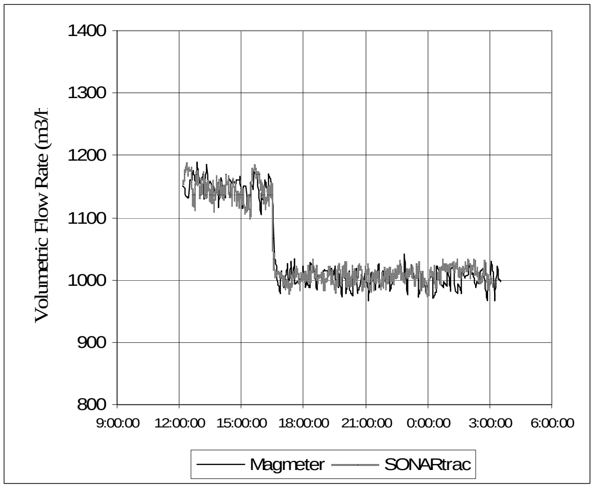

Figure 9 Sonar Array - Based Flowmeter Operation in Water Pipe with Two Inches of Scale Buildup. Comparison to Recently Cleaned Magmeter is Shown.

Measuring Flow in the Presence of Magnetic Ore such as Magnetite, Arsenopyrite or Pyrrhotite

Magnetic ore 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 magnetic ore in or near their ore body. The magnetic ore, 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 magnetic ore 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 10 in which a sonar-based flowmeter is compared against a magmeter. In the figure, one can see that as the density of the magnetic ore increases, the magmeter erroneously reports a higher flow rate, whereas the sonar based flowmeter correctly continues reporting no change in the flow rate.

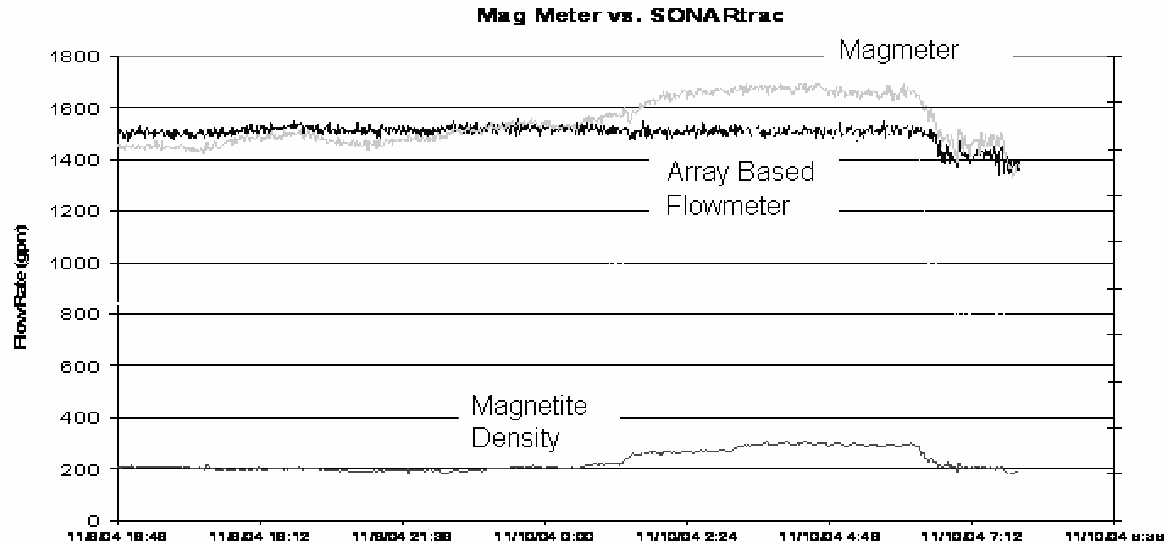

Figure 10 Magmeters Erroneously Respond to Magnetite while Array Based Flowmeter Reports Correct Reading

GAS VOID FRACTION (ENTRAINED AIR) MEASUREMENT AND VOLUME FLOW MEASUREMENT IN PRESENCE OF ENTRAINED AIR

The same sensor head and transmitter used to measure the volumetric flow rate is used to measure the fluid composition. In the mineral processing application area, this typically entails using the sonar based flowmeter to determine the amount of air entrained within the slurry. In most cases, plant engineers are unaware of the amount of air entrained within their slurry. Despite the best care in plant design, air can enter the slurry through a variety of sources including leaks on the suction side of pumps, low sump levels, discharge into a sump, from hydrocyclones, and from mills.

Entrained air can impact a process by causing errors in the measurements performed by nuclear density gauges and flowmeters. It can also impact the operation and life of pumps. In other cases, entrained air is beneficial and is intentionally injected into a pipe to assist in the separation of materials such as bitumen from the sand in the oil sands industry, or metals from ores via an external sparging system in a flotation column. In all these cases it is necessary to measure the amount of entrained air or gas void fraction. In some of these processes, the amount of entrained air is controlled with defoamers where the use of a gas void fraction meter is needed to properly control the dosing of the defoaming agent, thus ensuring the proper reduction of air bubbles while saving money.

In terms of volumetric flow measurement, most flowmeters are adversely affected by air entrained within a liquid or slurry. As a minimum, they cannot provide the true liquid or slurry flow, while in many cases the entrained air will cause a large increase in flow meter noise or a total loss of flow readings. The ability of the array based technology to measure flow in the presence of high levels of entrained air as well as the entrained air level itself lead to better control of the process. In summary, it is necessary to measure the entrained air or gas void fraction in order to compensate the outputs of the nuclear density gauges and flowmeters, to operate pumps better, to properly dose defoamers, or to ensure that the correct amount of air is being injected into a process. Some of these entrained air situations and the use of the array based technology to resolve these measurement and control problems by simultaneously performing flow and entrained air measurements are given in the following sections.

Measurement of Air Entrained within the Slurry on Hydrocyclone Feedlines

In Figure 11, an example is given for the measurement of both flow and gas void content in a 24-inch hydrocyclone feed line. In this case the customer was unaware of the presence of the air and the resulting nuclear density gauge and flowmeter errors.

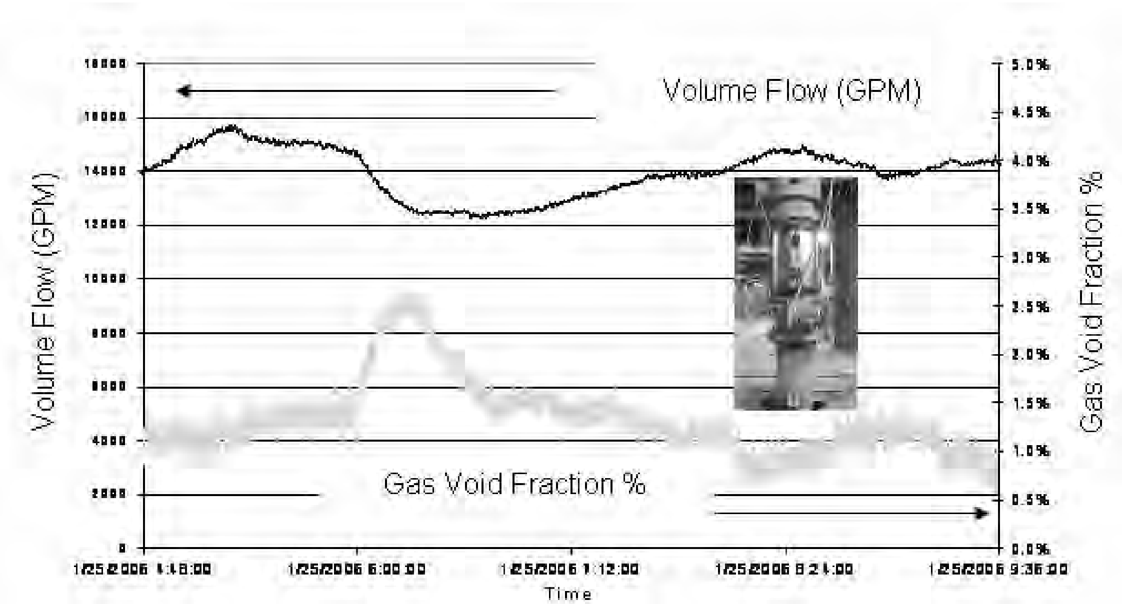

Figure 11 Flow and Gas Void Fraction in a Hydrocylone Feed Line

Correction of Nuclear Density Gauges Due to the Presence of Entrained Air

The presence of entrained air or gas void content will directly reduce the specific gravity reported by a nuclear density gauge. In order to obtain the correct density measurement of the slurry itself, the gas void fraction must be measured and used as a correction factor. To validate this approach, we ran a test in which varying levels of air were introduced into a flow loop containing a nuclear density gauge. As expected, when the air injection rate, shown as standard cubic feet per hour (SCFH) in Figure 12, was increased the nuclear density gauge output seen in the light solid line decreased. The sonar array-based flowmeter on the same line accurately measured the resulting air content as seen in the dashed line. Using this measurement, we applied a simple linear correction of the nuclear density gauge output to reduce the error from 5% down to +/- 0.25%.

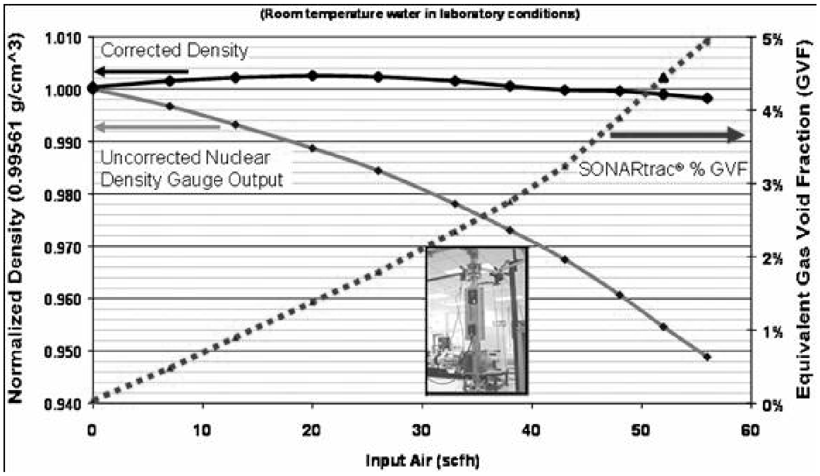

Figure 12 Nuclear Density Gauge Correction using Sonar Array-Based flowmeter

Case Study Flow and Entrained Air Measurement at Kemess Mill

Northgate Minerals uses CiDRA Corporation's sonar array-based (SONARtrac®) technology to measure bulk concentrate flows and the feed to the flotation columns at Kemess mine in British Columbia, Canada, as shown in Figure 13. The non-intrusive technology measures these abrasive slurries accurately with no process downtime due to maintenance issues with the flow meter.

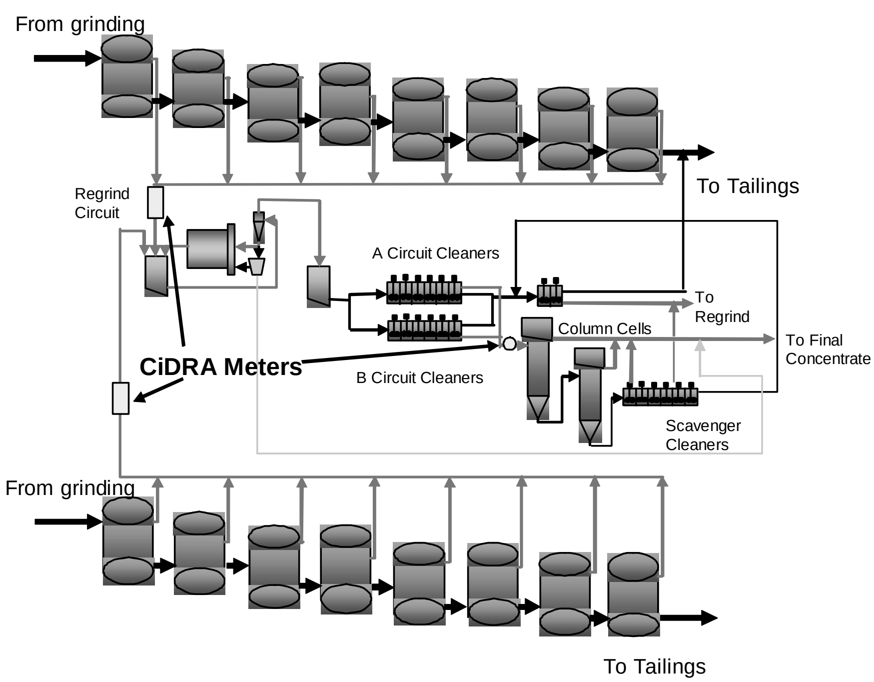

Figure 13 Kemess Mills Flowsheet Showing Locations of Three Sonar Array-Based (CiDRA) Flowmeters

Kemess also uses the Gas Void Fraction capability of the sonar array-based meter as a tool to monitor increases of air in these lines. Increased air will cause pump inefficiencies and could lead to pump damage due to cavitations. Knowing the volume of entrained air provides a true volumetric flow rate and provides operators with another tool for process control. In the following figure the step increase of entrained air from approximately 6% to 8% coincides with the decrease in flow from ~2300 GPM to ~1900 GPM. This may indicate that the increased entrained air is impacting the operation of the pump and alert the operator to a condition that needs attention.

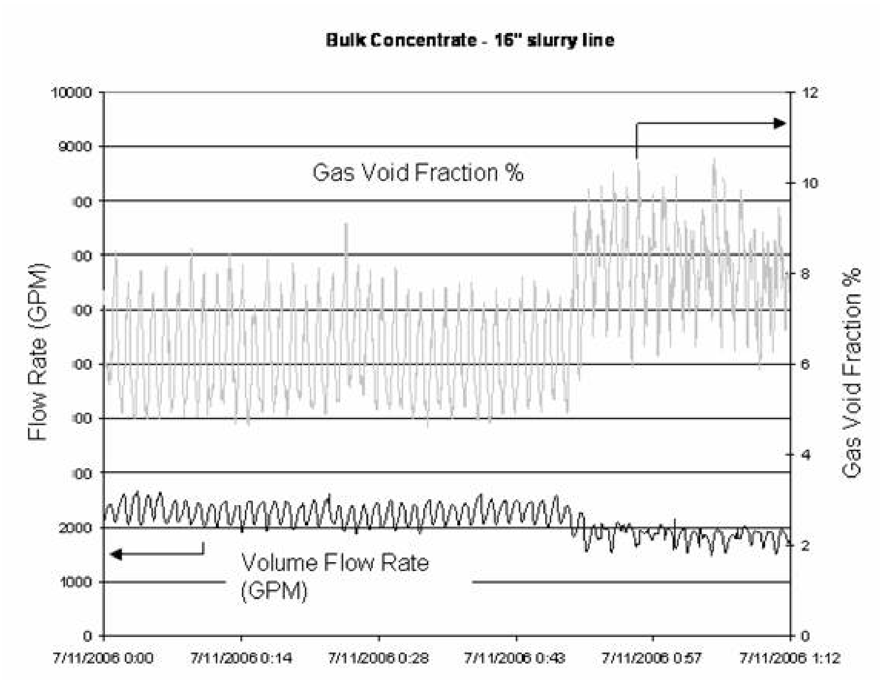

Figure 14 Flow and Entrained Air (Gas Void Fraction%) Measurements Show Impact of Air on Flow Rate

Entrained air levels vary from 8% to 0.1% in flotation feed lines as seen in Figure 15. The ability of sonar array-based technology to measure flows with large amounts of entrained air over varying conditions improves the accuracy and reliability of the flow measurement. Also, it is possible that the varying air content of the feed will affect the gas holdup within the flotation process itself.

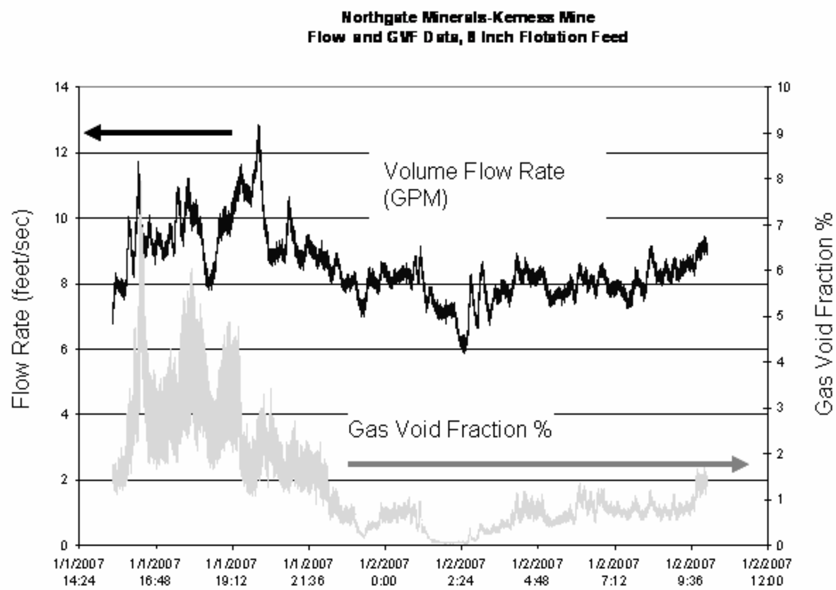

Figure 15 Flotation Feed Line and Varying Air Levels Measured by Sonar Array-Based Instrumentation

The sonar array-based meter is used as a control set point in the flotation expert control system and allows the operator to maximize throughput. Thus the sonar array based flowmeter provides the flow accuracy and slurry characteristics to improve the operation of the flotation system.

Case Study: Volume Flow and Entrained Air Measurement in High Air Content Flotation Overflow Lines at Newmont Facility

The flotation process, by its very nature, will always introduce large amounts of air into the overflow line. Thus it is very difficult for older generation flowmeters such as magmeters or ultrasonic meters to accurately measure the flow or even operate in these applications. Even when a sump or tank is used to collect the flotation overflow, thus allowing for some of the air to escape, the amount of air is still too high for older generation flowmeters. A secondary impact is that the amount of air can change quite dramatically with operating conditions thus making it difficult to determine the true slurry flow rate. A sonar array based flowmeter was used in this application to solve both problems. The meter not only robustly measured the volumetric flow, but it also measured the quantity of entrained air (gas void fraction %). This is illustrated in Figure 16.

In this case not only were the desired flow measurement problems solved, but the impact on pumping efficiency could be seen. During periods of high pumping speeds, even with the same levels in the sump, the amount of air changed by a significant amount. The corresponding drop in flow rate was explained by the increase in entrained air, which in turn affected the pumping efficiency.

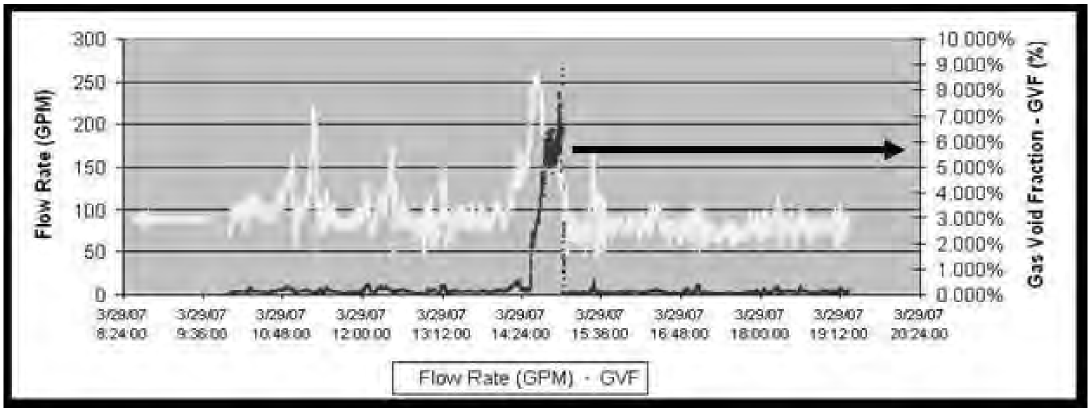

Figure 16 Problems Measuring Flow and Gas Void Fraction in a Flotation Overflow Circuit is Solved

Additional Measurement Capability – Valve Movement Monitoring

During the course of measuring flow, the passive sonar-array based flowmeter developed by CiDRA detects the acoustic levels within the pipe. By monitoring these acoustic levels over selected frequencies, additional information about events occurring in a pipeline can be obtained. As an example, valve movement in a pressure reduction choke station corresponds with changes in the acoustic levels during the movement, as well as before and after the movement as the flow is diverted through a different pipe. The flow shown as the dark line in Figure 17 changes by about 8% due to a change in the valve position which directs the flow through a different path in the choke station. The acoustic level changes by a factor of three to four (200% to 300%) during the valve movement and by a factor of three (200%) between valve positions. The combination of the flow measurement and acoustic level provides the necessary information to monitor the valve.

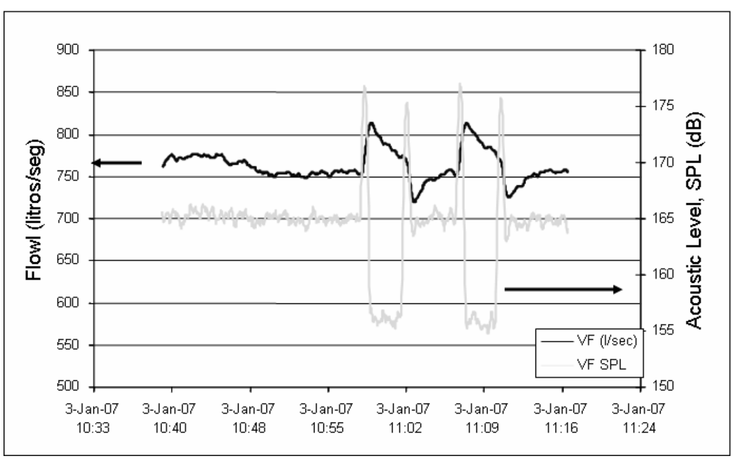

Figure 17 Flow Measurement and Acoustic Level Measurement for Valve Movement Monitoring at Choke Station

SUMMARY

Sonar array-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 array-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. Besides performing flow measurements that can be achieved by older generation flowmeters, the sonar array-based technology can measure flow in situations in which these other flowmeters technologies fail. These include robust measurements in the presence of magnetic ore slurries, scale build-up, abrasive slurries, high pressures, and entrained air.

Sonar array-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, and acoustic levels.

ACKNOWLEDGEMENTS

The authors wish to thank our customers for adopting the *SONARtrac*® flow and process meters, providing data and other support. For this paper, these include, but are not limited to Newmont Gold, Anglo American Chile, Escondida, and Kemess Mine. The authors wish to acknowledge the work performed by mineral processing team members at CiDRA including Tim Griffin for analyzing data and performing the nuclear density gauge tests, and Paul Rothman for his support.

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