Ultrasonic Gas Measurement
in a
Production Environment

Introduction
While ultrasonic meters are widely accepted in larger pipeline transportation applications; ultrasonic meters (USMs) are not as commonplace as you move up into the gathering and production pad metering points. This paper will discuss why ultrasonic meters are an outstanding choice for these applications. It will also present a summary of data collected from a location where a gas ultrasonic meter was installed in series with a traditional orifice meter on a multi well pad site.

Ultrasonic flowmeter technology
Ultrasonic meters have been used for decades and are most commonly found in transportation measurement applications within the gas industry. These segments recognize the benefits that USMs present and how they provide an excellent ROI. Upstream and Gathering segments have not widely used

USMs due to unique challenges these applications present, and in the past, there were valid concerns when considering UFMs for these applications. Today, USM vendors recognized that customers in these segments are very interested in upgrading their measurement quality to the next level over conventional differential measurement techniques and are adapting their existing, proven technology to these demanding applications.

Traditional measurement techniques – pros and cons
The historical approach to these applications has always been to use differential-based meters, and the most commonly type found in this market today is without question the orifice meter. Orifice meters have been around for decades and virtually everyone involved in measurement can relate to them – they are well documented, simple to understand, they have a relatively low upfront capital cost for smaller meter sizes, there are no moving parts and most importantly “they always give you a number.”

However, orifice meters also have limitations, especially with recent improvements to ultrasonic solutions. The argument for orifice meters has always been that ultrasonic flowmeters were too costly. But now when you consider the total cost-of-ownership, the overall ROI for an ultrasonic meter is comparable to or even –better – than an orifice meter.

Rangeability vs. plate changes
Orifice meters have some limitations that should be noted. They can have a very large measurement

range only if users are willing to constantly change plates and allow very large differential pressure values. In reality, this solution has a low rangeability if you consider a typical DP target of 20" to 200," then an orifice with single beta will be limited to about a 3:1 turndown at a constant pressure. If users are able to change plates as needed in an application with varying flow, then a 20" to 200" DP over a 0.2 to 0.6 beta may approach a 30:1 turndown.

- Thus, the turndown of an orifice is severely limited if you are not willing to spend the time and effort to change the plates as needed.

- However, over ranged or under ranged, the orifice will always give you a number. So, if accuracy matters to your application, this may not be the best solution.

No moving parts, but not as robust
Orifice meters do not have any moving parts, but their design inherently places an obstruction in the flow path – the plate.

- Other than the obvious pressure drop this creates, this may not be an issue in clean dry applications, but that is hardly ever the case in upstream and gathering applications.

- The sharp-edged plate can be worn, the plate's bore can be damaged, they can be warped from high flow rates or if slugging occurs, they can trap liquids upstream of the plate, they become dirty, and leaking seal rings are among some of the common problems that an orifice meter may succumb to.

Low initial capital costs add up over time
Initial capital cost can be enticing, however orifice's higher operating costs can paint a very different picture. For upstream applications rangeability and diagnostics become very important and there are other cost factors related to orifice plates to consider. Potential customers should also consider maintenance costs, inspection costs, and the costs of parts and replacement. It all adds up over time. As a result, a solution that may appear initially to offer lower up-front costs requires more personnel time and maintenance in upstream or gathering applications.

- Highly varying flows are common in these applications, especially with the increase of unconventional multi-well shale gas pads. There are many cases where either an oversized run is put in, or even multiple runs are put in, to accommodate the high initial production rates. Then over time, one run is pulled from a dual run site or a single run site is swapped out for a smaller diameter meter run.

- Even after initial production, many of today's wells experience a high decline curve, which result in continually changing plates to try to match the current flow with acceptable DPs and betas.

- Also, it can be a challenge to correctly size separation equipment on site, which can result in misting carry over that drops out between the well and the meter, or in a worse case, the separator cannot keep up, and from time to time, a slug of liquid passes through the measurement point. In either case, at a minimum, your uncertainty suffers and often plates can get damaged.

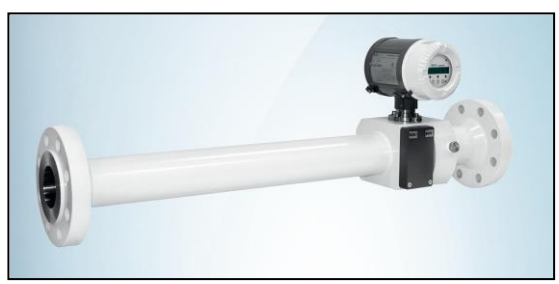
Considering just the capital cost does not take into account the substantial additional lifetime cost associated with correcting run sizes, changing plates, repairing meters, higher uncertainty and high loss and unaccounted for and needless inspections

Measurement uncertainty
Traditional orifice meter installations provide little if any diagnostic information relating to its health, performance and overall quality of measurement.

In addition to the obvious dirty plates and/or damaged plates, an installed orifice meter's uncertainty is affected by many different inherent sources. They include the uncertainties associated with discharge coefficient, velocity factor, expansion factor, orifice diameter, pipe diameter, concentricity, fluid pressure, temperature, differential pressure, and fluid characteristics.

- Coefficient of discharge uncertainties are the lowest at a beta or 0.55. Higher or lower betas add to the basic orifice meter calculation's uncertainty.
- The Expansion factor's uncertainty increases dramatically with DP's above 50" and static pressures below 100 to 200 PSI.
- Next add in factors such as dirt, poorly developed velocity profiles, damage, moisture and you can very quickly arrive at total installed uncertainties well over 1% - all without any indication that the metering point may need attention.

Technical details – why is ultrasonic flowmeter technology better?
Ultrasonic meters are extremely simple devices. At the core of a wetted transducer type of ultrasonic meter are 1 or more pairs of transducers. One transducer located upstream (facing downstream) emits a sound wave that is received by its corresponding transducer located across the meter and downstream from the first transducer.
A second sound pulse is generated from the downstream to the upstream transducer. The electronic head on the ultrasonic meters simply measures the difference in between the sound wave when traveling upstream to downstream, as compared to when it travels downstream to upstream. This time difference is used to calculate the actual cubic feet of the gas going through the meter. This ACF is then provided to the flow computer where the AGA 7/8 calculations are applied to calculate and log the SCF flowing through the meter.



While this is the basis for the operation of an USM, there is additional diagnostic information that can be monitored which give the user a great amount of information on how the meter and the meter run is performing. The additional parameters include for each path, the speed of sound, turbulence, the automatic gain control value, the signal validity parameter and analysis of the actual raw signal wave forms.

With this information, a user can tell when something has occurred that needs attention such as a changing velocity profile, blockage, contamination, wall build up and moisture/liquids presence.

Since there are no moving parts or parts that wear, USMs are typically not calibrated after installation. As long as the meter run and the meter is clean then the measurement uncertainty will remain at the level at which it was installed. Diagnostics can indicate when it is time to clean a meter run by noting the change in the diagnostic parameters over time. Once a meter is identified as dirty, many test have been conducted and it has been shown that once the meter run is cleaned, the performance returns to its original performance when it was first installed.

USMs are also different from orifice meters in that there are no obstructions within a USM which means there is no pressure drop, and pressure loss often directly translates into higher compression cost. Because USM provide no restriction and the cross sectional area of the meter is often the same as the pipe, USMs have extremely high range abilities, without having to make any physical changes to the meter. USMs can measure well past the typical piping velocities that companies impose on their facilities resulting in turndown ratios of over 45:1.

Reduce exposure to potentially unsafe situations
Ultrasonic flowmeters eliminate unnecessary venting into the atmosphere of process fluids for monthly inspections. One orifice plate manufacturer dedicates more than 20 pages to the plate changing process and identifies 12 warnings for workers, ranging potential explosions to fluid releases that may occur during the plate change process. The use of ultrasonic technology helps reduce that risk.

Applications for ultrasonic flowmeters

The most common applications for USMs are in the transmission and pipeline segments. Today there are some USMs on the market that are specifically targeting these upstream and gathering system market segments. Modifications to the transducers, their location, and body configuration are allowing them to become an attractive alternative for some of the measurement points where orifice meters once ruled. In addition, some ultrasonic meters now incorporate a real-time liquid detection algorithm that can identify certain level of liquids at a relatively high confidence level.

- Pad meters
    - Shale gas well pads. Pad meters on unconventional and shale gas multi well production sites are a prime example of this. Often, a low range is needed before all wells come on. However, a high range is needed after all wells come on, and then

the production has a steep decline curve over time. Operators are forced to constantly change plates, deal with over range conditions, put multiple runs in, over or undersize meters or swap out complete meter runs over time. This application also benefits from the USM's high turndown ratio, robust non restrictive design, the advanced diagnostics and additional features like liquid detection algorithums

  - Plunger lift applications inherently have high liquids content. It is a common occurrence in these applications for separators to occasionally pass mist flows or even free liquids on to the pad meter. In these applications orifice meters will continually trap liquids upstream which will affect the measurement quality, not only for the event but it will remain trapped upstream until the liquid is removed. An ultrasonic will pass the fluid and return to its normal operating condition after the event passes. Slugging can also warp orifice plates. Not only will the USM not be damamged, it has an ideal rangeability for this application and can identify times where liquids may be passing through the meter.

- Storage Facilities
  - In these applications clean gas in injected but when it is recovered it is typically a less than ideal fluid stream often carrying high levels of moisture and liquids with it. USMs designed for the production enviroment along with their inherant ability to be used as bi-directional meters are ideal for storage field applications.

An ultrasonic meter and an orifice meter at a multiwell pad production site

A 3" SICK FLOWSIC600-DRU ultrasonic gas flow meter was installed in series with a single chamber 4" orifice meter at a well pad location in NW Colorado. The object of the test was to validate the ultrasonic's claims surrounding the benefits that is would provide. The test, if successful, would provide a good first step in establishing the acceptance of ultrasonic meter technology in upstream applications. The test would be considered a success if the ultrasonic meter demonstrated the following:

- Lower maintenance cost through high rangablity
- Lowest ownership from the ultrasonic meter's physical design
- Better measurement quality as a result of ultrasonic diagnostics
- Lower overall measurement uncertainty from the ultrasonic meter

The test was conducted over a 3 month period with first flow occurring in January 2015 and concluding in April 2015. The site was a typical multi well pad site with 6 horizontal wells, each with individual 3-phase separators. The gas from the well separators was combined in a single line where it flowed into a final vertical separator before entering the meter runs. A 4" line exited the final separator and was reduced to the 3" line which fed into the ultrasonic meter run. After the ultrasonic meter run, it was returned to a 4" line size where the 4" single chamber orifice meter was located. The ultrasonic meter was installed according to the manufacturer's recommended layout and was in accordance to AGA 9 recommended practices. The orifice meter run conformed to the AGA 3 Part 2 recommendations. The ultrasonic and orifice meter were set up as 2 individual meter runs within an Emerson FloBoss 107 flow computer. The meter runs shared the same static pressure and temperature transmitters. The transmitters were located physically on the orifice meter run since the orifice meter performed the actual custody transfer measurement. It is expected that minor differences in the calculated flow between the meters could be attributed to the shared transmitter set. The analysis only considered the effects of large flow discrepancies. The numbers from the analysis are well beyond any variations one might expect from the small temperature or pressure differences between the meter runs.

Figure 1

Typical individual well 3-phase separator (Left) and the final separation before entering the ultrasonic building, then into the orifice meter buildings (Right)

Figure 2

(Left) 3” FLOWSIC600–DRU untrasonic gas meter installed in a meter shed

(Right) 4” Single Chamber Orifice installed in its own meter shed

Over 2,100 hourly flow computer logs were recorded for the orifice and ultrasonic meter. Over 150,000 fifteen second ultrasonic diagnostic records were recorded during the test. Analysis of the data provided a good insight into the performance of the two meters. Simplistically, one might compare the overall total accumulations during the test and stop there. A more meaningful analysis would be sifting through the data and looking for individual trends that could explain the overall variance reported. This test did not have a final stage dehy unit and a third meter located downstream of the orifice and ultrasonic meters which could be used to report what the *actual* produced volumes were. These results are not intended to make defensible claims on what the *"correct"* gas volume should be. Based on the author's understanding of how the different measurement technologies react in different situations (such as an orifice with wet internals, DP over/under ranging, reduction in cross sectional areas), the test data points towards the ultrasonic meter as having the lower overall measurement uncertainty. The reader is encouraged to make their own conclusions. It should be pointed out that neither the orifice nor ultrasonic meter is a 2 phase meter. Both have increased uncertainty in typical production environments where wet conditions are commonly found. For the absolute lowest gas measurement uncertainty, orifice and ultrasonic meters should always be used to measure clean dry natural gas, which in upstream applications is often very elusive.

Therefore, the following section will focus more on other ultrasonic meter benefits and leave the reader, after reviewing the results, to decide on which technology might provide a lower overall uncertainty over time.

Data Results

$/MMBTU	$ 2.60
$/MCF	$ 3.33
Total Hourly Logs	2184

				Value of Gas Difference	
	Orifice	**FS600-DRU**	**Difference**	**Over Test Period**	**Estimated/Year**
Total Flowing Minutes	100567	144912	14345		
Total Accumulated MCF	216321	221380	5059		
Value of Gas ($)	$ 720,349.00	$ 737,195.00		$ 16,846.00	$ 67,386.00

Subsets of the original data were created to identify and substantiate variances between the orifice and the ultrasonic data. The contribution of each variance was then totaled and compared to the overall test results. Based on our understanding of the two technologies, the idea was to find out if the overall data set could be broken down into individual contributors. The question was: When the individual contributions were summed up would they come close to matching the overall test results?

DP Over-Ranging

This subset was defined by including only the data logs where the hourly record's average DP was equal to or greater than 250" H20. 250" H2O was the upper span limit of the DP transmitter. In this set, approximately 56 records were identified. If the flow for the periods were above 250" H2O, then the expected results should show the ultrasonic reporting more flow accumulation for the combined 56 (~2.3 days worth) records. This is exactly what happened, resulting in about 4600 MCF being reported by the FS600-DRU than the orifice.

Conclusion: The orifice missed this flow since it had a smaller than required plate size for those periods and the DP was pegged at 250" H2O.

DP Low Flow Cutoff

The records included in this subset were identified when flow did occur during the log, but the total flowing minutes of the orifice was equal to or less than 40% of the FS600-DRU's flowing minutes. The idea is that the only way the orifice would be reporting fewer flowing minutes would be if the meter run in the flow computer were going into and out of its low flow cut off region. During this time the FS600-DRU was still reporting flow well above its cutoff. As an example, some data sets calculated out that at a reading of 0.5 " DP (the low flow cutoff for the DP meter run), for the installed orifice plate size, the flow velocity was 6 fps which was well within the measurement range of the FS600-DRU. As expected, this data set showed 180 logs (~7.5 days worth) resulting in about 2500 more MCF being registered by the FS600-DRU than the orifice meter.

Conclusion: The orifice missed much of this flow due to the orifice plate being over-sized for these records and going into a low flow cutoff while relevant flow velocities still existed.

Low DP

These values were not included in the financial analysis, but it does provide an indication of the uncertainty of the orifice meter during these logs. In orifice measurement, as a rule of thumb operators like to keep the SQRT(DP_{max}/DP_{live}) < 3 to prevent the DP from registering in the low end of the span where higher DP uncertainties can occur. For this test, the DP's span was 250" H2O so ideally the DP should stay above 26" H2O as the lowest DP allowed before changing the plate. For this data set, being very conservative, only logs where the hourly DP average was < 10"H2O were included, which is a SQRT ratio of 5.1.

Conclusion: This resulted in 430 (~18 days worth) of logs responsible for ~560 MCF (over $8K) of gas that was measured with much higher DP uncertainty than desired. (average of 10 DP from a 250" transmitter)

Logs where a full 60 minutes of flow was registered by both meters

There were approximately 989 logs (~41 days worth) of flow where the orifice and FS600-DRU both showed a full 60 minutes of flow. The raw data showed the orifice registered a higher volume than the FS600-DRU by 2360 MCF. This was not expected since orifice meter inspections showed light liquid loading for which published orifice studies would suggest that under these conditions the orifice meter will under report while the ultrasonic meters over report. After an investigation, by comparing the measured speed of sound (SOS) from the FS600-DRU to the theoretical SOS in the flow computer's gas analysis, it was determined that for much of this time the orifice meter run in the flow computer was using a much lighter composition than what was actually flowing through the pipe. This higher gas density accounted for the orifice meter's over registration.

Conclusion: FS600-DRU ultrasonic diagnostics indicated that approximately 5059 MCF of gas could have been sold at a higher BTU, which for the period of the test could have resulted in an incremental $3,800.

Summary of Impacts

As stated before, this test cannot show precisely which meter had the lower overall uncertainty. However, a reasonable case can be made that during the test cycle the orifice meter greatly under reported the flow as supported by the individual subsets discussed above. Also, if it were not for the delay in entering a more representative gas composition, the difference of 5059 MCF reported through the flow computer would have been even larger. This analysis shows that the original 5059 MCF variation is reasonable since the MCF summation of 4750 from the individual subsets is not only in the same magnitude, but closely approximates the flow computer's reported difference.

Conclusion: While an exact number cannot be gathered from the data, it is a reasonable conclusion that the gas produced from the well pad was under reported by the orifice meter.

Reason	MCF	Value @ 3.36/MCF
1) Missed flow due to DP Over-Ranging	4,600	$15,410
2) Missed flow due to DP Under-Ranging	2,500	$8,375
3) Over registration during to 60 Min Flows due to composition difference	-2,360	$-7,906
90 Day Test Period Totals	**4,740**	**$15,879**

Ultrasonic Benefits

In addition to the above discussion surrounding reported totals, the original goals of the test were achieved.

Lower maintenance cost through high rangablity

Clearly there were times where the orifice meter plate should have been changed to keep the orifice meter in its "sweet spot". There were many hours where the DP was pegged at 250 as well as many hours where the DP was below 10". This study was being generous and could have looked at the recommended 26" desired cutoff. As it were, the orifice meter averaged 1 plate change a month to arrive at these tests results. It is easy to understand how many more trips would have been needed to keep the orifice DP in the preferred range. Considering the true time involved by operations and measurement staff to change a plate, the costs add up quickly. Your choice becomes, settle for a higher uncertainty from an orifice meter or settle for higher cost to maintain the proper plate size.

Conclusion: The rangability that an ultrasonic meter can provide demonstrates real value in highly variable flow applications.

Lowest ownership from the ultrasonic meter's physical design

This test proved that the ultrasonic meter worked well through the duration of the test. No damage was incurred by the ultrasonic meter from wetness or over ranging flows. To be fair, the orifice meter did not suffer any damage over this short period of time either, but the typical issues orifice meters and orifice plates face in these conditions are well known..… from bowed plates to nicks and damage which all affect an orifice meter's performance. One can also consider the effect of liquids trapped upstream of an orifice. In this short test, the benefit of the ultrasonic's full bore design that allow liquids to pass

was clearly exhibited as compared to how the orifice trapped moisture upstream of the plate. Dropout still occurred with the last stage separation immediately upstream of the meter runs and were trapped upstream of the plate. Liquids trapped upstream of the plate certainly increases an orifice meter's uncertainty.
Conclusion: FS600-DRU are rugged and are not susceptible to common issue which orifice plates face

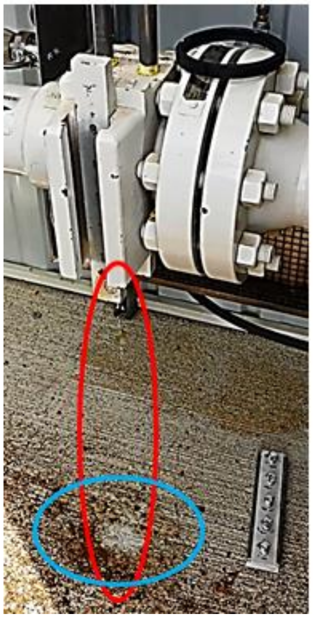


Fig x
(Left) liquid dripping from the fitting (Center) contamination on the plate (Right) moisture line formed during the test

Better measurement quality as a result of ultrasonic diagnostics
By monitoring the ultrasonic diagnostics, many benefits can be realized. An operator can use the ultrasonic meter's SOS to indicate when a gas composition should be revisited. At the beginning of the test the original composition yielded a BTU of 1280. After 1 month into startup, the ultrasonic meter's measured SOS indicated the composition had most likely changed. After a new sample was analyzed, the measured BTU of 1336 more closely aligned with the new gas sample's SOS. Large pipeline companies use online GCs to ensure the proper gas composition is always in the flow computer. This is unreasonable for production sites. However, an understated benefit of the ultrasonic became clear when the measured SOS could be used as an indicator that a new sample should be taken instead of waiting for the regularly scheduled analysis. In this test, approximately $4K over 2 months could have been realized by considering the measured SOS value from the FS600-DRU. Though not relevant in this test, other diagnostics from the ultrasonic can provide indication of contamination, liquid loading and blocked flow conditioners. On the other hand, orifice meters provide no indication of health and simply give you a DP no matter the state of the plate or meter run.
Conclusion: An Ultrasonic can provide valuable information about the meter runs health, a typical orifice meter installation… not so much.

Lower overall measurement uncertainty of the ultrasonic meter
As discussed above, this test could not definitely determine which meter provided the more accurate results. However certain statements are defensible – The orifice missed flow when the DP was pegged at 250”. The orifice missed flow when it entered low flow cutoff well before the fps at which the ultrasonic stopped reporting. The orifice clearly spent several days’ worth of measurement well below the desired DP of 26” H2O. Overall, the logs when evaluated pointed towards the FS600-DRU providing more defensible readings than the orifice meter.
Conclusion: Indications point towards the ultrasonic having a much improved uncertainty compared to the orifice meter but this test could not establish a true delivered gas volume for the test period.

Summary/Conclusion
Ultrasonic meters are well established as the preferred measurement technology for transmission pipeline applications. It is imaginable that every cubic feet of gas delivery for end user consumption at one point has passed through an USM. Recent advances in some USMs have added features that are clear benefits to measurement points upstream from the pipeline meters while incorporating features to drive the entry level price down. When considering the total initial and long-term ownership cost associated with an orifice meter, ultrasonic meters are now, more than ever, becoming an attractive choice for some production and gathering applications. Recent field tests are starting to demonstrate the real value of ultrasonic meters in upstream and gathering applications

Author Information:
Irvin Schwartzenburg is the Business Development Manager, Natural Gas for SICK, Inc. Mr. Schwartzenburg has more than 24 years of experience in the oil and gas measurement industry in various engineering and management roles. He has a Bachelor’s Degree in Electrical Engineering from Louisiana State University. He is a frequent speaker at industry events.

You can reach him at Irvin.Schwartzenburg@sick.com.

SICK
Sensor Intelligence.