# Contamination affects accuracy

**The ability to remotely monitor and diagnose the health of an ultrasonic meter ranks high among the reasons ultrasonic meters have grown in popularity.**

John Lansing,
*Daniel Industries, Houston, Texas*

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The use of ultrasonic meters for natural gas custody applications has increased at a remarkable rate over the past few years. The growth rate increased after the publication of Measurement Canada's PS-G-E-06 Provisional Ultrasonic Specification[1] and AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*[2] in June of 1998. The many benefits of ultrasonic meters have been well documented over the past few years[3]. With the increased population of ultrasonic meters in the gas industry, many users are asking more questions about this technology.

One frequent inquiry is about the accuracy of an ultrasonic meter once the internal surface changes from the original clean calibrated condition. The accuracy of all metering devices is affected when less-than-clean pipeline quality gas contaminates the inside of the meter, associated piping and flow conditioner. The impact on an ultrasonic meter's performance is generally thought to be less than traditional metering technologies, but little data has been published to date.

What happens to a meter's accuracy when it becomes contaminated? These effects have been well documented for orifice metering and other technologies, but little has been published relative to ultrasonic meters. Before discussing results shown in this paper, it might be helpful to review some of the issues that come into play regarding clean vs. dirty ultrasonic meters.

AGA Report No. 9 does not require an ultrasonic meter to be calibrated prior to using for custody transfer applications. This is due in part to the limited number of calibration facilities available in the mid-1990s. Back then, many users felt manufacturers could build meters with very reproducible performance characteristics[6]. With the increased information available from independent testing[4], customers now recognize that flow conditioners and meter piping can impact the meter's baseline accuracy. Consequently, virtually all customers today are flow calibrating ultrasonic meters prior to use.

Section 7.2.4 of AGA Report No. 9 states the following: "The internal surface of the ultrasonic meter should be kept clean of any deposits due to condensates or traces of oil mixed in with mill-scale, dirt or sand, which may affect the meter's cross-sectional area." Report No. 9 goes on to say, "The UM's operation depends on a known cross-sectional area to convert mean gas velocity to a flow rate." If pipeline buildup occurs inside the meter body, its effective diameter changes. The electronics are not aware of this change and convert velocity data into an incorrect volume flow rate.

There are other issues that can contribute to mismeasurement when the inside of a meter becomes contaminated with deposits. Today's ultrasonic meter provides more diagnostic information than other primary element technologies. A paper presented at the 2000 AGA Operations Conference[5] discussed how the ultrasonic meter's diagnostic information can be used to help determine a meter's health and answer such questions as: "Is the meter's performance being affected by pipeline contamination?"

This article discusses contamination on the face of the transducers and the impact it can have on the meter's accuracy. As the speed of sound through natural gas differs from the speed through the contamination material, the meter's accuracy can be affected by the same buildup that coats the meter. This contamination adds a second component in determining the uncertainty of a dirty meter (in addition to the inside diameter changes).

A third factor to consider in quantifying the impact buildup has on accuracy relates to the change in the velocity profile, as seen at the meter, due to changes in surface roughness. The surface roughness of both the meter and upstream piping influences the velocity profile. When a meter is placed in service, and all internal components are clean, the velocity profile seen by the meter will be different than that observed after pipeline contamination occurs. This can cause a change in the meter's accuracy.

Unlike orifice meters, not all ultrasonic meters perform the same when they are subjected to a variety of flow profile conditions. This can be observed by reviewing the GRItest results published by Terrance Grimley[4] at the 2000 AGA Operations Conference. Since different designs respond differently to installation effects, it can also be assumed they will respond differently to pipeline contamination.

The dirtiest transducer was located closest to the bottom of the meter body and faced upstream.

Thus, it should not be assumed that data presented in this paper is representative of other ultrasonic meter designs.

In 2000, a 24-in., four-path ultrasonic meter was removed from service and flow-calibrated. This meter was used as a check meter and compared to orifice measurement. This application subjected the ultrasonic meter, and orifice meter, to relatively dirty gas. Good correlation was observed between the ultrasonic meter and orifice meter immediately after the orifice plate was removed and cleaned. However, after several weeks, the two would begin to differ again. Each time the plate was removed and cleaned, the discrepancy was substantially reduced.

Since the ultrasonic meter is used as a check meter, and no facility in North America could calibrate such a large meter at the time of installation, it was not initially flow-calibrated. Sending it to Europe for calibration, at the only facility that could handle a meter of this size, was deemed too expensive. To resolve the ongoing discussion about accuracy and differences between the orifice and ultrasonic measurement, the customer decided to remove the ultrasonic meter and have it flow-calibrated.

This meter was installed with a Gallagher System I TAS flow conditioner that incorporates tube bundles with the perforated plate. The entire assembly — upstream spools, meter and downstream spool — was removed in one piece and shipped to the CEESI facility in Ventura, Iowa. The 40-ft. meter assembly, which required a large flatbed trailer for transport, was removed in one piece to minimize any potential impact disassembly would have on the results.

Upon arrival, a crane was used to remove the meter assembly from the truck before installing it in their facility. The meter was then tested to determine the "as found" performance. Since the internal condition was very dirty, it was decided to not calibrate beyond 40 fps to avoid displacing any of the debris into the calibration facility.

The meter was then removed and disassembled. All meter components, including the flow conditioners, piping spools and transducers, were removed and thoroughly cleaned by the calibration facility. After cleaning, the meter was re-assembled by the lab and tested at similar velocities as before, but a higher velocity point was added. Figure 1 shows a summary of the "as-found" dirty meter and the "as-left" clean test results.

It's important to remember this ultrasonic meter was not previously calibrated. This explains why the performance was approximately 0.3% fast. This summary shows the result of the "as-found" performance, in red, prior to any cleaning. The blue line shows the "as-left" result. Taking the raw data and determining a Flow Weight Mean Error (FWME), as described by AGA Report No. 9, for the dirty meter would result in a meter factor of 0.9966. After the meter was cleaned, the FWME would have been of 0.9970 (using the same velocity points as for the dirty meter results). The meter factor changed by 0.04% from dirty to clean. That is, the meter reading on average was slightly lower after cleaning.

Unfortunately, there were no measurements taken of the buildup thickness inside the body or associated spools, making it difficult to determine how much the cross-sectional area might have changed from dirty to clean. Judging from the pictures, one can see that this is a dirty meter. In spite of the amount of contamination the meter, flow conditioner, and associated piping had, the meter's performance was virtually unaffected (approximately 0.04%).

It might be reasoned that the larger the meter, the less impact buildup has on accuracy. This may be true since a 0.010-in. buildup on a 10-in. meter would have more cross-sectional area impact than on a 24-in. However, contamination within the metering system can also impact the meter's performance in other ways. The conclusion that can be drawn from the 24-in. ultrasonic meter example is that in spite of the amount of contamination and buildup encountered, there was no significant impact on the meter's accuracy.

As smaller meters will probably exhibit more impact on metering accuracy for the same given amount of contamination, a logical question might be: "What would the results for a 10-in. meter show if tested in a similar fashion as the 24-in.?"

Following are pictures of a 10-in. meter removed from service late in 2000 and tested dirty and clean in February 2001. The meter was installed with a Gallagher VAS flow conditioner. The upstream piping consisted of 3.5-D and 5-D spools, and the downstream section was a 5-D spool.

The meter body had a significant buildup of an oily, gritty substance. After careful removal of the fine mill-scale building under this coating, the mill-scale was measured and found to have a thickness of approximately 0.010-in. A surface roughness gauge recorded mill scale readings of 473 µ in. After the mill-scale was removed, the roughness reading of the meter body was 125 µ in. (very close to the original surface finish).

Upon inspection of the transducer ports, there was a very oily, gritty buildup of material. The transducers were all very clean. The dirtiest one was located closest to the bottom of the meter body, and faced upstream. Since these transducers do not protrude into the stream, their faces remained extremely clean. This is important since any coating on the face will impact the meter's accuracy[3].

The upstream meter spools all had much less oil on them than the meter body. This is because the meter assembly was removed late in December and stored for a couple of

The photo above shows the buildup found on the meter.

months. Unfortunately the spools and meter body were not protected from the atmosphere. Thus, it is probable the oily substance in the upstream and downstream spools evaporated over time.

A surface roughness gauge was placed in the upstream spool (5-D in length) and the intermediate spool (3.5-D in length) that is located between the plate and vane. The roughness reading on the 5-D spool was between 201 and 377 µ in. The roughness on the 3.5-D spool was between 323 and 394 µ in.

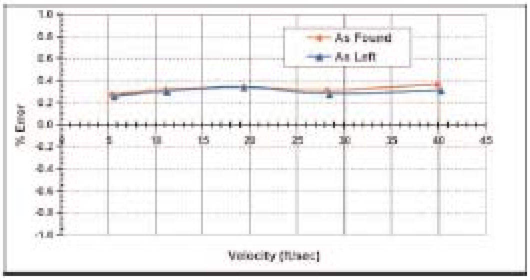

Figure 1. The above table shows why the performance was approximately 0.3% fast.

The flow conditioner showed very consistent buildup. Upon close inspection it is obvious the holes were coated throughout. There was more buildup on the face of the plate than there was relative to the inner surface of each hole. The vane remained fairly clean.

Figure 2 shows three calibration test results for this meter. Included are the "as found" with dirty meter and spools, the results after cleaning only the GFC VAS, and the results after cleaning the entire meter assembly. Note that no components were changed for this test, and the meter's configuration remained the same for all three tests. The meter was returned to Houston, disassembled and cleaned before the final testing was completed.

Before discussing the test results, it is important to review the history of this meter. It was previously calibrated at another facility prior to being installed. It was not practical to perform the dirty vs. clean meter testing at this same calibration lab. Thus, the meter factor was returned to the original value (1.0000) prior to testing to eliminate potential concern about any difference that might have been seen between the two labs and focus on the actual test results. There were no other changes other than the meter factor. Also, no components were changed for any of the tests. All were the same as when the meter was initially calibrated at the other facility.

As was mentioned earlier, the meter body had a mill-scale buildup of about 0.010-in. This buildup effectively reduced the cross sectional area of the meter. The smaller diameter will cause the velocity to increase for the same given flow rate and result in a meter reading faster when compared to its clean condition. However, the meter registered slower when dirty compared to its clean condition.

A simple method to quantify the impact on this meter is to determine a change in the FWME as described in AGA 9. The FWME for the dirty results in Figure 2 is 0.9975; i.e. the meter was reading about 0.25% fast when compared to the CEESI facility. After cleaning only the GFC VAS the meter factor was 0.9959, and after cleaning the meter body, flow conditioner and spools the FWME changed to 0.9939. This equates to an average change in meter performance of 0.16% when only the flow conditioner was cleaned, and 0.36% when the entire meter was cleaned. So, why does this meter's performance go slower instead of faster when dirty?

Figures 3 and 4 can be used to help diagnose the meter's data and explain why the meter went faster when cleaned. These graphs represent the velocity ratio, in percentage, of each chord relative to the meter's reported velocity. The red bar graphs in Figure 4 represent the relative percentage of the specific chord relative to the meter's output in the dirty condition and blue for the clean. Notice the two graphs look virtually identical. This means the velocity profile for each chord is relatively independent of gas velocity. Thus, it is not necessary to have a variety of gas velocities, or a proving system, in order to perform this test in the field and determine if the velocity profile has changed. Since users generally collect "start-up" information on the meter, this velocity profile analysis can be used to later help determine if the meter is dirty during regularly scheduled inspections.

When looking at the chord ratios for B and C, notice the difference between the clean and dirty meter. In both graphs, the dirty velocity ratio for the center paths is higher than the clean. The A and D outer chord ratios showed a bit more pronounced effect from dirty to clean, but in the opposite direction. These readings were much lower when compared to the meter's average velocity. The surface friction has clearly changed the velocity profile to be more pointed than when the meter was clean.

Although these graphs show a change in profile, perhaps there is an easier method to analyze the data. Rather than look at the ratio of each chord to the meter's reported average, computing one value might prove easier for monitoring. Averaging the middle two chord's velocity readings and then dividing this value by the average of the two outer chord velocity readings ((B+C)/(A+D)) would provide just one number. Figure 5 is a comparison performed at each of the flow velocities during the calibrations. The new monitoring values are called "Profile Ratios."

The profile ratio technique in Figure 5 clearly shows the dirty meter condition (red) has a much higher profile ratio than when clean (blue). In other words, it has a more pointed velocity profile. It is also important to note that all three ratios remained very constant, and linear, over the entire range of velocities. Thus, even if the profile ratio from a previous inspection was obtained at a different velocity, it will still be valid.

Notice the profile ratio changed only slightly when the flow conditioner was cleaned (magenta). There was only a minimal change in the profile caused by the dirty conditioner. It appears a majority of the profile effect was due to the upstream piping and the meter internal coating.

Collecting data and determining the profile ratio is important when performing a periodic inspection. There are at least three things that occur in a meter when the meter and associated upstream piping become dirty. Since there was no build-up on the transducer face, there would be no impact on meter's gain or the SOS. Thus, it could not be determined this meter was dirty by looking at the gain or SOS. This leaves the profile ratio as probably the best method to non-intrusively determine if the meter is still relatively clean.

Since the internal diameter was reduced when it was dirty, the accuracy affect should have been to over-register when dirty.

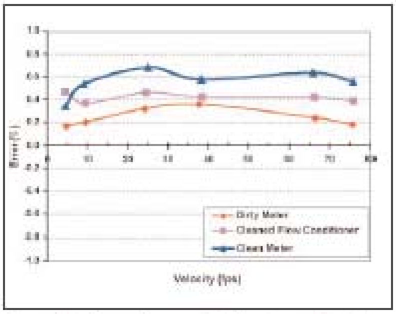


Figure 2. The above table shows the "as found" with dirty meter and spoons, the results after leaning only the GFC VAS, and the results after cleaning the entire meter assembly.

However, since the opposite occurred, what can be the cause? As can be seen from the above flow profile ratio, there was a definite change. This profile change appears to have caused the meter to under-register more than the inside diameter (ID) reduction caused it to over-register. Thus, one affect somewhat cancelled out the other.

With today's more powerful user interface software, diagnosing field related performance problems is becoming much easier. This type of profile analysis is now standard in ultrasonic interface software. Thus, each time an inspection is performed (either monthly or quarterly), data is being collected that can be used to track a meter's condition and better predict if internal cleaning is warranted.

## Conclusions

The two meters presented in this paper show that the effects of contamination on the ultrasonic meter are significantly less than other technologies. Unlike orifice metering, where a design standard exists, ultrasonic manufacturers utilize different techniques for velocity integration. These various methods produce different results when they are subjected to a variety of installation effects[4]. Pipeline contamination is just another installation effect that is more difficult to quantify. Thus, it should not be assumed that all ultrasonic meter designs respond in the same manner as the two meters presented here.

Pipeline buildup can cause at least three different effects on a meter's accuracy. First, it reduces the effective inside diameter of the meter. When the ID becomes smaller, the meter will read high. AGA Report No. 9 discusses this in Section 7.2.4. Second, if a buildup occurs on the transducer faces, the transit times are shortened, causing the meter to also read higher[3]. Neither of these meters had any buildup on the transducer faces. Thus, there was no shift in the meter's performance from this effect. And third, if the velocity profile changes due to surface roughness, there will most likely be an effect on meter accuracy[4].

The profile ratio, computed from the chordal velocities, is probably the most powerful diagnostic tool for identifying dirty meters. Data on the 24-in. meter for wall thickness build-up and chord velocities was not available for this paper. Thus, the impact on profile ratio could not be determined. The 10-in. meter data was available, and the profile ratio in Figure 5 clearly showed a change from the "as-found" dirty condition to the "as-left" clean condition.

The 10-in. meter read lower when dirty, not higher, as generally was expected. The reduction in ID should have caused the meter to go faster when dirty. However, the integration method of the 4-path chordal design caused the meter read slightly lower, somewhat compensating for the ID change.

With the use of powerful and easy-to-use interface software, diagnosing a meter's health is becoming much easier. Today's generation of software permits users to monitor a meter's performance on a real-time basis, often from around the world. This ability to remotely monitor, and diagnose a meter's health, is just one more reason ultrasonic meters have gained such widespread acceptance in such a short time. ✣

*References:*

*1. Provisional Specification for the Approval, Verification and Installation and use of Ultrasonic Gas Meters, Measurement Canada PS-G-E-06, 1998.*

*2. AGA Report No. 9, "Measurement of Gas by Multipath Ultrasonic Meters," 1998.*

*3. Lansing, "Field Verification Procedures for Ultrasonic Gas Meters", 2000.*

*4. Grimley, "Ultrasonic Meter Installation Configuration Testing", 2000.*

*5. Lansing, "Smart Monitoring & Diagnostics for Ultrasonic Gas Meters", 2000.*

*6. Lansing, "Benefits of Dry Calibrating Ultrasonic Gas Meters", 1999.*

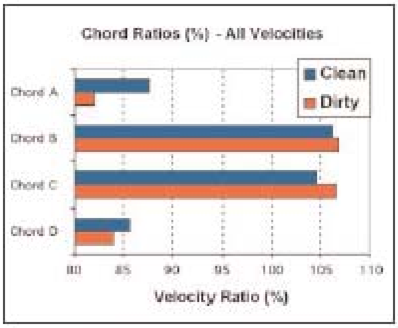


Figure 3. This chart can be used to help diagnose the meter's data and explain why the meter went faster when cleaned.

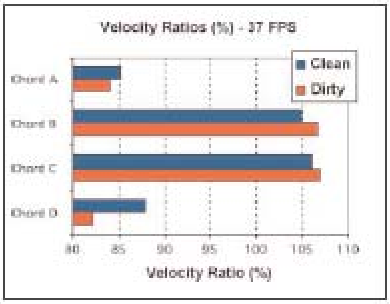


Figure 4. The red bar graphs represent the relative percentage of the specific chord relative to the meter's output in the dirty condition and blue for the clean.

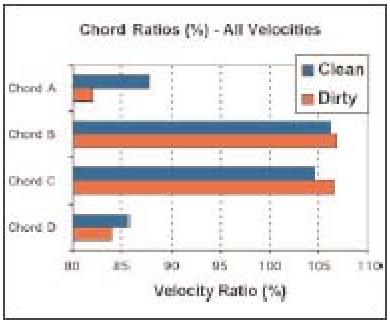


Figure 5. The above table is a comparison performed at each of the flow velocities during the calibrations.