North Sea Flow Measurement Workshop

Paper 2.3

Dirty VS. Clean Ultrasonic Gas Flow Meter Performance

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DIRTY VS. CLEAN ULTRASONIC GAS FLOW METER PERFORMANCE

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1 ABSTRACT

The use of ultrasonic meters (USMs) for natural gas custody applications during the past few years has increased at a remarkable rate. The many benefits of USMs have been well documented over the past few years [Ref 1]. With the increased population of USMs in the gas industry, many users are asking ever more searching questions about this technology.

One of the issues often inquired about is the performance (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, the associated piping and flow conditioner. The impact on an ultrasonic meter's performance is generally thought to be less than traditional metering technologies.

Dirty versus clean meter comparisons have been conducted in the past on other types of primary meters such as orifice and turbine. As one would expect, a meter's accuracy changes when it is subjected to a buildup of pipeline material such as oil, grease and mill scale. Conventional wisdom suggests that a USM will over-register when it becomes dirty. This has been documented in several papers at various flow conferences [Ref 2, 3, 4 & 5]. However, as the integration technique used by various manufacturers does differ, this may not always be the case. This paper discusses how the performance of a 4-path chordal ultrasonic flow meter is affected when it is subjected to dirty natural gas.

2 INTRODUCTION

The subject of meter performance in the field shouldn't be discussed without including the question "What happens to a meter's accuracy when it becomes contaminated with pipeline oils, mill-scale, dirt and other debris sometimes found in the pipeline?" These effects have been studied in orifice metering for years, but little has been published relative to ultrasonic meters.

Before discussing results it might be helpful to review some of the issues that come into play regarding dirty vs. clean meters. Figure 1 (following) shows some of the typical velocity integrations techniques used manufacturers [Ref 6]. As one can see the techniques differ and thus responses to different velocity profiles may also differ. The profile the meter sees is developed upstream. Thus, as buildup occurs on the piping, the velocity profile will change due to the change in surface roughness. The meter's response may also change depending upon the integration method used. In this paper all data will be presented on a meter design that is represented by meter design D in Figure 1.

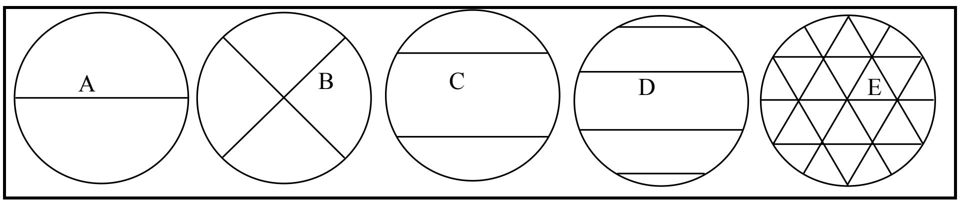


Figure 1 – Typical Velocity Integration Methods for USMs

Users of ultrasonic meters are advised by AGA 9 [Ref 7], in Section 7.2.4, of the following: "The internal surface of the UM [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 that "The UM's operation depends on a known cross-sectional area to convert mean gas velocity to a flow rate." If pipeline buildup occurs on the meter body, its effective diameter changes. The electronics, however, are not aware of this change and would then convert velocity to an incorrect volume flow rate.

There are other issues that can contribute to mismeasurement when the inside of a meter becomes contaminated with deposits. The effect of contamination on the face of the transducers will have an impact 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.

A third issue 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.

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 GRI test results published by Terrance Grimley [Ref 8] 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. Thus, it should not be assumed that data presented in this paper is representative of other presentations on different ultrasonic meter designs [Ref 2, 3 & 4]. All the results presented in this paper are based upon the British Gas 4-path chordal meter design.

3 DIRTY VS. CLEAN DATA

This section discusses results from several meters that were installed in the field, were removed and re-calibrated to identify if there were any changes in accuracy. Sizes include 10, 16, 20 and 24-inch meters.

3.1 24-inch Dirty Meter Results

In 2000 a 24-inch, 4-path ultrasonic meter was removed from service and flow calibrated. This meter is used as a check meter for an orifice meter. Since the USM is 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 costly at the time. To resolve an on-going discussion about accuracy differences between the orifice and ultrasonic measurement, it was decided to remove the ultrasonic meter and have it flow calibrated.

This meter was installed with a flow conditioner that incorporated 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 decision was made to remove the meter assembly in one piece in order to minimize any potential impact disassembly would have on the results. This meter assembly was approximately forty feet long and required a large flatbed trailer to transport.

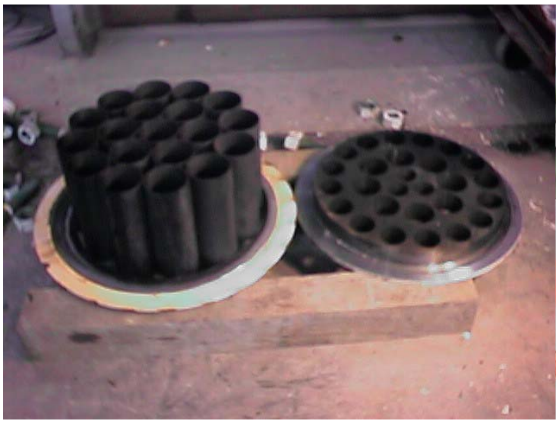
Once the meter arrived at the calibration facility a crane was used to remove the meter assembly from the truck and installed it in their facility. The meter was then tested to determine the "as found" performance. Since the internal condition was very dirty, it was decided to not calibrate beyond 12 m/s to avoid displacing any of the debris into the calibration facility. Following are pictures that show the condition of the internal components.

Picture 1 – Bottom of Meter

Picture 2 –Meter Buildup

Picture 3 – Bottom of Meter

Picture 4 –Transducer Port



Picture 5 – Flow Conditioner

Picture 6 –Flow Conditioner

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

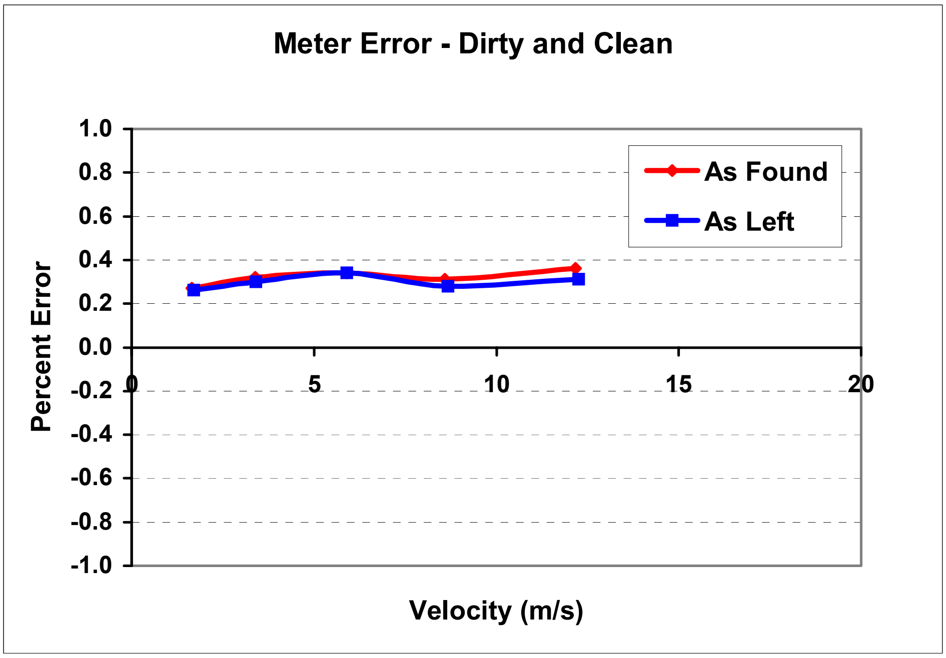


Figure 2 – 24-Inch "As-Found" and "As-Left" Meter Results

It's important to remember this ultrasonic meter was never calibrated. This explains why the performance was approximately 0.3% fast in Figure 2. Taking the raw data and determining a Flow Weight Mean Error (FWME), as described by AGA 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 (same velocity points used as for the dirty meter results). In other words the meter factor changed by 0.04% from dirty to clean (meter reading on average was slightly lower after cleaning).

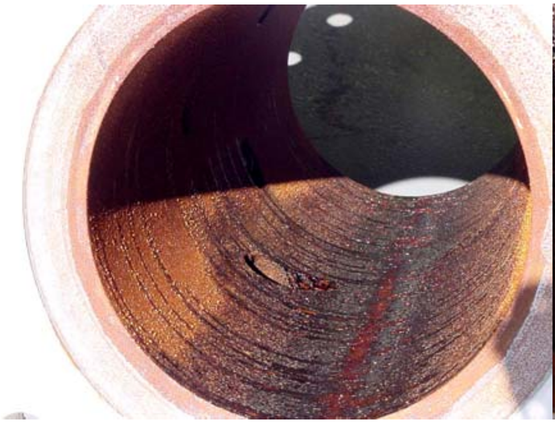
Unfortunately there were no measurements taken of the buildup thickness inside the body or associated spools. Thus, it is difficult to determine how much the cross-sectional area might have changed from dirty to clean. Nevertheless, from the above photos it can be seen that this is a dirty meter. In spite of the amount of contamination the meter, flow conditioner, and associated piping had, the meter's performance was affected by approximately 0.04%. Since this is well below the uncertainty of the calibration facility, the difference between dirty and clean could be considered negligible.

3.2 10-inch Dirty Meter Results

It might be reasonable to assume that the larger the meter, the less impact buildup has on accuracy. This may be true since a 0.010-inch buildup on a 10-inch meter would have more cross-sectional area impact than on a 24-inch meter. However, as was discussed earlier, contamination within the metering system can also impact the meter's performance in other ways. The conclusion that can be drawn from this 24-inch USM 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-inch meter show if was tested in a similar fashion as the 24-inch?"

Following are pictures of a 10-inch meter that was removed from service late in 2000 and tested dirty and clean in February of 2001. The meter was installed with a flow conditioner. The upstream piping consisted of a 3 & 3.5-D spools and the downstream section was 5D.



Picture 7 – Inside of 10-Inch Meter

Picture 8 –Inside of 10-Inch Meter

Picture 9 –Bottom of 10-Inch Meter

Picture 10 –Upstream Spool Piece

Picture 11 –Transducer Port

Picture 12 –Transducer Port

Picture 13 – All 8 Transducers

Picture 14 –Dirtiest Transducer

Picture 15 – Flow Conditioner Plate

Picture 16 – Flow Conditioner Vane

As can be seen in these pictures, the meter body had a significant buildup of an oily, gritty substance (Pictures 7-9). What isn't clear in the picture is the fine mill-scale buildup under this coating. After careful removal of this material it was measured and found to be approximately 0.010 inches in thickness. 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.

Upon inspection of the ports in Pictures 11-12 one can see there is a very oily, gritty buildup of material. Note the face of the transducers in Pictures 13-14. They are all very clean. The dirtiest one, shown in Picture 14, 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 [Ref 9].

All of the upstream meter spools had much less oil on them (Picture 10) than the meter body. This is due to the fact that the meter assembly was removed late in December and stored for several months. Unfortunately the spools were not protected from the atmosphere as well as the meter body was. 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 (3D in length) and the intermediate spool (3.5D in length) that is located between the plate and vane. The roughness reading on the 3D spool was between 201 and 377 μ in. The roughness on the 3.5D spool was between 323 & 394 μ in.

Picture 15 shows the he flow conditioner had a 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, shown in Picture 16, remained fairly clean.

Figure 3 shows three test results for this meter. Included are the “as found” with dirty meter and spools, the results after cleaning only the flow conditioner, and the results after cleaning the entire meter assembly was cleaned. No components were changed during these tests, and the meter’s configuration remained the same for all three calibrations. The meter was returned to Houston, disassembled and cleaned before the final testing was completed.

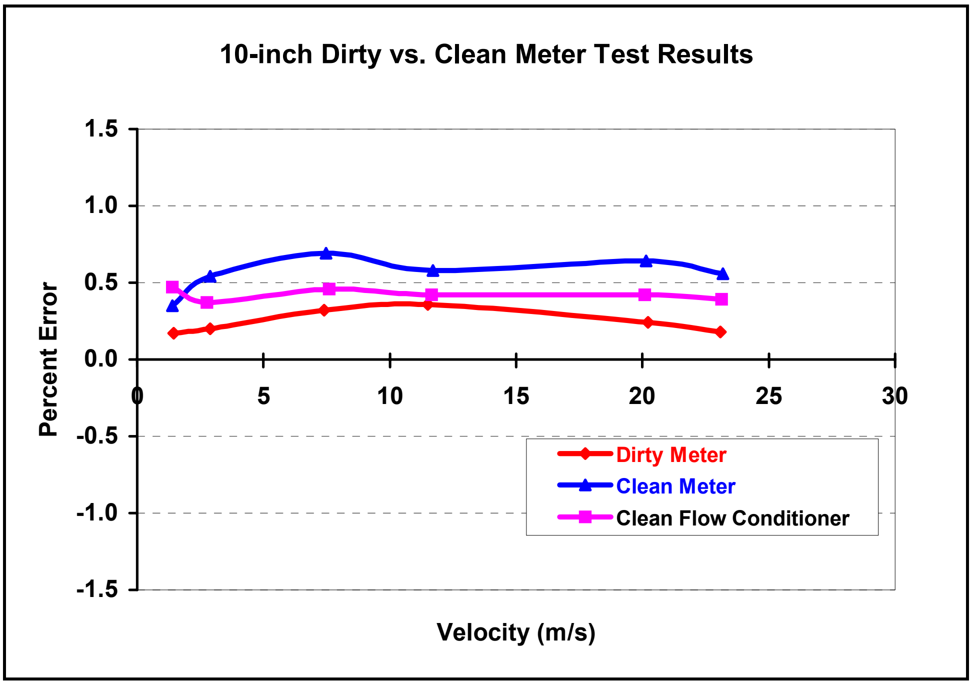


Figure 3 – 10-Inch “Dirty” and “Clean” Meter Results

This meter was previously calibrated at another facility before installation. 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. This was done 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.

As was mentioned earlier, the meter body had a mill-scale buildup of about 0.010-inch. This buildup effectively reduces the cross sectional area of the meter causing the velocity to increase for the same given flow rate. This would result in a meter reading faster when compared to its clean condition. However, the meter registered slower when dirty as compared to when it was clean.

The FWME for the dirty results in Figure 2 is 0.9975. After cleaning only the flow conditioner the meter factor was 0.9959, and after cleaning the meter body, flow conditioner and all meter 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 when dirty instead of faster?

Following is a graph that can be used to help diagnose the meter’s data and explain why the meter went faster when cleaned. This graph represents the velocity ratio, in percentage, of each chord relative to the meter’s reported velocity. It was computed from the data taken at 11 m/s.

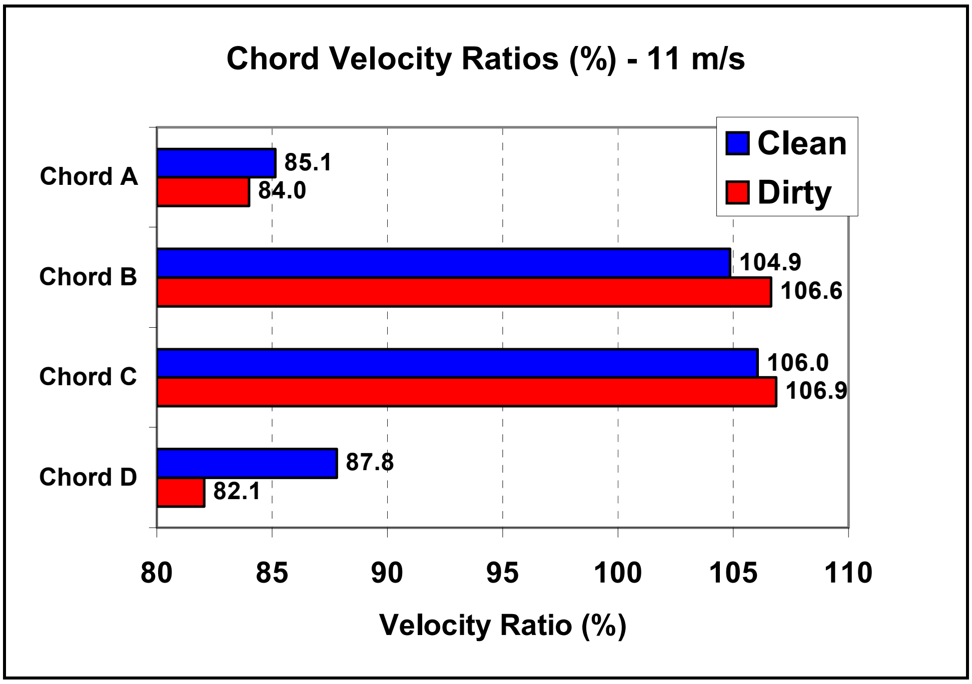


Figure 4 – Chord Ratios at 11 m/s

From the graph in Figure 4 it is clear the velocity profile has changed from the clean to dirty meter (red bar graphs are for dirty and blue for clean). The chord ratio profile remains virtually the same over the entire velocity range. Thus, it is not necessary to have a variety of gas velocities, or a prover system, in order to determine if the velocity profile has changed (from the original clean to dirty condition). Since the technician generally collects "start-up" information on the meter, the velocity profile analysis can be used to later determine if the meter is dirty during regularly scheduled inspections.

When looking at the chord ratios for B & C (the middle two chords) notice the difference between the clean and dirty meter. In both graphs the dirty velocity ratio is higher than the clean. The A & D chord ratios showed a bit more pronounced effect from dirty to clean, but in the opposite direction. Their 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 this graph is helpful in identifying a changed profile, a simpler method would be beneficial. Rather than look at the ratio of each chord to the meter's reported average, a single value to monitor would make diagnosing problems easier. One such method would be to average the two center chord velocity readings and then divide by the average of the two outer chord velocity readings ((B+C)/(A+D)). Figure 5 is a summary of this comparison performed at each of the flow velocities during the test, and for all three conditions (dirty, clean flow conditioner, and clean meter). The single value used to monitor the chord ratios is called "Profile Factor."

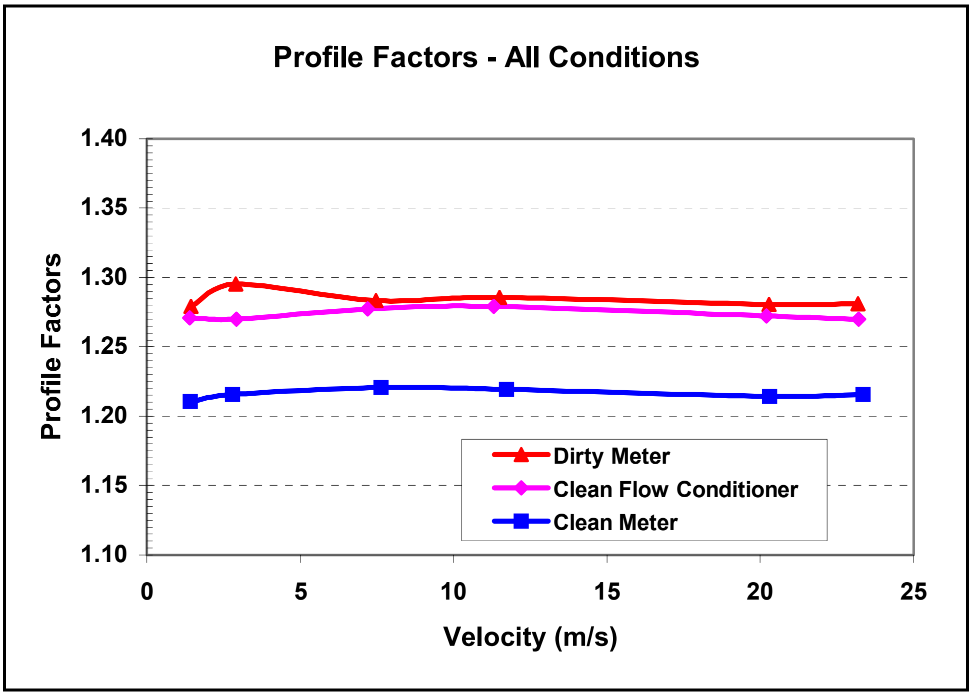


Figure 5 – Profile Factor for All Velocities

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

Notice the profile factor changed only slightly when the flow conditioner was cleaned (**magenta** color). It appears the majority of the profile effect was due to the upstream piping and perhaps the meter's internal coating.

Collecting data and determining the profile factor is very important when performing a periodic inspection. As was mentioned in Section 2, there are at least 3 things that occur in a meter when the meter, and associated upstream piping, becomes 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. So, this leaves the profile factor 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. However, since the opposite occurred, what can be the cause? Well, as can be seen from the above flow profile factor, there was a definite change. This profile change (from a flatter profile to a more pointed one when dirty) caused the meter to under-register more than the inside diameter (ID) reduction caused it to over-register. Thus, one effect somewhat cancelled out the other. The theory says that the chordal design should be insensitive to wall roughness effects [Ref 10]. However, the velocities derived from the 4 different chordal paths integrate over an area between the transducers probably contributing to the meter not following exactly the theory.

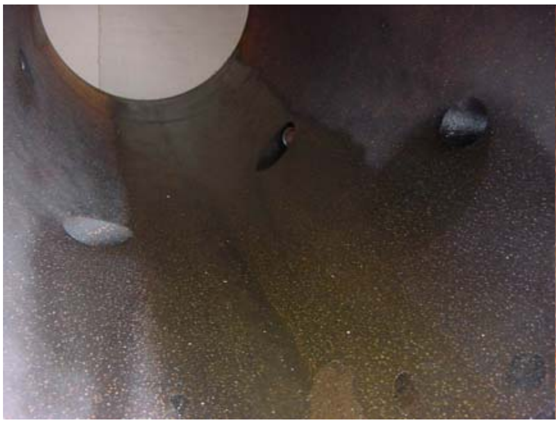
With today's more powerful user interface software, diagnosing field related performance problems is becoming much easier. This type of profile analysis is now standard in the ultrasonic interface software. Thus, each time an inspection is performed (either monthly or quarterly), data is being collected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

3.3 16-Inch Dirty Meter

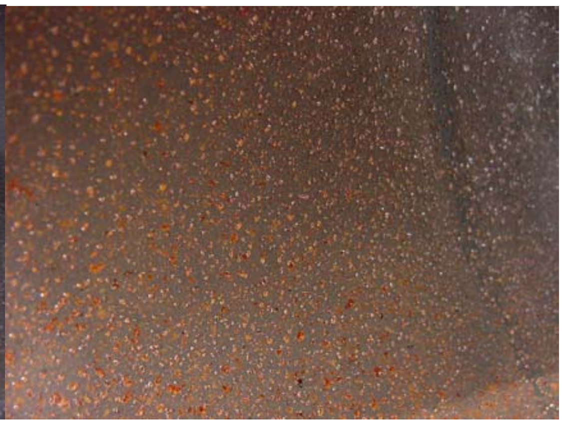
Both of the previous meter results were obtained in 2002 and presented in a paper at the AGA Operations Conference [Ref 5]. Since that time additional meters have been tested and also more has been learned about meter performance once the USM does get dirty.

In July of 2004 a 16-inch meter was removed and calibrated dirty and clean. This meter had been in service since 1996. It was never calibrated because it was a check meter at an electric generation facility. The customer decided to remove and calibrate to reduce measurement uncertainty. Typically most users have flow conditioners. However, for this application, the designer did not specify a flow conditioner, so the upstream piping was not sent with the meter. The calibration facility supplied the upstream and downstream piping for the calibration.

These following pictures show the condition of the meter and transducers prior to cleaning.



Picture 17 – 16-inch Body



Picture 18 – 16-inch Body

Picture 19 – 16-inch Transducers

Picture 20 – 16-inch Transducers

Picture 17 shows the interior of the meter coated with an oily substance. Picture 18 shows this coating has some texture to it and is merely not just a thin coating of oil. Unfortunately the thickness of the coating was not measured.

Picture 19 shows the transducer faces are clean. They're clean because they don't protrude beyond the meter wall. Thus, with this meter design, transducer buildup is virtually non-existent. As there was nothing coating the transducers, the gain and SOS were not impacted. This is important since a coating on the transducer faces will cause the meter to register faster than with no coating [Ref 9].

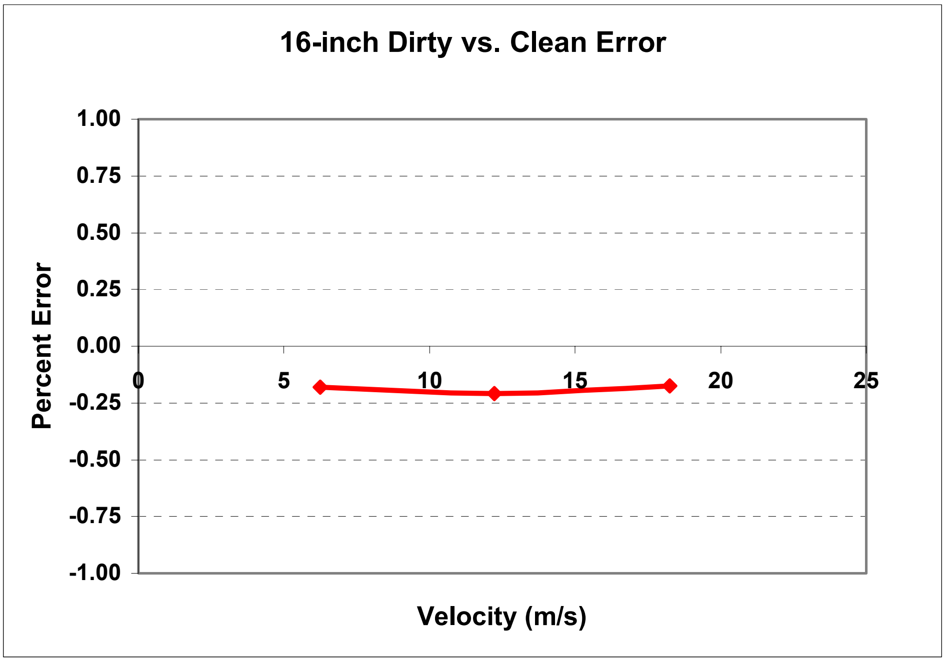


Figure 6 – 16-Inch Dirty vs. Clean Difference

Figure 6 shows the difference in meter error when it was dirty versus clean. That is, this meter registered slower by about 0.2% when dirty just as the 10-inch in Section 3.2 showed.

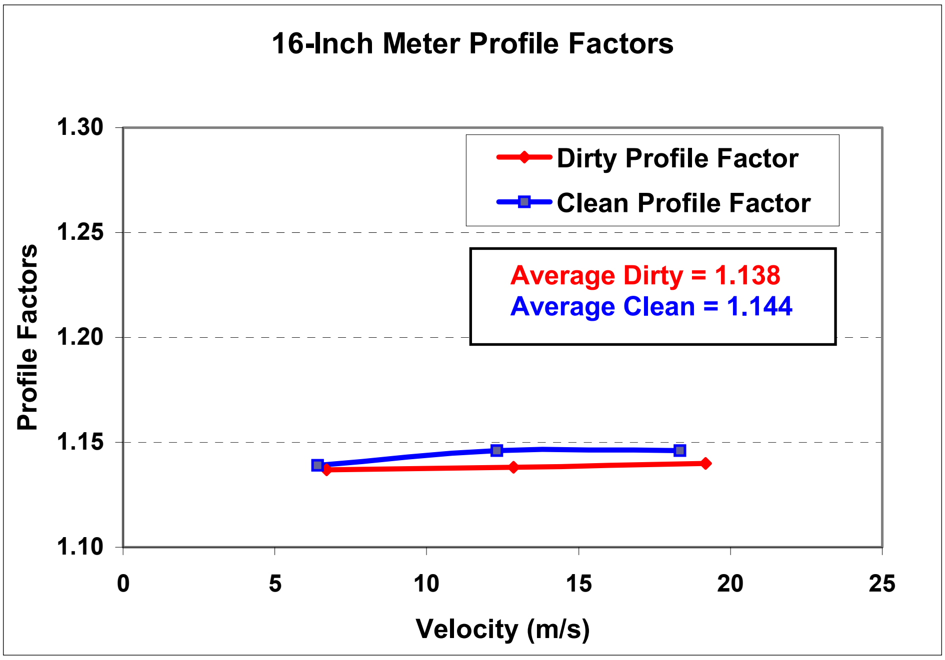


Figure 7 – 16-Inch Profile Factors

Figure 7 shows the profile factors, both dirty and clean, at the three calibration velocities. In this example there is virtually no difference in profile factor between dirty and clean, or at the different velocities. The 10-inch meter in Section 3.2 showed a significant change in profile factor (0.06). This change did not occur for the 16-inch as the difference was only 0.006.

It takes several diameters of piping to establish a flow profile. Since the upstream piping was clean, simply cleaning the meter essentially did not change the velocity profile as seen by the meter. From this it might be concluded that it is important to calibrate the USM with the upstream piping if the true performance of the meter in the field is to be realized.

3.4 20-inch Dirty Meter

A 20-inch meter removed for calibration after they had been in service for almost 4 years. This meter was installed with a one-piece flow conditioner. The user wanted to determine if meter accuracy had shifted during this time. For this calibration the upstream spool and flow conditioner, along with the downstream spool, were shipped to the lab. They were sent to the lab assembled in order to minimize any change in the coating inside the meter and piping.

Picture 21 – 20-inch Body

Picture 22 – 20-inch Body

Picture 23 – 20-inch Transducers

Picture 24 – 20 inch Transducers

As Picture 21 shows this meter had some contamination throughout the meter body. Picture 22 shows that the coating was more than just an oily film as it had a very rough texture. Picture 23 shows contamination exists on the transducer housings, but in Picture 24 there is again no contamination on the face of the transducer.

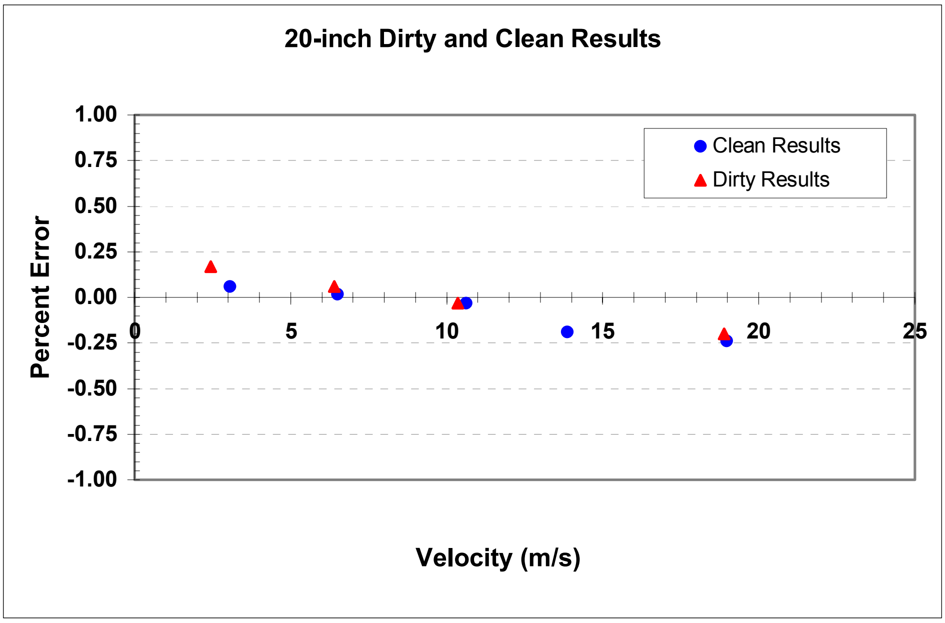


Figure 8 – Error Results from 20-Inch Meter

The results of the calibration show virtually no difference between the dirty and clean results. The average difference in error for the data points is about 0.05%. This is below the stated repeatability of the facility and the meter. The extra data point at 14 m/s was taken after cleaning as this customer elected to re-calibrate before returning the meter to service. Thus, one might conclude there was no effect on meter accuracy.

Graph 9 shows the profile factor for both conditions (dirty and clean). Since the error from dirty to clean was virtually zero, it isn't too surprising to see that both profile factors are virtually identical. The upstream coating inside the piping had very little impact on the profile, and thus little impact on the meter. Probably the reason the coating had little impact was due the larger diameter. The same amount of buildup on a larger meter appears to cause less shift in meter performance.

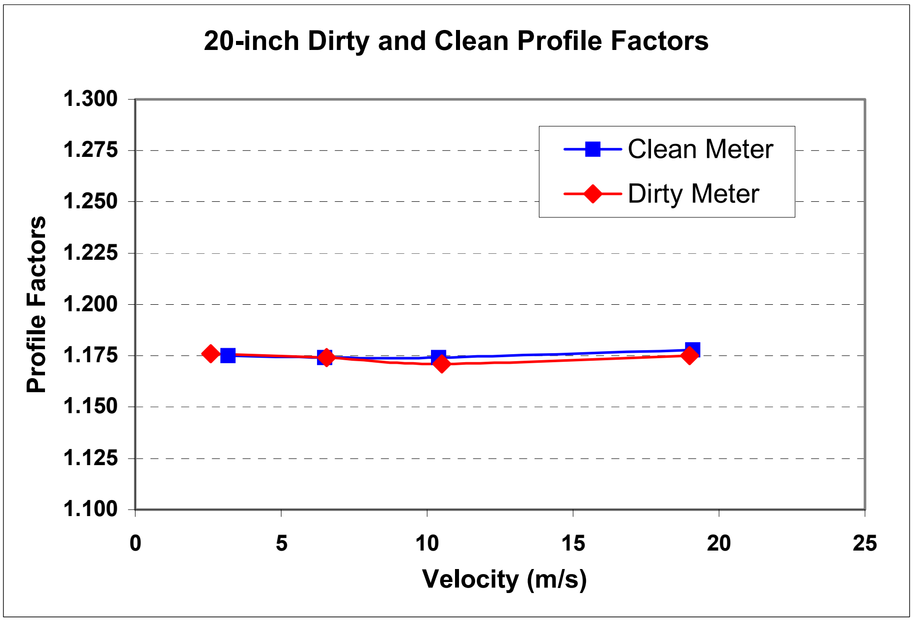


Figure 9– Profile Factor for 20-Inch Meter

4 Conclusions

The meters presented in this paper show that the effects of contamination on the USM 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 [Ref 8]. Pipeline contamination is just another installation effect that is more difficult to quantify. Thus, it should not be assumed that all USMs 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 (ID) 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 read higher [Ref 9]. Neither of the meters in this paper 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 [Ref 4].

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

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

The results on the 16-inch meter also showed that it registered slower by approximately 0.2% when dirty. The profile factor was virtually unchanged for this meter. The reason for the small change is clean upstream piping was used for the test. The customer did not send piping from the installation, so the calibration facility used their clean piping. If the field piping had been included, most likely the profile factor would have changed more.

The results from the 20-inch showed virtually no shift in meter accuracy from dirty to clean. The profile factor also showed very little effect. For larger meter sizes it might be concluded that the profile factor will shift less for the same amount of build-up. Thus, the meter's accuracy is also less affected.

From the results of these the meter calibrations presented in this paper, an interesting conclusion might be drawn. It appears that the larger meters are less sensitive to buildup. The 20 and 24-inch meters showed virtually no change in performance. This my seem intuitive to some since a 2 mm buildup on a 10-inch meter has more impact on the meter's cross-sectional area than on a 20-inch. Also, it appears that the same amount of buildup on both meters affects the 10-inch profile factor more than the 20-inch.

Traditionally most feel that using more meters in parallel reduces the uncertainty. <u>However, if the gas is not clean, and the metering is subjected to oils and mill-scale, using fewer, larger meters may actually reduce total uncertainty</u>.

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 anywhere in the world. This ability to remotely monitor, and diagnose a meter's health, is just one more reason ultrasonic meter have gained such widespread acceptance during the past several years.

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