North Sea FLOW Measurement Workshop

Paper 1.2

Wet Gas Test Comparison Results of Orifice Metering Relative to Gas Ultrasonic Metering

John Lansing
SICK | MAIHAK, Inc.

Toralf Dietz
SICK AG

Richard Steven
CEESI, Inc.

TÜV SÜD

nel technology for life

Wet Gas Test Comparison Results of Orifice Metering Relative to Gas Ultrasonic Metering

John Lansing, SICK │MAIHAK, Inc.
Toralf Dietz, SICK AG
Richard Steven, CEESI, Inc.

1. ABSTRACT

Traditionally orifice meters have been used in wet gas applications rather than gas ultrasonic meters (USM). There are many reasons for this, but certainly one has been the question regarding reliability of a gas ultrasonic meter when subjected to liquid loading. The question is this: "How does the accuracy of the orifice compare to the gas USM when liquids exist?" Another question might be asked is: "Can the USM clearly identify when liquids are present, and give the operator an idea of what gas volume has passed through the meter during this time?"

To investigate these questions, two different meters were tested at the CEESI Nunn Wet Gas loop in Nunn, Colorado. The first test involved a 4-inch orifice and 4-inch USM in series (the USM was a 4 and 2-path meter all in one body). For the second test a 3-inch orifice and 3-inch, 2-path USM was tested. Both tests involved several flow rates, 2-3 different pressures, and up to 8 different levels of liquid loading. The fluid used in most of the tests was Exxsol, a kind of kerosene that is popular for this type of testing. For the 3-inch tests, a limited number of data sets were also taken using water.

This paper shows the results of these tests including transducer performance (the USM never failed even with a liquid loading of 95% gas volume fraction (or GVF)), and most importantly documents the errors seen by both types of technologies.

2. INTRODUCTION

The CEESI Nunn Wet Gas facility consists of a closed-loop test stand with up to 650 horsepower that permits flow rates from about 83 to 620 ACMH. This corresponds to 3 to 23 m/s in 4-inch Schedule 80 piping. Pressures can range from 1,380 kPa up to 7,500 kPa (13.8 Bar – 75 Bar). Gas flow is measured using a calibrated 6-inch turbine meter, and the injected liquid is measured using one of 2 different Coriolis meters (1/2" and 2" sizes). The liquid typically used is Exxsol D80, but water, or a mixture of both can also be used.

The first test involved a 4-inch dual-chamber orifice meter with the gas USM were installed in series. The second test incorporated a 3-inch dual-chamber orifice and 2-path USM, both in series. In both cases the USM was located upstream to minimize, if not totally eliminate, any affect on the orifice meter. In order to ensure that the flow profile is as realistic as possible to what would be seen in the field, the non-intrusive USM was located upstream of the orifice meter.

The 4 inch meter testing was conducted at 3 pressures (approximately 13, 33 and 55 Bar(a)), with 2 beta ratios (0.40 and 0.62), 3 differential pressures (from around 3.98 kPa to as much as about 60 kPa), and with GVFs including 100, 99.9, 99.5, 99.0, 98, 97, 96 and 95%. The 4-inch USM was a special meter built to obtain data on wet gas conditions. It includes a traditional Westinghouse® 4-path meter along with a conventional 2-path "mid-radius" meter, all within the same meter body. All testing included a Canadian Pipeline Accessories (CPA) 50E flow conditioner located at 10D upstream. Both the orifice and USM meters are Schedule 80, as well as most of the piping at the facility. Data was collected on both USMs and the orifice meter during the testing conducted in December 2009.

The 3-inch meter package tests were conducted at 2 pressures (approximately 13 and 55 Bar(a)), only one beta ratio (0.517), several differential pressures from 2.23 to 153 kPa, and GVFs including 100, 99.95, 99.90, 99.8, 99.5, 99, 98, and 95%. From testing done previously on orifice meters [Ref 1], it was decided 2 beta ratios weren't needed, and that 2 pressures would suffice. This allowed more time to focus on added liquid loading, especially lower levels. A limited number of test points were also taken with water. These included GVFs of

99.90, 99.59 and 99.15%. The intent was to see if a different viscosity fluid would have any significant affect on the results.

3. INSTALLATION DETAILS FOR THE 4-INCH ORIFICE-USM PACKAGE

Figure 1 shows the facility during data collection in December. In the foreground part of the reference gas system and the Coriolis meter (used for the liquid measurement) can be seen. The meters under test are located after a 90 degree turn and more than 100 nominal diameters of straight pipe upstream of the USM. The orifice meter was located approximately 55 nominal diameters downstream of the USM. A standard CPA 50E flow conditioner was located upstream of the ultrasonic meter at 10D.

Figure 1 – CEESI Nunn West Gas Test Facility, 4-inch Testing, December, 2009

Figure 2 shows a picture of the ultrasonic meter (a 4-path and 2-path meter in one meter body). The 4-path and 2-path meters each have separate electronics.

Figure 3 shows the inside of this USM meter. Note that the 2-path meter has protruding transducers. Often times in wet gas applications this configuration has been show to be more “durable” and able to handle higher levels of liquid loading. At the right of the picture two of the four paths of the 4-path meter can be seen. The 4-path transducers are mounted in the traditional location and are the “typical” sensor used for dry gas applications. Since these sensors are totally sealed, there is no concern about failure due to liquid contamination within the sensor itself.


Figure 2 – Ultrasonic 4+2 Meter


Figure 3 – Transducers in the 4+2 Meter

Figure 2 also shows the flow conditioner mounted with differential pressure transducers. A CPA 50E was used for all testing regardless of pressure or liquid loading. Data was collected during the tests to document the differential pressure during all tests. This information will not be presented in this paper. A traditional 19-tube bundle was installed upstream of the dual-chamber orifice meter and was there for all testing.

4. INSTALLATION DETAILS FOR THE 3-INCH ORIFICE-USM PACKAGE

The second meter tested was a modified 2-path, 3-inch Schedule 80 meter located upstream of the 3-inch orifice fitting. Based on "lessons learned" from the 4-inch testing in December, 2009, it was decided to concentrate on two pressures (13 and 55 Bar(a)), and only one Beta ratio (0.517). Previous test results didn't indicate any significant issue at the intermediate pressure (33 Bar(a)), and the second Beta ratio (0.62) previously tested with the 4-inch didn't show any "surprises" either. Eliminating these from the test plan allowed more time to focus on lighter liquid loading as requested by some end users. Thus, for most of the tests on the 3-inch, liquid loadings included 100, 99.95, 99.90, 99.8, 99.5, 99, 98, and 95% percent GVF (approximate values). The highest level of GVF was not tested at 13 Bar(a) as the mass of the gas was too low compared to the liquid and this would cause slugging and very erratic results.

The testing at 55 Bar(a) was conducted both with and without a CPA 50E flow conditioner as many users incorporate flow conditioners at the higher pressures. At the lower pressures, users have to pay for compression. Thus there was little benefit in testing the package with a flow conditioner since few, if any, would install in this configuration. Some additional testing with water was also conducted at 55 Bar(a) (fewer liquid loadings) in lieu of the Exxsol D80 with the CPA 50E flow conditioner installed.

Figure 4 shows the installation of the ultrasonic meter (on the right) upstream of the orifice meter. Flow is from right to left. The CEESI piping consists of 4-inch, Schedule 80 piping. Upstream of the meter a 4x3 eccentric reducer was used. This eliminates "damming" at the reduction part. Approximately 39D of straight 3-inch, Schedule 80 pipe delivered flow to the upstream section of the USM meter package. The piping of the USM consisted of a 10D section of straight Schedule 80 pipe upstream of the CPA (when used) and then the 10D section upstream of the meter body (this part was welded to the measurement section). The USM was a straight through bore with no taper. After the USM there was approximately 16D of straight Schedule 80 piping prior to the orifice meter package. The orifice meter package included an upstream section that was 15D, a 19-tube bundle, and 13D of straight pipe in front of the dual-chamber fitting.

Figure 5 shows a close up of the meter and its associated, integrated upstream piping. The upstream section where the CPA flow conditioner is located for some of the tests is on the right. Figure 6 shows the CPA 50E flow conditioner. This was a modified flow conditioner with a tab welded to the unit to insure proper rotational alignment after installation. The two holes side by side are for two studs that bolt the flanges together. This makes orienting the CPA to top dead center very easy during installation, and simplifies future alignment.

Figure 4 – 3-inch Orifice and USM Installation, August 2010

Figure 5 – 3-inch USM and Piping

Figure 6 – 3-inch CPA 50E

5. 4–INCH METER TEST RESULTS

A week of testing was scheduled for collecting the 4-inch meter package data. Typically CEESI will run the meter with no liquid loading (GVF of 100%) to obtain a baseline, and then start the liquid loading with the highest first working to the lowest as the final test.

As discussed earlier, the 4-inch USM meter contained essentially two different meters. The 4-path version is a well tested and proven design with all the appropriate coefficients well known. The 2-path was a special meter, and as such there was no experience regarding the coefficients. Thus, the results of the dry testing (GVF of 100%) show the meter is on the order of 2% fast. This would, of course, normally be close to zero, and this offset should be subtracted from the various liquid loading tests to provide a more representative liquid loading result.

With so much data to present, and as there was little difference in the 33 Bar(a) and the 55 Bar(a) results, this paper will focus on 13 and 55 Bar(a). This will also be important when comparing the results of the 3-inch meter (tested at only 13 and 55 Bar(a)) to the 4-inch (both

USM and orifice). The flowing gas temperature varied from about 25 to 26 ºC for most tests with a couple being around 22 ºC.

In order to achieve the range of flows as shown in Figures 7 and 8, two beta ratios were used. For the lower flow rates, a beta of 0.4037 was used, and for the higher rates, 0.620 was used. Differential pressures varied from about 4 to a high of 57 kPa for the 0.4037 beta, and from 3.2 to 95 kPa for the 0.620 beta tests.

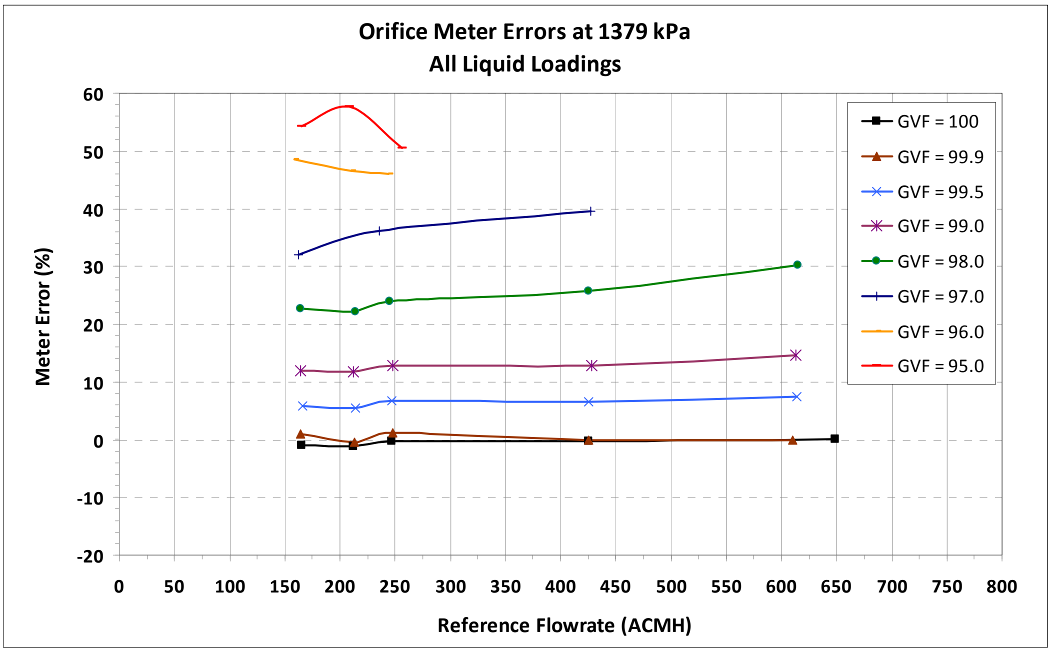

Figure 7 – 4-inch Orifice Meter Results – 13 Bar(a) – All GVF Values (ACMH)

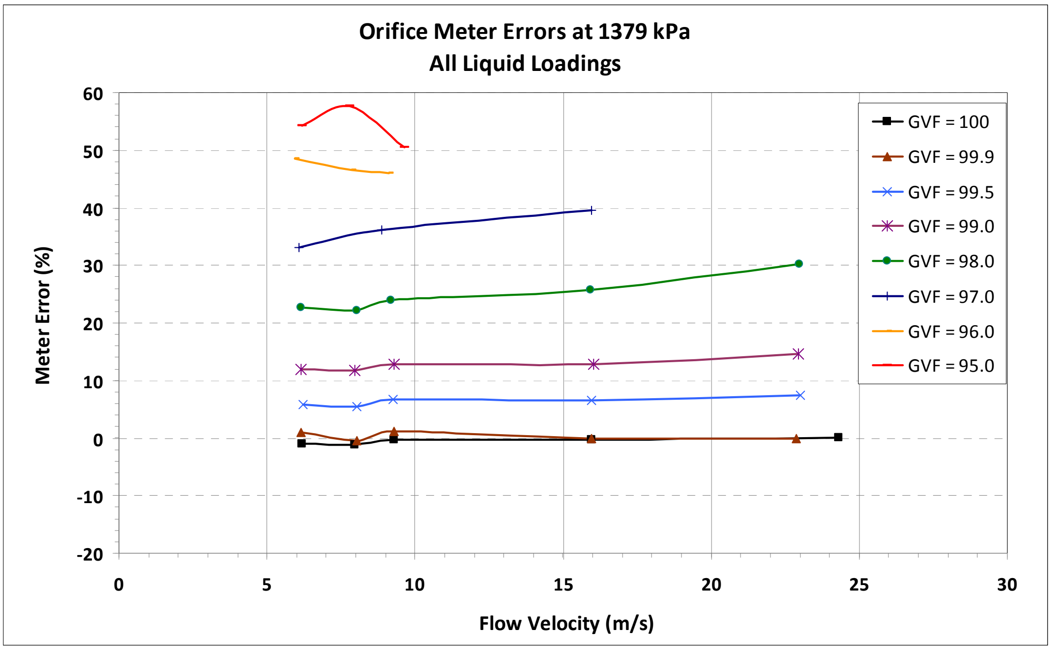

Figure 8 – 4-inch Orifice Meter Results – 13 Bar(a) – All GVF Values (Velocity)

Figure 8 is identical to Figure 7 but shows the flow in the X axis in velocity. Figure 7 uses the same axis as the USMs for simplicity, but of course we don't talk about flow in an orifice in ACMH. This Figure 8 provides the error as a function of gas velocity. It can be seen that as the liquid loading increases, the orifice meter has an increasing positive bias (usually called an "over-reading").

Figure 9 shows the results of the 2-path meter at about 13 Bar(a) (1379 kPa) with all test conditions. This includes GVF values starting at 100 and ending at 95.0%.

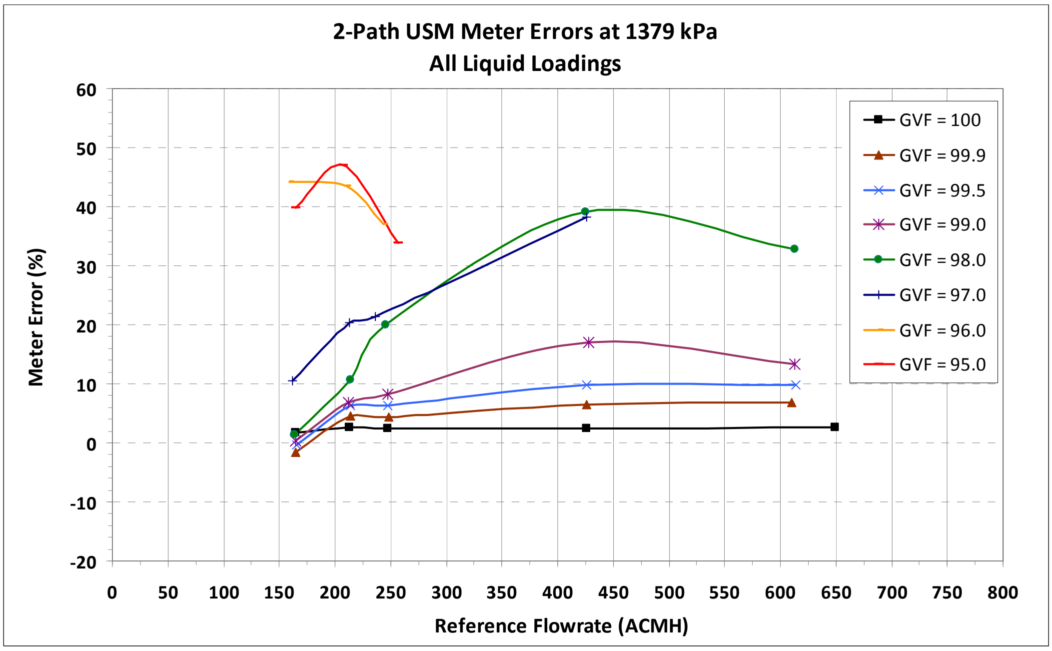

Figure 9 – 4-inch 2-Path Meter Results – 13 Bar(a) – All GVF Values

The 2-path meter was similar in accuracy to the orifice meter as can be seen by comparing the over-readings in Figure 7 with Figure 9.

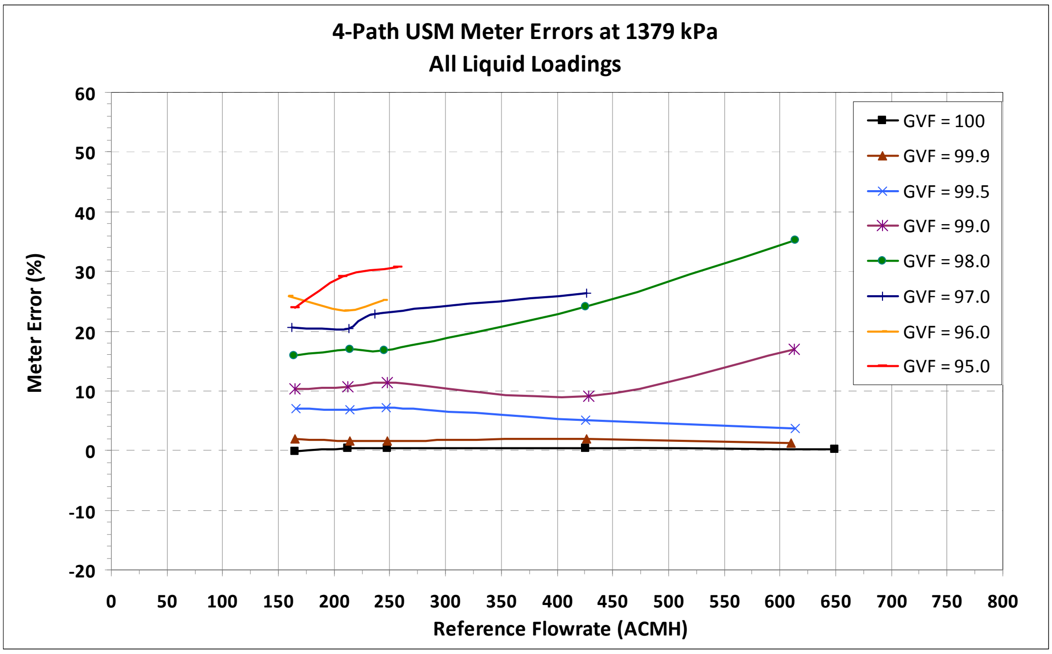

Figure 10 –4-inch 4-Path Meter Results – 13 Bar(a) – All GVF Values

Note that all graphs for the 13 Bar data contain the same scales for both the flow rate (X-axis) and the Meter Error (Y-axis). It is clear that liquid loading generally causes all meter errors to be positive (over-reading). At low liquid loadings on the 2-path, and at lower velocities, the errors are typically within less than 2%. However, once the liquid loading approaches a GVF of 98.0%, all meters begin experiencing significantly more errors. In all but the lowest flow rates, and lowest liquid loading, these 3 meters over registered. How much was mostly a function of GVF, but there is some correlation to meter error from flow rate. The following graphs are from the 55 Bar(a) testing for the same conditions.

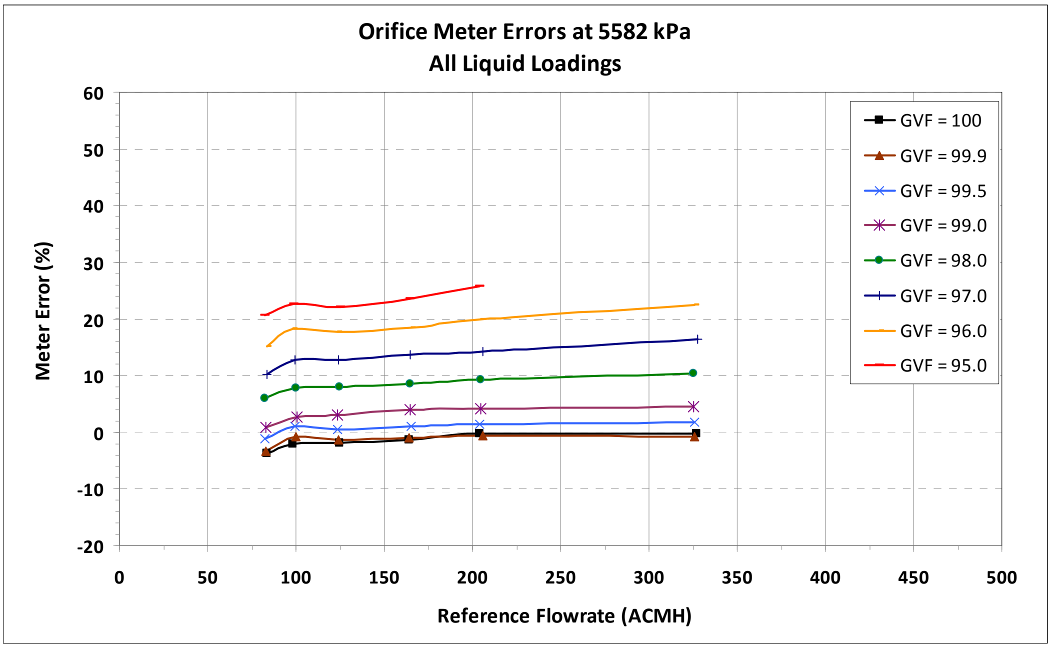

Figure 11 – 4-inch Orifice Meter Results – 55 Bar(a) – All GVF Values (ACMH)

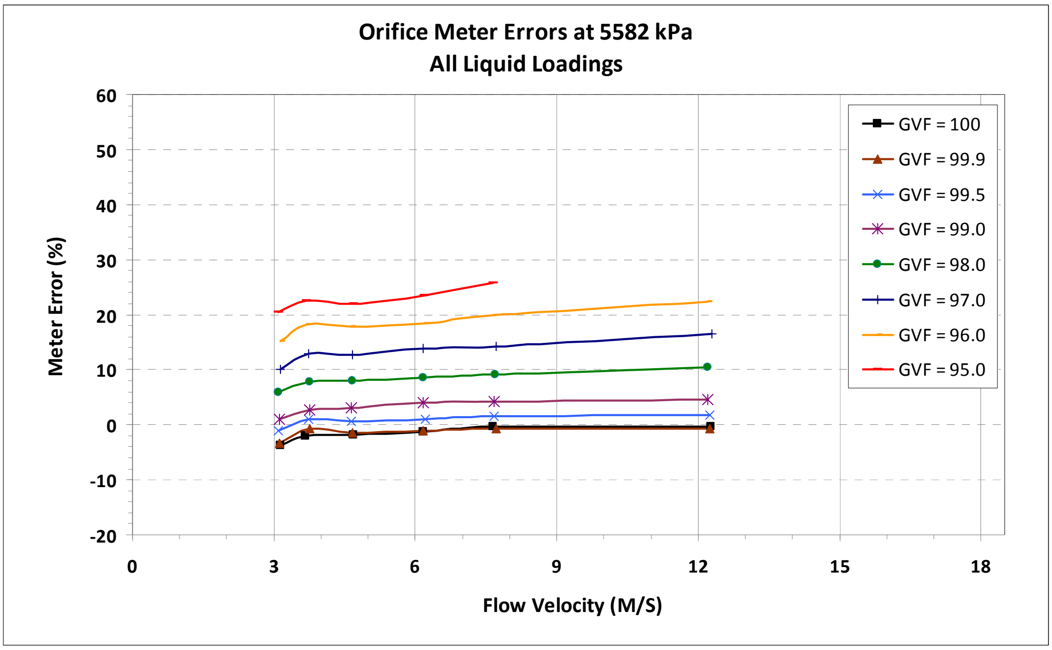

Figure 12 – 4-inch Orifice Meter Results – 55 Bar(a) – All GVF Values (Velocity)

As before, Figure 12 is identical to Figure 11, but it shows the flow in the X-axis in velocity and re-scaled to provide a similar X-axis result. Figure 11 uses the same axis as the USMs for simplicity.

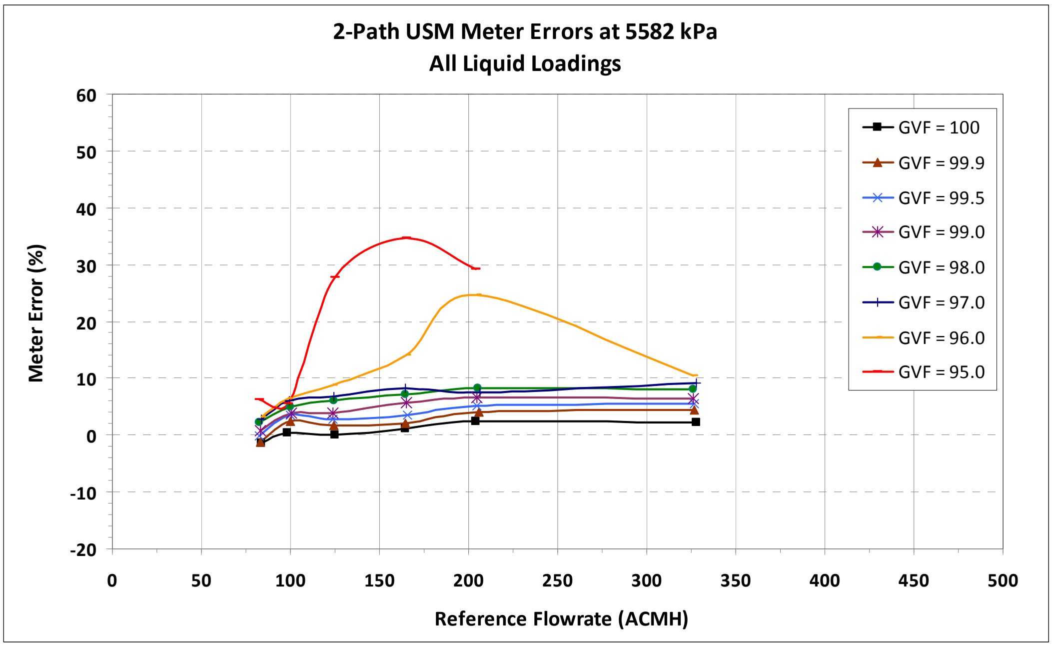

Figure 13 – 4-inch 2-Path Meter Results – 55 Bar(a) – All GVF Values

Figure 13 results indicate the 2-path meter performs better for liquid loading of 97% GVF and less, but at the higher loadings (96% and higher) the error begins to increase and at 95% its error is greater for the higher flow rates than the orifice. In Figure 14 the results show the 4-path meter to have similar errors to the orifice with no significant differences relative to the various GVFs tested.

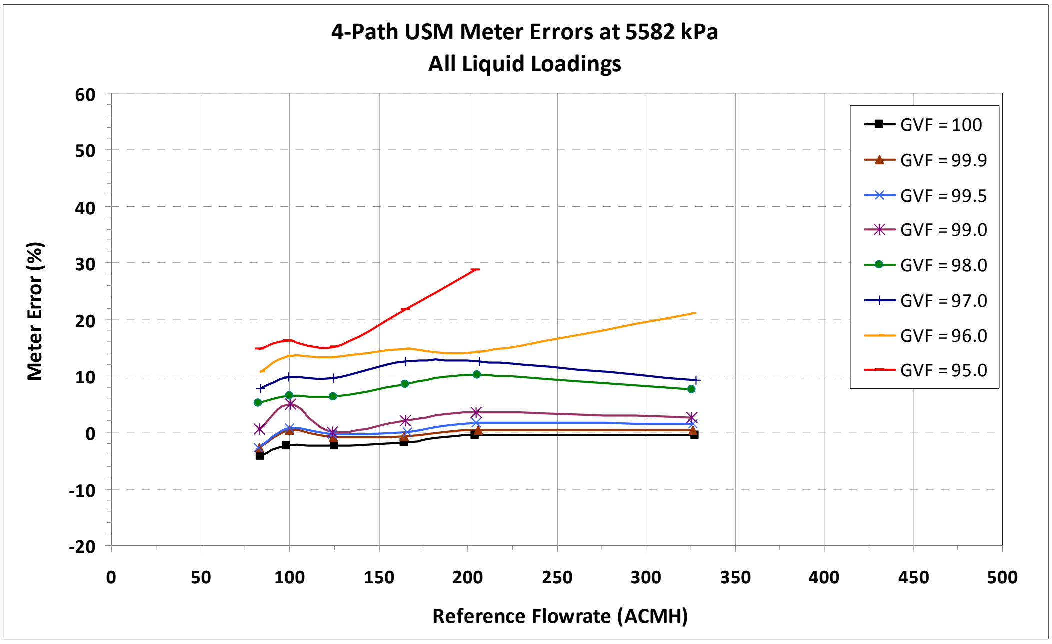

Figure 14 – 4-inch 4-Path Meter Results – 55 Bar(a) – All GVF Values

6. 4–INCH GAS ULTRASONIC METER DIAGNOSTICS

By reviewing the 4-path meter diagnostics, it is clear the meter is having no problems with GVF values of 100 and 99.9% GVF. As the liquid loading increases, so do the “Warnings” and eventually path failure (below 5% accepted) occurs at a GVF of 98.0%.

As the liquid loading increases beyond 99.9% (lower GVF), several diagnostic indicators are warning the user of potential issues. First the Turbulence on Path 4 exceeds normal conditions and it goes into a "Warning" condition at 99.5% GVF. As liquid loading continues to increase there are now "SOS" and "Performance" Warnings.

Finally at 98% GVF the lowest path fails. Beyond this level of liquid loading, additional "Warnings" are activated, but there are no additional path failures. The important thing to note is the meter continues operation while several "Warnings" are indicating problems to the user. Obviously if the measurement were an orifice meter, no one would know that liquid is present. Just one of the many benefits of using a meter with advanced diagnostics.

The following Health diagnostics were from 55 Bar(a) and a gas velocity of 7.6 m/s. These are representative of the other velocities. All of these tests included a CPA flow conditioner.

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	ok	Path Error	ok	ok	ok	ok
Warning Symmetry	ok	Warning Turbulence	ok	ok	ok	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	ok
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	ok
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	ok
		Warning Performance	ok	ok	ok	ok

Figure 15 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 100 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	ok	Path Error	ok	ok	ok	ok
Warning Symmetry	ok	Warning Turbulence	ok	ok	ok	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	ok
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	ok
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	ok
		Warning Performance	ok	ok	ok	ok

Figure 16 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 99.9 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	ok	ok
Warning Symmetry	W	Warning Turbulence	ok	ok	ok	W
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	ok
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	ok
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	ok
		Warning Performance	ok	ok	ok	ok

Figure 17 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 99.5 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	ok	ok
Warning Symmetry	W	Warning Turbulence	ok	ok	ok	W
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	ok
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	ok
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	W
		Warning Performance	ok	ok	ok	W

Figure 18 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 99.0 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	ok	E
Warning Symmetry	W	Warning Turbulence	ok	ok	W	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	W
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	W
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	W
		Warning Performance	ok	ok	ok	W

Figure 19 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 98.0 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	ok	E
Warning Symmetry	W	Warning Turbulence	ok	ok	W	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	W
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	W
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	W
		Warning Performance	ok	ok	W	W

Figure 20 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 97.0 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	ok	E
Warning Symmetry	W	Warning Turbulence	ok	ok	W	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	ok	W
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	W
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	W	W
		Warning Performance	ok	ok	W	W

Figure 21 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 96.0 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	W	Path Error	ok	ok	E	E
Warning Symmetry	W	Warning Turbulence	ok	ok	W	ok
Warning High Gas Velocity	n.a.	Warning SNR Limit	ok	ok	W	W
Warning Low Input Voltage	n.a.	Warning AGC Dev	ok	ok	ok	ok
Warning logb. full of unackn. entries	n.a.	Warning AGC Limit	ok	ok	ok	W
Warning Diagnostic Difference	n.a.	Warning SOS dev	ok	ok	ok	W
		Warning Performance	ok	ok	W	W

Figure 22 – 4-inch, 4-Path Meter Health – 55 Bar(a) – 95.0 GVF

Figures 23 thru 27 summarize the various 4-inch, 4-path diagnostic data that supports the Health Warning data in Figures 15-22. This data is from the 7.6 m/s flow rate that provides examples of what the diagnostics do with liquid loading values varying from 100% GVF to the 95% values. They are representative of other flow rates.

The following graphs (Figures 23-26) represent various diagnostics from the meter from a GVF of 100% to 96.0%. Figure 23 shows total path failure occurred first on Path 4 at a GVF of 99% (also shown by the Figure 19 of the Meter Health graphs). Figure 22 show that Path 3 had failed (red with “E” in the box from Figure 22), but this only means the performance was below 5%. In actuality the performance was 1.5%, and explains why there is a Path Ratio even at 96% GVF. Figure 25 shows the SOS of each path (until it failed), and Figure 26 shows the Turbulence of each path. Path 4 Turbulence exceeded 100% at the 99.0 GVF value, but the graph scale was set at 25 so as not to compress all the other data.

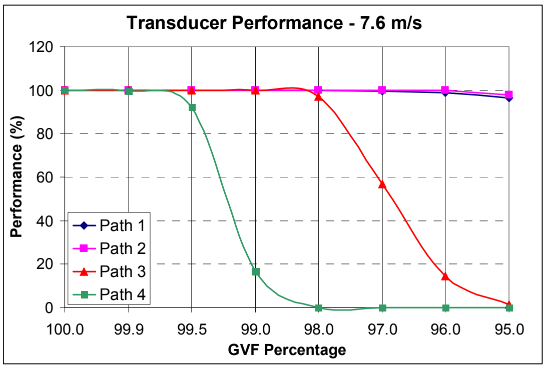

Figure 23 – Path Performance

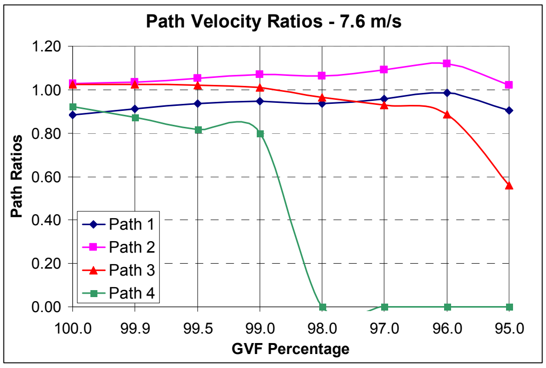

Figure 24 – Path Ratios

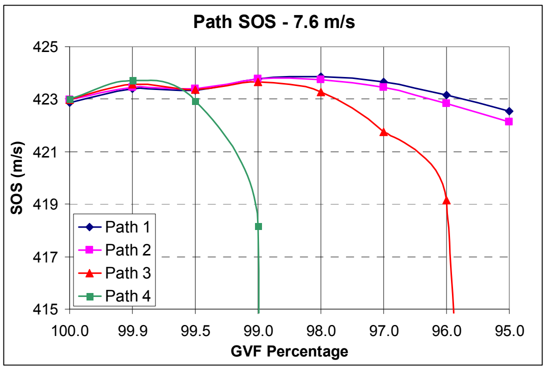

Figure 25 – Path SOS

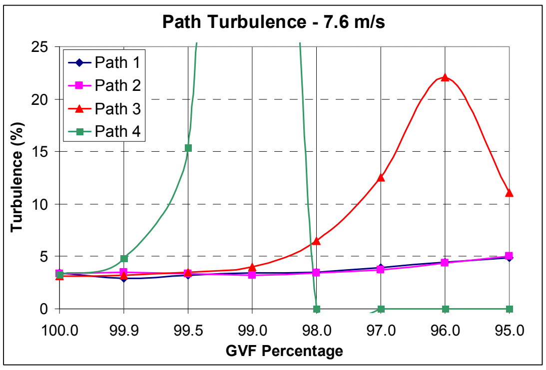

Figure 26 – Path Turbulence

Figure 27 shows the Profile Factor and Symmetry over the range of liquid loading. Note that the Profile Factor starts at 1.13 with a GVF of 100%, and the Symmetry is 0.981, both of which are normal for this meter and within expected tolerances. As the liquid loading increases (GVF value decreases), both Profile Factor and Symmetry gradually increase until the GVF exceeds 99%. At this liquid loading the gas velocity profile becomes much more distorted and there is significant step-change in both Profile Factor and Symmetry. This is also the level of GVF where the Turbulence becomes excessive on Path 4. Only when the GVF is less than 98% does Path 3's Turbulence increase significantly. Paths 1 and 2 increase some, but not to the same degree because the liquid is not affecting the profile as much at the top of the meter as it is at the bottom.

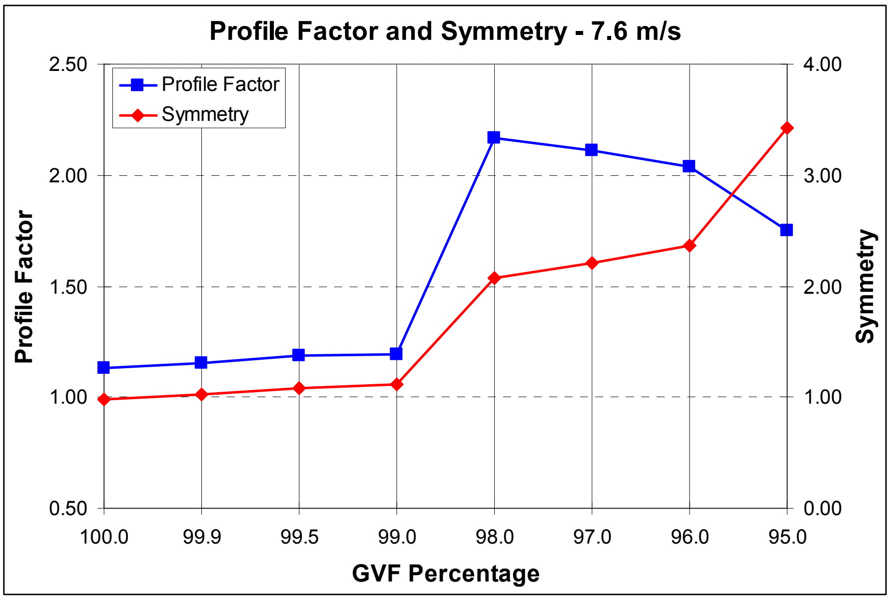

Figure 27 – Profile Factor and Symmetry

7. 3–INCH METER TEST RESULTS

From all data that was obtained in December, 2009 from the 4-inch USM and orifice package, and after analysis of the results, a modified 3-inch meter was developed. This meter had some minor changes to the design, and also incorporated the upstream meter tube (typically 10D) as part of the "package." Rather than have a separate 10D section bolted to the meter body, which is common for USMs, this upstream section was welded to the meter body.

The primary purpose of the integrated upstream section is to help reduce manufacturing costs, and ultimately the cost of ownership. One of the key considerations in using the orifice in lieu of the USM has been price. In order to be competitive (total cost of ownership), packaging the meter more cost effectively is very important. Thus welding the upstream section reduces the cost by 2 flanges and also insures alignment of the piping with the "measurement section", or meter body.

Most orifice meters used in "upstream" and "midstream" production markets range from 2-6 inches. Often the gas well is brought on line, produces at high rates for a period of time, and before long the output may decrease. The user is then often replacing the plate with a small beta in order to keep the differential within company guidelines. In many cases it isn't long before the orifice meter is at the lowest beta the company permits, and now the meter run must to be replaced with a smaller line size.

With the much greater rangeability of today's ultrasonic meter, many companies believe the 3-inch USM is the optimum size for these applications (equivalent rangeability to use in lieu of 2-4 inch orifice meters). As the gas well flow rates are generally higher upon commissioning, the USM can easily handle these. When the well production decreases, the USM is still well within its operational range. With the shorter tube lengths needed with the USM, the far lower maintenance (no orifice plate checks and replacements), and the added benefit of diagnostics, the 3-inch is the good choice for a majority of these applications.

The CEESI Wet Gas Facility was built primarily for testing 4-inch meters. All of the compressors and filter-separators are optimized for this size. With a 3-inch meter being tested, the lowest flow rates the lab can achieve with stability are higher than a typical low beta ratio 3-inch meter might be operated. For this reason the differential pressures (dP) on the 3-inch orifice, with a 0.517 beta, were no lower than about 6.2 kPa. In order to obtain the higher flow rates (rangeability), dPs (dry) were planned for as much as 153 kPa with dry gas, and of course much higher with liquid loading.

The testing for this meter was performed at two pressures: 1,344 kPa(a) (13.44 Bar(a)) and 5,500 kPa(a) (55 Bar(a)). From all the previous testing, there wasn't any significant difference between the 34 Bar(a) and 55 Bar(a) data. This permitted running more differential pressures and liquid loading tests during the same period of time. Also, from previous feedback from end users, there was more interest in lower levels of liquid loading, so additional points were taken. The goal was to obtain data on the following GVF values: 100, 99.95, 99.90, 99.8, 99.5, 99, 98, 97 and 95%. These were the targets with the 95% test only suitable for the higher pressure due to the increased gas density.

For the low pressure testing, no flow conditioner was used with the USM, but the traditional 19-tube bundle was used with the dual-chamber orifice meter. The purpose of testing at this low pressure is because many field applications operate around 700 kPa(a). Pressure drop in these measurement systems is critical as this gas must be compressed for transportation. Thus, having a USM with no pressure drop is a significant benefit. Therefore, it was decided to test the meter without the CPA at the 13 Bar(a), and also at the 55 Bar(a) level. For those users that prefer a flow conditioner, testing was also conducted at 55 Bar(a) with the CPA installed.

Figure 28 shows the results of the orifice meter with all the liquid loading tests at 13 Bar(a). All graphs relating to the 3-inch testing are shown comparing the various GVF errors relative to the baseline with a GVF of 100%. This makes it easier to relate what shift the meters have by comparing the results to clean, dry natural gas.

Figure 28 shows similar results to the 4-inch meter presented earlier. Errors were not significant until the liquid loading exceeded 99.8% GVF. Beyond this the errors became much more significant. In fact the highest liquid loading (GVF of 97.83%) showed results very similar to the 4-inch at a GVF of 98% shown in Section 3. Figure 29 shows the same results as Figure 28 but with the X-axis scaled in velocity (m/s).

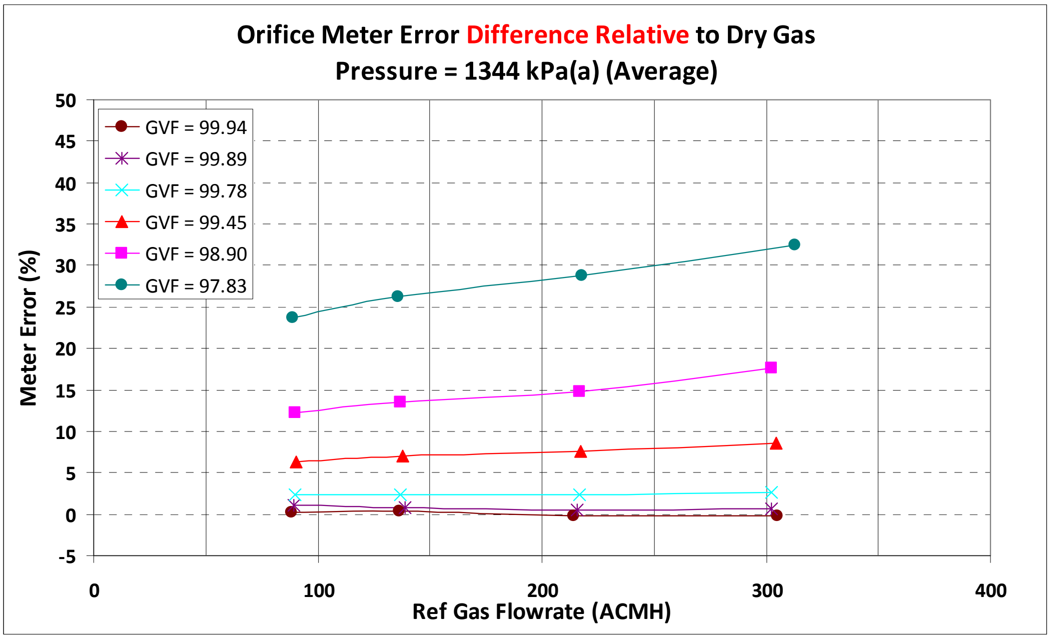

Figure 28 – 3-inch Orifice Results – 13 Bar(a) – Baseline Difference – All GVFs

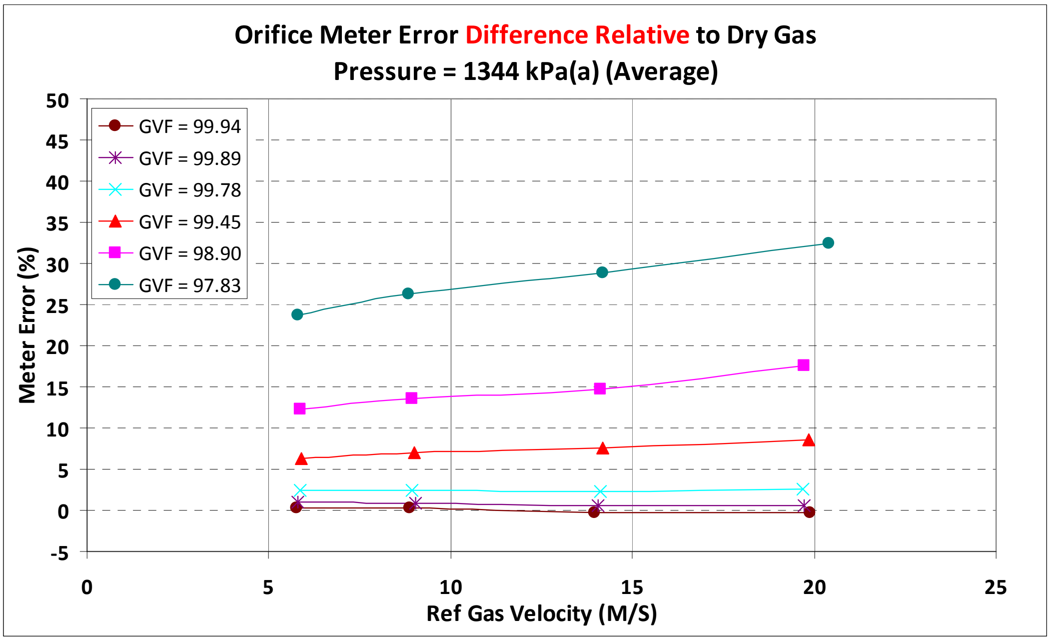

Figure 29 – 3-inch Orifice Results – 13 Bar(a) – Baseline Difference – All GVFs

Figure 30 shows the results of the 3-inch, 2-path USM with no CPA flow conditioner. It also represents the difference between the dry gas baseline and all of the liquid loading tests. Previous to this graph, all Meter Error axis ranges (Y-axis) were the same scale (0-50% error) to simplify understanding of the data. However, due to the significantly improved performance of this 3-inch meter, the Y-axis scale has been changed (-2.5% to +2.5% error) so the various results would be more legible.

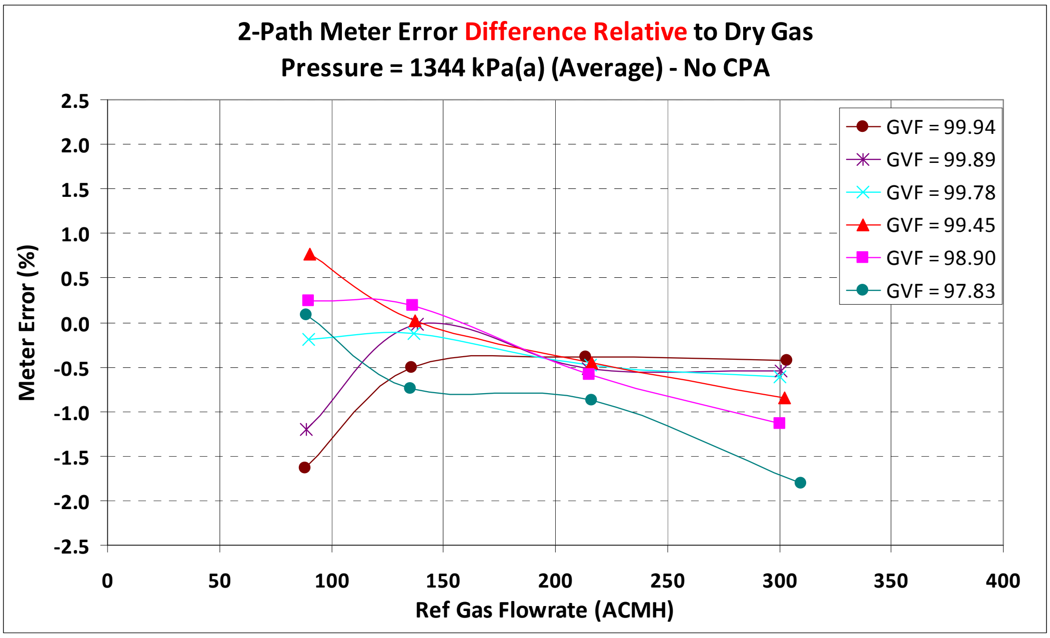

Figure 30 – 3-inch 2-Path USM Results – 13 Bar(a) – All GVFs – No CPA

These results show this meter is essentially within ±1% for GVF ≤99% or less than ±2% for virtually all tests, even the GVF of 97.83%. This prototype meter's initial test results indicate it is possible to use this USM design in these difficult applications.

The next series of tests were conducted at approximately 55 Bar(a). The same procedure was used as before. Figure 31 shows the results of the 3-inch orifice meter errors relative to the dry baseline. The USM was first tested without the CPA, flow conditioner and then the tests were repeated with the CPA.

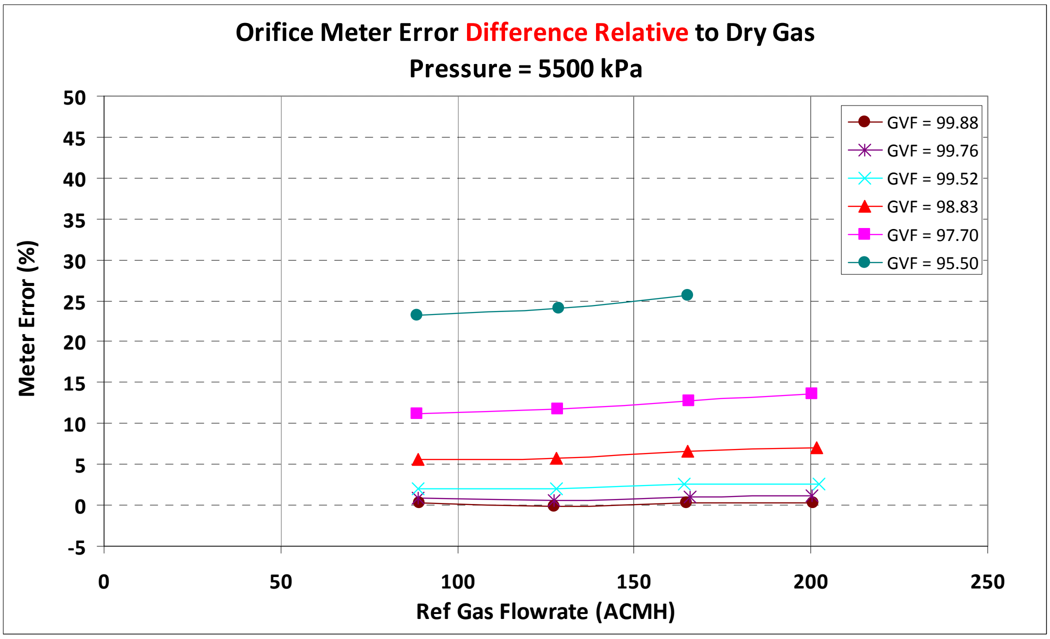

Figure 31 – 3-inch Orifice Results – 55 Bar(a) – Baseline Difference – All GVFs

The errors at 55 Bar(a), as shown in Figure 31, are very similar to those shown at 13 Bar(a) in Figure 28 (perhaps slightly less for most GVF levels). For the highest liquid loading, 95.5% GVF, there is no flow rate data due to the differential pressure exceeding the transmitter's upper limit (248 kPa). Figure 32 shows the same results but uses gas velocity in the 3-inch Schedule 80 piping for the X-axis.

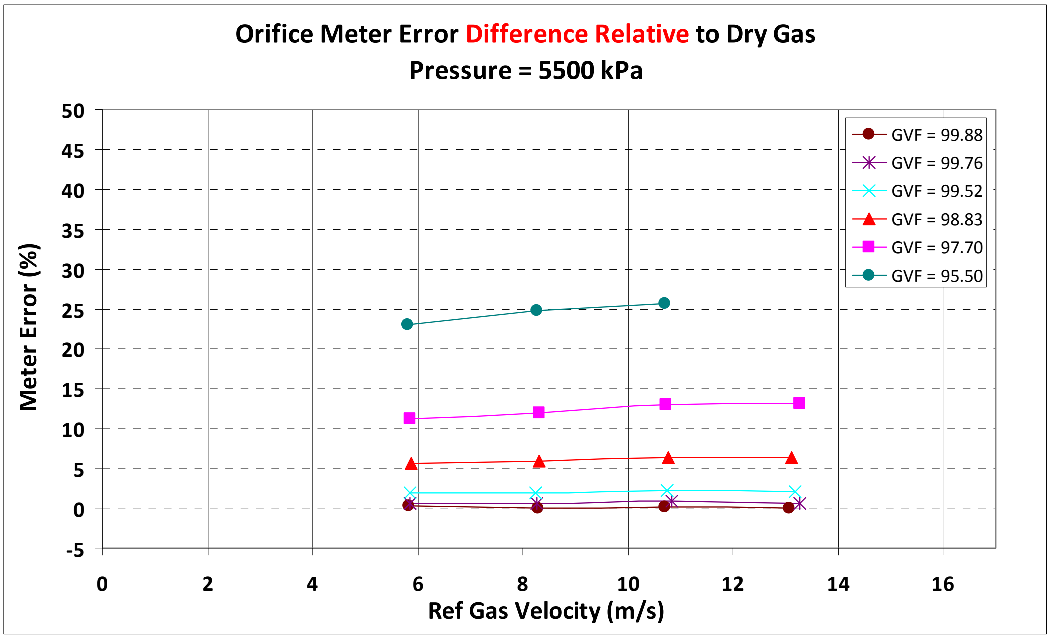

Figure 32 – 3-inch Orifice Results – 55 Bar(a) – Baseline Difference – All GVFs

Figure 33 shows the results of the 2-Path USM under the same conditions. These results were obtained with no CPA flow conditioner.

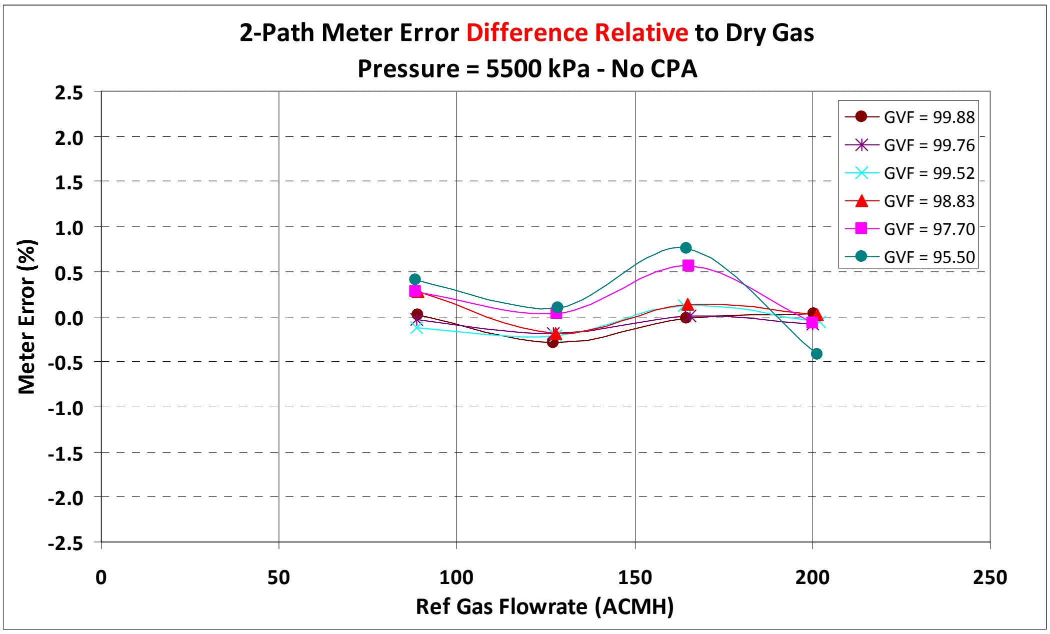

Figure 33 – 3-inch 2-Path USM Results – 55 Bar(a) – All GVFs – No CPA

The results of the 3-inch USM shows even less shift from baseline at 55 Bar(a) than at 13 Bar(a). The meter is now within ±0.75% for virtually all test conditions including the highest GVF of 95.5%. The meters were not tested at this high GVF at the lower pressures as gas density was too low. Figure 34 shows the results using the CPA.

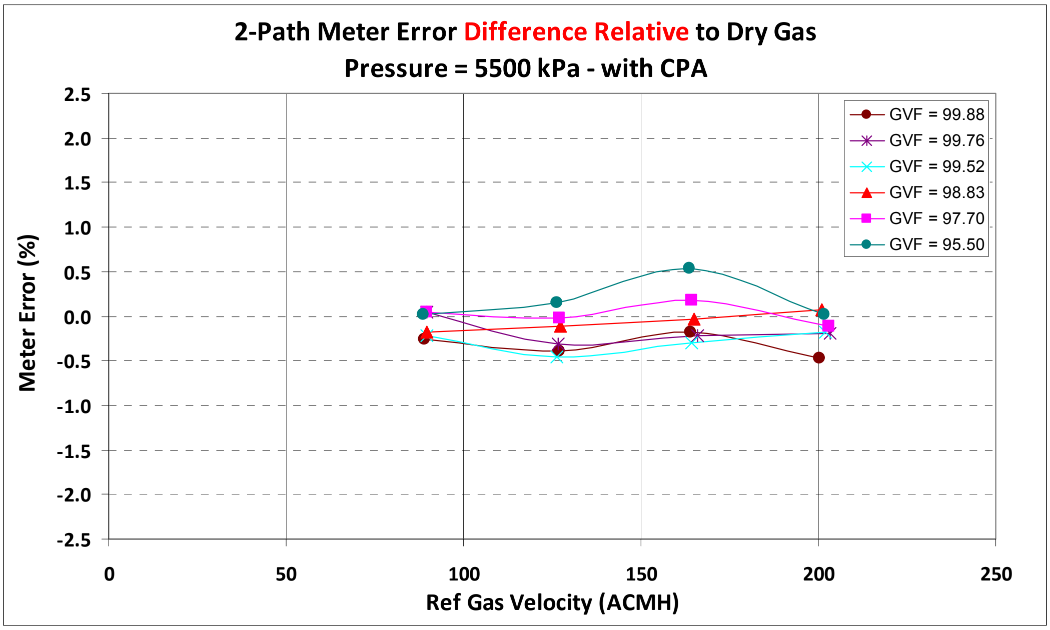

Figure 34 – 3-inch 2-Path USM Results – 55 Bar(a) – All GVFs – With CPA

The results in Figure 34 show the CPA flow conditioner produced almost identical results to those shown in Figure 33 when no flow conditioner was used. Once again test results were within ±0.5% relative to the dry gas baseline results.

The benefit of using a flow conditioner is to reduce the installation affects of upstream swirl and asymmetry flow that may be present when the meter is installed in the field. There is always concern the flow conditioner might influence the meter's accuracy during liquid loading tests, but these results show that is not true. Another concern with using a flow conditioner is the possible formation of hydrates under some conditions, but this didn't occur in these tests.

8. 3–INCH GAS ULTRASONIC METER DIAGNOSTICS

One benefit of using an ultrasonic meter is the diagnostics. This gives the user the ability to understand more about the operation of the meter. Problems such as blocked flow conditioners, dirty meters, pulsation and liquid in the pipeline are easily identified. This can be seen by either connecting to the meter, or if the meter incorporated automated diagnostics, obtaining it from the audit logs.

"Meter Health" summary information for the 3-inch, 2-path meter at all GVF levels is shown in Figures 35-41. Data was taken from the "Maintenance Report" that was collected during the testing. The following were obtained at 8.2 m/s to approximate the same flow velocity for the 4-inch, 4-path data that is shown in Figures 15 - 22. These tests used the CPA flow conditioner with pressure at about 55 Bar(a) (same condition as the 4-inch data). There was no difference in results when compared to no CPA. The yellow "W" in "Warning Diagnostic Difference" was not present for the 4-inch testing as show in Figures 15-22 as that firmware didn't yet have the "Fingerprint Function" (which is called Diagnostic Difference). This warning was caused by significant changes in the diagnostic parameters caused by the liquid loading tests.

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	ok	ok	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	ok	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	n.a.	n.a.
		Warning Performance	ok	ok	n.a.	n.a.

Figure 35 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 100 GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	ok	ok	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	ok	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	n.a.	n.a.
		Warning Performance	ok	ok	n.a.	n.a.

Figure 36 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 99.88% GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	ok	ok	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	ok	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	n.a.	n.a.
		Warning Performance	ok	ok	n.a.	n.a.

Figure 37 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 99.76% GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	ok	ok	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	ok	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	n.a.	n.a.
		Warning Performance	ok	ok	n.a.	n.a.

Figure 38 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 99.52% GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	ok	W	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	W	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	ok	n.a.	n.a.
		Warning Performance	ok	ok	n.a.	n.a.

Figure 39 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 98.84% GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	ok	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	W	W	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	ok	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	W	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	W	W	n.a.	n.a.
		Warning Performance	ok	W	n.a.	n.a.

Figure 40 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 97.71% GVF

Meter Health			P 1	P 2	P 3	P 4
Warning Profile Factor	n.a.	Path Error	ok	E	n.a.	n.a.
Warning Symmetry	n.a.	Warning Turbulence	W	ok	n.a.	n.a.
Warning High Gas Velocity	ok	Warning SNR Limit	ok	W	n.a.	n.a.
Warning Low Input Voltage	ok	Warning AGC Dev	ok	ok	n.a.	n.a.
Warning logb. full of unackn. entries	ok	Warning AGC Limit	ok	W	n.a.	n.a.
Warning Diagnostic Difference	W	Warning SOS dev	ok	W	n.a.	n.a.
		Warning Performance	ok	W	n.a.	n.a.

Figure 41 – 3-inch, 2-Path Meter Health – 55 Bar(a) – 95.51% GVF

From these "Meter Health" summaries it is clear the meter was performing normally until the GVF value was below 99.52%. Higher liquid loadings caused Warnings in Turbulence and AGC Limit (Turbulence exceeded 6% and the AGC limits exceeded normal value by 6 dB). As liquid loading increased, even more Warnings became present including SOS Deviation (greater than 0.25% SOS deviation from Path 1 to Path 2), and Transducer Performance (less than 80% accepted for the Performance Warning to be activated). Once the liquid loading was at the highest level (GVF of 95.51%), then Path 2 Performance fell below 5% accepted, and thus the meter reported it as failed ("E" in the box and it turned red).

The following graphs (Figures 42-45) represent various diagnostics from the meter from a GVF of 100% to 96.0%. Figure 42 shows the path performance was running 100% until the GVF reached 98.84%. As the liquid loading increased, performance fell and at 95.51 GVF, Path 2 had totally failed. Figure 43 shows per-path SOS. Note that the SOS on Path 2 was identical when the GVF was 100%, but was lower for all other liquid loadings until it finally failed. Turbulence is shown in Figure 44. As the liquid loading increased, all Turbulence values increased. Above a GVF of 99.52, the Turbulence on Path 2 started increasing significantly until the path failed at the lowest GVF value. Figure 45 shows the Symmetry. As the GVF value decreased from 100%, the Symmetry began to increase. This means the Path 2 velocity readings were becoming slower relative to Path 1.

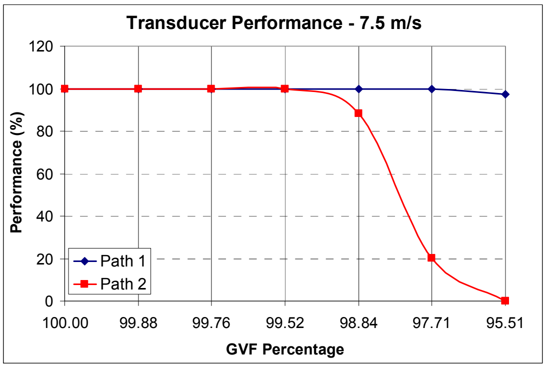

Figure 42 – Path Performance

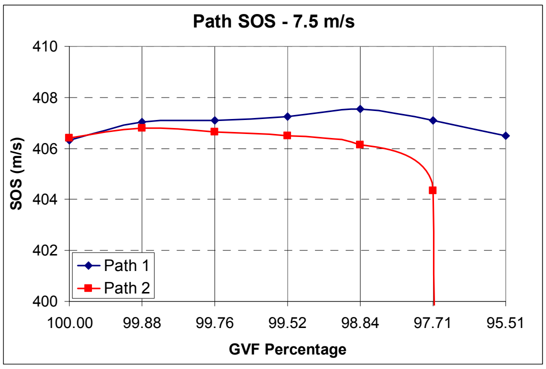

Figure 43 – Path SOS

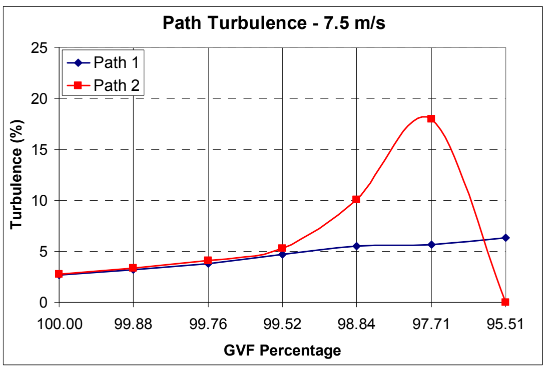

Figure 44 – Path Turbulence

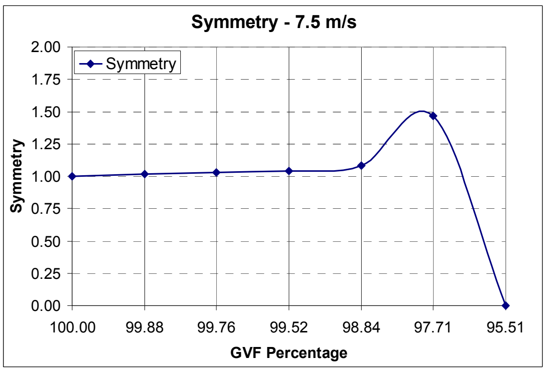

Figure 45 – Symmetry

One additional set of tests was conducted using water. All the previous data was taken with Exxsol D80 but there was interest in seeing if the results would be different using water. Thus

6 additional test points were included. Two flow rates of 8.2 and 13.1 m/s were run and three GVF approximate values of 99.88, 99.53 and 99.14% (there are some minor differences between the Exxsol and Water tests). The focus here was on the lighter liquid loading and whether the meters performed essentially the same with water as with the Exxsol D80. This testing also included the CPA flow conditioner since it was in line at the time the 55 Bar(a) data was taken with Exxsol D80.

Figure 45 shows the results of both the Exxsol D80 and the water for the orifice meter, and Figure 46 show the results for the 2-Path meter.

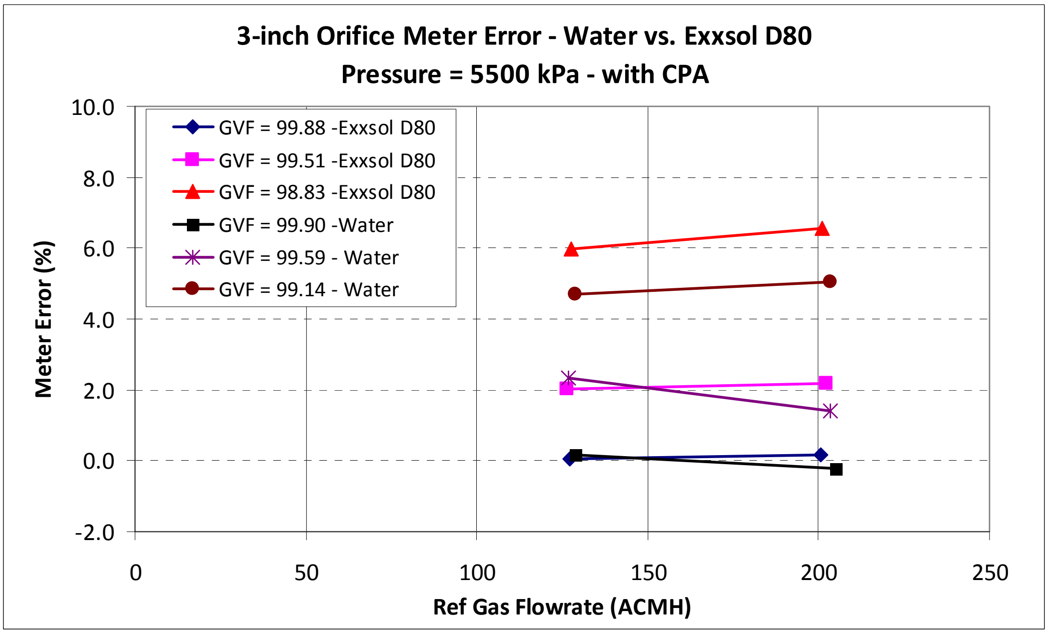

Figure 46 – 3-inch Orifice Meter Water and Exxsol D80 Errors– 55 Bar(a)

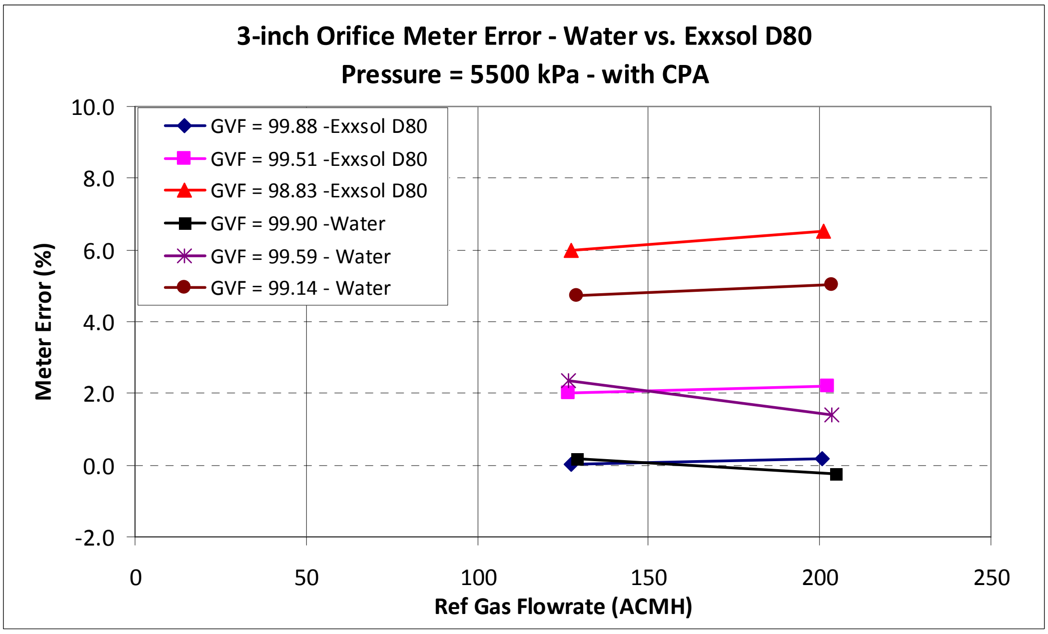

Figure 47 – 3-inch Orifice Meter Water and Exxsol D80 Errors– 55 Bar(a)

Figure 48 is a comparison between the Exxsol D80 and water for the orifice meter, and Figure 49 show the difference between Exxsol D80 and water for the 2-path meter. As these tests were conducted at the end of the program, they include the CPA flow conditioner.

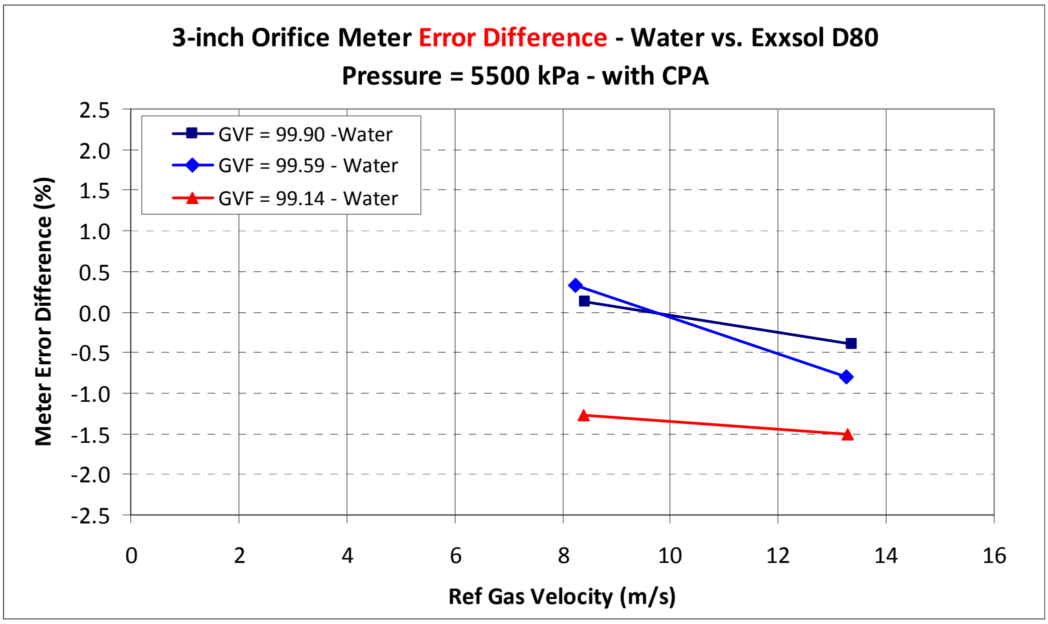

Figure 48 – 3-inch Orifice Meter Water and Exxsol D80 Difference – 55 Bar(a)

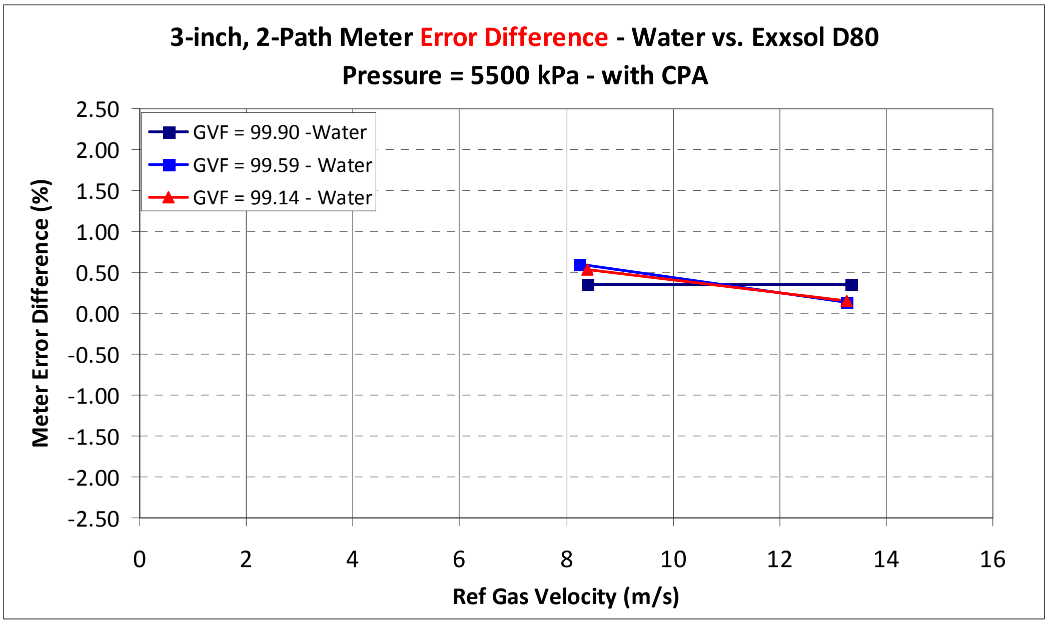

Figure 49 – 3-inch, 2-Path Meter Water and Exxsol D80 Difference– 55 Bar(a)

Figures 48 and 49 show there is no significant different between the Exxsol D80 and water although the higher level of liquid loading (GVF = 99.14) showed a difference of approximately -1.5% compared to the other levels of GVF. The difference in the 2-path USM was on the order of +0.25 to 0.5% and probably would be considered within the acceptable limits of repeatability for these tests.

Figure 50 is a graph of Gas Mass Flow Ratio (GMFR) vs. Lockhart Martinelli plotted at both 13 and 55 Bar(a).

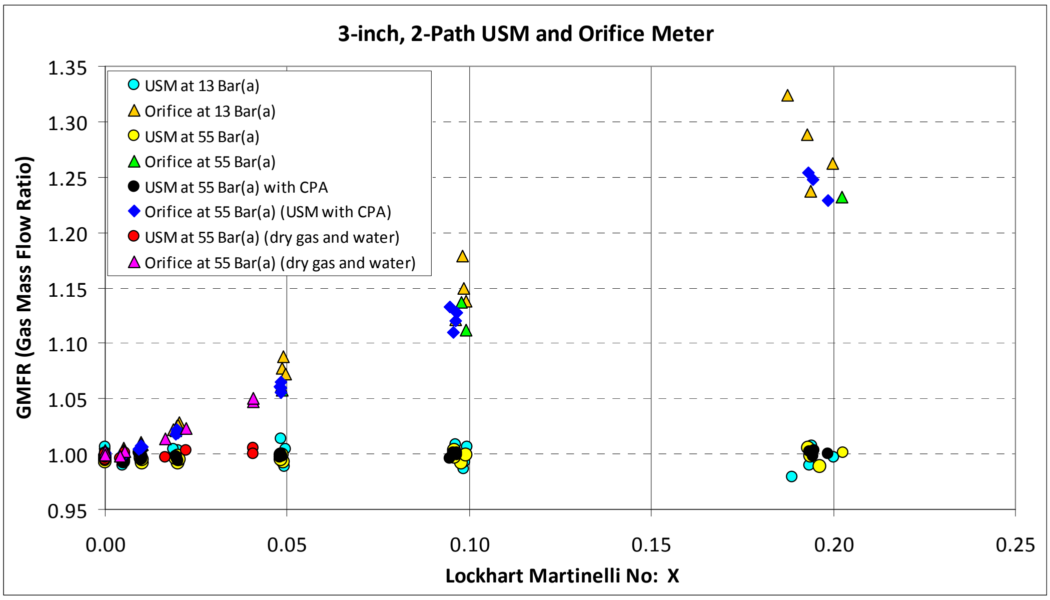

Figure 50 – Lockhart Martinelli for 3-inch Orifice and 2-Path USM

Figure 50 shows all the 2-path USM data remains very close to 1.00 GMFR as the Lockhart Martinelli Parameter increases to almost 0.2. The round circles represent the results of the USM and the diamonds and triangles represent the orifice meter. As expected the orifice meter trends in a fairly straight line with an increasing GMFR as the Lockhart Martinelli Parameter increases.

The integrity of the test data might be questioned since the results of the 3-inch USM were perhaps better than expected. The performance behavior of the orifice in wet gas applications has been documented several times. Most recently a paper was published at the Southeast Asia Conference in 2008 entitled "Further Evaluation of the Performance of Horizontally Installed Orifice Plate and Cone Differential Pressure Meters with Wet Gas Flows" [Ref 1]. In this paper an equation was developed to predict the over-reading of an orifice meter if the liquid content was known.

Figure 51 shows a graph of the Lockhart Martinelli vs. the 3-inch orifice meter over-reading, and also the predicted results using the equation that was developed and presented in this paper [Ref 1].

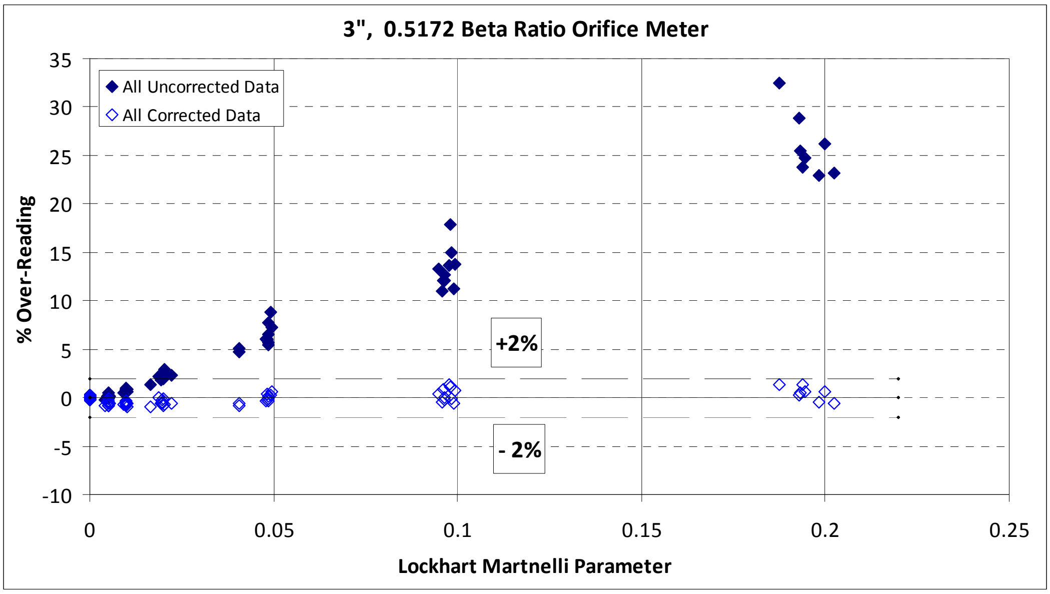

Figure 51 – Lockhart Martinelli for 3-inch Orifice with Predicted Correction

Results of the corrected data show all values to be within ±2.0% of baseline when the liquid flowrate is known. This graph agrees with the model very well and thus shows the results from the CEESI Wet Gas Loop are valid.

The data in Figure 52 represents the same data as Figure 51 with separate gas to liquid Density Ratios (DR).

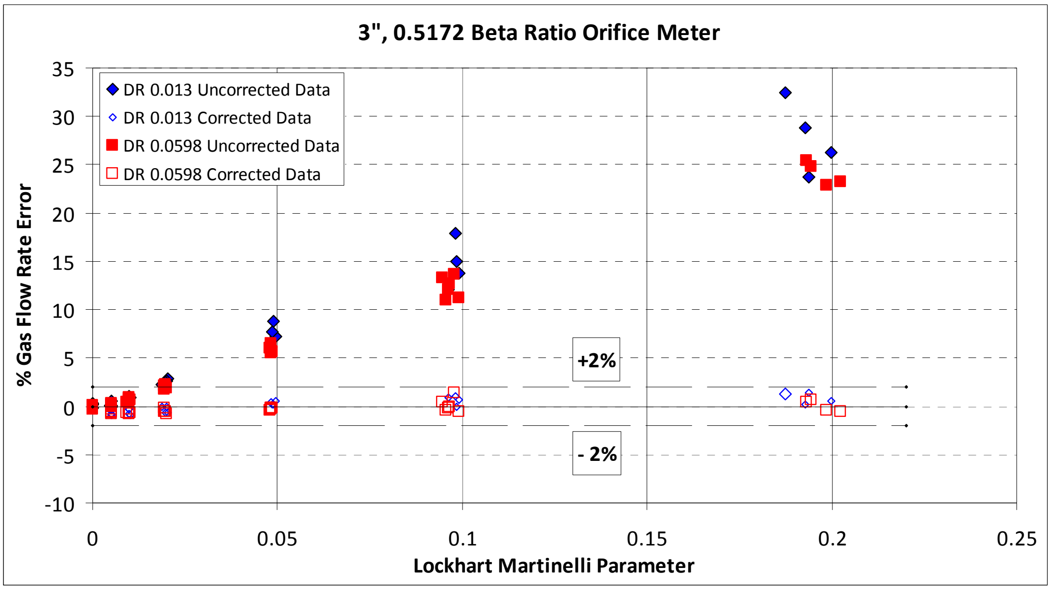

Figure 52 – Lockhart Martinelli for 3-inch Orifice with Predicted Correction – Both Pressures

The data in Figure 53 represents the low pressure (DR of 0.013) with separate gas densiometric Froude Numbers (Fr_g).

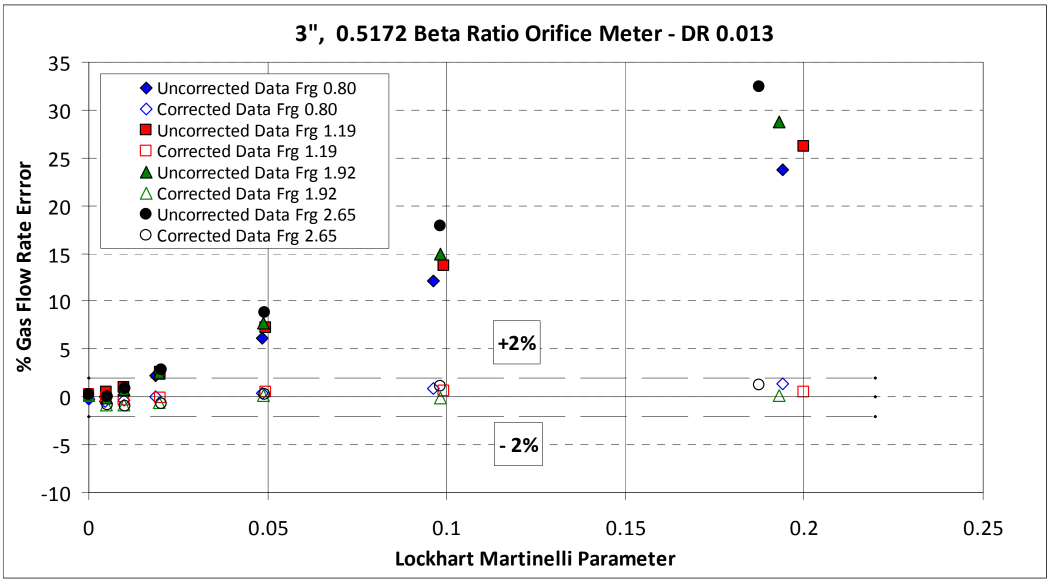

Figure 53 – Lockhart Martinelli for 3-inch Orifice for DR of 0.013

The data in Figure 54 represents the low pressure (DR of 0.06) with separate gas densiometric Froude Numbers (Fr_g).

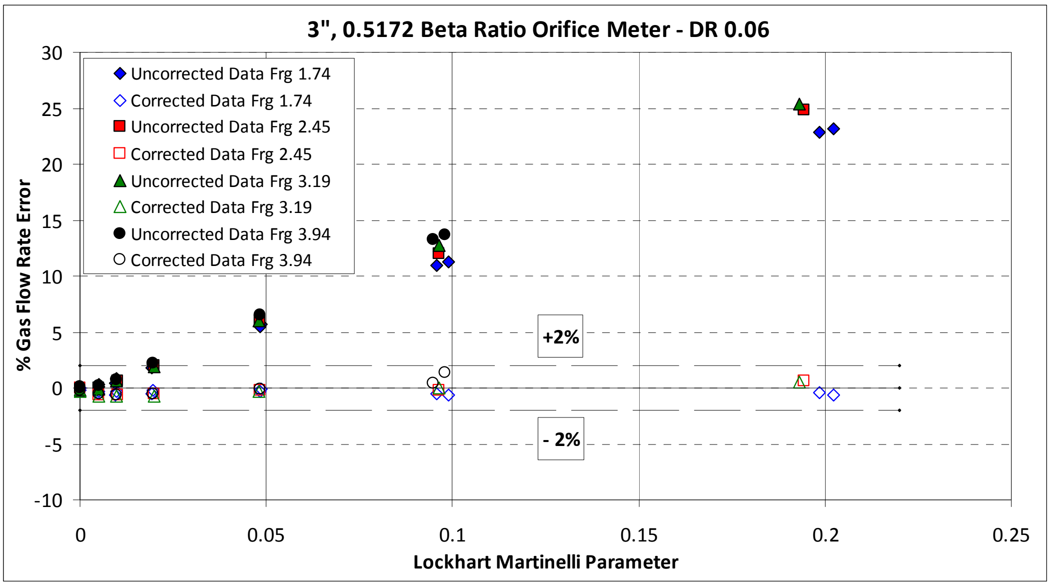

Figure 54 – Lockhart Martinelli for 3-inch Orifice for DR of 0.06

The point of these correction graphs, Figures 51-54, is to validate that the data collected for the orifice meter agrees very closely with the predicted results from this paper. Hence, the orifice meter has all the wet gas trends as previously published [Ref 1]. Thus it confirms the precise over-reading values as predicted by this independent reference [Ref 1]. It can be concluded that the test procedure and the facility reference meters are accurate and reliable.

9. CONCLUSIONS

Traditionally orifice meters have often been used in "wet gas" applications because they are "tolerant" of liquid in the gas stream. Being "tolerant" just means they aren't generally damaged by the presence of liquids, as are turbine, rotary and other traditional measurement devices. The benefit of gas ultrasonic meters has been documented in many papers over the years. Certainly for small production applications the price of the primary element has to be considered, and once again the orifice meter has a significant advantage.

One of the wet gas problems is typically transducer damage due to the liquids penetrating the sensor. This has been solved in this prototype meter by using hermetically sealed, titanium transducers that can withstand hydrostat testing.

During December, 2009, the testing of a special 4-path and 2-path combination 4-inch meter at the CEESI Nunn, Colorado facility provided insight into what a traditional gas ultrasonic meter would do with a variety of liquid loadings. The values of GVF tested were based on some recommendations from production users. After reviewing the data, there was renewed interest in the results, and more data was requested with lighter liquid loading (higher values of GVF).

As expected, the first test results showed the gas ultrasonic meter over-registered as did the orifice meter. Both had significant errors with higher levels of liquid loading, with errors exceeding 30% as the GVF levels decreased below 98%. This was not unexpected. Both the 2-path and 4-path meters behaved similarly and thus there wasn't really any significant benefit to using a 4-path meter in these difficult applications.

After analysis of the data, a modified version of a 2-path was constructed. As many users traditionally use 2-4 inch orifice meters, the 3-inch USM was identified as the best compromise to replace all three of these line sizes. Thus the second series of tests, conducted in late August 2010 was performed using only a 2-path meter constructed as it might be for the field applications.

This meter is a prototype designed with two goals in mind. First, reduce the cost of manufacturing in order to make the use of the ultrasonic meter more cost-attractive. This was part of the reason for incorporating the upstream 10D piping into the meter body. Reducing 2 flanges impacts the cost of manufacturing, and eliminates a leak path at the same time.

Second, attempt to improve the performance, and also use the diagnostics to help identify when liquids are present.

The accuracy results (shift from the 100% GVF baseline) for the new 2-path design were much better than expected. Once again the orifice meter shifted on the order of 30% at the highest liquid loading levels (both 3 and 4-inch meters), but the 3-inch modified ultrasonic meter was generally within ±1%.

Not only did this prototype gas ultrasonic meter, in this initial test, continue operating in these difficult conditions, it was more accurate under all levels of GVF when compared to the orifice meter. This data suggests that it is practical to use the USM in these applications.

9. REFERENCES

[1] R. Steven, G. Stobie, A. Hall: "Further Evaluation of the Performance of Horizontally Installed Orifice Plate and Cone Differential Pressure Meters with Wet Gas Flows," SEA 2008, Kuala Lumpur, February 2008.

[2] M. B Wilson, "The Development and Testing of an Ultrasonic Flow Meter for Wet Gas Applications," Seminar on the Measurement of Wet Gas, October 1996, NEL, East Kilbride, Glasgow, UK.