# EFFECTS OF WET GAS FLOW ON GAS ORIFICE PLATE METERS

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## INTRODUCTION

Orifice plate meters are one of the most widely used technologies in industry for gas flow metering. This is due to their relative simplicity, the extensive publicly available data sets that led to several orifice plate meter standards [1, 2, 3, 4] and the fact that they are a relatively inexpensive method of gas metering. However, it is common in industry for gas meters to be installed in applications where the flows are actually wet gas flows, i.e. flows where there is some liquid entrainment in a predominantly gas flow. This is usually done out of economic necessity or due to the fact that the system designers were not aware at the systems conceptual design stage that the gas flow would have entrained liquid. Therefore, with the orifice plate meter being such a popular gas flow meter it is by default the most common wet gas flow meter.

The affect of wet gas flow on an orifice plate meter configured for gas flow service is complicated. There are on going research programs aimed at improving the understanding of the reaction of the orifice plate meter to wet gas flow. Whereas much of this research is published in recent conference papers it is very technical and is not always immediately relevant to the technician in the field how this information can be practically applied. This paper attempts to review the current scientific knowledge from a practical user's stand point.

## WHAT IS WET GAS?

A practical and universally accepted definition for the term "wet gas" flow has proved illusive. Industry has as yet no universally agreed definition for wet gas flow. In fact, many in industry now feel there is no need for a precise definition. The term could remain an undefined term. Any "wet gas" metering application simply requires the relative amount of liquid to gas flow rate to be stated and then all that practically matters is the question of whether the metering technology being employed will cope with that level of "gas "wetness". Hence, for the purpose of this paper the definition of wet gas flow is simply said to be "a two-phase flow of gas and liquid where the predominant phase is that of the gas phase".

All the same, it is necessary to quantify the relative amount of liquid in a gas flow if we are to discuss the orifice meters wet gas flow performance. This can, and is, done in many different ways. However, for this paper, only two methods are discussed. These are the commonly used Gas Volume Fraction (GVF) and unfortunately a rather abstract term called the "Lockhart-Martinelli parameter".

The gas and liquid volume flow rates (at flowing conditions) are denoted by $\dot{Q}_g$ and $\dot{Q}_l$ respectively. The GVF is probably the most common method amongst technicians of quantifying the amount of liquid with a gas flow. The GVF is defined as equation 1. (Note that whereas the GVF is at flowing conditions, barrels / MMSCFD is the equivalent to the GVF at standard conditions.)

$$GVF = \frac{\dot{Q}_g}{\dot{Q}_l + \dot{Q}_g} \tag{1}$$

The most common method amongst flow meter designers and wet gas flow researchers of quantifying the amount of liquid with a gas flow is the Lockhart Martinelli parameter. Fortunately, it is not necessary to understand the history and precise scientific meaning of the Lockhart Martinelli parameter in order to apply the results of the research which utilized this parameter. This term is typically denoted by "$X_{LM}$" and it is calculated by the Equation 2. Note that the gas and liquid mass flow rates are denoted by $\dot{m}_g$ & $\dot{m}_l$ respectively while $\rho_g$ & $\rho_l$ are the gas and liquid densities of the wet gas flow respectively.

$$X_{LM} = \frac{\dot{m}_l}{\dot{m}_g}\sqrt{\frac{\rho_g}{\rho_l}} \tag{2}$$

For a measured pressure and temperature and known gas and liquid properties the gas and liquid densities of a wet gas flow are calculated independently of any flow meter. Therefore, for a set pressure and temperature the Lockhart Martinelli parameter is directly proportional to the liquid to gas mass flow rate ratio. The Lockhart Martinelli parameter can be thought of in simple terms as a measure of the "wetness" of the wet gas flow. For a set pressure and temperature, the higher the Lockhart Martinelli parameter the wetter the flow (i.e. the more liquid mass flow relative to a unit mass of gas flow).

With all scientific endeavors it is beneficial for a common language to exist. Hence, the meter designers and wet gas flow researchers only prefer the abstract Lockhart Martinelli parameter over the GVF out of scientific necessity. It has been shown that it is far easier to describe the performance characteristics of DP flow meters with wet gas flow using the Lockhart Martinelli parameter than the GVF. Unfortunately, there is no direct conversion between these two "liquid loading" parameters. They are related through the gas and liquid densities. The relationship between GVF and $X_{LM}$ is shown as equation 3. Two popular wet gas flow definitions are $X_{LM} \leq 0.3$ and $GVF \geq 0.9$. However, from equation 3 it can be seen that they are not equivalent definitions (other than at one gas to liquid density ratio).

$$X_{LM} = \frac{1-(GVF)}{(GVF)} \sqrt{\frac{\rho_l}{\rho_g}} \tag{3}$$

**WHAT DOES WET GAS FLOW LOOK LIKE?**

The way that a liquid phase is dispersed in a gas pipe flow is called either the "flow regime" or "flow pattern". Figure 1 shows a generic sketch of typical wet gas flow patterns in horizontal flow. Figure 2 shows a generic sketch of typical wet gas flow patterns in vertical up flow.
Vertical down flow patterns, where gravity and flow do not appose each other, are usually considered to be mist flows although little research is published on the matter. Information on inclined pipe flow patterns is very rare in the literature.

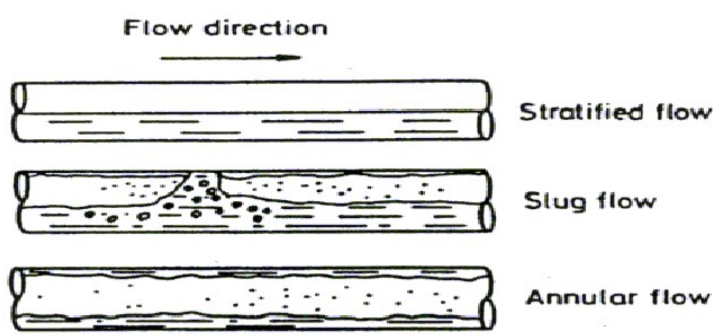


**FIGURE 1. Horizontal Wet Gas Flow Pattern Maps**

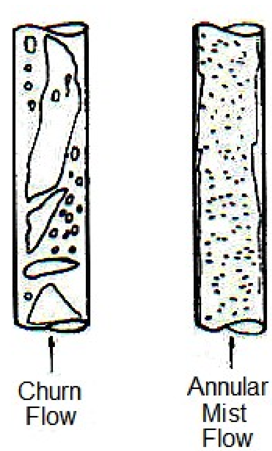


**FIGURE 2. Vertical Up Wet Gas Flow Pattern Maps**

The majority of wet gas flow pattern knowledge comes from practical experiment. Theory as yet does not exist that can predict flow patterns well across various parameter changes (e.g. pipe diameter, pressure, liquid properties, gas velocity, GVF, pipe orientation etc.).

Figure 1 shows three possible horizontal wet gas flow patterns. The first is “Stratified Flow” (sometimes called “Separated Flow”). This is usually prevalent at low gas flow rates and low pressures. Here, the liquid flows at the base of the pipe (like a river) with the gas phase flowing over the top of the phase interface. In many actual industrial wet gas flows the stratified flow pattern does not have the smooth gas / liquid interface drawn here but rather a wavy interface. As wet gas flow conditions change such waves can become large compared to the diameter of the pipe. If the waves are large enough to cover the cross-sectional area of the pipe the flow pattern is called “slug flow”. Slug flow is not stable and therefore this condition is not ideal for flow metering. Finally, if there is enough energy in the gas flow (i.e. high pressure and / or high gas velocity) an annular flow (sometimes called “annular mist flow”) exists. Here, a liquid film flows on the pipe wall with the gas phase, laden with liquid droplets flows down the centerline of the pipe.

Vertical up wet gas flow has effectively only two flow patterns. These are dictated by whether the gas has enough energy to overcome the liquids weight or not. If the gas has enough energy (i.e. an appropriate combination of pressure and gas flow rate) then the vertical up wet gas flow pattern will be a steady annular mist flow. If the gas does not have enough energy to steadily move the liquid, then the liquid is forced up the pipe in an unsteady manner. This is called churn flow. Churn flow is unstable flow and therefore this condition is not ideal for flow metering.

It should be noted that slug flow and a special pipe flow condition called “severe slugging” are not the same phenomenon. Slug flow as described above, where the slug (i.e. the liquid mass that fills the cross section of the pipe) is caused by the interaction of the gas phase with an unstable liquid / gas interface produces slugs with low to moderate kinetic energy. It is unlikely (but not impossible!) that a slug flow pattern could cause significant damage to an orifice plate. However, “severe slugging” is a term often used to describe a different more problematic phenomenon. Even trace liquids entrained with a gas flow can collect over time at low points in the pipe work. Alternatively, sections of pipes can flood during shut in. Flowing gas blocked by this liquid build up can then propel the liquid column or “slug” downstream at high velocity. The impact of such a slug with high kinetic energy on pipe work components can cause significant damage. Orifice plate meters have been buckled by such impacts. Figure 3 shows an example courtesy of Chevron Inc. Such slug strike damage on orifice plates has led to the “wok with a hole” meter phrase. Also note that wet natural gas production flows can be dirty and entrained particulates can accelerate the rate of wear of the sharp leading edge of the plate.

Buckled and worn edge orifice plate meters have unknown single-phase performances (as all plate damage is unique). As all wet gas flow performance is based on knowing the meters single phase base line performance it is important that the condition of the plate is checked regularly when in service with wet gas flow. (Removing a buckled orifice plate from an orifice fitting can be a very time consuming and awkward task.)

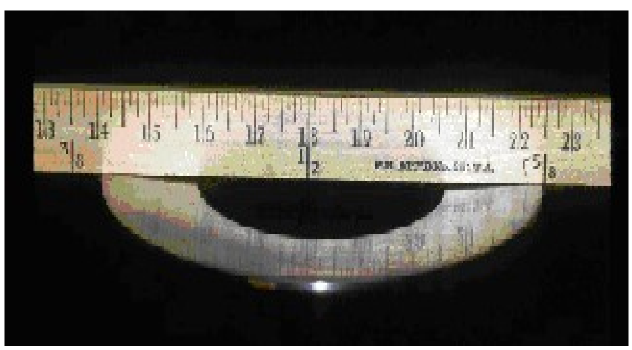

**FIGURE 3. Orifice Plate Buckled by a Slug Strike**

## ORIFICE PLATE METER WET GAS FLOW PERFORMANCE

## GENERAL DISCUSSION

The original work on the response of orifice plate meters (and other generic DP meters) to wet gas flows was carried out by Schuster [5], Murdock [6] and Chisholm [7,8]. Much of the research up until the end of the 1970’s was conducted by the power industry focused on wet steam flow. By the 1980’s interest in researching wet gas flow metering had waned. However, by the early 1990’s the natural gas production industry used this existing knowledge as the starting point for further research.

In general, though, the new researchers assumed with out evidence that orifice plate meters could not be good wet gas meters. It was suggested that the plate could potentially act as a dam, causing liquid hold up with an associated instability in the meter readings. However, none of the early research from highly respected researchers ever suggested such a problem had been found with their comprehensive data sets. Furthermore, in the last ten years a significant amount of wet gas flow data has been recorded from orifice meters. The data shows that orifice meters can be successfully used to meter wet gas flow.

In 2011 CEESI placed an orifice plate in the middle of a view port and recorded various horizontal wet gas flow conditions through the orifice plate. It was shown that no significant liquid hold up occurred at the plate regardless of the flow pattern. Figures 4 & 5 show sample stills from the resulting videos for stratified and annular mist flows respectively.

Figure 4 shows stratified flow (flowing left to right) coming up against the plate, but crucially no significant liquid depth increase was seen over time as the steady wet gas flow passed the meter. At the downstream side of the plate it can be seen that liquid is entrained (or "trapped") in the plates recirculation zone. However, it was noted when viewing repeat stratified flow tests that immediately after start up a pseudo steady liquid dispersion through the meter was set up. That is, there was no liquid hold up problem over time.

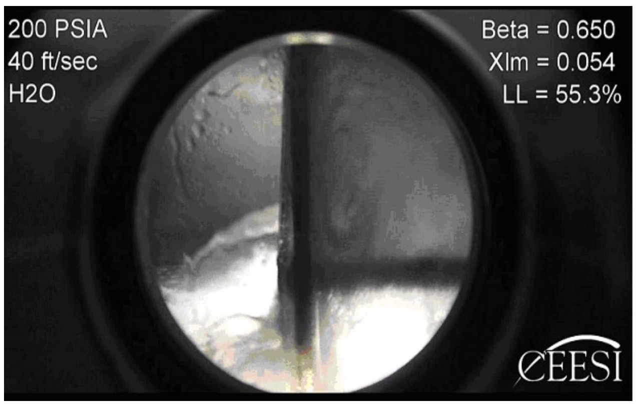


**FIGURE 4. Stratified Flow Through an Orifice Plate**

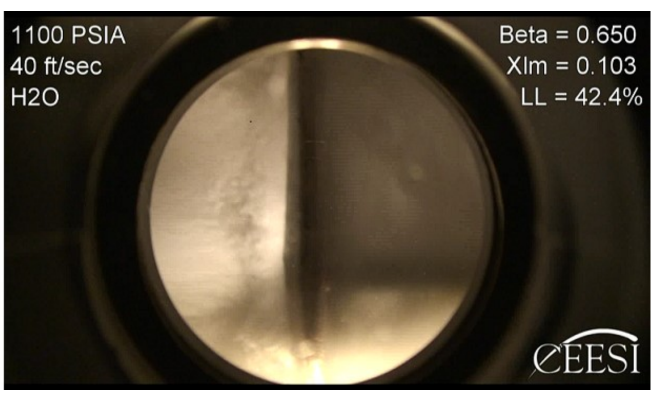


**FIGURE 5. Annular Mist Flow Through an Orifice Plate**

Figure 5 shows annular mist flow (flowing left to right) through the plate. The annular mist coming up against the plates upstream re-circulation zone can be seen. However, again there is no significant liquid damming effect over time. Again, liquid entrainment in the downstream re-circulation zone can also be seen. However, again it was noted when viewing repeat annular mist flow tests that immediately after start up a pseudo steady liquid dispersion through the meter was set up. That is, there was no liquid hold up problem. In fact, videos were taken of many wet gas flow conditions with various flow patterns each for extended periods of time and liquid hold up was never an issue for the orifice plate meter.

However, clearly from Figures 4 & 5 the liquid entrained in the downstream re-circulation zone could potentially


**FIGURE 6. 4", Orifice Meter Under Wet Gas Flow Testing**

However, clearly from Figures 4 & 5 the liquid entrained in the downstream re-circulation zone could potentially make the orifice meters DP's unsteady. In fact, wet gas flow can indeed increase the standard deviation of an orifice meters DP readings. It has therefore been falsely suggested by various sources that such relative instability makes the orifice meter an inappropriate choice for wet gas flow applications. However, just as the early researchers never suggested that this is a practical problem limiting an orifice meters use with wet gas flow, modern research has shown that this is indeed not a real problem.

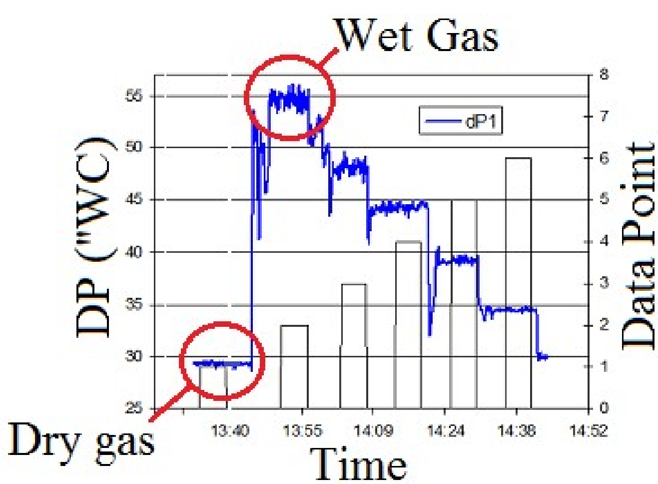


**FIGURE 7. DP Stability Through an Orifice Plate at Various Lockhart Martinelli Parameters**

Figure 6 shows a 4", 0.5 beta ratio orifice meter installed at CEESI under wet gas flow testing. (Note that the meter is orientated such that the pressure taps in use are at top dead center. This is 90º from the standard dry gas meter orientation. This orientation is used with wet gas flow to minimize the chances of liquid flooding of the impulse lines and maximize the chance of any liquid in the impulse lines draining out.)

Figure 7 shows wet gas flow data from the meter shown in Figure 6. Data point 1 was for dry gas. The average DP is 29.5"WC. There is a small standard deviation seen (i.e. the result circled as dry gas shows that the DP varies very slightly over time but can be averaged to a repeatable value of 29.5"WC). Point 2 (i.e. the result circled as a wet gas flow condition) is the same gas flow once liquid is entrained in the gas flow. Point 2 shows a Lockhart Martinelli Parameter value of 0.25. Clearly the presence of the liquid for this set gas flow rate has induced not only a significant increase in the absolute average DP value, but also a substantial increase in the standard deviation of the DP reading. However, crucially, it can be seen that even though the standard deviation is high a repeatable average value of 54.5"WC is measured. So the increase in DP standard deviation has not significantly adversely affected the meter operators ability to read a reliable repeatable pseudo-steady DP value. Hence, the fact that wet gas flow can significantly increase the standard deviation of DP's read from an orifice meter has no practical adverse consequences when using an orifice meter with wet gas flow.

## ORIFICE METER WET GAS FLOW PERFORMANCE AT LOW LOCKHART MARTINELLI PARAMETERS

Rare, brief, descriptions of wet gas flow orifice meter performances at very low Lockhart Martinelli Parameters were released by McConaghy [9] in 1989 and Ting [10] in 1995. These papers discuss the effect of extremely small Lockhart Martinelli parameters that are at or below the minimum values considered in the published wet gas flow orifice meter correction factors. McConaghy and Ting agree that for very small liquid content the gas orifice plate meter gives a lower gas flow prediction than the actual gas flow rate. That is, at very low Lockhart Martinelli parameters orifice meters under-read the actual gas flow rate. Ting states:

"McConaghy studied the effect of low liquid entrainment rate for 4" and 8" meters at $\beta = 0.6$. A relatively large under-measurement error of up to 1.0% was detected at a Reynolds number range of 3 to 8 million. Lower measurement errors were detected at $\beta = 0.2$."

Ting then showed wet gas data for 2" orifice plate meters with three beta ratios ($\beta = 0.37, 0.54, 0.68$). The test was with air and water at low gas flow rates and a low pressure of 4 psig. The maximum Lockhart Martinelli parameter was approximately 0.0052. Like McConaghy, Ting found a small under-prediction of the gas flow rate. The maximum under-reading was approximately -1.5%. From all available orifice meter wet gas flow data sets it is generally assumed possible to have an under-reading of up to 2% at $X_{LM} \leq 0.01$.

Ting suggested such a wet gas flow is possible downstream of inefficient separators or if liquid was to condense out of a gas flow. Ting reported a visual description of the flow pattern: "No liquid accumulation in front of the orifice plate was observed for the beta ratios tested. Water streaks were seen flowing over the orifice plate to the other side." That is, there was such a low liquid quantity that none of the above described flow patterns could form.

## ORIFICE METER WET GAS FLOW PERFORMANCE AT HIGHER LOCKHART MARTINELLI PARAMETERS

The majority of the wet gas flow orifice meter data recorded by industry is for much higher Lockhart Martinelli Parameters than were tested by McConaghy and Ting. Most wet gas flow orifice meter data is for $0.005 \leq X_{LM} \leq 0.3$. Also, the majority of data is for ≤ 4" orifice meters and for gas with light hydrocarbon liquid wet gas flows. There is much less data for gas with water flows, or gas with water and hydrocarbon liquid wet gas flows.

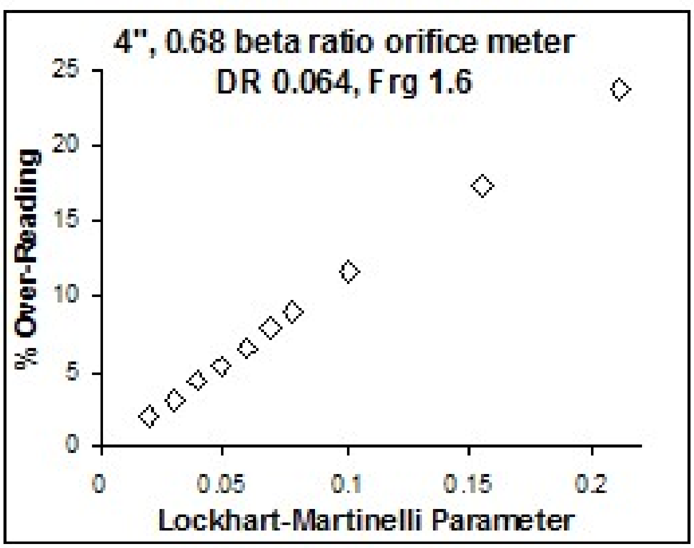


**FIGURE 8. Orifice Meter Wet Gas % OR vs. $X_{LM}$ Effect**

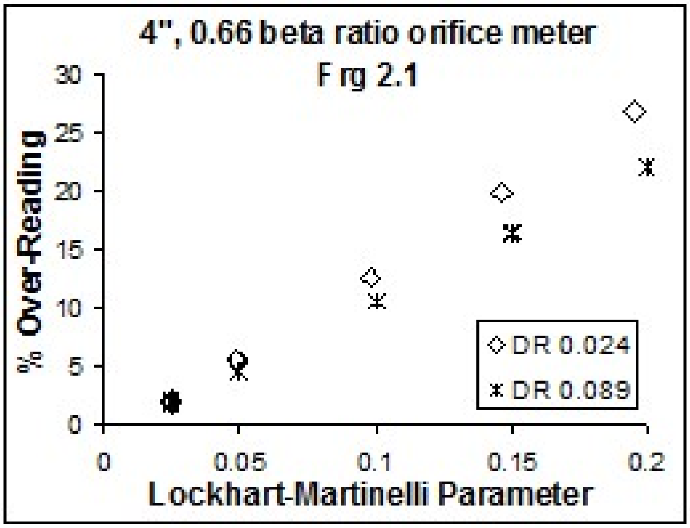


**FIGURE 9. Orifice Meter Wet Gas DR Effect**

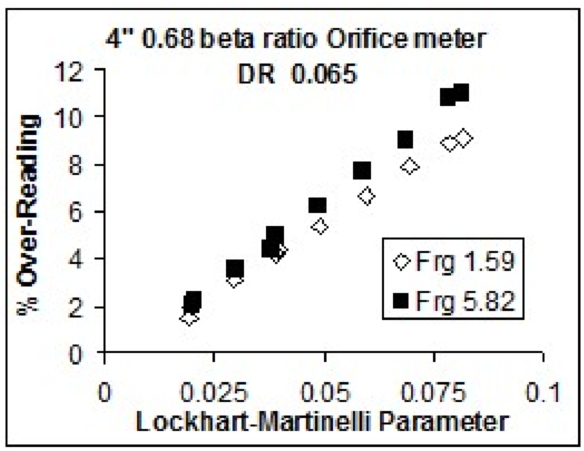


**FIGURE 10. Orifice Meter Wet gas $Fr_g$ Effect**

In order to review the orifice meters wet gas flow performance trends, it is necessary to first review the relevant associated wet gas flow parameters. The presence of liquid with a gas flow induces an error on the orifice meters gas flow rate prediction. The uncorrected gas flow rate prediction from an orifice meter operating with wet gas flow is called the "apparent" gas mass flow rate (denoted by $\dot{m}_{g,apparent}$). The majority of the Lockhart Martinelli Parameter range considered to be wet gas (i.e. approximately $X_{LM} \leq 0.3$) induces a positive bias on the gas flow rate prediction. Only at very low Lockhart

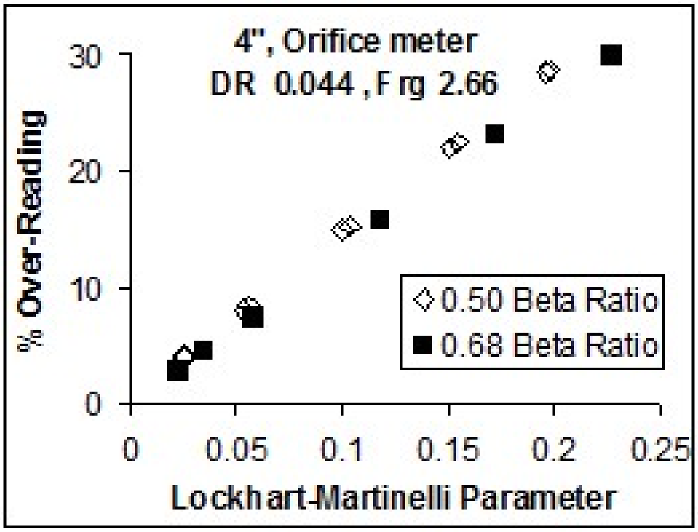


**FIGURE 11. Orifice Meter Wet Gas Beta Ratio Effect**

Martinelli Parameter values (typically $X_{LM} < 0.01$) does the liquid induce a negative gas flow rate prediction bias. Therefore, industry tends to call an orifice meters wet gas flow gas prediction error the "over-reading". The over-reading is the ratio of the apparent to actual gas mass flow rate ratio. It is often expressed as a percentage, as shown in equation 4. The percentage over-reading is just the percentage error induced on the gas flow prediction by the liquids presence. (The case of very low Lockhart Martinelli parameters giving negative gas flow rate errors means that the over-reading would be negative.)

$$OR\% = \left( \frac{\dot{m}_{g\ Apparent}}{\dot{m}_g} - 1 \right) * 100\%$$

(4)

The ratio of the gas to liquid densities has an influence on an orifice meters response to wet gas flow. This is denoted as "DR" and is shown as equation 5. For a system with set gas and liquid properties the density ratio is effectively just a number representing the pressure of a system.

$$DR = \rho_g / \rho_l$$

(5)

The gas flow rate has an influence on an orifice meters response to wet gas flow. The wet gas parameter called the "gas densiometric Froude number" (denoted by $Fr_g$) is shown as equation 6. The terms A & D are geometry terms and g is the gravitational constant. For a set geometry of orifice meter with set gas and liquid densities the gas densiometric Froude number is effectively just a number rep

$$Fr_g = \frac{\dot{m}_g}{A\sqrt{gD}} \sqrt{\frac{1}{\rho_g (\rho_l - \rho)_g}}$$

(6)

In 1962 Murdock [6] effectively showed that an increasing Lockhart Martinelli Parameter induced an increasing percentage over-reading, as shown in Figure 8. Such an orifice meter wet gas flow data plot of $X_{LM}$ vs. %OR is now called a "Murdock Plot". In 1967 Chisholm [7] showed that, for all other wet gas flow parameters held constant for a given orifice meter, increasing the density ratio reduced the magnitude of the percentage over-reading, as shown in Figure 9. In 2007 Steven et al [11] and Hall et al [12] showed that, for all other wet gas flow parameters held constant for a given orifice meter, increasing the gas densiometric Froude number increased the magnitude of the percentage over-reading, as shown in Figure 10. In 2011 Steven et al [13] showed that for a given orifice meter pipe size and a set wet gas flow condition larger beta ratio orifice plates (i.e. larger orifice diameters) gave smaller over-readings, as shown in Figure 11.

$$X_{LM} = \frac{\dot{m}_l}{\dot{m}_g}\sqrt{\frac{\rho_g}{\rho_l}} \qquad (2)$$

$$\dot{m}_g = \frac{\dot{m}_{g,apparent}}{\sqrt{1 + CX_{LM} + X_{LM}^2}} \qquad (7)$$

$$C = \left(\frac{\rho_g}{\rho_l}\right)^n + \left(\frac{\rho_l}{\rho_g}\right)^n \qquad (8)$$

$$n = 0.214 \qquad \text{for Frg} \le 1.5 \qquad (9a)$$

$$n = \left(\left(\frac{1}{\sqrt{2}}\right) - \left(\frac{0.3}{\sqrt{Fr_g}}\right)\right)^2 \qquad \text{for Frg} > 1.5 \qquad (9b)$$

Steven et al [13] give a correction factor for the case of gas with light hydrocarbon liquid. It is reproduced as equation set 2,7,8,9a & 9b. <u>In order to predict the actual gas flow rate, the operator must initially know the liquid mass flow rate</u>. That is, the liquid mass flow rate must be supplied to this correction factor from an external source. Once this information is supplied the equation set has one unknown, i.e. the actual gas mass flow rate. This value can be found by iteration – i.e. by use of computer software. The wet gas flow parameter limits of this correlation are:

| | |
|---|---|
| Orientation: | Horizontal Only |
| Fluids: | Gas with Light Hydrocarbon Liquids |
| Meter Size: | Nominal 2" to 4" |
| Beta Ratio Range: | $0.25 \le \beta \le 0.74$ |
| Lockhart Martinelli Parameter Range: | $0.005 \le X_{LM} \le 0.3$ |
| Density Ratio Range: | $0.007 \le DR \le 0.111$ |
| Gas Densiometric Froude No.: | $0.2 \le Fr_g \le 7.25$ |

Figure 12 shows massed orifice meter wet gas flow data sets. The uncorrected data are the solid points with an approximately linear relationship to the over-reading.

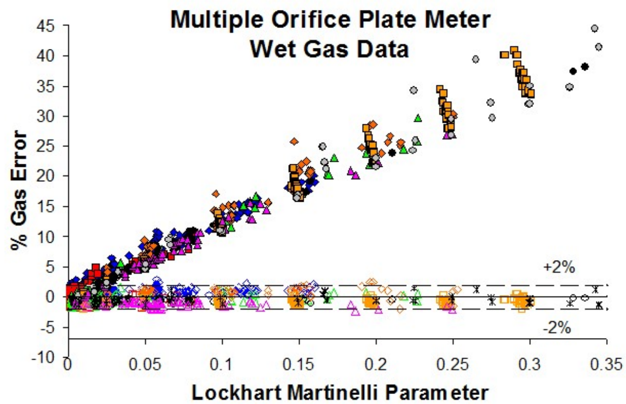


**FIGURE 12. Massed Orifice Meter Wet Gas Data**

Note the significant error that wet gas can induce on an orifice meters gas flow rate prediction. At the higher Lockhart Martinelli Parameters considered to be wet gas flow the over-reading can be in excess of 40%. The corrected data (from a known liquid flow rate) is the hollow points bound by the ±2% dashed lines along the x-axis. This data was recorded by multiple independent parties over 13 years using three different test facilities at two independent institutions. Much of the *apparent* scatter in the uncorrected data is actually the density ratio, gas densiometric Froude number and beta ratio effects shown in Figures 9, 10 & 11. However, although the beta ratio effect does exist it was found by Steven et al [13] to be small enough that it could be practically ignored. Hence, the correction factor does not have a beta ratio term. The reproducibility of orifice meter wet gas flow performance, and the resulting uncertainty rating of the correlation, is considered remarkable by many engineers that are well versed in the response of various gas flow meter designs to wet gas flows. For within the correlations specifications, and the case of a precisely known liquid flow rate, the correlation can predict the gas flow rate to within 2% at 95% confidence.

## MISCELLANEOUS COMMENTS

The over-reading originates from the fact that adding a liquid mass flow to a set gas mass flow rate increases the DP read by the orifice meter. The more liquid per unit mass of gas the greater the increase in DP. That is, the DP created by a wet gas flow through an orifice meter is higher than if the gas phase of the wet gas flow flowed alone through the meter. It is therefore important to understand that wet gas flow causes orifice meters to produce unusually high DP's. DP transmitters should be selected accordingly to avoid exceeding a DP transmitters range. A good rule of thumb for wet gas flows with $X_{LM} \leq 0.3$ is to size the DP transmitter range for orifice meters to be twice the upper range limit than would be expected for if the gas phase flowed alone.

The Achilles heel of this orifice meter wet gas correction is that the liquid mass flow rate is required to be known before it can be applied. Liquid flow rate information in natural gas flow production pipe lines is not easy to come by. Three common methods for obtaining the liquid flow rate in natural gas production are to use test separator history, apply a wet gas tracer dilution technique or use a PVT based prediction model. (Further details of these technique are out with the scope of this paper.) The test separator or tracer dilution technique methods of predicting the liquid flow rate are spot checks, and hence the operator has to assume that the liquid flow rate does not change between measurement intervals. Also, none of these methods are particularly accurate. Liquid flow rate estimates of wet natural gas flows are often not considered to have an uncertainty better than 10%. Fortunately, (and rather surprisingly) the gas flow rate prediction of the correlation is not very sensitive to liquid flow rate uncertainty. For a known precise liquid flow rate an orifice meter wet gas correlation has a typical gas flow rate prediction uncertainty of 2%. If the liquid flow rate is only known to an uncertainty of 10% then the knock on associated uncertainty in the wet gas correlation is typically in the order of another 2%. However, taking the root mean square of the correlations stated uncertainty and the liquid flow rate uncertainties contribution to the gas flow rate prediction uncertainty we get an over-all gas flow rate uncertainty of approximately 3%.

Note that the correlation is for orifice meters installed in horizontal pipes. The correlation is not applicable to vertical up, vertical down or inclined pipe meter installations. Pipe orientation strongly influences the flow pattern (as shown in Figures 1&2) and the flow pattern strongly influences the orifice meters wet gas over-reading. Therefore, application of an orifice meter wet gas flow correlation created for a particular meter orientation will give significant errors if applied to an orifice meter installed in a different orientation.

Finally note that recent research (i.e. Steven et al [13]) has shown that liquid properties can affect the wet gas flow response of an orifice meter. Hence, gas with water or gas with water and light hydrocarbon liquid wet gas flow can produce slightly different over-readings than gas with hydrocarbon liquid flow only. Therefore, if applied to gas with water or gas with hydrocarbon liquid and water wet gas flows this stated correlation could have a liquid property induced bias. A more complicated correlation has been publicly released (Steven et al [13]) for the case of different mixes of water and hydrocarbon liquid with the gas. However, this is a newer correlation, fitted to less data and not yet as proven as the stated correlation here. Further details are outside the scope of this paper.

## CONCLUSIONS

It is very important to regularly check an orifice plate for damage when the orifice meter is in wet gas service. A damage plate must be replaced.

Nearly all published research is for horizontal wet gas flow (although for various tap positions – whether an orifice meter has flange taps, corner taps or pipe taps appears to make little difference to the wet gas response). No information is available for vertical up or down, or inclined wet gas flow orifice meter installations.

An operator should check that the DP transmitter is not reading the upper range limit of the device. If it is the DP is possibly being read incorrectly. This is a very common problem with orifice meters in use with wet gas flow.

Trace liquids (i.e. $X_{LM} \leq 0.01$) in a gas flow can cause an under reading of the actual gas flow rate by up to 2%. Higher Lockhart Martinelli parameters will cause an orifice meter to over-read the gas flow rate. Unfortunately, so far the available data is mainly for $\leq 4$" meters. Using correlations out with their range can lead to unspecified additional uncertainties. However, for a known liquid mass flow rate there are correction factors published for horizontal applications that within the correlation range can predict the gas flow rate to an uncertainty of 2%. If the liquid flow rate is estimated (as it is in the field) the over-all uncertainty of the resulting correlation is approximately 3%.

## REFERENCES


1. International Standard Organization, 5167 Part 2.
2. American Gas Association Report No. 3, Part 1.
3. Gas Processors Association GPA 8185-90, Part1.
4. American National Standard Institution ANSI/API MPMS 14.3.1
5. Schuster R.A., "Effect of Entrained Liquids On A Gas Measurement", Pipe Line Industry Journal, February 1959.
6. Murdock. J.W., "Two-Phase Flow Measurements with Orifices" Journal of Basic Engineering, Vol.84, pp 419-433, December 1962.
7. Chisholm D., "Flow of Incompressible Two-Phase Mixtures through Sharp-Edged Orifices", Journal of Mechanical Engineering Science, Vol. 9, No.1, 1967.
8. Chisholm D., "Research Note: Two-Phase Flow Through Sharp-Edged Orifices", Journal of Mechanical Engineering Science, Vol. 19, No. 3, 1977.
9. McConaghy, B.J., Bell D.G., and Studzinski, W., "How Orifice-Plate Condition Affects Measurement Accuracy", Pipe Line Industry, December 1989.
10. Ting V.C. et al. "Effect of Liquid Entrainment on the Accuracy of orifice Meters for Gas Flow Measurement", Int. Gas Research Conference, 1993.
11. Steven R., Ting F. & Stobie G., "A Re-Evaluation of Axioms Regarding Orifice Meter Wet Gas Flow Performance", South East Asia Hydrocarbon Flow Measurement Workshop, Kuala Lumpur, March 2007.
12. Hall A. & Steven R., "New Data for the Correction of Orifice Plate Measurements in Wet Gas Conditions", South East Asia Hydrocarbon Flow Measurement Workshop, Kuala Lumpur, March 2007.
13. Steven R., Stobie G., Hall A. & Priddy B., "Horizontally Installed Orifice Plate Meter Response to Wet Gas Flows", North Sea Flow Measurement Workshop, Norway, October 2011.