Rosemount Orifice Plate in *Wet Gas*

This paper discusses the phenomenon of wet gas measurement, definitions, and the need to accurately measure this mixture. This paper also includes an introduction to the Rosemount Conditioning Orifice Plate technology, outlines the testing of the product, and discusses the results.

What is *Wet Gas*?

Within the oil and gas industry, the term *wet gas* has been acknowledged as multiphase flow (mixture of liquid and gas) with the percentage of gas volume overwhelming that of the liquid volume[1]. Wet gas implies the presence of small amounts of liquid within a gas stream. While there is no uniform definition of wet gas, gas volume fractions greater than 90% or 95% are accepted as a general interpretation throughout the industry. The Gas Volume Fraction (GVF) is defined as the gas volume flow rate, relative to the liquid volume flow rate at line temperature and pressure. Flow with a gas volume fraction lower than the values previously mentioned are considered multi-phase flow. The test data shown later in this paper is testing exclusively in the wet gas region.

Why Measure Wet Gas?

Two common flow measurements in the oil and gas industry are well-head and process metering. In *well-head metering*, the measurement point is typically upstream of any processing equipment where the gas is in its "raw" condition. The number of wells producing a true "dry gas" is negligible; generally all wells contain at a minimum, trace amounts of liquid which condense at surface conditions (lower temperatures and pressures). [1] *Process metering*, where liquid is formed in the processed gas stream due to changes in temperature and/or pressure, may be carried over from a separator system as a result of unexpected well conditions such as slug flow or even higher flow rates than the original design conditions.[1] Currently the well heads are combined prior to entering the test separator, with each of these being tested individually by routing the flow to the separator for a given period of time. This value is then assumed to remain constant and the sample data is used until tested again. Many ventures in drilling new gas well heads are in areas with increased risk and have multiple investors. With higher risk comes the need to reduce costs. Accurate and reliable wet gas meters have the potential to offer significant savings by eliminating expensive test separators and allowing constant monitoring of each individual wellhead. Wet gas is metered prior to the commingling of the well heads, which then are able to share common processing facilities. When allocation is the main issue, accuracy and repeatability comes to the forefront in the selection of wet gas meters for the oil and gas companies. This is why wet gas meters are becoming a key technology for the oil and gas industry.

[1] Stewart, David and Miller, Gary. "What is Wet Gas Flow and Where Does It Occur?" NEL Wet Gas Flow Measurement Training Course. Houston, TX. September 2004.

Background

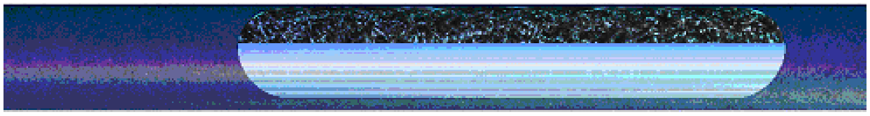
Multiphase and wet gas flow is complicated and difficult to understand or predict. Flow regimes have been identified to help understand and separate the behavior caused by the interaction of the liquid and gas. These regimes vary depending on numerous parameters such as liquid and gas velocities, liquid and gas densities, flow composition (fraction of gas and liquid) and many other factors. The region previously defined as wet gas is comprised of numerous flow regimes, ranging from mist to stratified flow. Some flow patterns are unsteady causing an unstable or erratic reading, but even in well established flow regimes the interface between gas and liquid is continuously changing. Below are some general definitions for the regimes that are observed in the pre-defined wet gas conditions for horizontal and vertical applications.

Flow Patterns

Horizontal Flow

Stratified flow: The gas and liquid flow in distinct layers within the pipe. The liquid flows along the bottom of the pipe with the gas above it. The contact area between the gas and liquid is at the minimum in this flow pattern.

Figure 1: Stratified flow

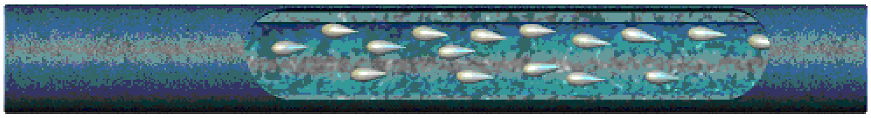


Stratified Wavy flow: Is developed as the gas velocity increases causing the stratified region to develop a wavy appearance.

Figure 2: Stratified Wavy flow

Annular / Annular Mist flow: Occurs when liquid forms as a film on the pipe walls and the gas forms inside this liquid. A large percentage of the liquid phase can become entrained in the gas stream as droplets (mist) travel close to the same velocity as the gas.

Figure 3: Annular/Annular Mist

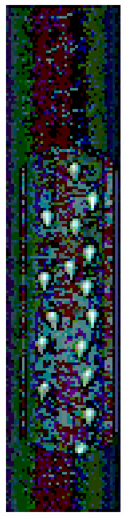


Vertical Flow

In Vertical flow, as with horizontal, the regimes begin with mist, but skip the stratified region, going directly to the Annular flow. This is shown in figure 4.

Annular Mist flow: Develops when the velocity of the gas increases and some of the liquid becomes entrained as droplets (mist) in the gas core stream. [2]

Figure 4: Annular Mist



[2] Stewart, David and Miller, Gary. "Why Measure Wet Gas?" NEL Wet Gas Flow Measurement Training Course. Houston, TX. September 2004.

Differential Pressure Wet Gas Meters

There are two basic approaches to wet gas measurement: single-phase and two-phase meters. A *single-phase* meter is a dry gas meter applied to wet gas flow with corrections applied for the amount of liquid content in the measurement. A *two-phase* meter is a meter designed to measure the flow rates of both gas and liquid phases. [3] This paper focuses on single-phase meter types only. Single-phase meters can be divided into two groups: DP measurement technologies and non-DP measurement technologies. In general, the measurement response of DP based meters (such as Orifice Plates, Venturi meters, V-cone® meters) is as an over-reading of the gas flow rates due to the presence of liquid. The amount of over reading is correlated directly to the amount of liquid that is in the flowing medium. The most common of these correlations is a dimensionless number called the Lockhart-Martinelli number. From the Lockhart-Martinelli number the amount that the meter is over-reading can be determined, thereby giving the true gas flow rate.

Test Introduction

The Rosemount 405C Compact Conditioning Orifice Plate and 1595 Conditioning Orifice Plate enable users to extend the use of orifice plates into measurement points previously limited by existing piping configurations. The products deliver accurate and repeatable results downstream of a variety of flow disturbances. This patent-pending technology represents an important innovation in DP flow measurement in that it can be installed with as little as two diameters of straight pipe-run downstream of virtually any flow disturbance and achieve ±0.5% accuracy.

Figure 5: Rosemount 405C and 1595 Conditioning Orifice Plate

1595 405C

[3] Stewart, David and Miller, Gary. “Wet Gas Measurement Techniques.” NEL Wet Gas Flow Measurement Training Course. Houston, TX. September 2004.

Two styles of Conditioning Orifice Plates that have been developed are the 1595 and 405C. The first is a paddle-style plate, designed for use between flange-tapped orifice flanges. This style is easily retrofitted into existing orifice flanges with flange taps and can be used to improve the measurement of an orifice that was installed without the proper straight run requirements. The second style is the “Compact” version of Conditioning Orifice. This wafer style meter incorporates a direct mount 3-valve head with corner taps into a one piece design and allows the direct connection of a DP or multivariable transmitter. The 405C platform simplifies flow meter installation and reduces the number of potential leak points by eliminating impulse lines. In addition, the 405C can be installed between standard ANSI flanges thereby reducing the labor costs associated with a typical orifice meter.

The Rosemount Conditioning Orifice Plate models differ from standard orifice plates primarily in the number of holes bored through the plate, the Conditioning Orifice Plate having four whereas a standard plate has only one. The four hole design conditions the flow as it passes through the meter, reducing the requirements for upstream straight run to 2 pipe diameters downstream of most disturbances. Inherent in the four hole design is the ability to place the meter such that the dam height can be minimized to allow less restricted flow of liquid in wet gas applications. The dam height is reduced considerably when compared to a conventional orifice plate. For example, a 63% reduction is seen when comparing dam heights in a 4-inch (sch40) pipe with a 0.4 beta. Physical advantages, accuracy and requests for use in wet gas applications fuel the need for testing in the wet gas environment.

Testing Program

The approach to wet gas metering discussed in this paper involved taking measurements using the single phase meter and applying a correction factor based upon the amount of liquid that is present in the gas. The testing plan covered a broad range of flowing velocities, pressures, gas volume fractions, and mass ratios, such that a basis for the over reading of the meters could be determined based upon ratio of liquid to gas. From the test results, equations have been developed which enable the determination of a dry-gas flow rate given the wet-gas measurement and an assumed or independently measured level of liquid in the flow.

Test Meters

The flow meters used in testing are production meters with the model numbers, serial numbers and Beta ratios listed below in Table 1.

Table 1: Meters used in testing

Model Number	Serial Number	Line Size	Beta
1595P030A6SA040	03D408006	3-in.Sch40	0.40
1595P030A6SA065	03D657899	3-in.Sch40	0.65
405CS030N040A3	WG001	3-in.Sch40	0.40
405CS030N065A3	WG002	3-in.Sch40	0.65

Facility and Instrumentation

See Appendix A for a description of the wet gas testing facility Colorado Engineering Experiment Station (CEESI) as well as a complete list of all instruments used throughout the tests.

Testing Parameters

Tests were conducted simultaneously on both the Rosemount 405C wafer meter and 1595 paddle style orifice plate, for each of the beta values 0.40 and 0.65 at pressures of 200 and 700 psi. The different pressures allow for the investigation of different gas densities. The meters were installed in horizontal piping and tested across a wide range of gas and liquid flow rates to determine the effect of the entrained liquid on the gas flow measurement. The range is shown in Table 2, expressed in gas densiometric Froude number (Fr_g) and Lockhart-Martinelli number (X).

Table 2: Range for Conditioning Orifice wet gas tests

β	Pressure (psi)	X
0.40	200	0.0 – 0.3
	700	
0.65	200	0.0 – 0.3
	700	3-in.Sch40

The maximum Lockhart-Martinelli value (X) was 0.3 where pressure and β would permit. The Lockhart-Martinelli number is defined as follows:

Equation 1:

$$X = \frac{\dot{m}_l}{\dot{m}_g}\sqrt{\frac{\rho_g}{\rho_l}}$$

Where:

$\dot{m}_l$ = Mass flow of liquid

$\dot{m}_g$ = Mass flow of gas

ρ_l = Density of liquid

ρ_g = Density of gas

Beta is defined as follows:

Equation 2:

$$\beta = \frac{d}{D}$$

Where:
d = Orifice plate bore
D = Pipe inside diameter

The term *Mass Ratio* will be referenced throughout this document. This term is defined as follows:

Equation 3:

$$\text{Mass Ratio} = \frac{\dot{m}_{liquid}}{\dot{m}_{gas}}$$

Where:

$\dot{m}_{liquid}$ = Liquid mass flow

$\dot{m}_g$ = Gas mass flow

Test Procedure

The wet gas metering tests were conducted following the procedures outlined below:

1. A complete run matching the gas velocities of the testing plan was completed without any entrained liquid to establish a baseline that will enable us to measure the change in flow rate due to the liquid that will be introduced into the pipeline.
2. A constant gas velocity was set, five different liquid loadings were tested, the liquid mass ratio varied dependent upon the pressure and β of the plates being tested.
3. Each data point was averaged over a five minute time frame with approximately 54 samplings used in the averaging of the individual data point.

4. A second dry run was completed after all mass ratios were tested to ensure no sensor drift occurred during the test.
5. The above procedures were repeated for the remaining gas velocities as well as tests with different pressures and plate βeta.

Calculation Methods

The over-reading of the meter caused by the entrained liquid present in the pipe is calculated using the following equation:

Equation 4:

$$\text{OverReading} = \sqrt{\frac{\Delta P_{tp}}{\Delta P_g}}$$

Where:
ΔP_{tp} = Total DP reading of wet gas
ΔP_g = The DP of gas only
The ΔP_g is calculated using the dry gas calibration data and measured gas flow rate and density.

Equation 5:

$$\Delta P_g = \left(\frac{Q_{m,ref}}{0.09970190 \quad C_{d,calc} \quad Y_1 \quad d_c^2 \quad E \quad \sqrt{\rho}} \right)^2$$

Where:
$Q_{m,\,ref}$ = Gas mass flow read by the reference turbine meter
$C_{d,}calc$ = Calculated discharge coefficient based on dry gas run and
$Re_{,ref}$ = Reynolds number based on gas reference flow

Results

The wet gas summary data is plotted below for the Rosemount 1595 and Rosemount 405C wafer style meter. Figure 6 and 7 are plotted using the over-reading vs. the Mass Ratio and show both the tested betas as well as the different pressures.

Figure 6: Rosemount 1595 over-reading vs. Mass Ratio

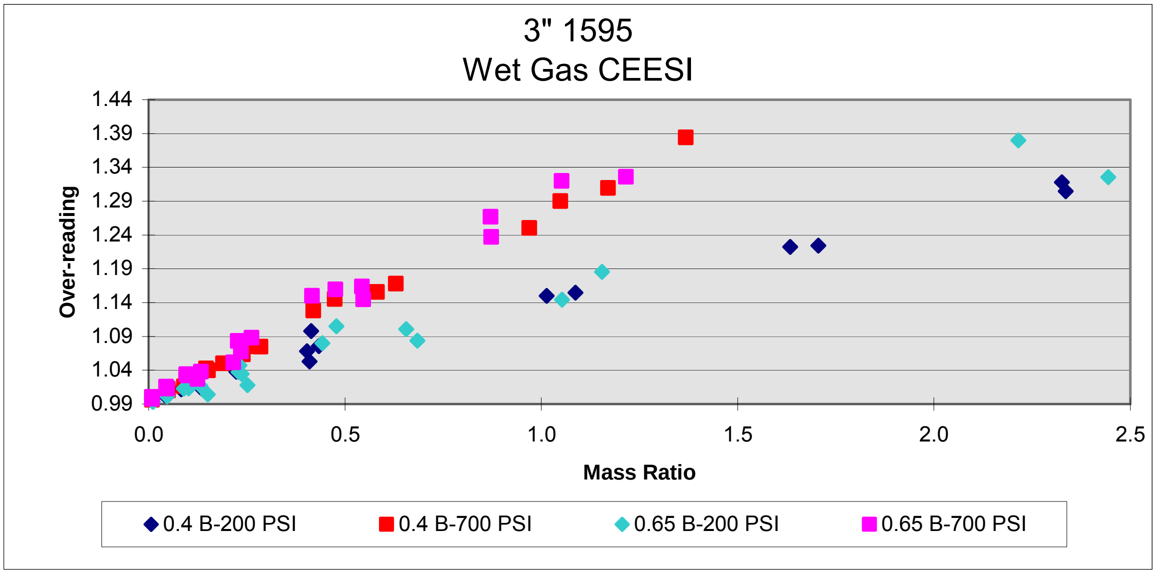
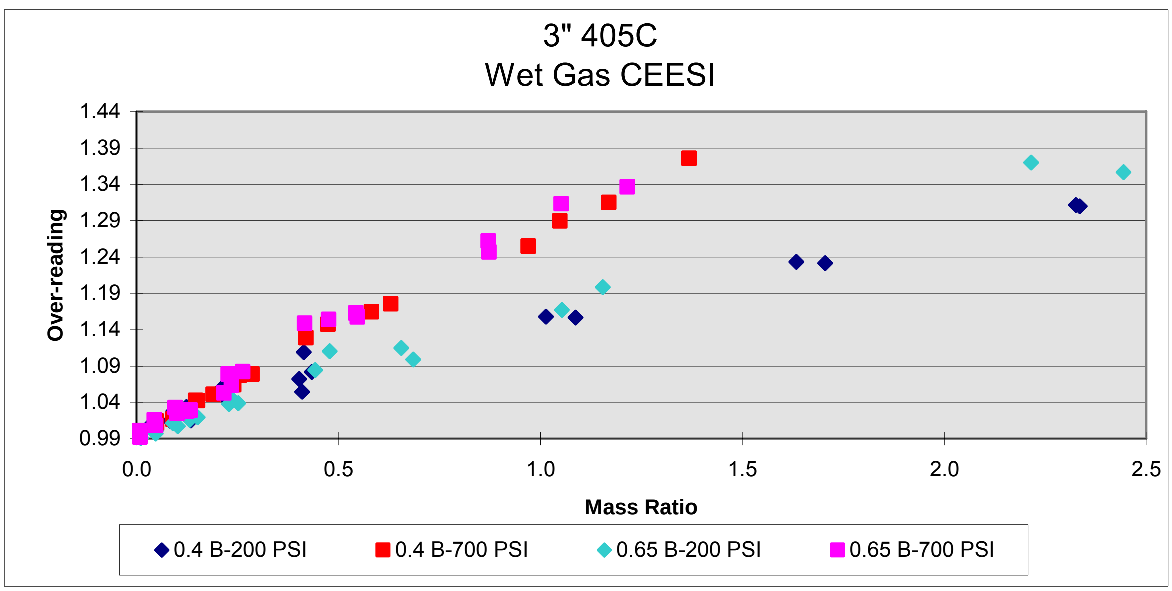


Figure 7: Rosemount 405C over-reading vs. Mass Ratio



Looking at Figures 8 and 9 there are two distinct trends that follow the pressure of the meters being tested, which is a direct correlation to the density of the gas. In an effort to isolate the meter performance the data is plotted as over-reading vs. Lockhart-Martinelli number.

Figure 8: Rosemount 1595 over-reading vs. Lockhart-Martinelli Number

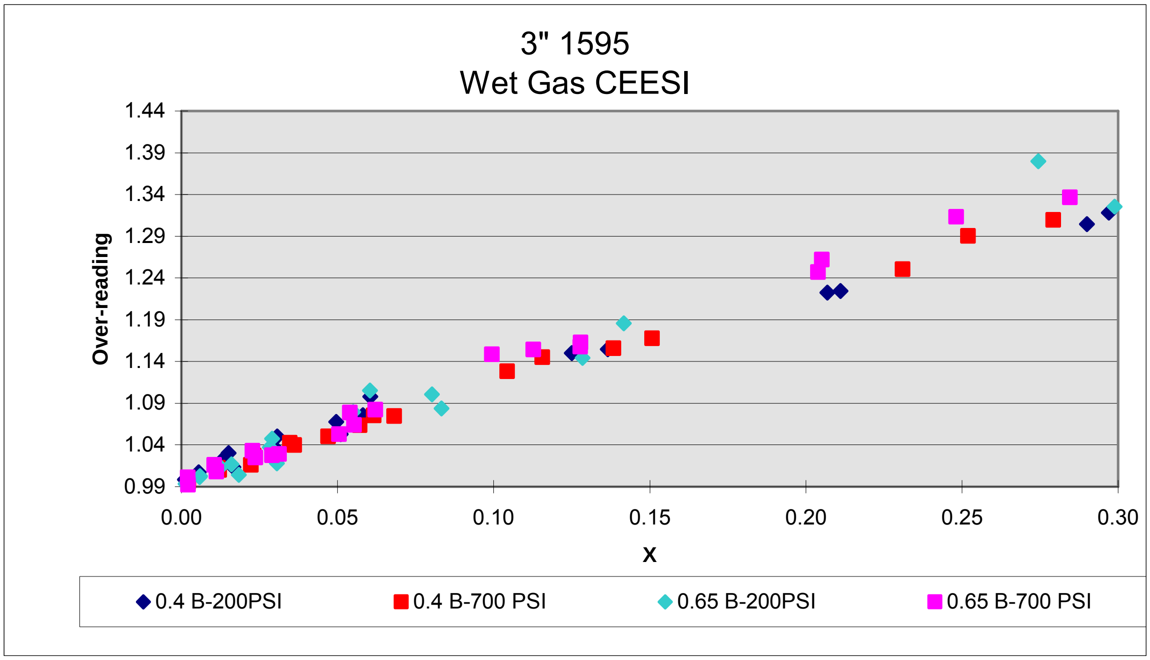
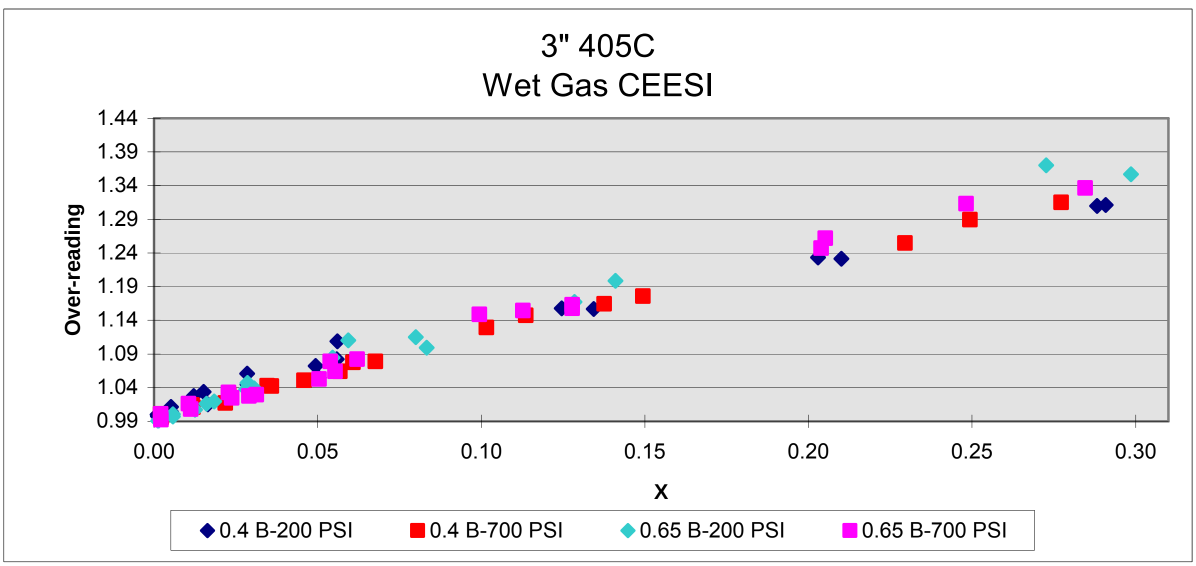


Figure 9: Rosemount 405C Over-reading vs Lockhart-Martinelli



From Figure 8 and 9 it can be observed that both the Rosemount 1595 and the 405C meters follow the same trend with the main source of scatter or variance in the trend being that of the different betas.

From the above observations the meters were separated by beta and have been plotted (Figure 10, 11, 12, and 13) as over-reading vs. Lockhart-Martinelli number with a trendline and equation to enable calculations to be performed to determine the over-reading based on the amount of entrained liquid.

Figure 10: Rosemount 1595 over-reading vs. Lockhart-Martinelli 0.40 Beta with curve fit

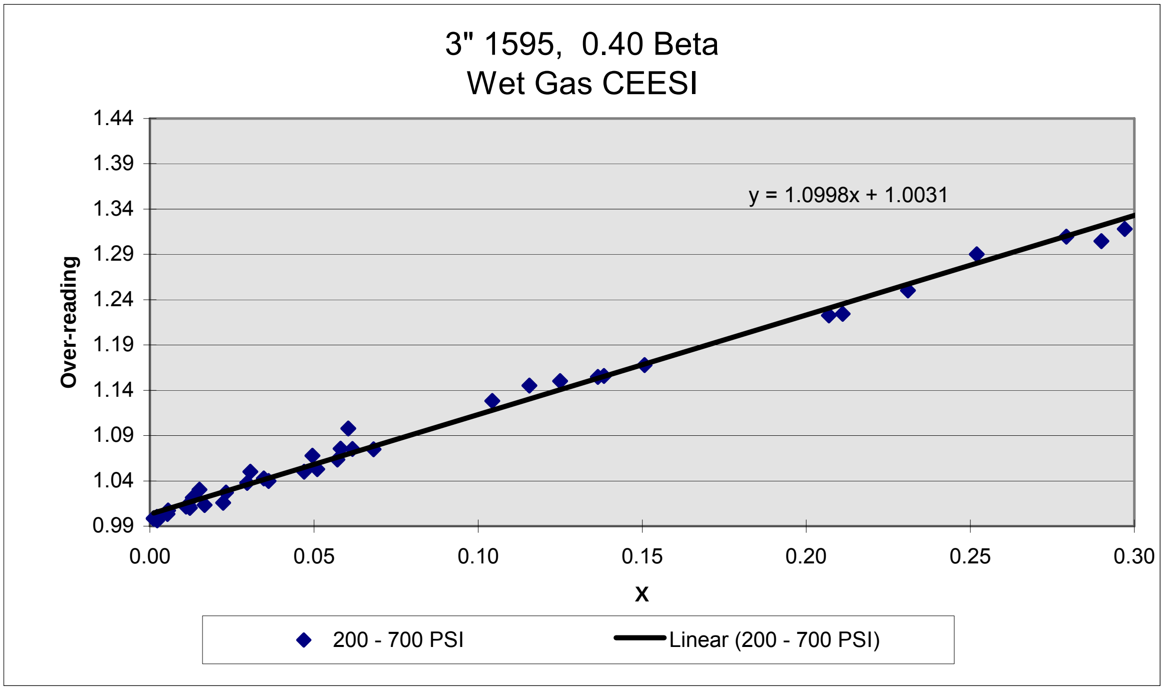


Figure 11: Rosemount 1595 over-reading vs. Lockhart-Martinelli 0.65 Beta with curve fit

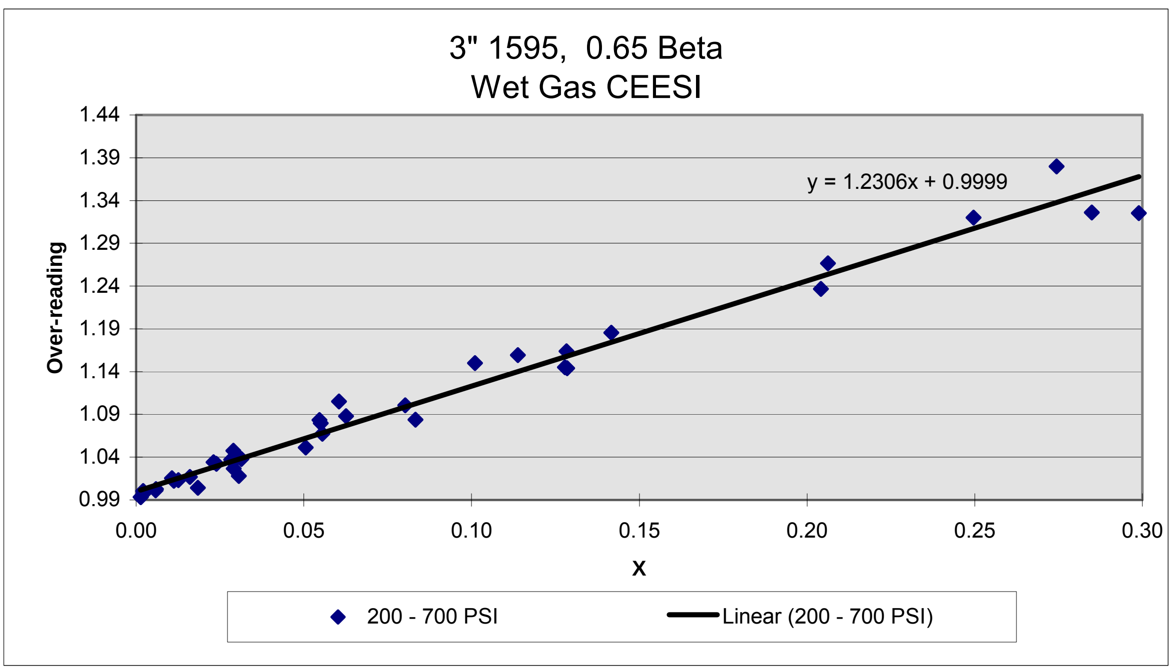


Figure 12: Rosemount 405C over-reading vs. Lockhart-Martinelli 0.40 Beta with curve fit

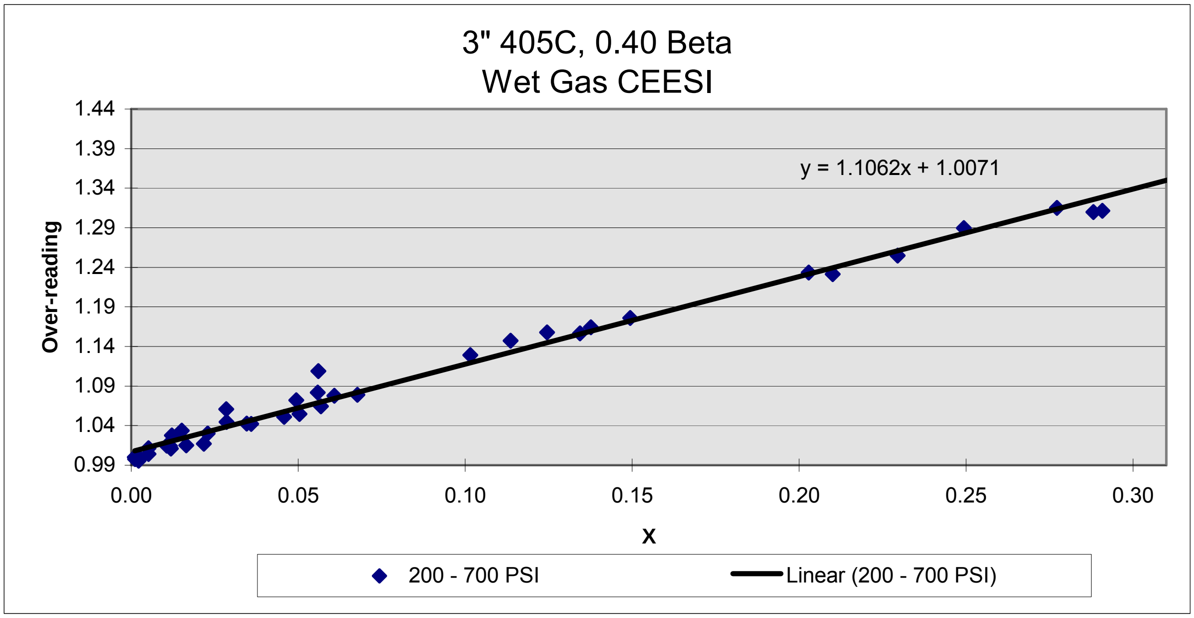
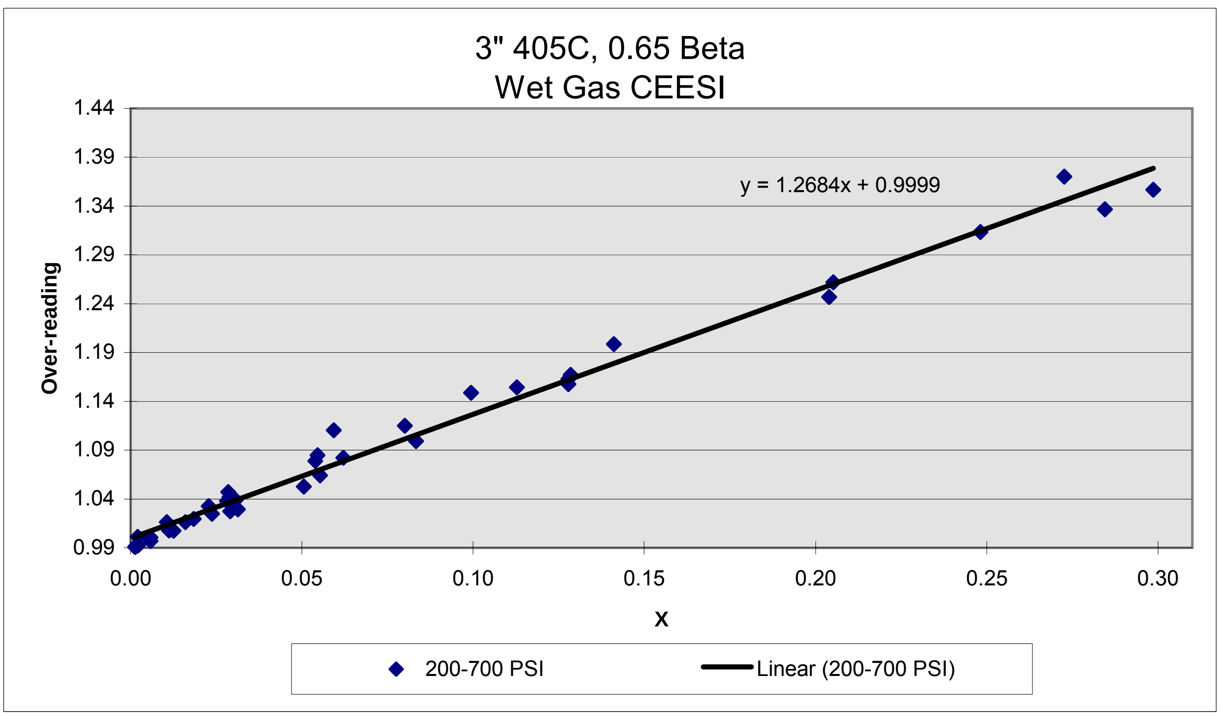


Figure 13: Rosemount 405C over-reading vs. Lockhart-Martinelli 0.65 Beta with curve fit



To determine the offset of the calculated values versus measured values the following steps were taken.

1. The calculated Lockhart-Martinelli number at each measured data point was inserted into the equations from the curve fits, equations used are shown below:

Equation 6: Rosemount 1595 0.40 beta

O.R.=1.0998*X+1.0031

Equation 7: Rosemount 1595 0.65 beta

O.R.=1.2306*X+0.9999

Equation 8: Rosemount 405C 0.40 beta

O.R.=1.1062*X+1.0071

Equation 9: Rosemount 405C 0.65 beta

O.R.=1.2684*X+0.9999

Where for equations 8 – 11
O.R.=Over-reading
X=Lockhart-Martinelli number

2. The percent offset was then calculated using the following equation.

Equation 10: Percent Offset

$$\text{Percent Offset}\,\frac{(O.R_{measured} - O.R._{calculated})}{O.R._{measured}} \times 100$$

Figure 14 and 15 are graphical representations of how well the curve fit matched the actual data in both the Rosemount 1595 and 405C.

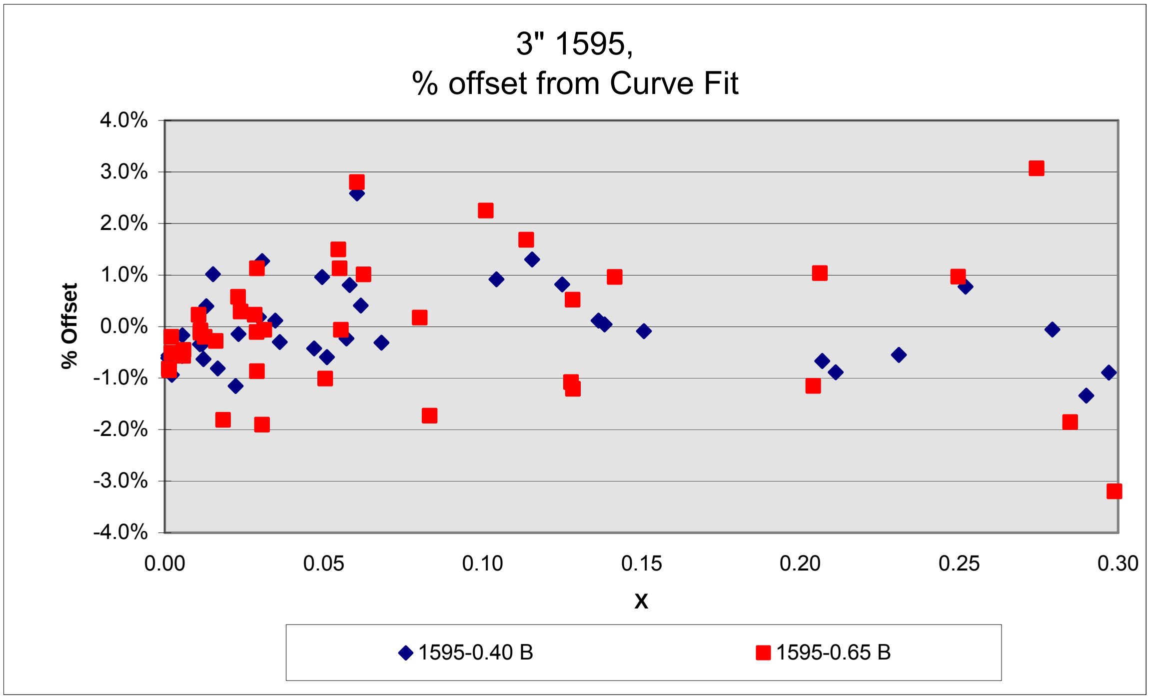


Figure 14: Rosemount 1595 Calculated offset from measured versus Lockhart-Martinelli Number

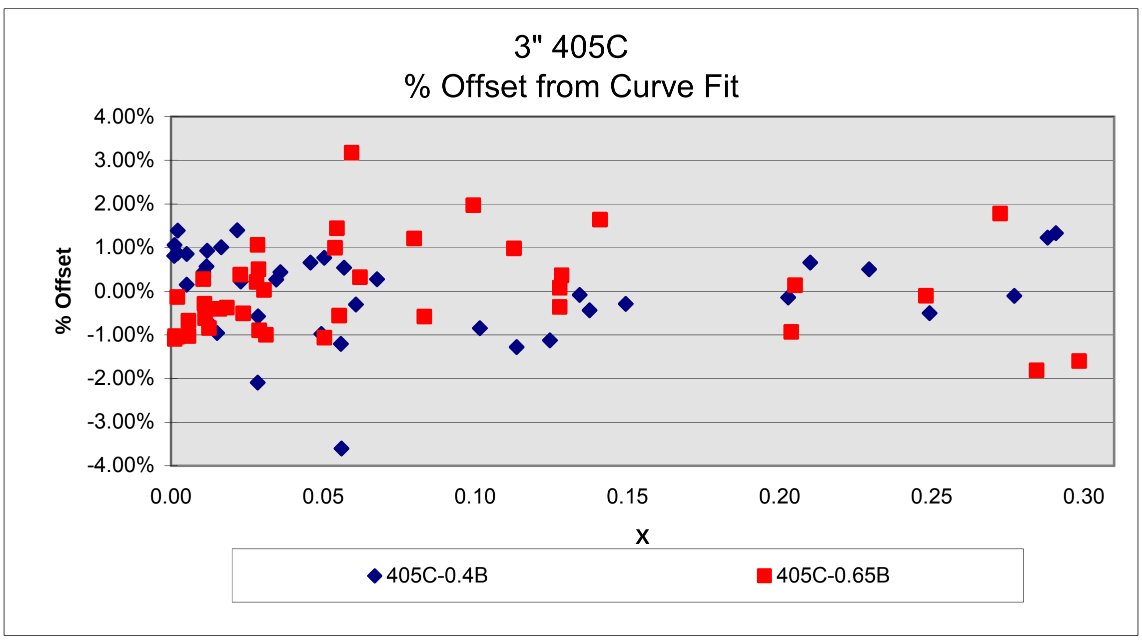


Figure 15: Rosemount 405C Calculated offset from measured versus Lockhart-Martinelli Number

Conclusion

Both the Rosemount 1595 and 405C Conditioning Orifice Plates were tested over a wide range of liquid loads at 200 and 700 psia in CEESI's wet gas test facility.

As liquid was introduced into the meter section simulating typical field installation conditions the meters responded in a predictable and repeatable manner. As expected, the meters showed an over-reading for the gas mass flow rate as liquid was introduced into the meter sections. The amount of over-reading was correlated to the amount of liquid that was introduced and the pressure of the gas using accepted industry techniques.

After compensating for the liquid fraction with the established correlation relationship for each meter, the residual flow error for the 0.40 Beta was found to be less than ±2% with a 2 sigma confidence level and the 0.65 Beta was found to be less than ±3% with a 2 sigma confidence level.

Appendix A

Description of Facility

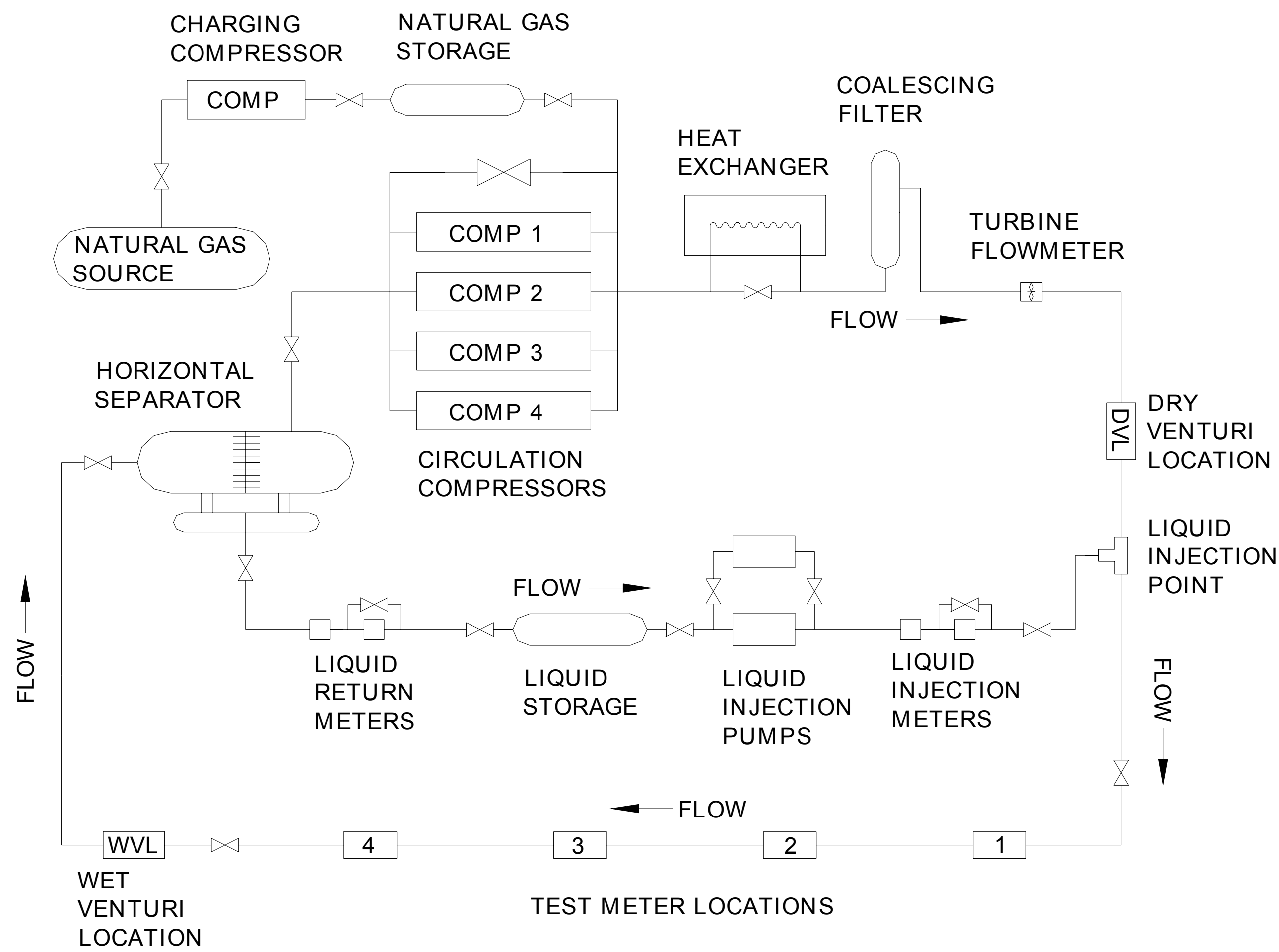
Colorado Engineering Experiment Station, Inc. (CEESI) in Nunn, Colorado is a multi phase facility consisting of natural gas and hydrocarbon liquids. The facility accommodates line sizes from 2 to 8 inch at a max pressure of 1440 Psi. The facility operates at temperatures ranging from ambient to 122°F (50°C).

Lean natural gas is brought into the CEESI complex at a low pressure of near 50 psi (0.3 Mpa). A charging compressor is used to pressurize the test loop to the desired operating pressure for the test being conducted. The normal operating pressure range is between 100 to 1440 psi (0.7 to 9.9 Mpa). Once the loop is pressurized, any combination of the four positive displacement compressors can be used to circulate the natural gas around the test loop at the desired velocity. Both a turbine meter and a subsonic venturi measure the mass flow rate of the natural gas. The difference in mass flow rate between these two meters is monitored. If the difference exceeds a specified amount, the data is scrutinized for detrimental effects such as pulsation. If the difference is within tolerance, then all other meters installed in the test loop can be compared to the natural gas mass flow rate as measured by the turbine meter.

The hydrocarbon liquid, which resides in the liquid storage vessel, can be injected into the gas stream by positive displacement pumps (triplex pumps). The Micro Motion® Coriolis meters measure the liquid mass flow rate and the density of the injected liquid. The gas stream carries the liquid through the meter test locations to the horizontal separator where it is then returned to the liquid storage vessel. Coriolis meters again measure the mass flow rate and the density of the returned liquid. When the injected liquid mass flow rate is equal to the return liquid mass flow rate and all pressures and temperatures within the loop are constant with time; the system is at a steady state condition and test data can be acquired.

Figure 16 is a simplified block diagram that shows the major components of the wet-gas test facility.

Figure 16: Block Diagram of Wet Gas Test Facility



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