Wet Gas Diagnostic with Intelligent Differential Pressure Transmitter

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Introduction

Wet gas is a commonly occurring condition in the production of natural gas. Wet gas is usually encountered at the wellhead and after separators with carryover. Wet gas implies that a small amount of liquid, usually water, oil and/or gas condensates, with liquid amounts up to 10% by volume. Amounts higher than this can be encountered but are usually regarded as multiphase flow. With increased interest in well allocation, flow measurements at the wellhead or post separator are important and becoming more prevalent. The wet gas may be metered at the wellhead prior to commingling of multiple gas streams prior to the separator, utilizing common differential producers such as venturis, orifice plates and V-Cones. Differential producers will “over-read” the true gas flow rate due to the presence of the liquid in the fluid stream. The amount of overreading is directly correlated to the amount of liquid. The most common of these liquid content correlations is the Lockhart-Martinelli (L-M) parameter, which relates the mass flow of the liquid to the mass flow of the gas. From the L-M parameter the amount the meter is overreading can be determined and subsequently corrected. The relationship between the L-M parameter and overreading for a typical venturi, compact orifice plate and V-Cone is given in Figures One through Three.

The L-M parameter is usually determined by running the fluid stream into a test separator. Once determined, the overreading correction value is assumed to remain constant until the well is tested again. This approach is satisfactory until a significant change in liquid loading occurs. At this point, the correction value may no longer be valid and a significant measurement error incurred. Users would like a means to measure the actual liquid loading and would value a means to detect significant changes in the liquid loading that affect the overreading correction value.

Background

Over the past few years, several groups have investigated the relationship between the noise signals present in the Differential Pressure (DP) signal and the amount of liquid in the wet gas flow. In each case, the investigators’ goal was to create a wet gas measurement. Non-standard, high speed differential pressure transmitters and high speed data acquisition equipment were used, with data analysis completed on a PC or similar device.

At about the same time, Emerson Process Management developed a new generation of Differential Pressure transmitters with a unique, scalable architecture. This new pressure transmitter platform, called the Rosemount 3051S, provides best in class performance and reliability and also features advancements in power management that allows the easy addition of advanced functionality to the base pressure transmitter. This functionality, embodied in a feature board, can be ordered as part of the transmitter or simply added to an existing transmitter already installed in the field.

Making use of this advanced functionality, Emerson has developed a unique patented technology that provides a means for early detection of abnormal situations in a process environment. The technology, called Statistical Process Monitoring (SPM), is based on the premise that virtually all dynamic processes have a unique noise or variation signature under normal operation. Changes in these signatures may signal that a significant change in the process, process equipment, or transmitter installation will occur or has occurred. For example, the noise source may be equipment in the process such as pumps, agitators or the natural variation in the DP value caused by turbulent flow or any combination thereof.

The sensing of the unique signature begins with a high speed sensing device such as the Rosemount 3051S Pressure Transmitter equipped with patented software resident in a HART® Diagnostics or FOUNDATION™ fieldbus Feature Board. This powerful combination has the ability to compute statistical parameters that characterize and quantify the noise or variation and represent the mean and standard deviation of the input pressure. Filtering capability is provided to separate slow changes in the process due to intentional setpoint changes from inherent process noise which contains the variation of interest. The transmitter provides the statistical parameters to the host system via HART or FOUNDATION fieldbus communications as non-primary variables. The transmitter also has internal software that can be used to baseline the process noise or signature via a defined learning process. Once the learning process is completed, the device itself can detect changes in process noise and will communicate an alarm via the 4 – 20 mA output or alert via HART or FOUNDATION fieldbus.

With the design of this transmitter and feature board complete, Emerson initiated a test program to determine if this technology could be applied to the detection of significant changes to the liquid loading of wet gas.

Test Program Description

Two traditional wet gas differential producers and a new, increasingly popular differential producer, the Rosemount 405C Compact Orifice, were tested in August/September 2005 at TÜV NEL's wet gas test facility in East Kilbride, Scotland, UK. The traditional differential producers consisted of a 0.75 beta 100mm (4") McCrometer V-Cone and a 0.75 beta 100mm (4") Seiko venturi. The 405C was a 0.4 beta 100mm (4") device. The DP signal was measured by a 250" Rosemount 3051S Differential Pressure Transmitter (0.75 beta units) or a 1000" Rosemount 3051S (0.4 beta unit). Both transmitters had FOUNDATION fieldbus outputs, and were configured to output pressure data at the maximum rate of 22 updates per second. The data were recorded using standard PC FOUNDATION fieldbus tools and analyzed post test using standard Excel spreadsheets.

The V-Cone was tested at four flow rates (750, 663, 500 and 250 m^3/hr) at 15 bar and Liquid Volume Fractions (LVF) from 0 to 4.5%. The Venturi was tested only at 60 bar, three flow rates (427, 285 and 142 m^3/hr) and identical LVF's. The 405C was also tested at 60 bar, four flow rates (200, 175, 150 and 100 m^3/hr), and LVF's from 0 to 8.1%. All tests were performed over a Lockhart-Martinelli range of 0 to approximately 0.3, the range generally used to define wet gas.

Each test run lasted at least 90 seconds and at least two data runs were taken at each test condition. After each test run, the DP mean and standard deviation were calculated for each data set. In addition, the average gas and liquid flow were determined along with line pressure and temperature.

Test Results and Analysis

The test data for each differential producer were overlaid on a flow map to illustrate the location of their predicted flow regimes. For this discussion the Shell Flow Pattern Map, a commonly used representation of two-phase horizontal flow, was used. Shell created this map using experimental data by observing the flow conditions at varying gas and liquid Froude values.

The gas and liquid Froude numbers are dimensionless numbers calculated by the square root ratio of fluid velocities (whether gas or liquid) as if the single phase completely filled the pipe to the gravity force on the other fluid. The ratio of the liquid Froude number to the gas Froude number equates to the Lockhart-Martinelli number. The equations are as follows:

$$Fr_g = \sqrt{\frac{SuperficialGasVelocity}{LiquidGravityForce}} = \frac{U_{sg}}{\sqrt{gD}}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}} = \frac{m_g}{A\sqrt{gD}}\sqrt{\frac{1}{\rho_g(\rho_l - \rho_g)}} \qquad (1)$$

$$Fr_l = \sqrt{\frac{SuperficialLiquidVelocity}{LiquidGravityForce}} = \frac{U_{sl}}{\sqrt{gD}}\sqrt{\frac{\rho_l}{\rho_l - \rho_g}} = \frac{m_l}{A\sqrt{gD}}\sqrt{\frac{1}{\rho_l(\rho_l - \rho_g)}} \quad (2)$$

$$\frac{Fr_l}{Fr_g} = Lockhart - Martinelli \quad (3)$$

Where g is the gravitational constant, A is the internal pipe cross-sectional area, D is the pipe inner diameter, U represents the superficial velocity for gas or liquid and ρ is the fluid density for either gas or liquid.

As the Flow Pattern Map was created based on experimental observations, the boundaries illustrated serve only as predictions of the indicated flow regime and carry with them a degree of uncertainty. Conditions such as pressure, temperature, flow rates, fluid properties, pipe diameter and primary element geometry all contribute to this uncertainty[1].

In Figure 4, as an example, the 0.75 beta Seiko venturi test data at 60 bar are shown. The data are represented in lines of constant LVF by varying superficial gas and liquid velocities. As seen, the bulk of the data lies in the Annular-Mist flow regime with a small portion of the low flow rate test points falling into the Stratified regime. The relative proximity of the process data to flow boundaries is significant in understanding the performance of the SPM diagnostic and will be discussed further.

For analysis purposes a very useful parameter is the ratio of the DP standard deviation (σ) to the DP mean (X). In many DP flow applications, this ratio has been found to remain relatively constant as the flow rate increases. This behavior is true for both gas and liquid flows. This ratio (σ/X) versus the mean DP was plotted on an X/Y chart for each primary element for a given line pressure.

As an example to discuss the test results, reference Figure 5. The data points for a given gas flow rate at various LVF's are indicated by the same style symbol and color. A trendline for each gas flow rate is also provided. The black arcs represent trendlines for constant LVF values at different flow rates. In this figure, the relationships between the σ/X ratio and the mean DP value for the 0.75 beta Seiko venturi at 60 bar are shown. As expected, per the DP flow square root relationship, the DP increases with higher gas flow rates at fixed LVF's as the σ/X ratio remains relatively constant. However, for a given increase in LVF percent, the σ/X ratio responds at a significantly higher rate. For this primary element at 60 bar, the slope (sensitivity) of σ/X ratio to increasing LVF is the highest at the lowest gas flow rate (140 m^3/hr). With increasing flow rates the σ/X ratio maintains its correlation to LVF but experiences a slight decrease in sensitivity to LVF changes. Referencing Figure 4, the Flow Pattern Map for the venturi, data contained in the Stratified region demonstrate far less sensitivity to changes in LVF relative to data in the Annular-Mist regime.

The results for the 0.4 beta 405C compact orifice plate at 60 bar are shown in Figure 7. While less sensitive than the venturi in terms of percent, the σ/X ratio clearly displays the same relationship to increases in gas flow rate and LVF. This is particularly evident with LVF's above 2.9%. The geometry of this primary element differs greatly from the venturi and may allow it a degree of sensitivity to wet gas detection even when operating around the Stratified regime boundary.

Figure 9 shows the results for the 0.75 beta V-Cone at 15 bar. Excellent sensitivity of the σ/X ratio is indicated at the three gas flow rates tested. At the low flow rate, LVF conditions above 1.47% result in significant increases to the σ/X ratio with this behavior once again attributed to the flow conditions straddling the Stratified boundary.

Conclusion

The test results for the three different differential producers indicate that the value of the ratio of DP signal standard deviation to the mean DP can provide a means to detect changing Liquid Volume Fractions in a wet gas flow stream. This ratio remains relatively constant with gas flow rate changes and fixed LVF, but increases significantly with increasing LVF and constant gas flow rates. Factors such as primary element geometry and flow regime have been shown to influence the ability of the transmitter to distinguish LVF's primarily at low flow rates. The sensitivity of this relationship is strongest at lower gas flow rates and decreases at higher gas flow rates.

Today, the Rosemount 3051S Pressure Transmitter can output the required SPM parameters via HART or FOUNDATION fieldbus digital communication protocols needed to determine these factors described in this document. Having these parameters can readily provide users with additional insight into their process conditions. With this capability, gas field operators can have an indication of significant changes in LVF that affect the overreading correction values for wellhead flow measurements or separator operation. In the former case, gas wells may only need to be tested when a change is detected by the transmitter rather than on a fixed periodic basis avoiding the costly efforts associated with retesting the well.

References

[1]"Wet Gas Flow Metering With Gas Meter Technologies" by Steven, R., CEESI

Figures

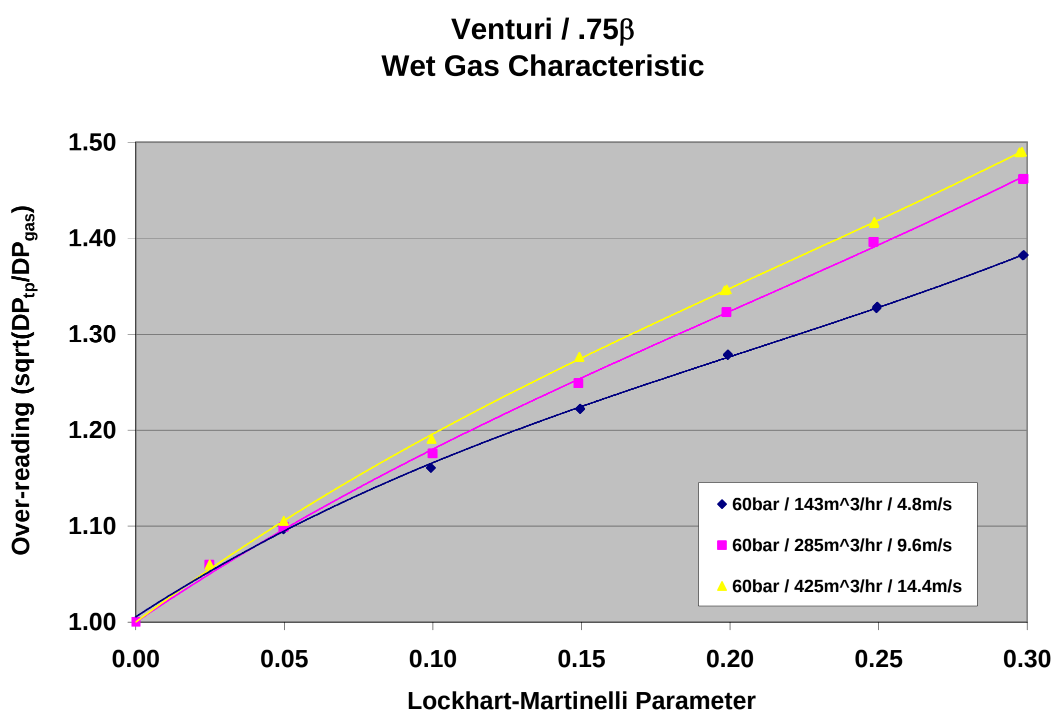

Figure 1: Relationship between Lockhart-Martinelli parameter and overreading for a typical Venturi

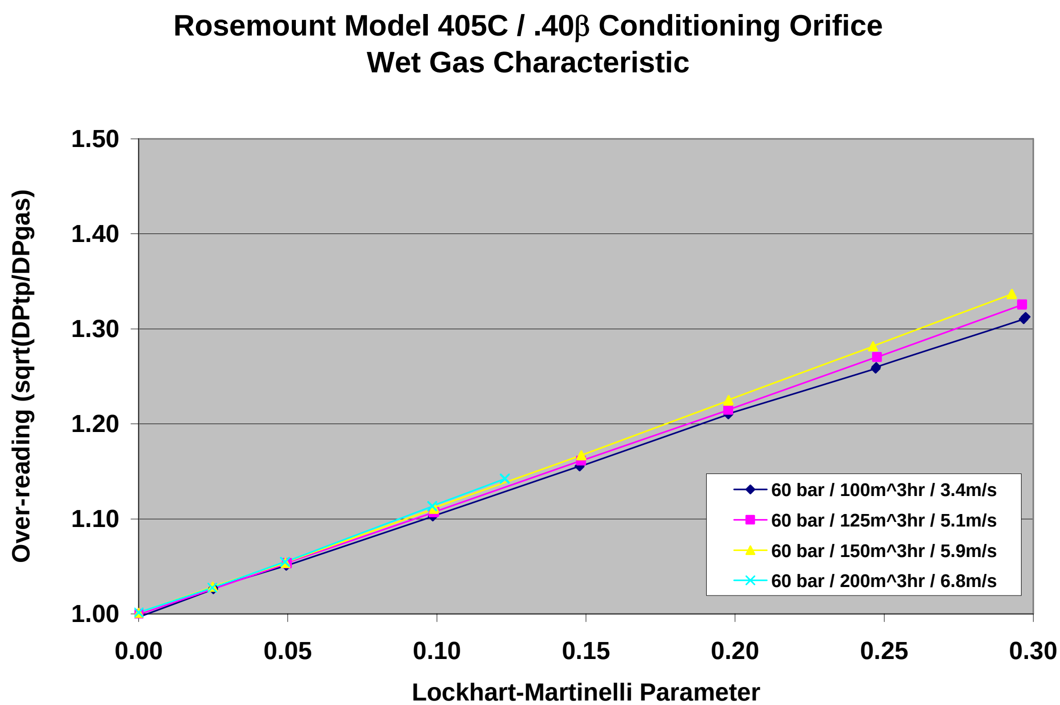

Figure 2: Relationship between Lockhart-Martinelli parameter and overreading for a Compact Orifice Plate

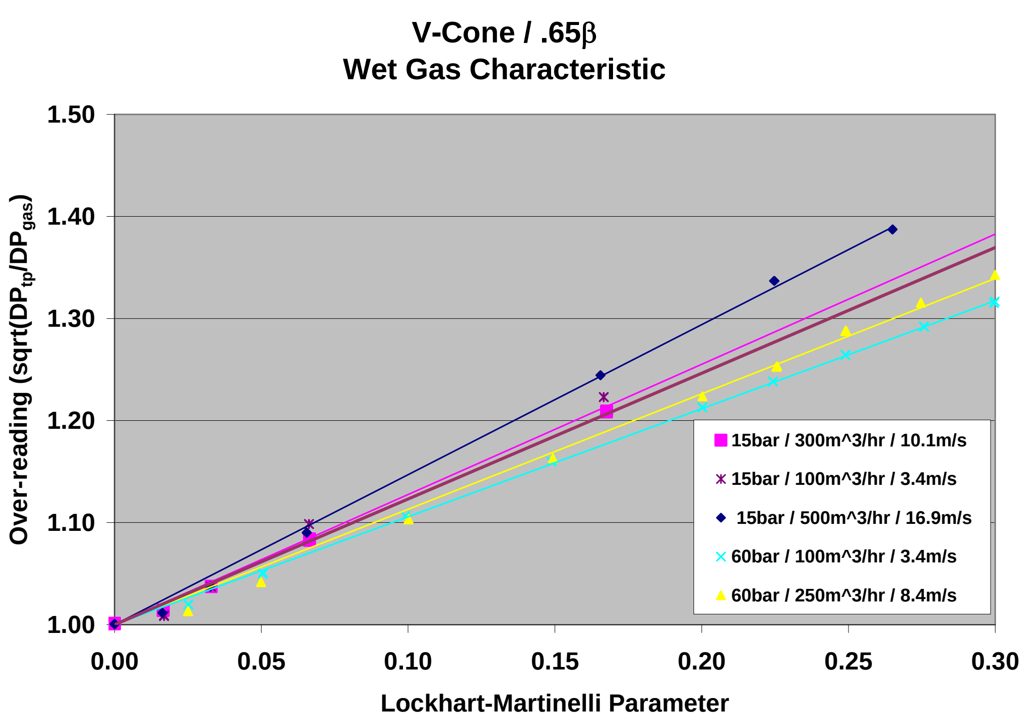

Figure 3: Relationship between Lockhart-Martinelli parameter and overreading for a typical V-Cone

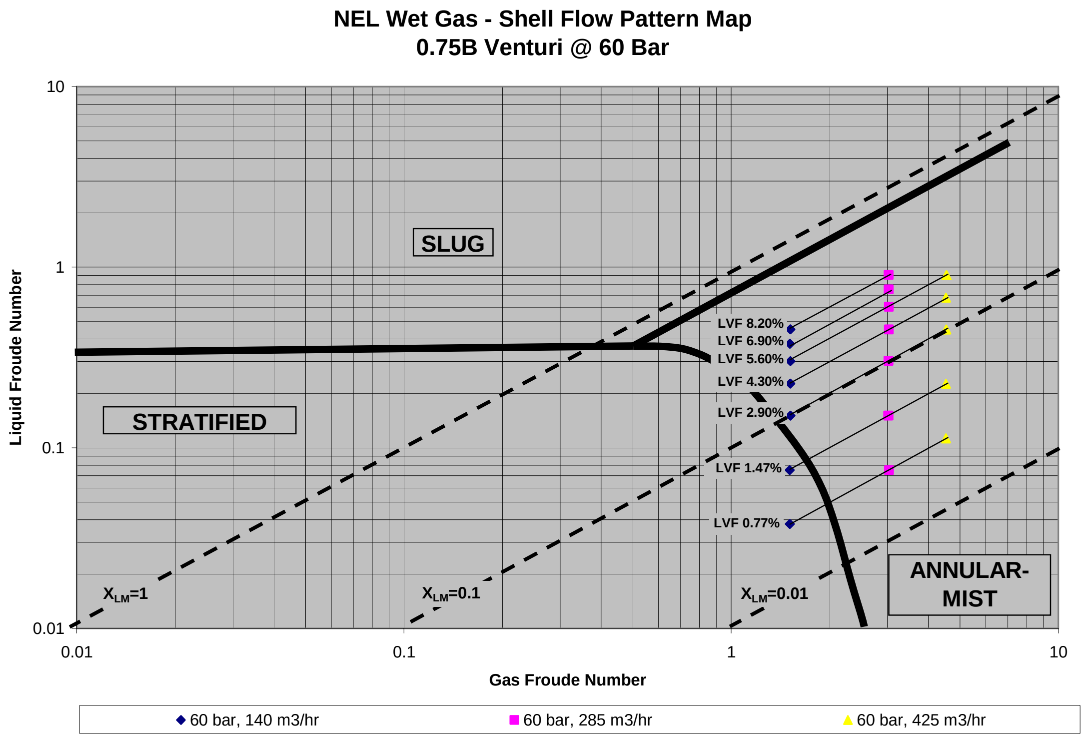

Figure 4: Shell Flow Pattern Map for 0.75 beta Seiko Venturi at 60 bar

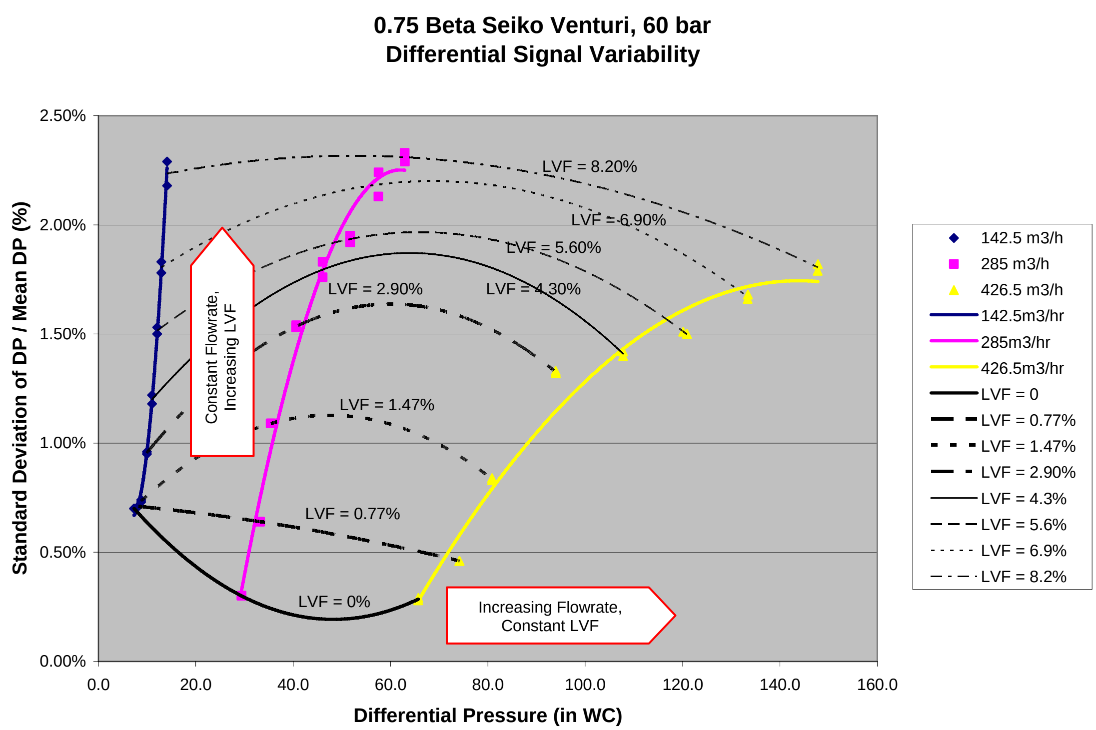

Figure 5: DP signal variability for 0.75 beta Seiko Venturi at 60 bar

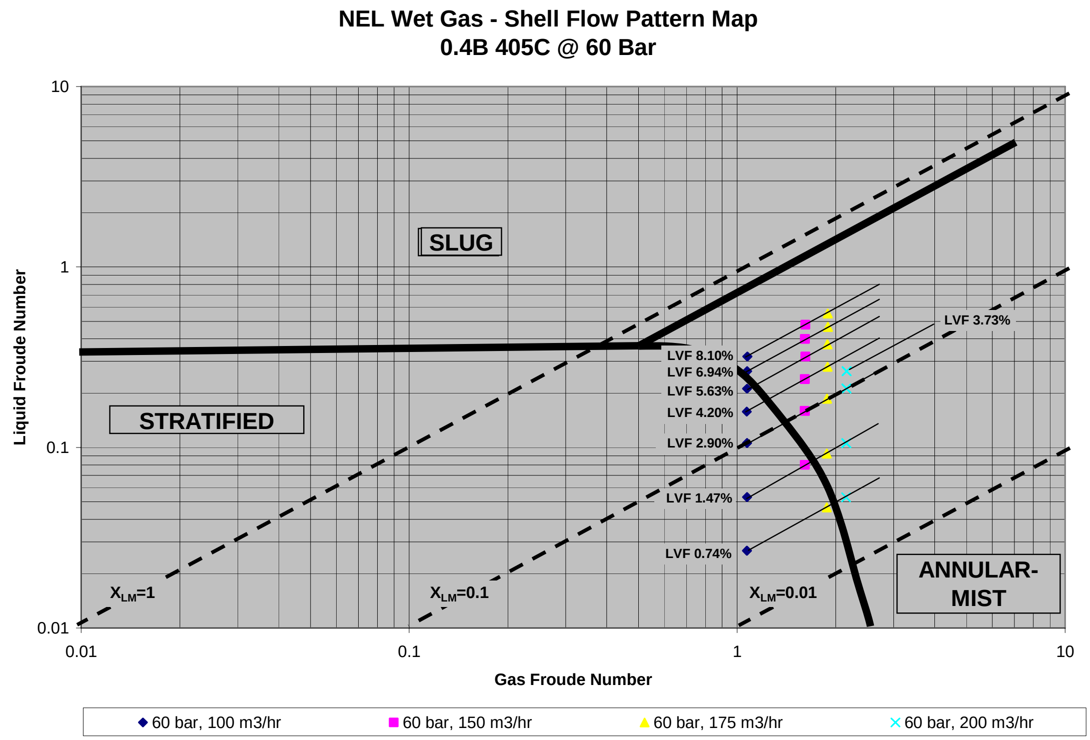

Figure 6: Shell Flow Pattern Map for 0.4 beta Rosemount 405C compact orifice plate at 60 bar

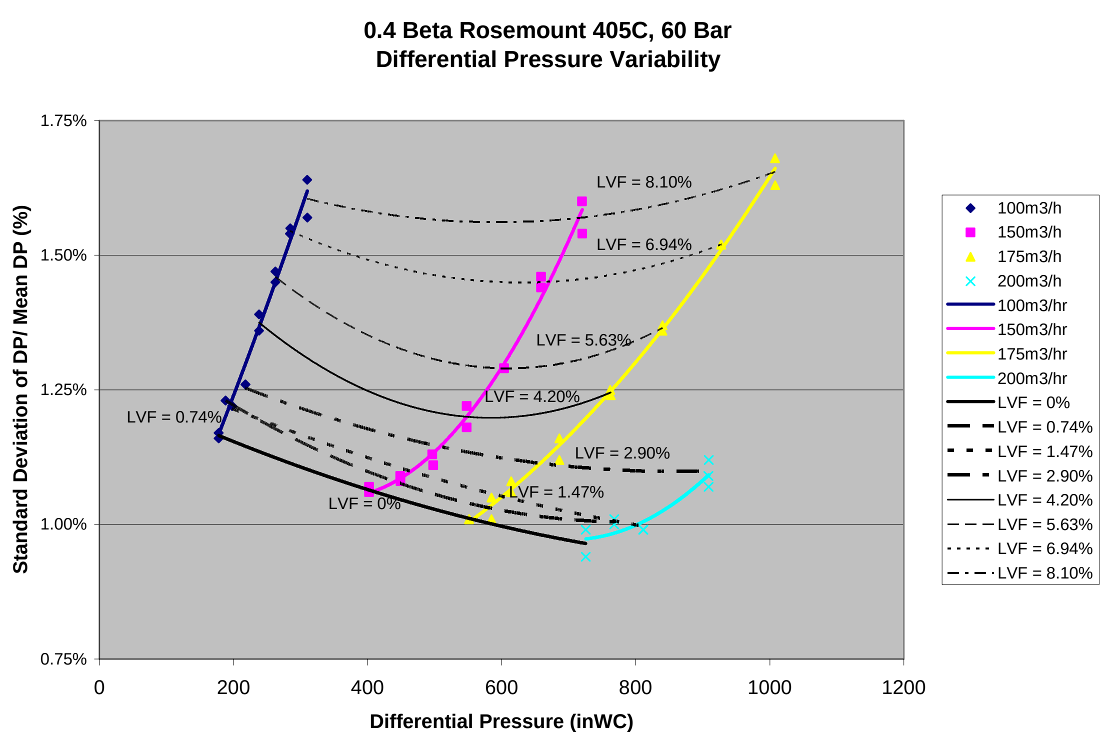

Figure 7: DP signal variability for 0.4 beta Rosemount 405C compact orifice plate at 60 bar

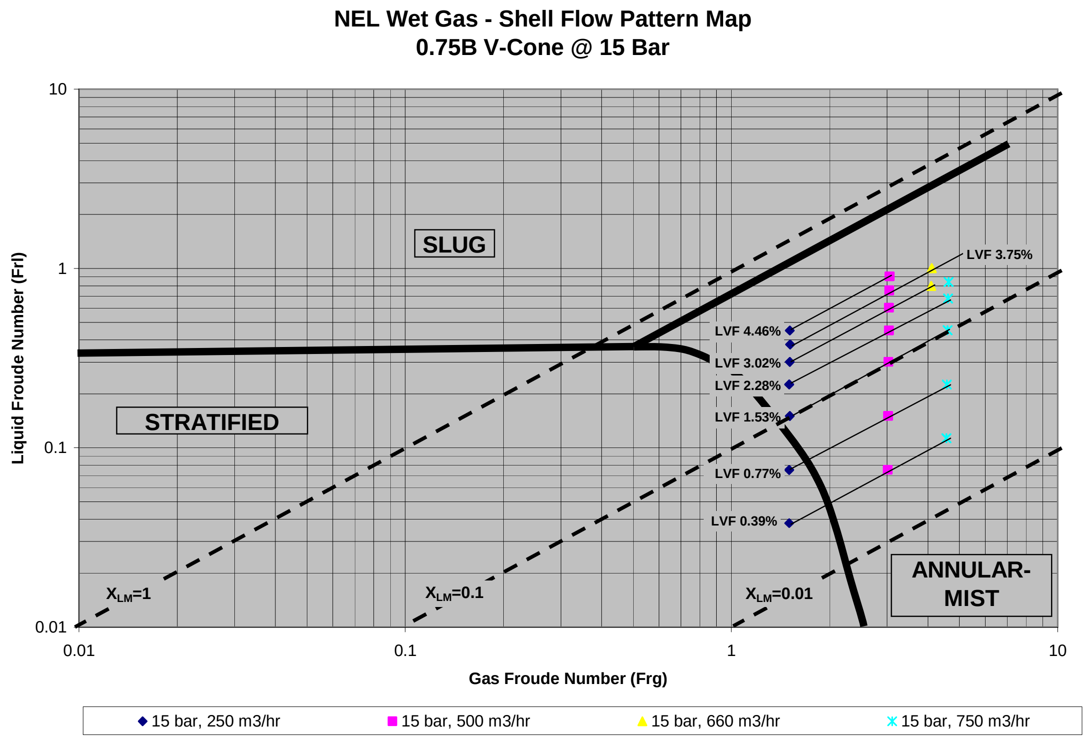

Figure 8: Shell Flow Pattern Map for 0.75 beta McCrometer V-Cone at 15 bar

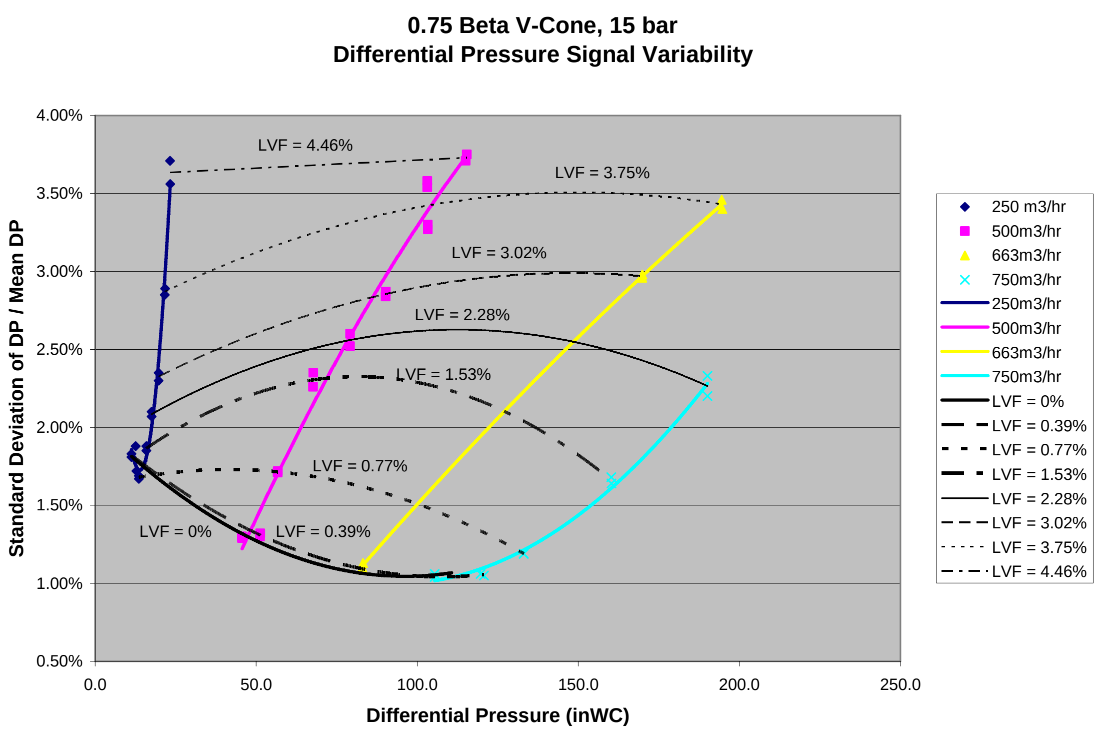

Figure 9: DP signal variability for 0.75 beta McCrometer V-Cone at 15 bar

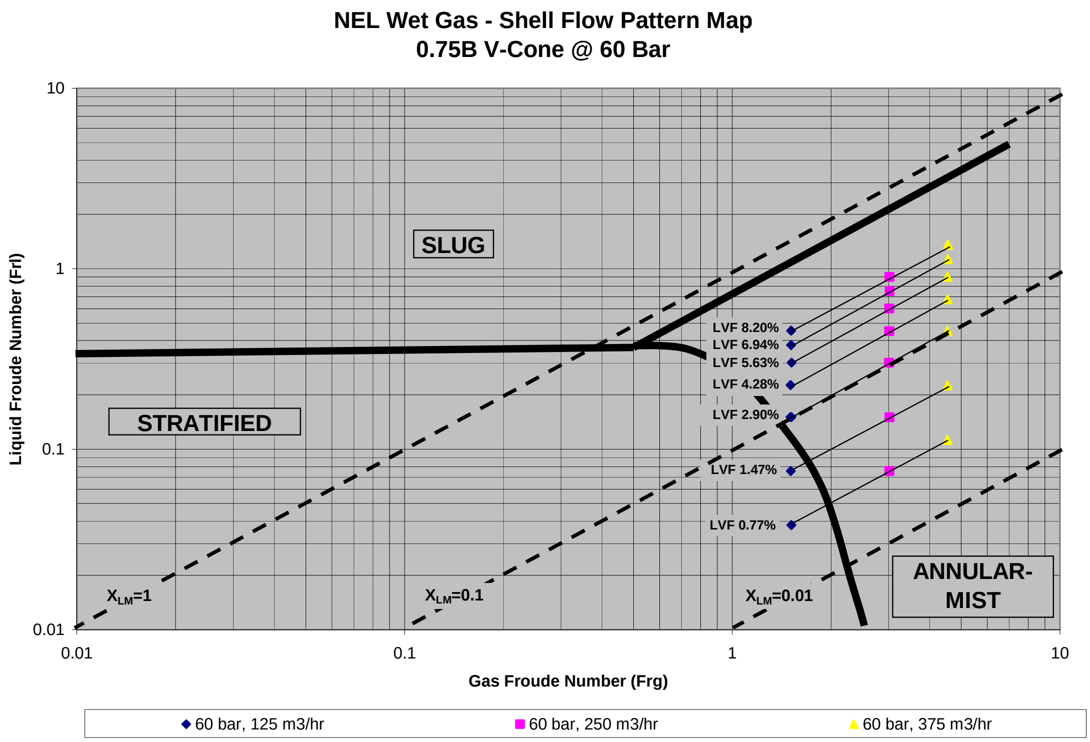

Figure 10: Shell Flow Pattern Map for 0.75 beta McCrometer V-Cone at 60 bar

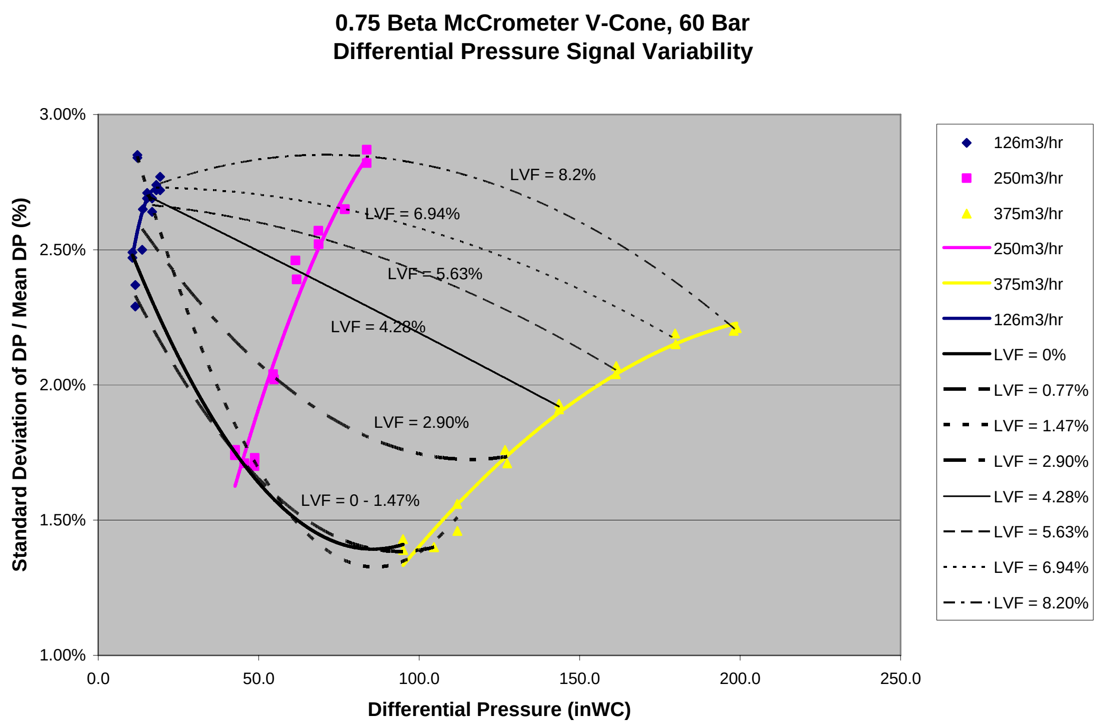

Figure 11: DP signal variability for 0.75 beta McCrometer V-Cone at 60 bar