Entrained Gas Diagnostic with Intelligent Differential Pressure Transmitter

Dave Wehrs - Director, Pressure Engineering
Andrew Klosinski - Application Engineer, Pressure Diagnostics
Emerson Process Management

Introduction

Issues with entrained gas in process fluids impact nearly every aspect of industrial applications. Negative effects due to entrained gas can be divided into three categories; measurement error, equipment risk and efficiency loss.

Measurement precision, the ability to make consistent repeatable readings of a process fluid containing entrained gas, becomes increasingly difficult as the gas content rises. For example, the density variation of two-phase flow will be translated into an increase in noise on the differential pressure (DP) output. This noise will reduce the probability of routinely achieving a repeatable process measurement.

Adverse effects on equipment include an increased likelihood of pipeline vibration, higher susceptibility to cavitation and an undesirable level of ambient noise around the process loop. Two-phase flow, in this instance liquid and gas, can escalate into a situation where fluid sections of significantly varying densities interact with the process infrastructure creating strong vibration forces. The results of this flow condition range from an increase in ambient process noise to fitting and seal leaks to a structural failure of the system.

Entrained gas will lower heating and cooling efficiencies, decrease system response times, cause process fluid foaming and inadvertent process fluid aeration. As one example, closed-loop boilers frequently include a deaerator in the feedwater line to minimize entrained gas in the steam system due to the detrimental effect of trapped gasses on heat transfer. Another common problem consists of pipe, valve, fitting or pump leaks leading to the unexpected introduction of air to the process.

Background

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 gas entrainment in process fluids.

Test Program Description

Two differential producers, the Rosemount 405P Orifice and the 405C Compact Orifice, were tested in December 2006 on Micro Motion's multi-phase flow test stand at their facility in Boulder, Colorado. The 405P was a 0.65 beta device with 50.8mm (2") diameter and the 405C was a 0.4 beta with 50.8mm (2") diameter. Both differential producers were tested with two liquids, water and a low density (.77 g/cc), low viscosity (<5 cP) mineral oil and were exposed to GVF's from 0 to 10 percent. The 405P 0.65β orifice plate was tested at four mass flow rates, 86 kg/min, 175 kg/min, 267 kg/min and 375 kg/min. The 405C 0.4b orifice plate was tested at three mass flow rates, 45 kg/min, 90 kg/min and 136 kg/min. Each test run was performed for a minimum of 60 seconds.

The DP signal for each differential producer was measured using a 250" Rosemount 3051S Differential Pressure Transmitter. The transmitter had FOUNDATION fieldbus outputs and was 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 and MiniTab.

Test Results and Analysis

The test data for each differential producer were overlaid on a two-phase flow map to indicate the location of their predicted flow regimes. For this discussion, a generic two-phase flow map was used[1]. As this map is based on experimental data, the boundaries represented are predictions of the indicated flow regime and are subject to a degree of uncertainty. Actual flow regime conditions are a function of pressure, temperature, flow rate, fluid properties, pipe diameter, pipe condition and differential producer geometries.

For this discussion, Figure 2 will serve as an example of the two-phase flow map. This figure illustrates the flow regime data for the 405P 0.65β orifice plate in water and was created by plotting the individual superficial fluid velocities, a value calculated as if each single phase completely filled the pipe, of the liquid and gas.

Four different flow rates are shown, represented by the horizontal bands of unique symbol shape and color and is indicated along the y-axis. Increasing gas volume fraction (GVF) is indicated along the x-axis moving from left to right.

Figure 3 demonstrates the diagnostic sensitivity of the 3051S to increasing GVF over a series of flow rates. The x-axis represents increasing GVF from 0 to 10 percent and the y-axis consists of a calculated value, the coefficient of variation (C_v), from 0 to 10. The GVF percent for a given flow rate was quantified by its corresponding coefficient of variation. This dimensionless number is an indication of the process noise relative to its signal and is determined by the ratio of the process standard deviation (σ) to the mean (x) of the differential pressure:

$$C_V = \frac{\sigma}{\overline{X}}$$

For all flow rates tested, the C_v for increases as a function of increasing GVF. The sensitivity of this diagnostic does diminish to a degree as the process conditions change such that the flow regime approaches the Bubble, or Dispersed section of the map (reference Figure 1). The effect of entering the Bubble flow regime is reflected in the decrease in the C_v slope over increasing GVF at the 375 kg/min flow rate.

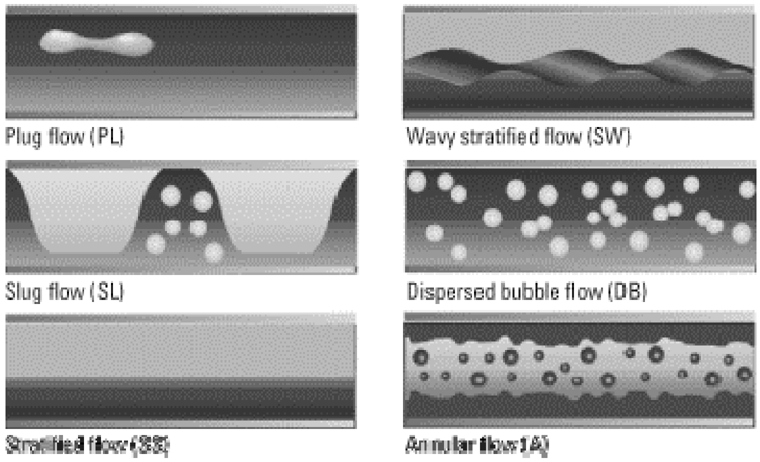

Figure 1: Two-phase flow patterns
http://www.glossary.oilfield.slb.com/

Based on the flow patterns illustrated in Figure 1, the source driving changes in the C_v value become quite clear. Slug flow consists of large pockets of gas interspersed with liquid. As these segments of varying densities pass through the differential producer they are detected as an increase in noise on the DP measurement. Flow conditions enhancing entrained gas detection include lower flow rates and higher GVF percents. Test data supports the ability of the transmitter to detect changes in GVF when operating in Plug and Slug flow regimes.

The test results for the 405P 0.4β orifice using oil as the process fluid behaves in a very similar fashion to its previous test with water. In Figure 5, the C_v responds well to increasing GVF when operating in the slug flow regime with the sensitivity to GVF decreasing as the flow conditions enter into the Bubble regime.

In Figure 6, some of the flow conditions fell outside of the generic two-phase flow map, indicated by the lighter shade background. For this discussion, flow regimes are considered to be consistent as the superficial gas velocity decreases. The 405C 0.4β tested with water reiterates the consistent ability to detect changes in GVF under varying flow rates when operating in the Plug or Slug flow regimes.

Concurrently, when tested with oil, the 405C 0.4β was once again able to annunciate that a change in GVF had taken place as seen in Figure 9.

Conclusion

The test results for the two differential producers indicate that the 3051S provides the user an indication of changes to the gas content of a process fluid across a wide spectrum of flow rates by monitoring the coefficient of variation. Based on the presented test data, this diagnostic is particularly effective when operating in the Plug or Slug flow regimes. Flow conditions in the Bubble regime, a result of higher liquid flow rates, are shown to influence the ability of the transmitter to distinguish changes to GVF. A standard pressure transmitter has been developed that can calculate and communicate the required statistical parameters via HART or FOUNDATION fieldbus digital communication protocols, readily providing users with additional insight into their process conditions. With this capability, operators can have an indication of significant changes in GVF that affect the measurement repeatability, equipment health and process efficiency.

Figures

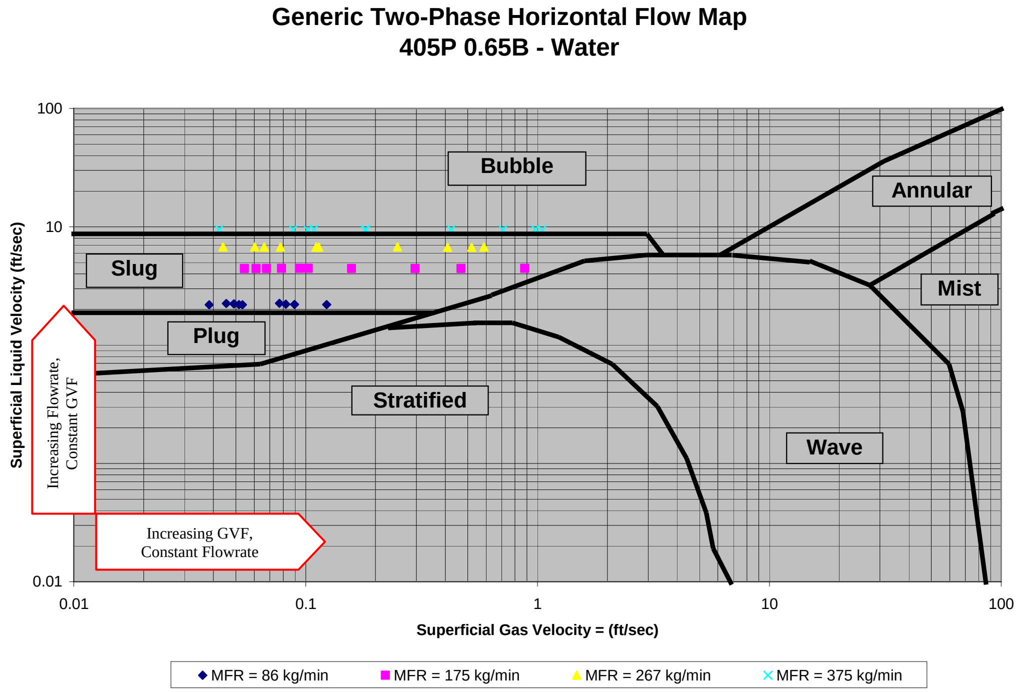

Figure 2: Two Phase Horizontal Flow Map for 405P 0.65β – Water

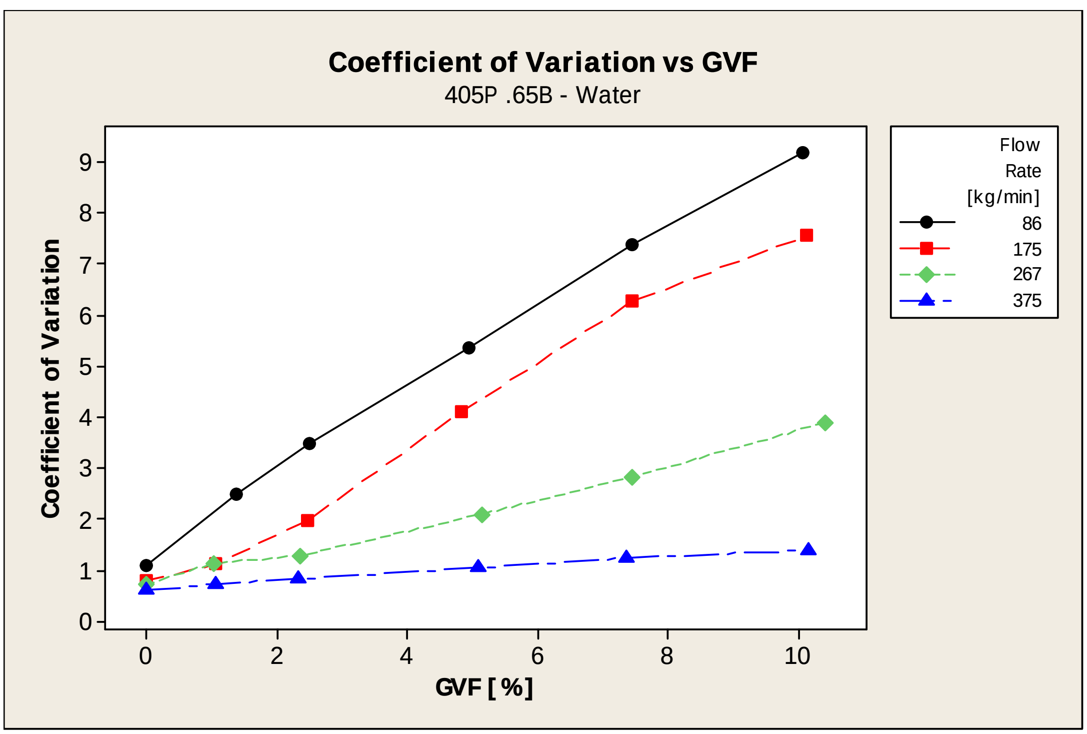

Figure 3: Coefficient of Variation Sensitivities to Varying GVF at Multiple Flow Rates
405P 0.65β with Water

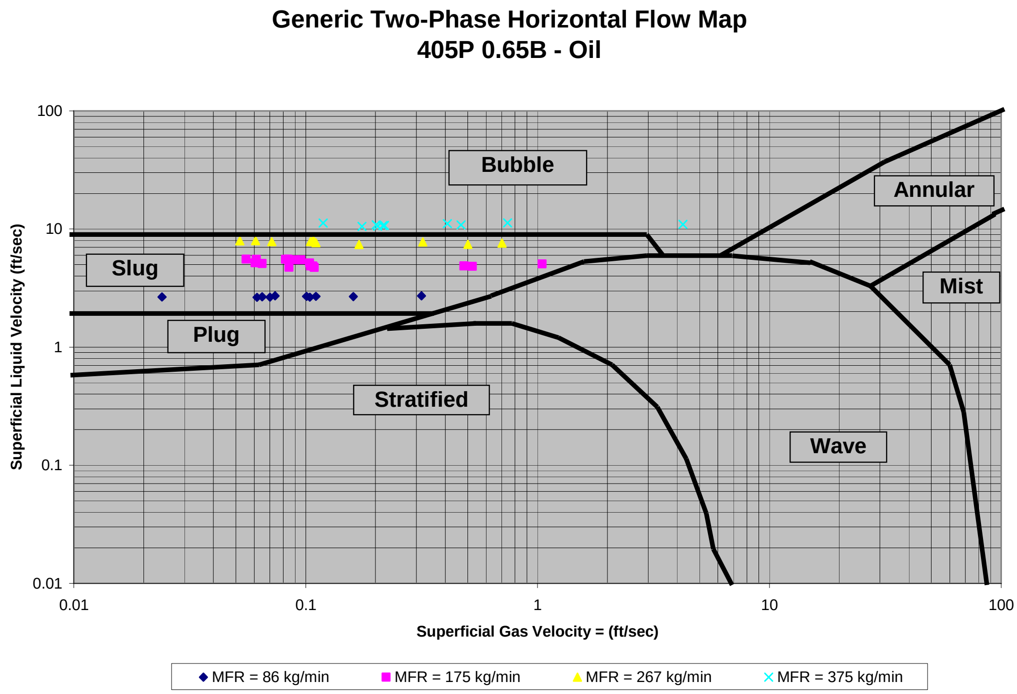

Figure 4: Two Phase Horizontal Flow Map for 405P 0.65β – Oil

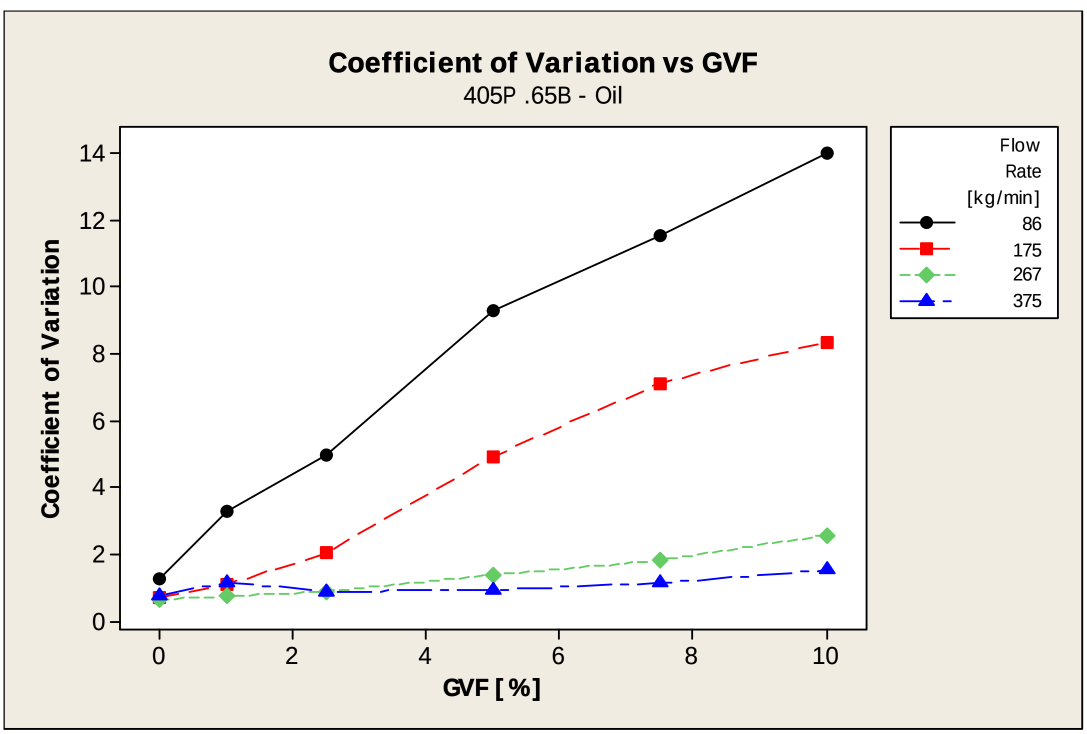

Figure 5: Coefficient of Variation Sensitivities to Varying GVF at Multiple Flow Rates
405P 0.65β with Oil

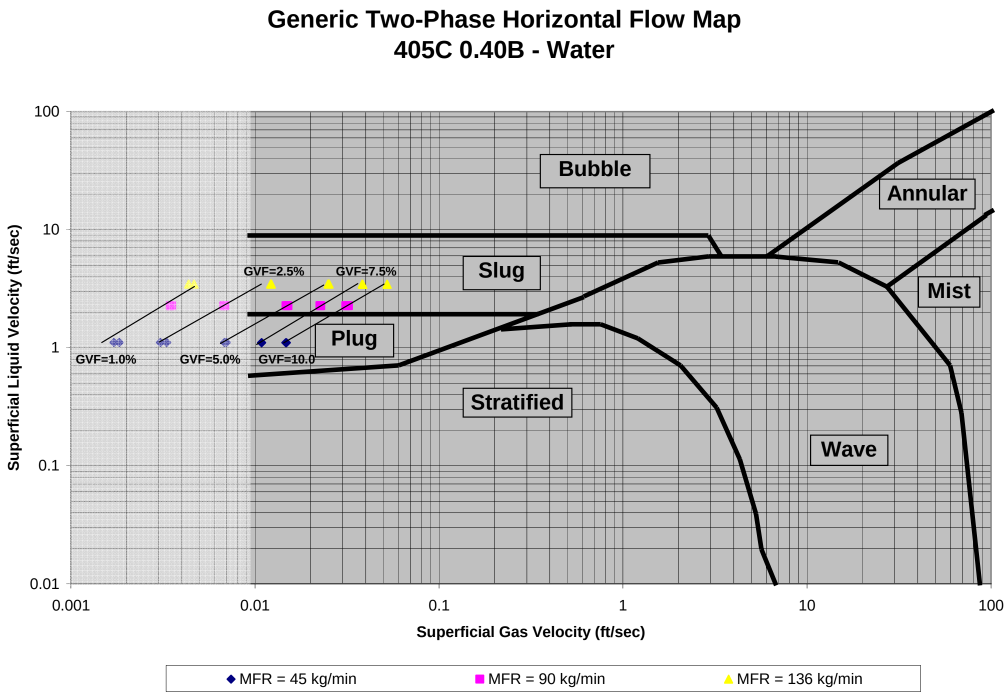

Figure 6: Two Phase Horizontal Flow Map for 405C 0.4β – Water

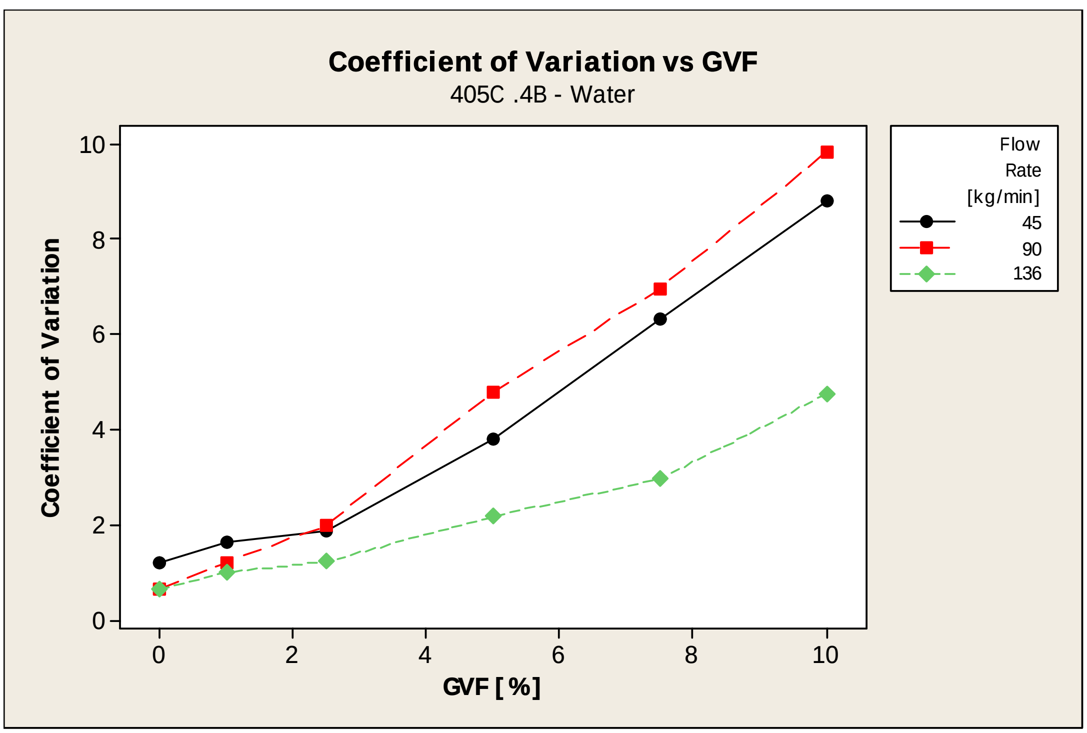

Figure 7: Coefficient of Variation Sensitivities to Varying GVF at Multiple Flow Rates
405C 0.4β with Water

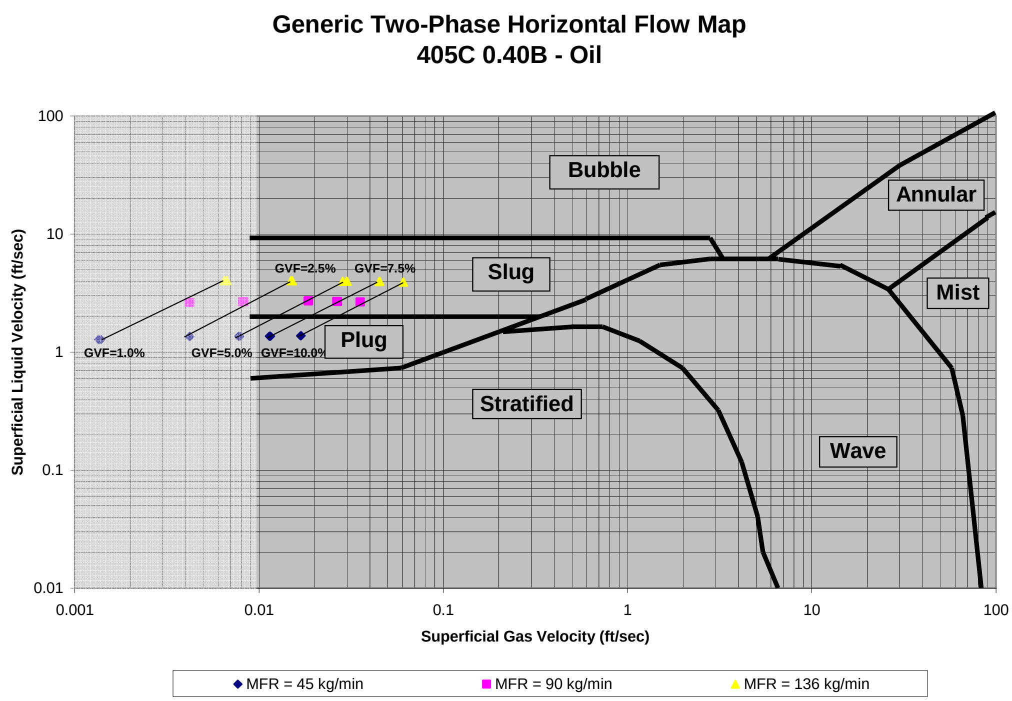

Figure 8: Two Phase Horizontal Flow Map for 405C 0.4β – Oil

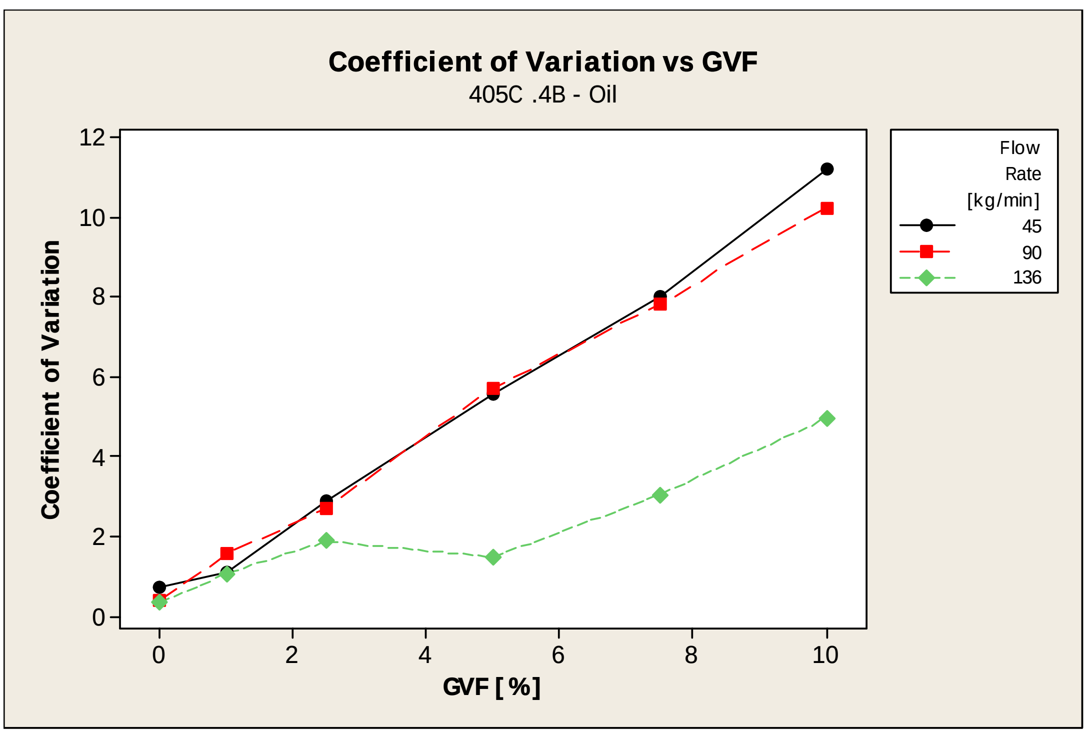

Figure 9: Coefficient of Variation Sensitivities to Varying GVF at Multiple Flow Rates
405C 0.4β with Oil