AADE-24-FTCE-010

Understanding the Impact of Two-Phase Flow on Coriolis Mass Flowmeter Measurements during Managed Pressure Drilling operations

Nitin Kulkarni, Bob Pilko, Landon Hollman - Blade Energy Partners Ltd, Chris Russell – Micro Motion Inc

Abstract

Managed Pressure Drilling (MPD) has emerged as a critical technology offering enhanced well control and safety during drilling in deepwater environment. Accurate flow rate measurement of the drilling fluid returning from the well is critical to MPD operations for gain/losses detection and control. Coriolis Mass Flowmeters are routinely used in MPD operations because of their high accuracy and reliable ways of measurement of fluid flow, density and temperature. Drilling engineers and geoscientists rely heavily on these parameters for decision making. Coriolis mass flowmeters have proven to be a useful tool and have become the standard device for fluid parameters in the industry.

However, their performance in the presence of two-phase flow remains an area of concern. The presence of gas and liquid phases often encountered in drilling operations presents certain challenges and introduces complexities in flow measurement of the Coriolis mass flowmeter. This technical paper aims to investigate the intricate interplay of two-phase flow conditions with Coriolis mass flowmeter particularly during MPD operations. The paper will discuss the fundamental principle of Coriolis Mass Flowmeter and the physical phenomena governing their operation in fluid flow measurement. This paper is a good resource to engineers, researchers, and practitioners involved in drilling fluids.

Introduction

The exploration and production of hydrocarbons from deepwater reservoirs have led to the evolution of drilling technologies, with Managed Pressure Drilling (MPD) emerging as a strategic approach to enhance operational safety and drilling efficiency. Within the intricate dynamics of MPD operations, accurate measurement of fluid flow rates is paramount for maintaining well control, preventing kicks, and optimizing drilling parameters is one of the key objectives. The industry has tried different flow measurement technologies to accurately measure the drilling fluid flowing out of the well. Amongst all the technologies tested, Coriolis mass flowmeters (CMFs) have gained prominence due to their ability to provide direct and real-time measurements of mass flow rates.

Figure 1 illustrates a standard Coriolis meter integrated into the MPD setup on an offshore drilling rig. The flow of the returning fluid is directed through the meter to capture measurements like flow rate, density, and fluid temperature. This configuration enables comprehensive data acquisition, allowing for a more thorough understanding and control of the drilling process in challenging environments.

Figure 1: Coriolis meter installation on a drilling rig.

Even though Coriolis mass flowmeters have demonstrated accuracy in single-phase flow environments, their performance in the presence of two-phase flow, a common occurrence in drilling operations, remains a subject of critical investigation. Two-phase flows, characterized by the simultaneous presence of gas and liquid phases, pose unique challenges to flow measurement devices, potentially influencing the accuracy and reliability of CMF measurements (Tim Patten, 2012). Understanding the impact of two-phase flow on Coriolis mass flowmeter measurements is essential for ensuring the precision of flow data in the context of Managed Pressure Drilling.

The two-phase flow dynamics during drilling operations and the performance of CMFs during Managed Pressure Drilling operation is an important subject of consideration. By investigating the influence of varying phase fractions and flow regimes on CMF measurements, we seek to provide insights that contribute to the optimization of flow measurement strategies in MPD environments. This study aims to bridge the existing knowledge gap and offer practical recommendations for improving the accuracy in flow measurement.

Importance of Accurate Flow Measurements in MPD

Accurate flow measurement is crucial for maintaining well control during drilling. In MPD, real-time monitoring of flow rates allows for the rapid detection of kicks—sudden influxes of formation fluids into the wellbore. The ability to quickly identify and respond to kicks is critical in preventing well control issues and blowouts (Steve, 2012).

The prevalent approach for identifying an influx involves analyzing the volumetric gain or loss of drilling fluid in the mud tanks. However, this method faces challenges in terms of accuracy. The primary issues stem from the limitations of the level sensor, disturbances in the mud tanks caused by agitation, and the presence of multiple mud tanks. The inaccuracies are further exacerbated by the transfer of mud into and out of the active system, making the determination of gain a complex task. The conventional method's reliability is compromised due to these factors, highlighting the need for more precise and robust techniques in detecting drilling fluid influxes during the drilling process (J.J. Orban, 1987).

Several research have indicated that the best approach to accurately identify an influx requires using delta flow(ΔQ)., which is calculated as the difference between flow-out and flow-in.

Mathematically, delta-flow is expressed as:

$$\Delta Q = Q_{out} - Q_{in}$$

In the equation, “Flow-out” (Q_{out}) represents the rate at which drilling fluid exits the wellbore and "Flow-in" (Q_{in}) corresponds to the rate at which fluid is pumped into the wellbore. By computing the delta-flow, the net flow difference is captured, allowing for a more precise detection of a gain or loss.

During MPD operations, delta-flow plays a crucial role in kick detection. A baseline or reference value for delta-flow is established under normal drilling conditions. This baseline represents the expected delta-flow when drilling is proceeding without any influx or kick. By continuously monitoring delta-flow, MPD systems can detect unexpected variations, such as the onset of a kick or influx, enabling proactive well control measures. As monitoring of delta-flow is integral to MPD systems, the Coriolis mass flowmeter emerges as a crucial component for the measurement of delta-flow in MPD operations. The Coriolis mass flowmeter provides a direct and accurate measurement of mass flow and density along with temperature. Unlike other flow measurement devices, Coriolis meters are not dependent on the physical properties of the drilling fluid, such as density or viscosity. This characteristic is especially advantageous in dynamically changing drilling conditions where fluid properties may vary.

Figure 2 shows the key parameters used by the MPD system for the detection of an influx. As can be seen from the first trendline, an increase in flow out can indicate a potential influx. The MPD operator monitors the trend on his human machine interface (HMI) screen to detect any variance in flow rates (delta-

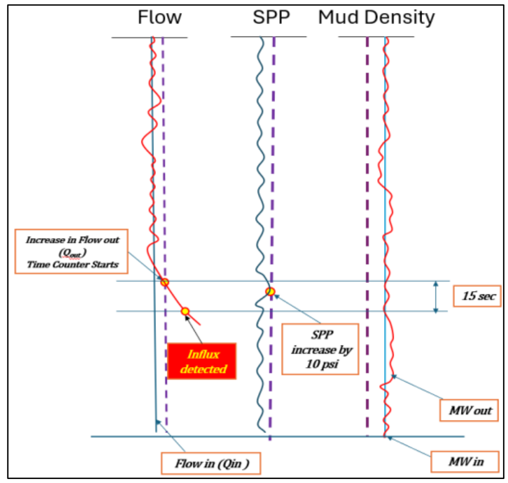

Figure 2 Influx Detection

flow). The increased influx in the wellbore increases the pressure in the well, therefore an increase in SPP, even a small value of 10 psi or more, can be indicative of an influx., this is illustrated in the second trend line of the schematic. Similarly, If the density of the drilling fluid approaches the predefined threshold, it can suggest the presence of formation fluids in the drilling fluid.

It is important to highlight that these parameters are continually monitored over a designated time period, referred to as the "time trend," which, in this specific example is set at 15 seconds.

In summary, MPD system utilizes flow difference (ΔQ), standpipe pressure increase, and trend time to continuously monitor and analyze the behavior of drilling fluid to detect any potential influx. An increase in standpipe pressure, flow difference, or density beyond set thresholds over a specified trend time can trigger alarms, alerting drilling personnel to take corrective actions such as increasing surface back pressure to regain control over the wellbore or utilize conventional well control to shut in the well.

Figure 3 shows a typical influx management sequence. If a kick is detected, the initial response is to stop drilling while maintaining drill string (DS) flow rate and RPM. To control the influx, additional surface back pressure (SBP) is applied within the predefined MPD limits. After a certain SBP is applied, the MPD operator and drilling personnel shall assess whether both SBP and influx volume are within the specified MPD limits by referring to the Influx Management Envelope (IME) and MPD Operations Matrix. If the influx is successfully arrested and SBP and influx volume are within the specified MPD limits, the influx is circulated out through the MPD system by Reducing RPM while maintaining constant bottom hole pressure (CBHP).

If the influx is not arrested and SBP or influx volume are at MPD limits, the well is shut-in using the assisted shut-in procedure at rig's Blowout Preventer (BOP) and conventional well control procedures are implemented to kill the well. At any

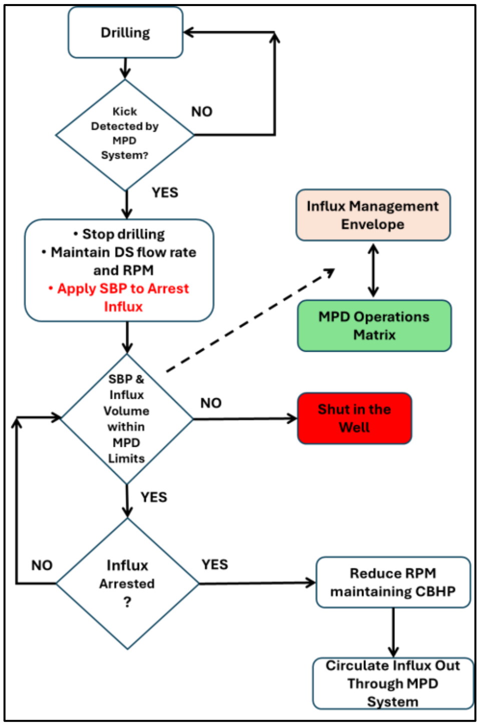

Figure 4 Influx management sequence

point during an influx detection and/or control, the drilling contractor and operator maintain full authority to shut the well in at the BOP and circulate out the influx using conventional methods.

Coriolis Mass Flowmeter Basics

Earlier in the paper, we discussed the Coriolis mass flowmeter as a tool that accurately measures mass flow, density, and temperature of fluids. The origin of this concept can be traced back to the year 1792 when a French mathematician and physicist named Gustave Gaspard de Coriolis first introduced the concept. The industry has adopted the name to describe the principle of operations and the device itself after him. (Persson, 1998).

Coriolis mass flowmeter works on the principle of Coriolis effect. Figure 4 shows a schematic of the instrument. (Jace, 2009)

The principle of mass conservation states that mass remains constant within a closed system therefore neither the measurement of pressure and temperature nor the utilization of equations of state are required for measuring mass flow. The Coriolis mass flowmeter instrument does not have any complex moving part. It comprises of a dual-tube meter oscillating at 180° out of phase at the natural frequency. The drilling fluid enters the sensor, and the flow separates by half the flow through each tube. The tubes are driven by a magnet and coil assembly at the first bend called "pick-offs". The oscillation frequency depends on the mass and stiffness of the system. The sensor flow tubes oscillate in opposition to each other by energizing a "drive coil". As each coil moves through the uniform magnetic field of the adjacent magnet it creates a voltage in the form of a sine wave as shown in figure 5.

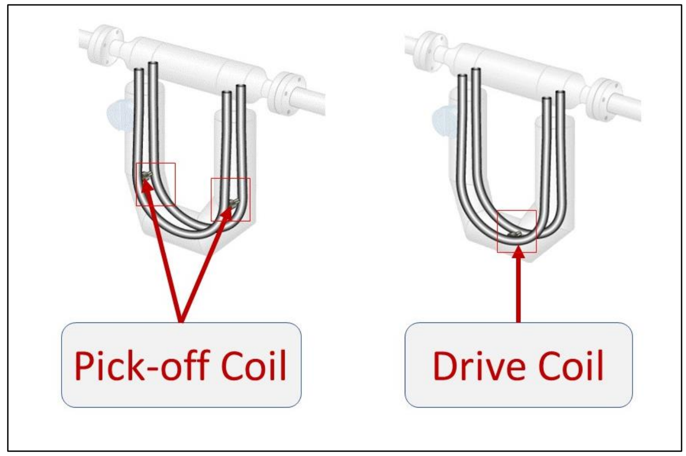

Figure 3 Coriolis mass flow meter Drive coil and Pickoff Coil

When there is no flow through the tubes, there is no Coriolis effect or twist in the tubes. The left and right pick-off coil signals are in phase as shown in figure 5. When there is flow, Coriolis effect causes twist in the tube and the left & right pick-off coil signals detect a "phase shift". The twist motion that introduces a phase shift is measured as time delay, ΔT, between the inlet and outlet sides of each tube, using signals from two pickoffs as shown in figure 6. Coriolis force acts in the opposite direction on the inlet and outlet sides, leading to a twist motion superimposed on the normal bend motion of the tubes.

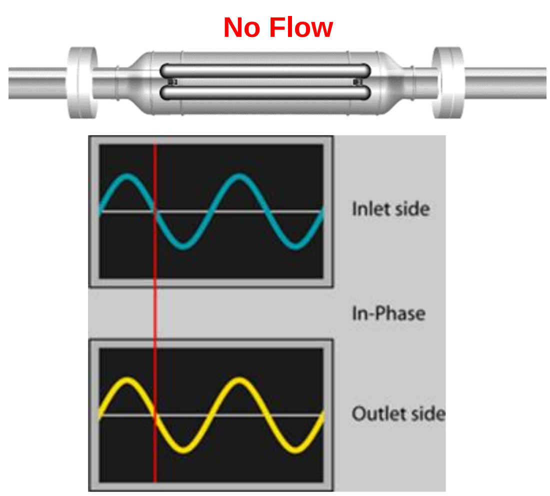

Figure 5 Coriolis Effect -No Flow

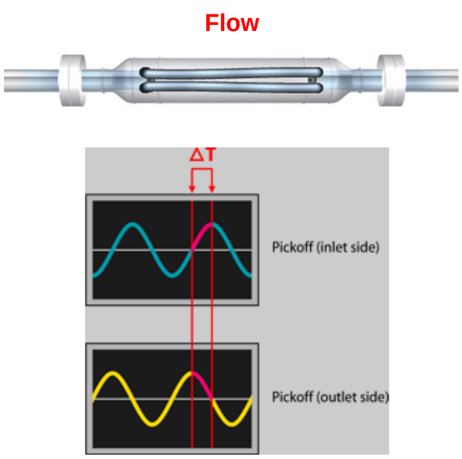

Figure 6: Coriolis effect - Flow.

The magnitude of time delay, Delta-T (ΔT) is linearly related to mass flow rate ($\dot{m}$).

$$\dot{m} \propto \Delta T$$

In the illustration of figure 7, as the fluid particle of mass m moves at velocity V in a flow tube with angular frequency ω, resulting in an applied Coriolis force F_c, on the flow tube by the fluid. The Coriolis force can be mathematically expressed as.

$$F_c = 2m\omega \times V$$

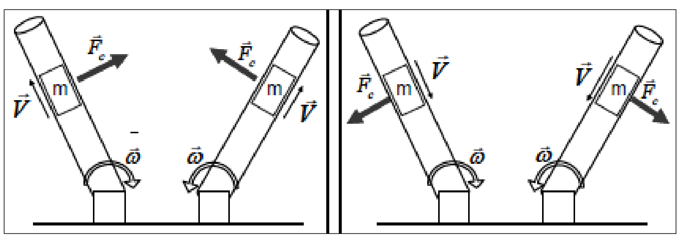

Figure 7 illustration of Coriolis forces on the inlet and outlet flowmeter tubes

Drilling Fluid Density Measurement

The flowmeter also measures density (ρ) in real time of the fluid commonly referred to as mud weight in the drilling industry, which is highly critical for drilling applications. The fundamental concept for density measurement involves the oscillation frequency (f) of the flowmeter tubes. The oscillation frequency depends on the mass and stiffness of the system. If the fluid in the tubes is light or has a lower density such as air, this will result in an increased natural frequency. Conversely, if the tube has a very dense fluid this will result in a decreased natural frequency. Upon calibrating for high- and low-density fluids, the density of an unknown fluid can be determined by measuring the frequency of oscillation of the tubes. The measurement is done through the pickoffs installed on the sensor tubes.

$$f \propto \frac{1}{\rho}$$

Volumetric Flow Rate

The Coriolis mass flowmeter precisely measures the time delay and the degree of twist, to determine the mass flow rate accurately. The density of the fluid is measured by assessing the natural frequency of vibration in the tubes as discussed above. The volumetric flow rate (Q) is then calculated by dividing the mass flow rate (W) by the density (ρ) of the fluid as expressed in the following equation (Weinstein, 2010).

$$Q = \frac{W}{\rho}$$

Two Phase Flow in Drilling Operations

In the realm of drilling operations, the term two phase flow also known as entrained gas refers to the concurrent presence of liquid and gas phases within the wellbore. This occurrence holds considerable significance as it may introduce distinct challenges to drilling operations. When drilling through formations containing hydrocarbons, the release of gas from the reservoir can lead to the formation of gas-liquid two-phase flow within the wellbore. The liquid phase typically is the mud in this case.

Four distinct flow regimes have been identified in the context of gas-liquid two-phase flow, namely bubble, slug, churn, and annular flow. Figure 8 illustrates the different flow regimes in a vertical tube. These flow regimes occur in a sequential manner with increasing gas flow rates for a specified liquid flow rate (Guo, 2019).

- **Bubble flow**: gas phase is dispersed in the form of small bubbles in a continuous liquid phase. The presence of small bubbles can alter the rheological properties of the drilling mud.
- **Slug flow**: gas bubbles combine into larger bubbles that eventually fill the entire pipe cross-section. Between the large bubbles are slugs of liquid that contain smaller bubbles of entrained gas. Slug flow can cause variation in annulus pressure. The CMF will also experience variations in density and flow patterns, affecting the precision of flow measurements during slug flow.
- **Churn flow:** The larger gas bubbles become unstable and collapse, resulting in a highly turbulent flow pattern with both phases dispersed. The turbulent nature of churn flow poses challenges during drilling operations impacting the performance of downhole tools. CMF accuracy is also impacted by the fluctuations in flow conditions.
- **Annular flow**: Gas becomes the continuous phase, with liquid flowing in an annulus, coating the surface of the pipe and with droplets entrained in the gas phase.

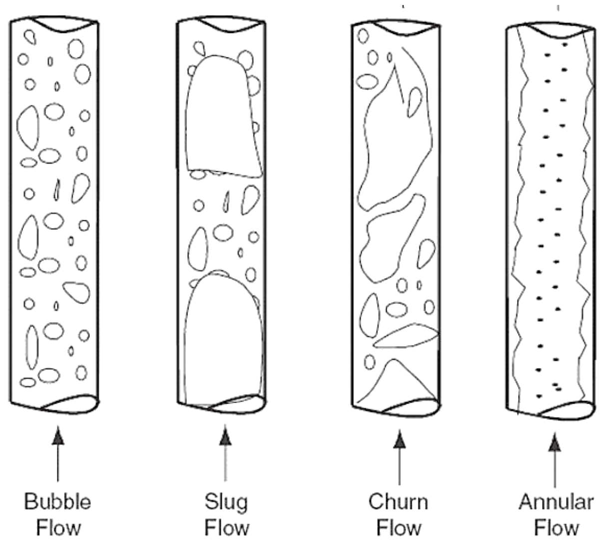

Figure 8 Vertical Two-phase Flow Regime

The density difference in the phases leads to the dense phase to slip downwards in an upward flow. The lighter phase travels faster than the denser phase. As a result, the in-situ volume fraction of the denser phase will be higher than the input volume fraction of the denser phase (i.e., the denser phase is ‘‘held up’’ in the pipe relative to the lighter phase).

Sources of Errors

Coriolis Mass flow meters are fundamentally designed as single-phase meters. The basis of their design requires that the center of Mass of the fluid move with the center of Mass of the vibrating tubes. In the presence of two phases, the meter will continue the measure; however, the accuracy of the measurement may be prone to deterioration. The excitation power also termed as “drive gain” is a diagnostics tool within the Coriolis Meters algorithm serves as a good indicator of when there is gas entrained in the liquid and the presence of two phases (Schafer, 2017). It is essential to monitor the drive gain, which is on a scale of 0 to 100%. Essentially it means how much excitation power is being consumed to keep the vibrating tubes inside the Coriolis meter vibrating at just the right distance from each other. If even a small amount of gas phase is introduced into the liquid stream, this value will increase significantly (Cahill, 2019).

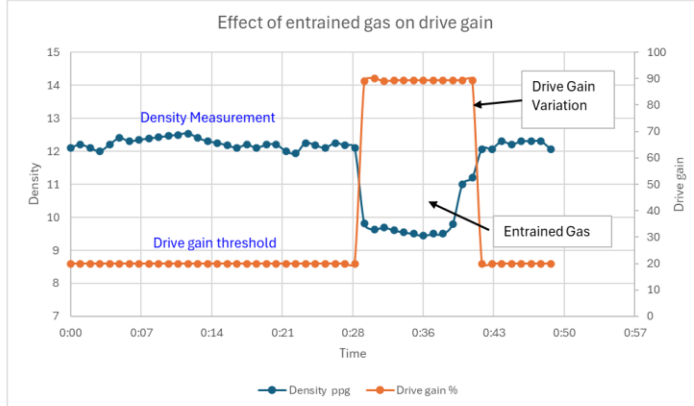

Figure 9: Effect of entrained gas on drive gain.

Figure 9 shows how entrained gas causes a error in density measurements and the density reduction occurs.

Decoupling Effect

Decoupling refers to relative motion between two components of differing density in the direction of tube oscillation. Decoupling occurs when the fluid within the tube does not in sync with the flow tube. This leads to measurement error. When that happens, errors occur. A pure liquid moves in the transverse direction exactly with the flow tubes, and the center of gravity of the fluid remains fixed. However, the presence of two phases with different density causes a decoupling of the transverse fluid motion from the tube motion. For instance, because of differences in mass, particles of the same volume of liquid and gas will accelerate differently. Gas bubbles will travel further than the surrounding liquid resulting in a small portion of the liquid not fully coupled with the tube and therefore have less inertia sensed by the Coriolis tubes.

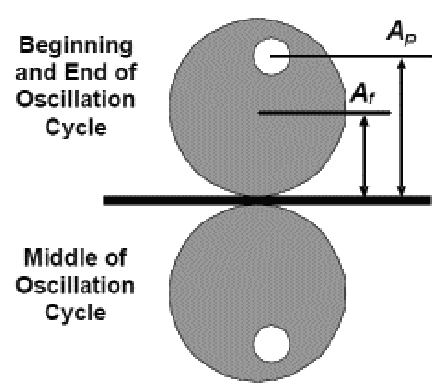

Figure 10 Decoupling Ratio

Figure 10 illustrates a cross-sectional view of a single vibrating tube at two instances during a vibration cycle. At the point of maximum deflection, the bubble has moved further than the fluid by a factor defined as the decoupling ratio,

$$F = {Ap}/{A_f}$$

Where F is the decoupling ratio, A_p is the amplitude of particle and A_f is the amplitude of fluid. The amplitudes are defined with respect to the distance from the midpoint of tube oscillation (Micromotion, 2018).

Decoupling phenomena can lead to the displacement of some liquid mass within tubes, and therefore it is not detected by the flow meter. This displacement causes the density readings to underestimate the actual mixture density, particularly in the case of a bubble flow. For instance, if a mixture comprises 10% volume fraction of gas in a liquid with a density of 8.34 ppg, the meter should ideally register 10% lower than the liquid density, equal to 7.51 ppg, assuming negligible gas density. However, the decoupling effects may inaccurately estimate the density as 7.49 ppg. (Micromotion, 2018). The extent of decoupling, indicated by the ratio of the oscillation amplitudes (F), directly influences the degree of undetected fluid volume and consequently, the magnitude of the resulting measurement error. In essence, the greater the decoupling of bubbles or particles from the fluid during each oscillation cycle of the tubes, the more substantial the undetected fluid volume becomes, amplifying the overall measurement discrepancy.

The article "Identifying Multiphase Conditions and Remediating Errors" by Emerson Automation Solutions discusses a dimensionless quantity called the Inverse Stokes number (δ), which is further explained in the Appendix of this paper. The parameter, δ, contains different variables, including fluid kinematic viscosity, particle size (specifically gas bubble size), and frequency (related to the tube vibration frequency). The careful consideration of these variables is crucial for enhancing the performance of the Coriolis meter in the context of two-phase flow (Justin Hollingsworth, 2018). The authors further suggest that by increasing δ, the decoupling ratio can be significantly reduced, resulting in smaller mass flow and density errors.

Best Practices for use of Coriolis Meter

The following practices are recommended for optimizing the performance, enhancing accuracy, and ensuring the reliability of Coriolis meters in drilling applications**.**

Monitor the excitation power "drive gain"

The Coriolis meters drive gain could be utilized to determine the presence of single or two-phase flow within the meter. Drive gain is directly linked to the excitation power employed for vibrating the flow tubes of the meter. In instances of two-phase flow, a significant portion of the energy dedicated to driving the flow tubes is directed towards the relative motion between the liquid and gas phases. This necessitates an elevated excitation power to sustain a consistent tube amplitude. Sharp spikes in drive gain serve as an indicator of two-phase flow. However, due to the inherent safety constraints limiting available power, drive gain swiftly reaches 100% with minimal gas quantities. At this juncture, tube amplitude starts to decline.

Choose a low frequency Coriolis meter:

Whenever entrained gas is expected a low frequency meter be used as they are less prone to decoupling errors. The figure shows the plot of measurement error vs drive frequency for fluids with different gas void fraction.

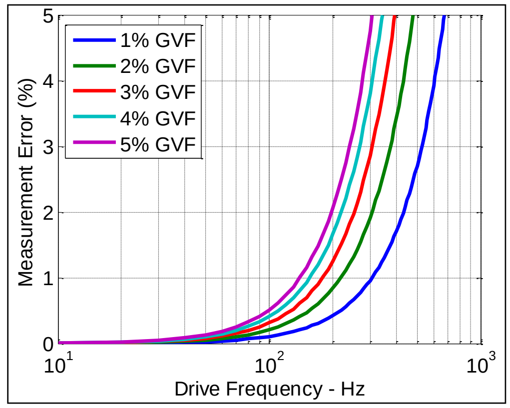

Figure 11 Drive frequency vs measurement error

Sizing of meter

A significant error can be induced if the meter is not sized properly, and the meter allows the bubbles of the entrained gas to be large.

Increase back pressure on the meter

When possible, increasing back pressure is helpful and serves two objectives, it decreases gas void fraction and also it decreases the bubble size, thus increasing the inverse stokes number (δ) and thus decreases the error.

Install meter in Flag Position

Install meter in a flag flow up position when entrained gas is expected. In a tube down position, bubbles will tend to accumulate at the inlet due to their buoyancy, and slip pass the resulting in fewer bubbles on the outlet side. This causes an imbalance in the tube.

Keeping flow rates high

Flow rates should be kept above a certain threshold to ensure that bubbles or particles flush out of the meter properly and prevent hold up and fluid tube asymmetry. This ratio depends on the viscosity of the fluid.

Conclusions

The Coriolis meter plays a pivotal role in MPD operations by providing crucial measurements such as flow rate, density, and fluid temperature. Its integration into the MPD setup on drilling rigs allows for real-time monitoring and precise control of fluid dynamics during the drilling process. This technology ensures accurate data acquisition, enabling engineers and operators to make informed decisions that enhance safety, and mitigate risks associated with well control events. The Coriolis meter's capability to capture and analyze essential parameters contributes significantly to the success and reliability of MPD operations in the challenging drilling operations.

CMFs are fundamentally designed as single-phase meters. In the presence of two phases, the meter will continue to measure; however, the accuracy of the measurement may be prone to deterioration. The excitation power “drive gain” serves as a crucial diagnostic tool within the Coriolis meters algorithm for detecting the presence of two phases. The change in density coupled with a noticeable spike in drive gain, indicates the presence of bubbles within the liquid phase.

Selecting a low-frequency Coriolis meter is advisable when anticipating entrained gas, as these meters are less susceptible to decoupling errors. Proper sizing of the meter is crucial, as errors may arise if it allows the formation of large bubbles from entrained gas. Increasing back pressure on the meter serves a dual purpose by reducing gas void fraction and minimizing bubble size, thereby enhancing the inverse stokes number (δ) and decreasing errors. Installing the meter in a flag flow-up position is recommended for situations involving entrained gas, as it prevents bubble accumulation at the inlet. Maintaining high flow rates is essential to ensure effective flushing of bubbles or particles from the meter, preventing holdup and fluid tube asymmetry, with the specific threshold dependent on the fluid viscosity.

Acknowledgments

The authors express their sincere gratitude to Blade Energy Partners for their valuable support and encouragement for the publication of this paper. Additionally, the authors would like to thank Emerson Automation Solutions and Micro Motion Inc for sharing technical information and granting permission for the use of their valuable information.

Nomenclature

MPD	=	Managed pressure drilling
CMF	=	Coriolis mass flowmeters
ΔQ	=	Delta-Flow
Q	=	Volumetric flow rate
Q_{out}	=	Flow out
Q_{in}	=	Flow in
SPP	=	Standpipe pressure
DS	=	Drill string
HMI	=	Human machine interface
SBP	=	Surface Back Pressure
BOP	=	Blow out preventer
CBHP	=	Constant bottom hole pressure
IME	=	Influx management envelope
$\dot{m}$	=	Mass flow rate
ΔT	=	Delta-T, magnitude of time delay
Fc	=	Coriolis force
ω	=	Angular Frequency, frequency of vibration
m	=	Mass of fluid particle
ρ	=	Measured density
W	=	Mass flow rate
V	=	Velocity
δ	=	Inverse Stokes number
A_p	=	Amplitude of Particle
A_f	=	Amplitude of Fluid
GVF	=	Gas void fraction

References

Cahill, J. (2019, Jan 31). *How Coriolis Meter Drive Gain Indication Works.* Retrieved from https://www.emersonautomationexperts.com/: https://www.emersonautomationexperts.com/2019/measurement-instrumentation/flow/how-coriolis-meter-drive-gain-indication-works/

Guo, B. (2019). *Well Productivity Handbook.* Lafayette: Gulf Professional Publishing.

J.J. Orban, K. Z. (1987). New Flowmeters for Kick and Loss Detection During Drilling. *Annual Technical Conference and Exhibition of the Society of Petroleum Engineers.* Dallas Texas: Society of Petroleum Engineers.

Jace, D. (2009). *Drilling Fluid Management.* Emerson Process Management.

Justin Hollingsworth, J. W. (2018). *Multiphase Flow in Coriolis Mass Flow Meters – Identifying Multiphase Conditions and Remediating Errors.* Boulder: Emerson Automation Solutions.

Micromotion. (2018). *Multiphase Flow in Coriolis Mass Flow - Identifying Multiphase Conditions and Remediating Errors.* Emersion.

Persson, A. (1998). How Do We Understand Coriolis Force ? *European Centre for Medium-Range Weather Forecasts,* 1373.

Schafer, L. (2017, 2 8). Enhancing Coriolis Performance in Entrained Gas with Advanced Phase Measurement.

Steve, N. (2012). Kick Detection in Closed Wellbore. *Journal of Petroleum Technology*.

Tim Patten, J. W. (2012). *Entrained Gas Handling in Micro Motion® Coriolis.* MICRO MOTION.

Weinstein, J. (2010). Multiphase Flow in Coriolis Mass Flow Meters - Error Sources and Best Practices. *28th International North Sea Flow Measurement Workshop.*

Appendix

Inverse Stokes number is defined as the square root of two times the kinematic fluid viscosity divided by the frequency of vibration of the meter times the particle radius squared.

$$Inverse\ Stokes\ Number\ (\delta)\ =\sqrt{\frac{2Vf}{\omega a^2}}$$

The equation's variables are V_f, which represents kinematic fluid viscosity, ω, the frequency of vibration of the meter, and a, the radius of the particle (in this case the gas bubble). The greater the Inverse stokes number, the less the decoupling ratio, thus less error expected in the mass flow rate and density measurements. Therefore, maximizing the Inverse Stokes number will minimize the expected error.

To examine the effect of each variable in maximizing the inverse stokes number, the numerator contains one variable "viscosity". The higher the viscosity, the higher the inverse stokes number, the lower the error. Further analysis shows that in a more viscous fluid, the bubble moves or decouples less. Unfortunately, we do not have the option of changing or modifying the viscosity of the drilling fluid for this purpose and therefore the parameter cannot be used to maximize inverse stokes number. The denominator contains two variables: frequency and particle radius. To maximize the stokes number, minimize the variables in the denominator. For situations where entrained gas is anticipated, the selection of a low frequency Coriolis meter can enhance the stokes number.

Another way of minimizing the error is to minimize the bubble size, especially in low viscous fluids. This can be achieved by promoting turbulent flow by maximizing flow rate, which can cause the bubbles to break. Changing the flow rate in oil and gas drilling applications is often difficult because it is defined by hydraulic analysis and has an impact on friction pressure losses, hole cleaning, and so on. Consider increasing the back pressure on the meter to effectively reduce gas void fraction and bubble size. Furthermore, putting the meter in a flag flow up position is advised, particularly when entrained gas is expected, to reduce bubble collection at the entrance and encourage a more balanced distribution.