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Entrained gas handling in Promass Coriolis flowmeters

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Abstract
This paper discusses the measurement challenges caused by process fluids that contain entrained gas on Coriolis flow technology and describes how to best overcome these challenges with Endress+Hauser Promass flowmeters.

Introduction

In recent decades, Coriolis mass flowmeters (CMFs) have been widely used in industry for mass flow, volume flow and density measurements. The measuring technique has reached a high degree of acceptance largely due to the low level of measurement inaccuracy it provides for various flow applications. Similar to many other measuring principles, it is known that accuracy of a Coriolis flowmeter can be affected by the existence of entrained gas in a liquid flow.

The severity of error introduced by entrained gas to Coriolis flowmeters is a function of many variables and thus the optimal solution for handling entrained gas in liquids for Endress+Hauser Promass Coriolis flowmeters is a combination of application design practices, meter selection, meter sizing and employing available fit-for-purpose software functions such as Promass Gas Fraction Handler (GFH).

It should be noted that Coriolis flowmeters report the mass and density of a flowing fluid. In an entrained gas condition, the reported mass contains the total mass content of both the gas and the liquid. The same principal holds as well for density. Typically, the errors associated with density measurement (and subsequently volume flow) are of a greater magnitude than those associated with mass flow for fluid streams with entrained gas.

Bubble type

In order to best understand how to mitigate the unwanted effects of entrained gas on Coriolis flowmeters, it is advantageous to first understand the type of bubble that is expected in a given process or application.

According to the effects on Coriolis metering, gas bubbles in liquid flows are classified as “free bubble” and “suspended bubble” that lead to “bubble effect” and “resonator effect”, respectively.

A free bubble in the measuring tube of a Coriolis mass flowmeter does not strictly follow the oscillation of the surrounding liquid with the same amplitude, because the liquid cannot “hold” the bubble well. The resulting amplitude of the bubble motion is greater than that of the tube vibration. Deviations for density and mass flow measurements occur due to this difference in vibration amplitude, which is named as “bubble effect”. This effect generally results in an under-reading. Meter operating frequency has little impact on the bubble effect.

A suspended bubble, by contrast, is one that is held by the liquid and is alternatingly compressed and expanded with the tube oscillation. Typically, a number of suspended bubbles form a homogeneous two-phase fluid and lead to a global and systematic motion of the fluid. This spring-like action means the fluid becomes more active and exerts more force on the tube wall. The result is higher than correct readings. Straight tube Coriolis flowmeters that usually have very high working frequencies are not generally recommended for applications with fluids containing small suspended bubbles or micro-bubbles.

The ability of the fluid to hold bubbles is a function of the fluid viscosity, bubble diameter, vibration frequency and liquid density, among which bubble diameter and viscosity are the decisive factors. Low viscosity fluids tend to exhibit bubble effect and high viscosity fluids tend to exhibit resonator effect for a Coriolis flowmeter (Fig. 1). Nevertheless, it has often been seen that many low viscosity fluids, such as milk products or various binders, can easily trap suspended micro-bubbles, and consequently show a significant resonator effect.

Diagnostics available in Promass Gas Fraction Handler (GFH) can be used to determine the type of bubble present and also indicate the relative severity of the entrained gas. This is discussed later in this document.

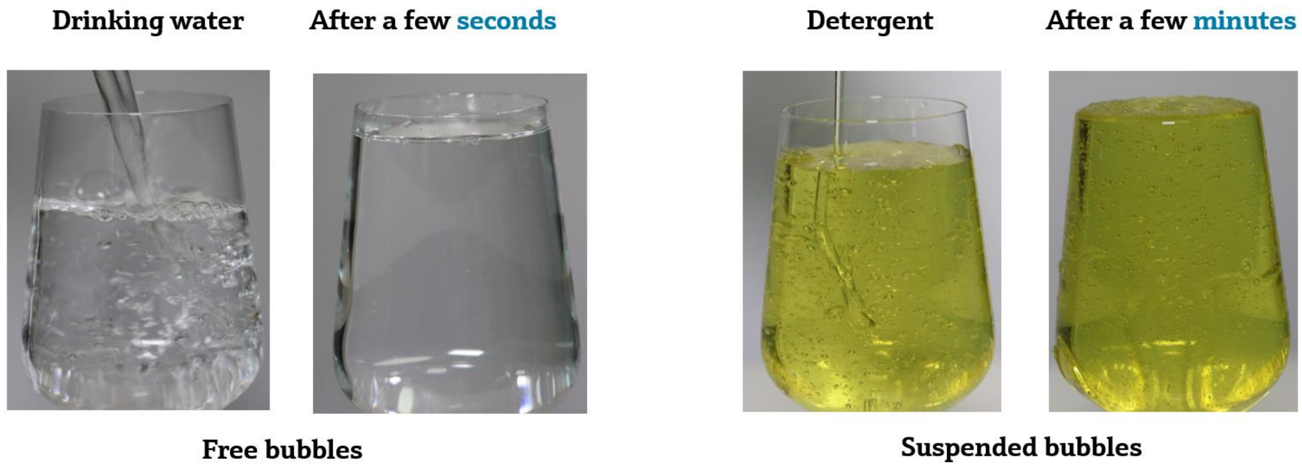


Fig. 1 – Free bubbles vs. suspended bubbles

Application design practices

Optimal Coriolis measurement performance in the presence of entrained gas begins with minimizing the amount of expected second phase flow through application and system design. This starts with ensuring there is adequate back pressure at the meter installation, which serves to keep bubbles from forming in the first place. When pulling fluids from tanks, it is advisable to ensure the tank level is high enough to prevent bubbles created by the falling liquid from entering the liquid flow to the meter, or to ensure the drop distance into the tank is not excessively long resulting in a high level of splashing. When metering an empty-full-empty application associated with a batch process (flowmeter is filled with gas, then fluid liquid, then gas) – it is advisable to install the meter as close as possible to the transfer point in a drainable configuration to ensure the meter can be filled quickly at the start and drained quickly at the end of the batch.

When gas phase will be known to be present, flowmeter performance will always benefit from the installation of air eliminators or settlement tanks provided that the viscosity of the fluid is low enough to allow for the release of the gas from the fluid in the eliminator vessel within a reasonable time.

An important factor for optimal performance is to keep the bubbles small, well distributed, and evenly distributed between sensor tubes on a dual tube Coriolis flowmeter. This is best accomplished by ensuring a high flow velocity through the meter. In addition, installing the meter in the vertical position with flow going up is recommended as bubble buoyancy works with the flow to keep the bubbles moving through the tubes. If vertical installation is not possible, then installation with the belly down would be the next best choice (Fig. 2). Meters with sharp bends in the tube are less desirable, since they have a greater possibility of trapping and collecting bubbles.

When entrained gas is in the form of suspended bubbles, for example those found in viscous fluids, these mechanical means are often not sufficient to remove the entrained gas. In addition, in some applications entrained gas content is an intentional characteristic of the process fluid. For example, with certain food items (such as ice cream or cream cheese) gas is intentionally injected into the fluid in order to achieve a particular desired consistency. In these circumstances, Promass flowmeters with Multi-Frequency Technology are recommended (e.g. Promass Q).

Fig. 2 – Preferred meter installation orientation for liquid applications with entrained gas

Multi-Frequency Technology

If entrained gas is expected to be present in the form of small suspended bubbles, some Promass models (e.g. Promass Q) have a feature called Multi-Frequency Technology (MFT) which can reduce errors to very small levels due to inbuilt, active compensation for the resonator effect. Coriolis flowmeters are designed to be driven at the natural resonance frequency of a given system (tube properties plus fluid properties) when in operation. This frequency is the primary mode of vibration; however, there are additional natural modes associated with the vibrating system and one of them can be driven in addition to the primary mode. With MFT the tubes are also driven at their third natural mode. By analyzing the signals filtered at this different frequency, one can obtain additional information about the vibrational properties of the fluid. Being driven at different frequencies, the same gas entrainment can have different influences on the primary mode and the auxiliary mode. By analyzing the characteristics of sensor signals at the two frequencies, one can obtain the unique resonance property of the entrained gas and compensate the associated measurement errors.

In simple terms, when analyzing a signal from one mode, one can see that there is indeed entrained gas present in the fluid due to a higher level of system dampening and/or signal fluctuation, but it is difficult to determine how much error the gas is creating. However, when a signal is also analyzed from a second mode, a quantitative level can be derived from the relationship between the two signals. This unique aspect of MFT allows for a better overall absolute accuracy performance, because the effects of the entrained gas are actively compensated. Additional information on MFT can be viewed here.

Meter sizing

From a meter sizing perspective, the key is to never oversize the meter and use the smallest meter possible to ensure the highest velocity (without creating cavitation), which helps to distribute the second phase more homogeneously and helps to prevent bubbles from regrouping to form larger bubbles in the form of slug flow. In batch applications smaller meters also reduce times associated with the meter tubes to become filled.

Software functions – Gas Fraction Handler (GFH)

All Promass 300/500 transmitters (HART/Modbus/PROFINET) are equipped with Gas Fraction Handler (GFH) software which continuously tests for the presence of disturbances in single-phase flow and will remove the influence of transient entrained gas conditions on the meter output, providing a stable output for optimal process control. This is achieved through a sophisticated smart filtering function. Additionally, GFH software provides dedicated smart diagnostics which can be used to directly monitor the severity and the type of the entrained gas condition.

GFH – Smart filtering

In many applications found in industry, operators have the challenge that large gas pockets in liquid flow streams form free bubbles or even slug flow. In this situation conventional Coriolis flowmeters have severely fluctuating measurement, which might cause undesirable alarms. With the GFH active, the measurement signal is stabilized and the repeatability is improved in the event of entrained gas, providing better readability for operators and easier interpretation by process control systems (Fig. 3).

The GFH filtering technology is adaptive and is only active in the presence of entrained gas and does not unnecessarily dampen or slow down measuring response under normal conditions. The influence of the disturbances can be configured with this switch in two steps: “Powerful” is used for applications with very significant levels of second phase. “Moderate” should be used for applications with low level or intermittent levels of second phase.

In addition, due to advanced digital signal processing techniques, Promass flowmeters will never stall across the full spectrum of 0 to 100% entrained gas and a continuous measurement and output is always provided.

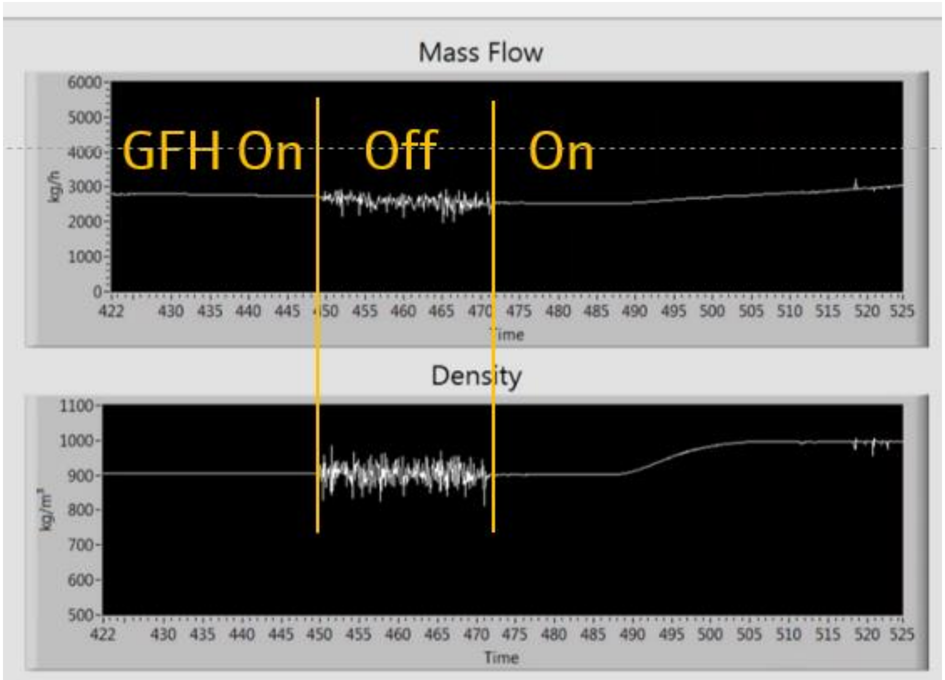


Fig. 3 – Meter output with GFH activated and non-activated

GFH – Smart diagnostics

As discussed earlier, the type of bubble has an impact on the overall performance of a Coriolis meter. Therefore, it can be important to detect the existence of entrained gas and identify the type of entrained bubbles that has relevance to the measurement reliability.

New measuring indices included in the GFH software provide additional insight into the relative magnitude and characteristics of the entrained gas contained in the process fluid. These measuring indices are robust and provide repeatable information giving users a true window into their process.

The Index Inhomogeneous Medium (MI-MI) diagnostic indicates the overall severity of the second phase associated with free bubbles. When there is no entrained gas in a liquid, the value is 0 and for very high levels of gas volume fractions (associated with severe slug flow, for example), the value exceeds 10 (Fig. 4). The diagnostic value becomes greater with increasing gas volume fraction. It will not saturate with excessive second phase. Although the index gives a qualitative correlation to the severity of gas entrainment, it should not be understood 1 to 1 as gas volume fraction. The Index Inhomogeneous Medium diagnostic is repeatable under the same entrained gas condition, and thus can be used to better understand process conditions and the level of gas entrainment on a relative basis.

Also note that the Index Inhomogeneous Medium diagnostic can also be used to similarly describe the relative level of solids in a liquid application or the relative level of liquid phase in a wet gas application.

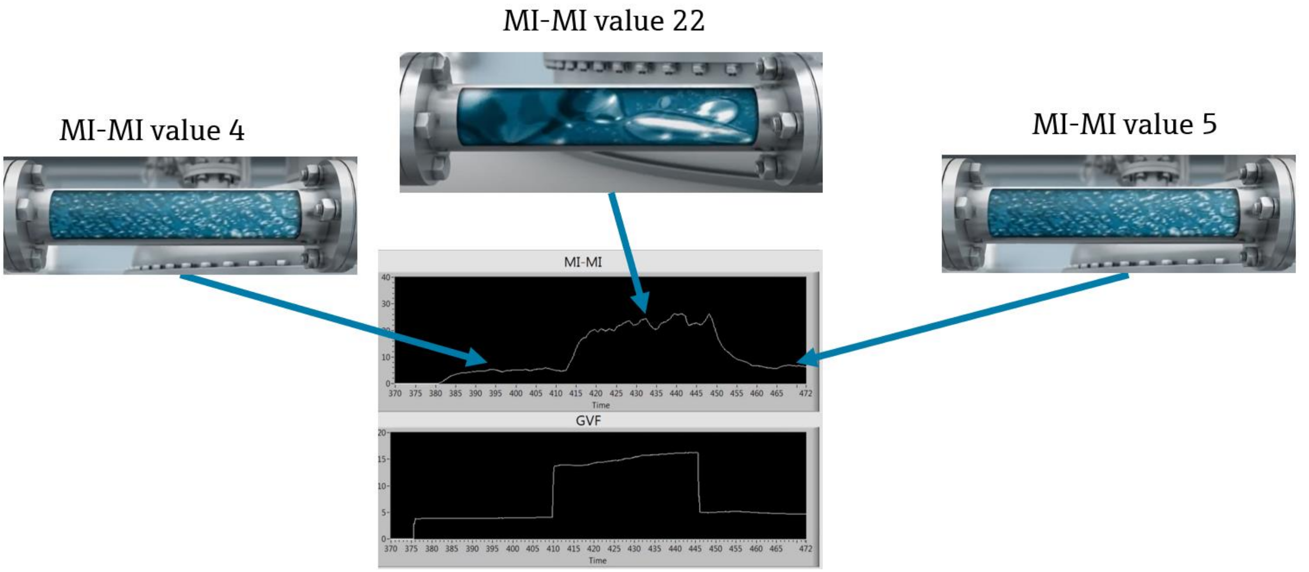
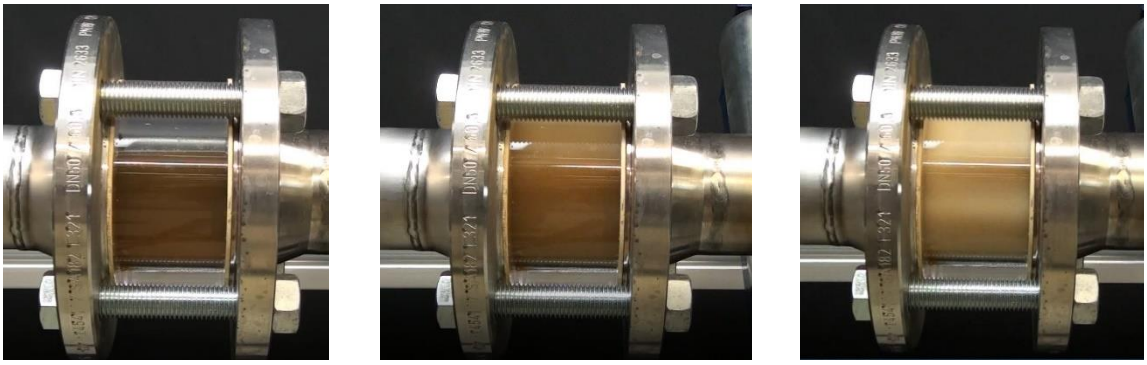


Fig. 4 – MI-MI diagnostic provides repeatable indication of the severity of entrained gas in a flowing liquid stream.

The Index Suspended Bubbles (MI-SB) diagnostic indicates the presence of small suspended bubbles for Promass flowmeters that utilize Multi-Frequency Technology (e.g. Promass Q). This diagnostic value index describes the relative amount of micro-bubbles or small suspended bubbles in a process fluid (Fig. 5). When there is no entrained gas in the form of suspended bubbles in a liquid, the value is 0 and for very high levels of suspended gas volumes, the value exceeds 10. The index will not saturate with excessive second phase. Like the Index Inhomogeneous Medium, the Index Suspended Bubbles diagnostic can be used to better understand process conditions, the type of bubbles present, and the level of gas entrainment on a relative basis.



MI-SB value 0 MI-SB value 2 MI-SB value 7

Fig. 5 – MI-SB diagnostic provides repeatable indication of the severity of entrained gas in the form of suspended bubbles in a flowing viscous fluid (shown above in a thickening and binding agent for foodstuffs).

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Summary
The undesirable effects of entrained gas on Promass Coriolis flowmeter performance can be minimized through an appropriate combination of application design practices, meter selection, meter sizing and employing available fit-for-purpose software functions such as Promass Gas Fraction Handler (GFH). New diagnostic indices included in the GFH software can be used to directly monitor the severity and the type of the entrained gas condition giving users a true window into their processes.