

BY TIM PATTEN, JOEL WEINSTEIN, MICHELLE MARCENY
MICRO MOTION, INC.

Entrained Gas Handling in Micro Motion® Coriolis Flowmeters

Introduction

This white paper discusses the measurement challenges caused by process fluids that contain bubbles of air or other gas, and describes how Micro Motion® sensor and transmitter technology can be used to overcome those challenges. This white paper also presents best practice suggestions to minimize measurement inaccuracies by improving application design.

Although the most common term applied to this issue is “entrained air,” the bubbles may contain any gas. This white paper uses the term “entrained gas” rather than “entrained air” in order to address the broader topic. Other frequently used terms include “two-phase flow” and “slug flow.”

Entrained Gas Applications

We define entrained gas flow in three specific regimes: bubble flow, slug flow, and empty-full-empty flow. They can both occur intentionally and unintentionally. Micro Motion® ELITE® Coriolis flowmeters are designed for best immunity to the effects of entrained gas.

Bubble Flow

Bubble flow is characterized by continuous, distributed bubbles (Figure 1) that occur usually when air is added intentionally into a process, as in the manufacture of food products such as whipped cream or butter.

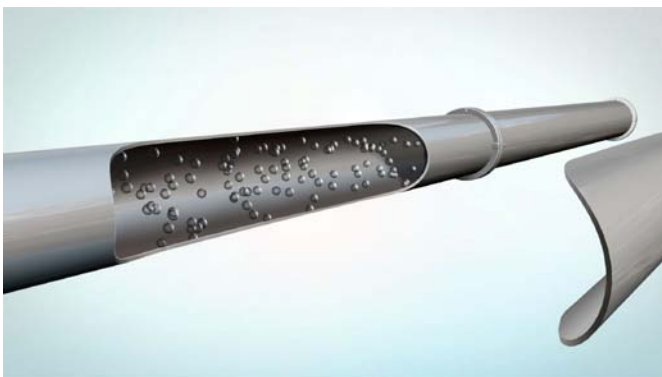


Figure 1. Entrained air, bubble flow

Slug Flow

Slug flow is usually unintentional and can occur as a result of a process upset in tank farm or oil well applications, where there are periodic, coalesced bubbles (Figure 2).

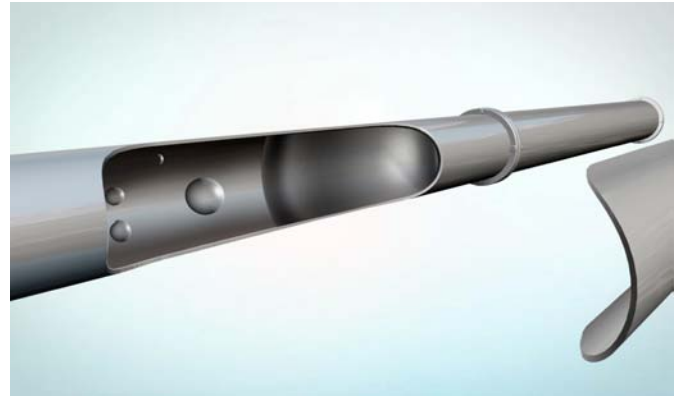


Figure 2. Entrained air, slug flow

Slug flow can occur as a result of long drops into tanks (Figure 3), where splashing occurs when the stream enters the liquid. The farther the liquid falls, the more air is entrained.

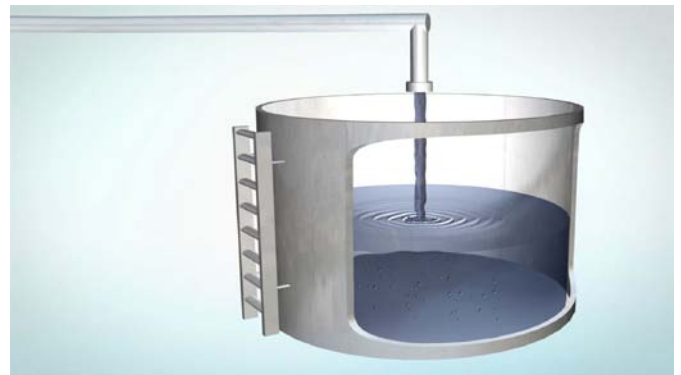


Figure 3. Slug flow, long drops

Agitators can produce a vortex that entrains air into a liquid, especially when tank levels are low (Figure 4).

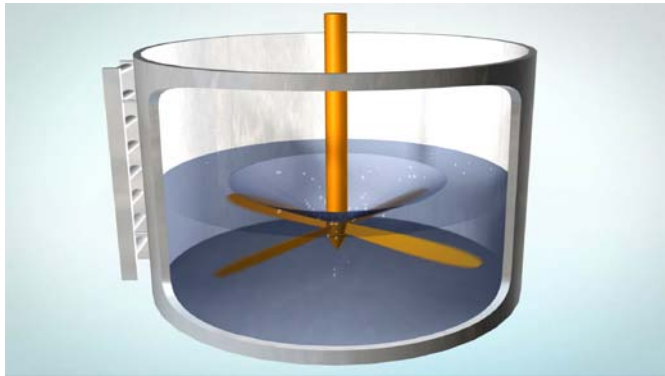


Figure 4. Vortex with entrained air as a liquid

Leaks in pump suction, and pumping out of near-empty tanks can introduce air. Air can also enter the process line through faulty seals.

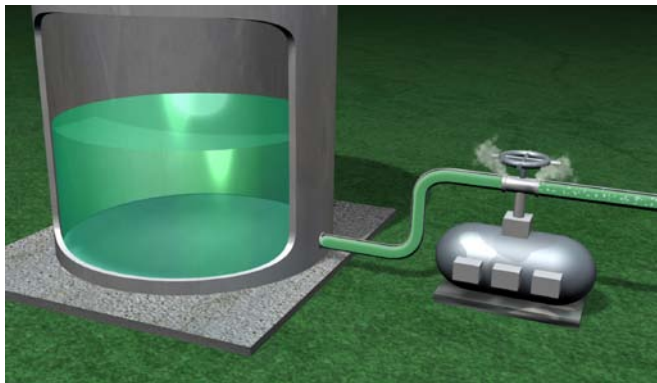


Figure 5. Entrained air caused by leaks in pumps

Empty-full-empty flow

Empty-full-empty flow is characterized by a precise liquid/gas interface, and can be caused when loading and unloading rail cars or other tanks or vessels.

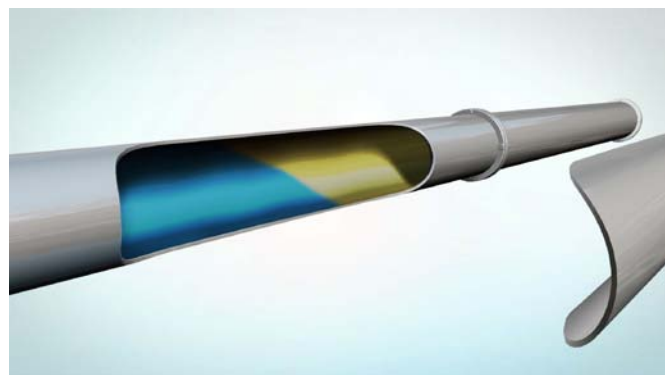


Figure 6. Entrained air, empty-full-empty

The entrained gas challenge

Micro Motion Coriolis sensor technology produces direct measurements of mass, density, and temperature. When gas is present in a liquid stream, it occupies volume. It is important to understand that entrained gas fundamentally does not cause significant primary measurement errors in mass flow measurement.

When a mixture of gas and liquid is present, the mass flow measurement represented by the flowmeter is a representation of the mass of the liquid plus the mass of the gas. Since the mass of the gas is very small compared to the mass of the liquid, the mass flow measurement of the mixture is very close to the mass flow measurement of the liquid and provides an excellent measurement.

$$M_{\text{measured Coriolis}} = M_{\text{liquid}} + M_{\text{gas}} \approx M_{\text{liquid}}$$

However, the measured density of the mixture (reported by the Coriolis meter) is actually an average of the liquid and gas densities, weighted by their respective volume fractions. The density measurement of interest is generally the density of the liquid only and the Coriolis meter will not be able to report that value.

$$\rho_{\text{mix}} = \rho_{\text{gas}} \times \text{GVF} + \rho_{\text{liq}}(1-\text{GVF})$$

Where:

ρ_{mix} = density of the mixture

ρ_{gas} = density of the gas

ρ_{liq} = density of the liquid

GVF= gas void fraction

Similarly, volume measurement from the Coriolis meter is the volume of the mixture or the sum of the volume of the gas plus the volume of the liquid. Again, the parameter of interest is typically the liquid volume only. Therefore, if entrained gas is present in the meter, only the mass variable will represent the liquid quantity. The density and volume measurements both represent the mixture quantities.

$$V_{\text{measured Coriolis}} = V_{\text{mix}} = V_{\text{gas}} + V_{\text{liquid}}$$



Figure 7. Entrained gas bubbles

Micro Motion technology

Existing Micro Motion technology can be used with excellent results in applications that contain entrained gas, if the correct meter and transmitter are used and configured appropriately. In addition, certain application characteristics can improve measurement. These application characteristics are discussed in the section entitled “Application recommendations.”

Sensor technology

For two-phase flow, the best measurement is provided by dual-tube sensors with a low tube frequency. If a sensor with high tube frequency is used, the two-phase mixture does not vibrate directly with the flow tube, resulting in large measurement errors. The faster the tube vibrates, the more likely that the gas and liquid can become decoupled and move at different speeds in the flow tube, which will cause measurement error. This is similar to a centrifuge. The faster a centrifuge spins, the more it separates heavy components from light components.

Micro Motion ELITE sensors are recommended for applications with entrained gas, but F-Series sensors meet application requirements in certain situations. Because the single-tube T-Series sensors have a high operating frequency, they are not recommended for applications with entrained gas. Figure 8 shows the 1% mass flow error for ELITE, F-Series and T-Series meters in the laboratory for water with entrained air. The points underneath each curve represent the conditions in which a better than 1% measurement is achieved.

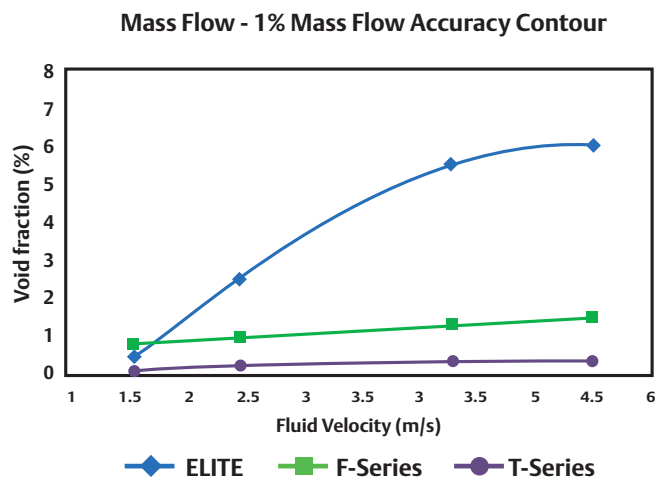


Figure 8. Laboratory conditions - water with air

Transmitter technology

Our latest standard Micro Motion MVD™ transmitter with the enhanced core processor, available with ELITE, F-Series and H-Series sensors, offers the most advanced digital signal processing (DSP) capability and is optimized for entrained gas measurement. The ELITE sensor with enhanced core processor is the best Coriolis meter available for measuring two-phase fluid. There are no special configurations required for the transmitter when a liquid with entrained gas is measured with an enhanced core processor.

The standard Micro Motion MVD™ technology (available with a standard core processor) also employs digital signal processing (DSP) and increases speed of response. In the case of entrained gas, the transmitter must remove, or “look through” the noise imposed by the two-phase flow, and report only the “real” flow measurement of the liquid. The DSP algorithms in the MVD electronics very effectively filter the noise and provide continuous measurement for liquids with some entrained gas present. Any standard MVD transmitter should be configured for “entrained gas” mode in order to increase the rate at which the sensor data is reported to the transmitter. It is also important to set the fault actions to “none” so the outputs will continue to report process data during two-phase flow conditions.

Transmitter zero

Unstable fluid conditions (e.g., air stuck inside flow tubes at zero flow) can cause significant measurement errors. For this reason, performing a zero calibration under unstable fluid conditions is highly discouraged. Micro Motion does not recommend performing a field zero calibration in a

two-phase flow application. The factory zero will provide the best results. If the meter has been zeroed in the field while two phases were present in the sensor, the best practice is to restore the factory zero. In most transmitters, the factory zero is stored in the memory.

Application recommendations

The most important application factor to improve two-phase flow measurement is bubble distribution. For best measurement results, the gas bubbles in the process fluid should be small, be distributed as evenly as possible between the two sensor tubes, and move through the tubes at the same rate that they entered the tubes. The following factors contribute to even bubble distribution:

- *Higher flow rates.* If flow rate is sufficiently high, bubbles move through the sensor tubes at approximately the same rate at which they entered the tubes, counteracting the effects of bubble buoyancy (produced by gravity) in low-viscosity fluids as discussed below. When it is known that entrained air is present, Micro Motion recommends a flow rate no lower than 5:1 turndown of nominal flowrate
- *Vertical pipe runs with upward flow.* Especially at lower flow rates, bubble buoyancy tends to result in bubble collection near the inlet of the sensor when it is installed in a horizontal pipeline with the tubes down. Bubble buoyancy works with the flow to move bubbles through the tubes. For this reason, the best practice is to install the sensor in a vertical pipeline with the flow going up. Keeping flow rate high also helps eliminate this problem (Figure 9).

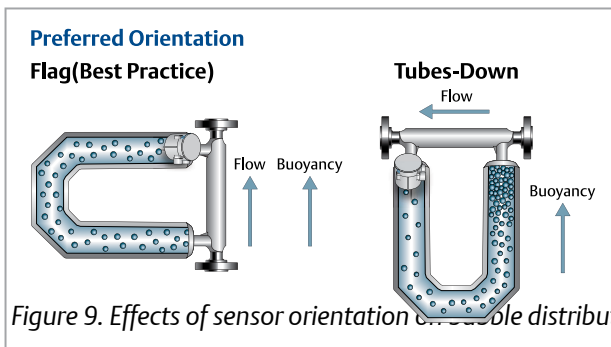


Figure 9. Effects of sensor orientation on bubble distribution

- *Viscosity.* High-viscosity fluids tend to hold the bubbles in suspension better than low-viscosity fluids, and maintain their original position and distribution. In high-viscosity fluids bubbles are more likely to stay dispersed, while in low-viscosity fluids small bubbles may coalesce into large bubbles that are more likely to collect together. Figures 10 and 11 show performance expectations for low and high velocity fluids in the laboratory.

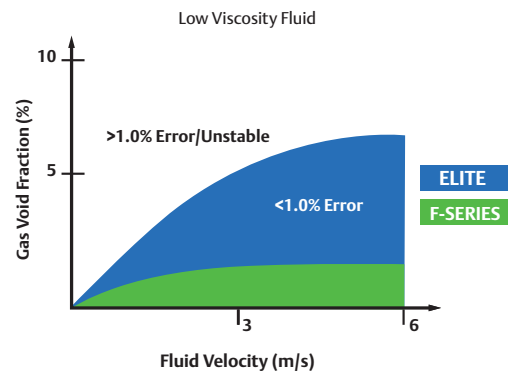


Figure 10. Laboratory operating conditions - water with air

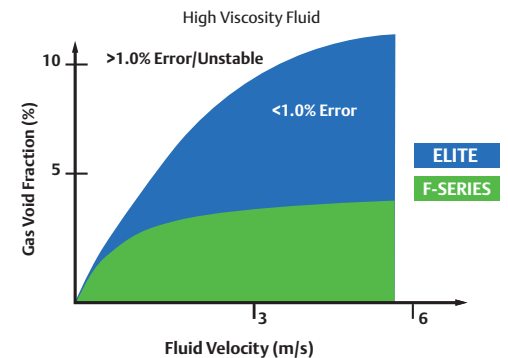


Figure 11. Laboratory operating conditions - mineral oil with air

- Empty-full-empty batches.* Entrained gas is found during the beginning and end of the batch during empty-full-empty applications. In laboratory testing, batches with a duration of one minute or longer tended to be immune to the transient errors caused by entrained gas remaining in the sensor tubes. As shown in Figure 12, repeatability improves as batch duration increases. Laboratory experience has demonstrated that if the meter fill time is less than 1 second and the batch time is greater than 10 seconds, good Empty-Full-Empty batching performance can be expected with mass repeatability well below 0.1%. Meter fill time is a function of meter size and flow rate. Care should be taken during meter sizing and installation to keep fill times as short as possible. The meter should be installed close to the transfer point in a drainable configuration, be filled quickly at the start, and drained or blown out quickly at the end of the batch.

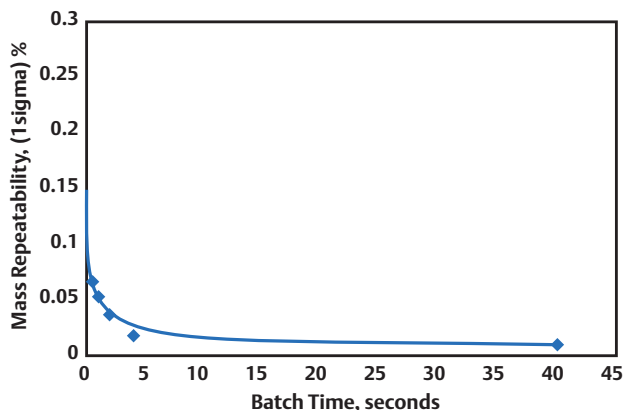


Figure 12. Effects of batch duration on repeatability (Data collected under laboratory conditions. Please consult the factory for specific application situations.)

Figure 13, below, shows that ELITE and F-Series meters can operate with an uncertainty of less than 1.0% with shorter batch times. Other meters show similar uncertainties with longer batch times.

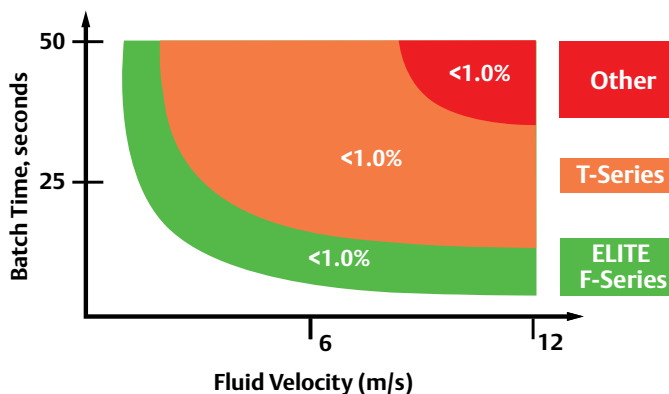


Figure 13. Empty-Full-Empty Performance: Laboratory Operating Conditions - water with air

Summary

With appropriate product selection, installation, and configuration, Micro Motion Coriolis sensors paired with MVD technology and the enhanced core processor minimize or overcome the measurement problems caused by entrained gas. As a result, the benefits of Micro Motion Coriolis technology are available to an expanded set of applications in a broad range of industries. Coriolis technology provides highly accurate measurement of mass flow of a two-phase fluid with a low-maintenance low-installed-cost device.

For more information on entrained gas handling in Micro Motion Coriolis flowmeters, check out our entrained gas videos at www.youtube.com/micromotion

Entrained Gas Handling in Micro Motion Coriolis Flowmeters

About the authors

Tim Patten has been with Micro Motion since 1989, in various engineering and marketing roles. He holds an M.S. in Mechanical Engineering from Worcester Polytechnic Institute in Massachusetts. He is currently the Director of Measurement Technology.

Joel Weinstein is a research and applications engineer for Micro Motion. He holds a Ph.D. in Mechanical Engineering from the University of Colorado at Boulder, and has recently completed a five-year joint research project with the University focused on improving Coriolis measurement with entrained gas for difficult industrial applications.

Michelle Marceny holds a BS in Chemical Engineering from the Colorado School of Mines, and graduated in 1985. She has held various engineering and marketing roles in industry, and is currently the Oil and Gas Product Line Business Manager for Micro Motion.

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Micro Motion, Inc. USA
Worldwide Headquarters
 7070 Winchester Circle
 Boulder, Colorado USA 80301
 T +1 303-527-5200
 T +1 800-522-6277
 F +1 303-530-8459

Micro Motion Europe
Emerson Process Management
 Neonstraat 1
 6718 WX Ede
 The Netherlands
 T +31 (0) 318 495 555
 F +31 (0) 318 495 556

Micro Motion Japan
Emerson Process Management
 1-2-5 Higashi Shinagawa
 Shinagawa-ku
 Tokyo 140-0002 Japan
 T +81 3 5769-6800
 F +81 3 5769-6840

Micro Motion Asia
Emerson Process Management
 1 Pandan Crescent
 Singapore 128461
 Republic of Singapore
 T +65 6777-8211
 F +81 6770-8003

