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Understanding the Challenges of Two-Phase Flow

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2-phase flow is difficult for all flowmeters

All flow meter technologies have limitations, and most have a tough time with two-phase flow, such as air mixed in a liquid stream. The fluid dynamic characteristics of a liquid and air mixture are extremely complex, and to a large degree are still not characterized by modern-day fluid dynamic models. It is not surprising that measurement of such an unpredictable flow stream is a challenge with all types of flow meters, including Coriolis.

Coriolis is better than most

Because Coriolis meters offer a tremendous value proposition with excellent accuracy and reliability and very low maintenance costs, there has been a trend to apply them in as many applications as possible. This trend has logically brought Coriolis meters to those applications where entrained air (and sometimes other gases) is common.

Fortunately for users, Coriolis meters offer a viable alternative to the challenges often found when other meters encounter two-phase flow. For instance, mechanical meters-turbines or positive displacement-can fail altogether.

Truck loading with a 3" Micro Motion Elite® meter

Performance of Micro Motion® meters in these applications has improved (with patented features like transient bubble remediation) over the past several years and research continues to make further improvements.

Still room for improvement

While Coriolis out-performs other technologies in challenging two-phase flow applications, the performance of Coriolis meters in these applications is still not good enough by Micro Motion's standards, nor many customers' desires. The challenges lie in two key areas: types of entrained air and how meters are sized.

Types of entrained air

Empty-start batch: Entrained air is encountered very often in empty-start batch applications. This occurs when a process, such as loading a truck or railcar, requires that the line be evacuated after the last fill operation. This is common with fluids that solidify, for instance. When the next load occurs, since the line was purged during the previous load, the meter must start from an empty state.

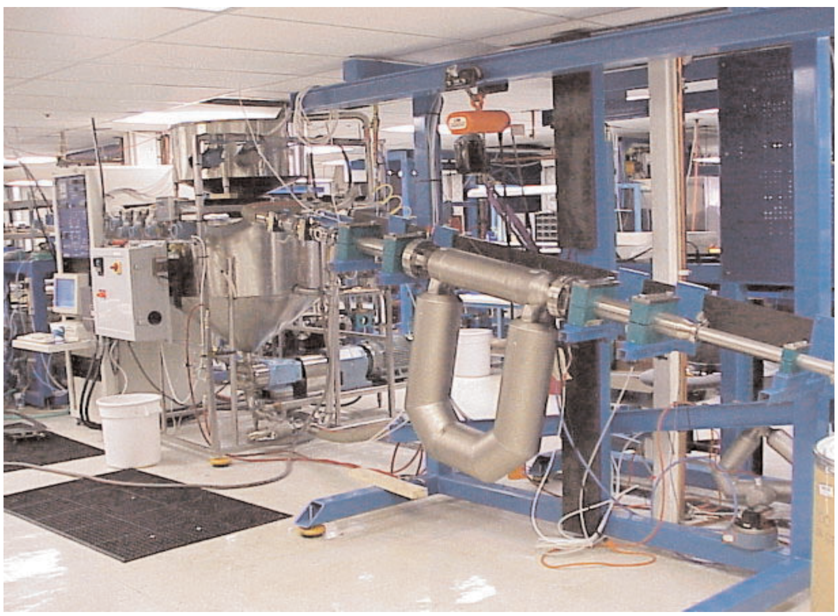
Micro Motion Coriolis meters have a long history of successful operation in empty-start batching applications. There are currently over 5,000 Micro Motion meters operating in this type of application, ranging in size from 2" to 6", on fluids including glucose, phenol, petroleum products, and liquid fertilizer. It is common to purge the line of these fluids and the meter operates well during the entire load, including the transient conditions at the beginning and end where air (or nitrogen) is used to purge.

Continuous Air: Another way air can be in the line is if there is a pump seal leak, air "sucked in" due to a low level in a vessel, or some other type of continuous introduction of gas into the pipeline. Applications that encounter this type of air will typically find low levels, 0-5%, entrained air in their lines. Micro Motion believes, and many customers agree, that no Coriolis vendor provides performance that is optimal. Micro Motion is working to improve performance with changes to signal processing, sensor design, and the drive mechanism. To evaluate meter changes, Micro Motion custom-built a test facility, able to test a very wide range of fluids. To date, fluids ranging from wort (beer) to soap (viscosity up to 5000 cp) have been tested. Many meter improvements have been made over the past year, and the next generation of Coriolis meters that are more robust to entrained air are expected to be released in the near future.

A small subset of the marketplace may encounter times when their fluids trap continuous air at levels of 30% or more. While Coriolis providers are attempting to develop their technology to address this, it is probably not the primary concern for the majority of users who have issues with entrained air. From our discussions with customers, we believe the focus should be on improving Coriolis performance for the most common two-phase applications that users face: empty batch starts and 0-5% continuous air.

The sizing solution

With an understanding of the types of entrained air that users encounter and the limitations of current technology, what can users do to improve the performance of their Coriolis meters? A simple solution exists to mitigate most entrained air problems: proper sizing.



Entrained air (up to 30%) and viscosity (up to 10000 cp) test facility.

Many entrained air problems happen in very viscous fluids, and most viscous fluids are non-Newtonian. Further, most non-Newtonian fluids metered by Coriolis meters are thixotropic (the viscosity of a thixotropic fluid decreases as the flow rate increases)*. Most sizing methodologies utilize the Newtonian viscosity, which can be several thousand times greater than the viscosity when the fluid begins to flow in a thixotropic fluid. This results in a meter that is oversized and susceptible to air and liquid separation because the velocity through the meter is low.

The first thing a user should do is to identify the viscosity characteristics of their fluid as a function of flow rate, especially the potential for thixotropic behavior. A good illustration of thixotropy is ketchup. In a still state, it becomes very thick and won't flow from the bottle when it is turned upside down. However, once it begins flowing from the bottle, it flows quite rapidly. Viscous fluids often perform this way in pipes. Therefore, if a user tells the Coriolis meter sales person the viscosity of their fluid in a still state, the meter will be sized incorrectly (much too large) for the fluid in its flowing state.

To demonstrate how meter sizing is highly dependent on using the proper viscosity, two examples are detailed below:

- Meter selected based on the Newtonian viscosity
- Meter selected using the thixotropic properties of the fluid.

Many differently sized meters could be selected for this application, but for simplicity only a 1" and a 3" meter will be compared.

Meter sized according to Newtonian viscosity: The following conditions are assumed for the example:

- Flow = 500 lbs/min
- Density = 1.01 g/cc
- Ambient temperature and pressure
- Newtonian viscosity = 4400 cp

The two meter options have pressure drops of:

- 1" meter with a pressure drop of 760 psid
- 3" meter with a pressure drop of 21 psid

The 1" meter has a pressure drop that is higher than what would normally be acceptable, so the 3" meter would usually be chosen for this application. The potential negative impact of the 3" meter selection is that if any air is present in the liquid stream, meter performance may suffer. This is primarily because at 500 lbs/min (10:1 turndown) the fluid velocity will be relatively low and the air will tend to coalesce into big bubbles inside the sensor tubes and disrupt the measurement.

Meter sized according to thixotropic characteristics: Knowing your fluid's viscosity at flow rate will not only dramatically affect the performance of your Coriolis meter, it will also help you optimize your entire system and save money. It will result

Author's note: Although not technically correct, it is common to refer to the viscosity of a thixotropic fluid at no flow as its Newtonian viscosity.

> If you need help determining the viscosity of your fluid at flow rate, it's probably worth the investment to have a rheology lab, like those found at Ohio State or University of Minnesota, perform the measurement for you.

in smaller line sizes, different valves and pumps and other system components including the Coriolis meter.

There are three primary advantages to a smaller meter in these situations:

- A smaller meter typically has better accuracy because, for a given flow rate, it is operating higher in its flow range
- Higher fluid velocity mixes air that may be in the liquid better, creating a more homogenous mixture
- Lower cost

A good sizing tool, like that used by Micro Motion sales people, will allow you to input the thixotropic characteristics of the fluid. The two required viscosity parameters that describe thixotropy are commonly referred to as "K & n" values, or "consistency index" and "flow-behavior index." These are the coefficients of a simple power-law equation.

A test fluid with K= 4400 cp and n=0.2 was used to evaluate the pressure drop of the 1" and 3" meters at the conditions outlined above. This is a fluid that at no flow has a viscosity of 4400 cp; at higher rates the viscosity will drop to as low as a few centipoise. The graph compares the pressure drop of the two meters at varying rates.

Pressure drop in all cases is less than or equal to the 21 psid of the 3" meter when using the Newtonian viscosity of 4400 cp. The selection of the 1" meter is viable when the thixotropic behavior of the fluid is considered - it is the proper selection for this example application.

A very important benefit of using the non-Newtonian fluid properties when sizing a meter is improved performance, especially when there is gas present in the flow-stream. The higher velocity mixes the fluid better; resulting in a more homogenous mixture that can be measured more reliably in the Coriolis meter's tubes. The relative velocity between Coriolis meters can be used to approximate how much air can be tolerated. For instance, the velocity in a 1" meter will be approximately six times higher than in a 3" meter, so its tolerance to air will be approximately six times better. The flow area of specific meters will vary; so consult the manufacturer for specific sizing values.

Summary

2-phase flow continues to be a measurement challenge for flow metering technologies. In the most common of these situations, empty-start batch applications, Coriolis has a proven performance record. Coriolis vendors still struggle with continuous air, but are developing solutions to better support these applications.

In addition, the difficulties with entrained air can be lessened through proper sizing. When a fluid is encountered that is likely to have air entrained in it, always try to put the smallest Coriolis meter possible into the application. Along with the normal parameters required (flow rate, temperature, pressure, etc), the non-Newtonian behavior must be considered. To ensure you get a properly sized meter, be prepared to tell your flow meter sales person:

- K & n values, or "consistency index" and "flow-behavior index"[1]
- Maximum pressure drop that can be tolerated

By sizing the meter such that the smallest meter possible is used, performance will be greatly improved in applications where entrained air might be encountered. With technology developments and proper sizing, entrained air will become more easily handled by Coriolis over the next few years.

About the author

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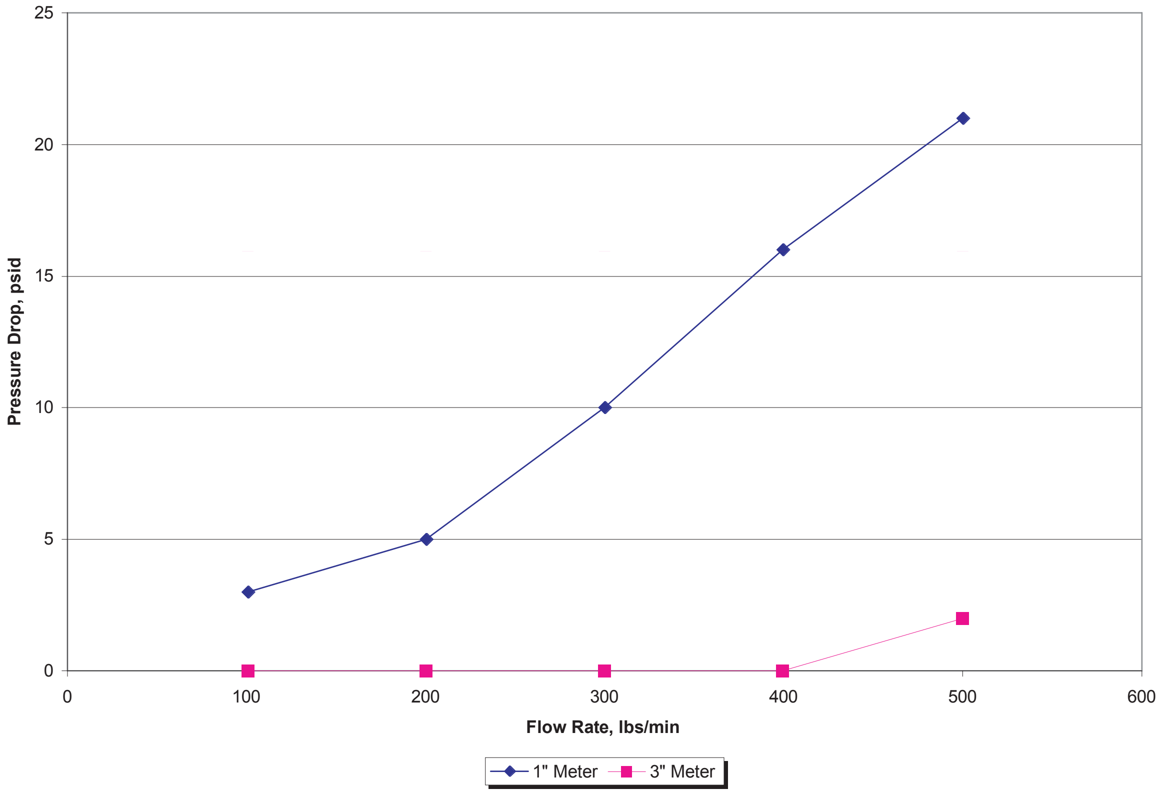
[1] See Flow Measurement Engineering Handbook, Third Addition by Richard Miller for a full discussion of Non-Newtonian fluids and how to characterize them.



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