BY JOHN DOLENC, EMERSON PROCESS MANAGEMENT

Mass Flow Measurement Accuracy in Process Industries

The Coriolis mass flow measurement technology developed by Micro Motion® provides several advantages: flexibility, ease of use, ease of engineering, high accuracy, and high device uptime. This white paper examines the benefits that accuracy delivers to process industries, both industries that focus on chemical reactions and industries that focus on blending. Sample industries include consumer goods manufacturing, food and beverage, and pharmaceuticals.

Benefits of Mass Flow Measurement Accuracy

There are many options when selecting flow measurements. One of the key factors in selecting the right flow meter is the degree of accuracy needed by the application. To meet high accuracy requirements in the chemical processing industries, Coriolis mass flow measurement is the technology of choice. Accuracy in mass flow measurement provides three major benefits:

Meeting Product Quality Specifications

- Product that meets quality specifications can be moved to the next stage of production or shipped to the customer. Typically, off-specification material must be (1) blended back into the product, (2) re-processed, then blended back into the product, or (3) discarded. In all three cases, off-specification product is costly in time, labor, and material. Lowering the percentage of off-specification product directly reduces costs, increases plant capacity, and increases profitability.
- Meeting product quality specifications also directly affects customer satisfaction. Product consistency helps to retain existing customers and attract new customers

Optimizing Component Yield

- In the chemical processing industries, the highest production cost component is typically the cost of the raw materials. When a process is run with the most accurate measurements possible, component waste is minimized and component usage is maximized. Again, this reduces costs and increases profitability

Increasing Process Robustness

- This is a corollary to the previous points. Robust processes are processes that can maintain output quality over time and across some degree of variation in process conditions. Accurate mass flow measurements enable robust processes, and can enable the use of mass balance techniques to control the process. In some cases mass flow technology can replace other control techniques that rely on analytical measurements, especially for difficult materials such as highly viscous fluids that coat probes and sensors. This increases process robustness, which in turn increases plant profitability

How Accurate is Accurate?

We sometimes lose sight of the expectations we place on the flow measurement devices and the capability of these devices to meet our expectations. The following case history illustrates the accuracy of Coriolis mass flow measurement in real terms.

The author was involved in start-up of a chemical facility, which was using a falling film reactor to produce a product from a gas/liquid reaction. For this process the gas stream was maintained at constant conditions and the liquid stream was manipulated to control the reaction. The nominal mass flow rate of the liquid was 3200 kg/hour.

No on-line analytical means were available to measure the product quality continuously, so the procedure called for taking a product sample periodically and sending it to the quality control laboratory. The laboratory analysis was then used to determine if the process was in-specification or if process changes were necessary.

In one particular sample, one variable was slightly out of specification. In response, the mass flow rate of the liquid was changed by 3 kg/hour. The follow-up analysis confirmed that the quality variable had moved into an in-specification value. Later, reflecting on what we had requested the Coriolis flow meter to measure and the control system to control, we realized we had requested a 0.09% change in the liquid flow rate. At a specific gravity of 0.95, this change is approximately one quarter of a cup per minute (60 ml/minute) - we were essentially measuring and managing drips.

Chemical Reaction Applications

Along with pressure and temperature, flow control is critical to ensure high quality reaction products. For continuous reactions, it is critical to control the flow rate. For batch reactions, it is critical to control the quantity, although in some batch processes a reactant may be added continuously, thus making control of flow rate also important.

Very commonly, reactants are not added in a perfect stoichiometric balance. Instead, one raw material is added in excess to help the reaction kinetics drive the reaction to an optimum conversion. The ratio between the reactants is called the mole ratio. For example, one mole of reactant A (Molecular Weight 255) is to be reacted with one mole of reactant B (Molecular Weight 85), with a mole ratio of 1.03 of reactant A to reactant B. The flow rates would be:

Reactant A 1.03 X 200 = 262.65 mass unit/time unit

Reactant B 1.00 X 85 = 85 mass unit/time unit

It is very common to specify the mole ratio to the hundredths place. Some manufacturers even control the mole ratio to the thousandths place.

Case Study: Importance of Mole Ratio

The following case history illustrates why close adherence to a mole-ratio specification is important.

A detergent facility was producing liquid dishwashing detergents in 10,000-gallon mixing vessels. During the production of a certain detergent the contents gelled in the mixing vessel. The total cost - in labor to empty and clean the mixing vessel, in raw materials, in shipping and disposal, and in lost production time - was estimated in the hundreds of thousand dollars.

The company's R&D department was tasked with determining what caused the product to gel. After a lengthy investigation the problem was traced to one of the raw material surfactants in the detergent. This particular surfactant was produced i n-house in a newly commissioned production unit. The R&D chemists found that a side reaction was occurring during the sulfation process. They also determined that if the mole ratio was increased from 1.01 to 1.02 the side reaction did not occur. The change was made in the production unit and proved to be successful.

Case Study: Batch Production

As was stated earlier, in the case of batch reactions, the quantity of the raw material, rather than the flow rate, is typically the critical measurement. Many older facilities use load cells to measure the amount of reactant transferred to the reaction vessel. Load cells can be an accurate method and are very good for powder additions, with either the receiving vessel or the source vessel on a load cell. However, load cells have several limitations:

- Because a scale is used for measurement, each raw material must be added separately. This takes time and limits process throughput, especially for processes that require blending.
- Because the load cell method measures not only the raw material but also the tank, the agitator (if present), and possibly other objects, measurement of very small quantities (e.g., less than 100 lbs) is difficult.
- If the mechanical isolation is not adequate, measurements may be inconsistent due to pipe rigidity and agitator torque forces.
- Calibration of the load cells is recommended on a six to twelve month schedule.

Because of these limitations, several batch production facilities are replacing their weigh tank/load cell systems with Coriolis mass flow meters. The following example illustrates the impact of one such modernization.

A chemical production facility that used batch reactors decided to update the unit with new instrumentation, valves, and control system. As part of the modernization, the existing load cells on the weigh tanks were replaced by Coriolis mass flow meters located on the raw material transfer line from the storage tank to the weigh tank.

Prior to the modernization, the production unit ran at an 85% in-specification quality factor, meaning that 85% of the batches were produced without the need of further processing before transfer to the next unit in the process. Operations personnel were adamant that this 85% value was an industry standard and could not be significantly improved.

After a shutdown to install and commission the new equipment, the first production batch was in-specification. According to operations, this was the first time in plant history that the first batch after a shutdown had met specifications.

After the first month of operation, the unit ran with an in-specification quality factor in the low 90%. Operations now predicted that that the quality factor would increase further, as most of the errors were tied to process modifications that had been applied to overcome problems with the previous automation system. Operations staff credited the improved in-specification quality factor to the combination of the new control system and the increased accuracy in raw materials addition.

Case Study: Process Robustness

Process robustness refers to the ability of the production unit to produce in-specification product over the required time period. High-accuracy flowmetering instrumentation can play an important role in improving process robustness. The following two examples illustrate the point.

The author was involved in a start-up of a multi-million dollar specialty chemical facility. The final step of the production process was a continuous neutralization loop used to neutralize an acidic intermediate product to a stable pH. The pH control was critical since the final product would revert to its acidic components if the pH if the storage vessel fell below a neutral (7) pH value. The product specification called for a pH just slightly over the critical 7 value, so it was necessary to control caustic to a slight excess.

In the original design, the industry-standard control strategy was used: a cascade control loop with the caustic flow rate set by the product pH control loop. However, at start-up it was evident that the high viscosity (approximately 15,000 centipoise) of the fluid would very soon cause the pH probes to coat and give a false reading. Since mass flow meters were installed in all the neutralizer incoming streams, the operation was converted to a mass balance control scheme. This control scheme maintained a ratio between the caustic stream and the incoming acid stream. The ratio was calculated to allow for the correct excess of caustic. The new control scheme worked perfectly, and allowed the facility to run for significant time periods with no fear of false pH readings and process or product instability.

In a second case involving a batch process, the pH of a reaction was continuously controlled throughout the batch process. Over the course of the process, the pH needed to move from a highly acidic state to a highly basic state. To control the pH environment, both sulfuric acid and sodium hydroxide were added to the batch at multiple times throughout the process.

The pH control scheme in use involved circulating a small product sidestream past a pH probe, and controlling the addition of the sulfuric acid and sodium hydroxide from load cell-based weigh tanks. Spot checks of the reactor contents using laboratory pH readings indicated that the in-line pH readings did not stay within calibration limits for the entire batch time period. This resulted in additional manual steps in the process, and excess raw material usage to correct for pH errors. Modifications to the continuous sampling system had not helped.

Two process modifications were applied: Coriolis mass flow meters were installed on the sulfuric acid and sodium hydroxide streams, replacing the weigh tanks, and the pH control scheme was altered to base the acid and caustic additions on a theoretical mass balance instead of a pH feedback loop. In the ensuing production runs, only scheduled batch adjustments were necessary. All batch adjustments due to process errors were eliminated.

An additional benefit in plant capacity also was also realized. This process was run in a dilute environment, with a 7% finished product concentration at completion of the batch. One of the major factors limiting the finished product concentration was foaming in the reactor during the reaction process. The new pH control scheme greatly reduced the foaming, allowing the finished product concentration to be increased to 14%. The facility had planned to add a third reactor, which, with the required building expansion, was a multi-million dollar project. By doubling the capacity of the two existing reactors, the manufacturer was able to cancel the planned expansion.

Accuracy in Blending Applications

While many manufacturers in the chemical processing industries have taken advantage of high-accuracy flow measurement in reaction-based processes, high accuracy has been seen as less critical for blending applications. This is true for both continuous and batch blending operations. In many cases, less accurate flow measurement devices are being used. In the case of batch blending, even tank-level measurement is used sometimes for quantity control. This has led to wide specification ranges and unnecessary product giveaway.

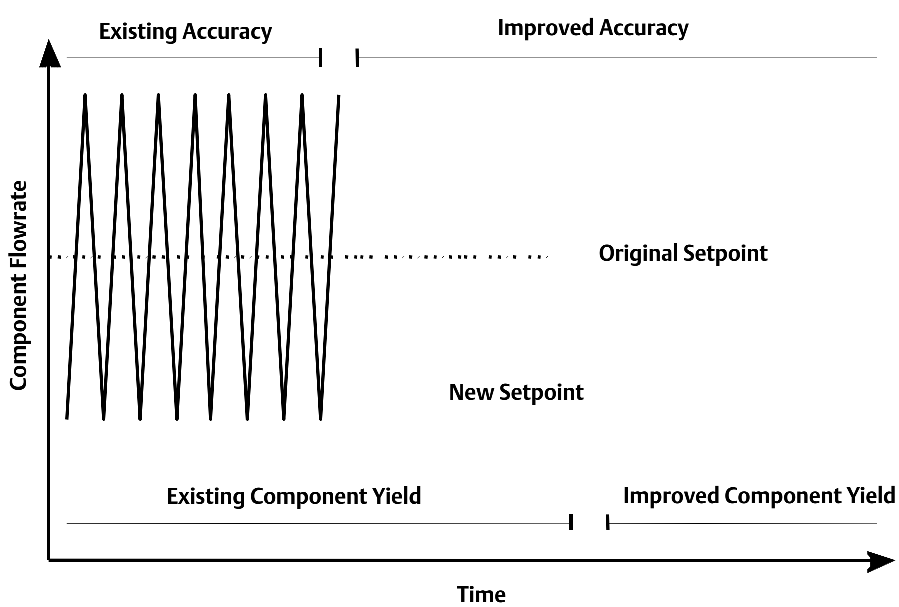

Figure 1. Accuracy in a blending process

A blending process, whether in a specialty chemical or consumer goods operation, can achieve the same benefits from high accuracy as a reaction process, and should be designed with the same principles and attention to detail. The "squeeze and shift" technique provides an example of the potential benefits of increased accuracy in blending applications. As shown in Figure 1, a component of a blended product must be above a minimum component quantity at all times. "Squeezing" the flow rate (reducing variation of the flow rate measurement) allows "shifting" of the setpoint to a lower value while still remaining above the minimum component quantity. This reduces component giveaway and increases component yield.

Economic Impact

While the amount of savings from accurate flow measurement will vary between applications and manufacturers, significant savings occur, with typical payback periods of less than one year for the investment in Coriolis mass flow meters.

Table 1 illustrates the savings per year for continuous flow applications. Improvements of only 0.1% and 0.5% are illustrated. The example assumes a raw material cost of $1.00 per pound, continuous 24 hours-a-day, 7 days-a-week production, with two weeks shutdown per year.

Component cost	*Component requirement*	*Change in requirement*	*Savings per year*
$1/lb	*5000 lb/hour*	*-0.1% (5 lb/hour)* *-0.5% (25 lb/hour)*	*$42,000* *$210,000*
	10,000 lb/hour	*-0.1% (10 lb/hour)* *-0.5% (50 lb/hour)*	*$84,000* *$420,000*

Table 1. Savings per year for continuous flow applications

Table 2 illustrates the savings per year for batching applications. For this case a 0.2% and 0.8% increase in accuracy are shown. It is assumed that 10 batches per day are produced.

Component cost	*Component requirement*	*Change in requirement*	*Savings per year*
$1/lb	*5000 lb/batch*	*-0.2% (10 lb/batch)* *-0.8% (40 lb/batch)*	*$35,100* *$140,400*
	10,000 lb/batch	*-0.2% (20 lb/batch)* *-0.8% (80 lb/batch)*	*$70,200* *$280,800*

Table 2. Savings per year for batching applications

Achieving the Benefits

While the installation of high-accuracy Coriolis mass flow meters is straightforward, it is good practice to follow correct engineering principles in selection, design and implementation for any automation project. Whether installing new meters in an existing process or building a new facility, the following engineering phases are recommended:

1. Conceptual and/or front-end engineering
2. Detailed Design
3. Implementation, Commissioning and Start-up

Attempts to short-circuit this sequence are can lead to unsatisfactory results such as poor measurement and control performance, or lengthy commissioning and start-up periods.

The following is an example of the problems that can happen with an installation that skips the engineering phase. The author was invited to a new textile facility to review the chemical preparation area. As part of the textile production process, "wet" processes are performed in continuous equipment "baths." These baths prepare the textile for further processing or for dyeing. The specific chemical baths are mixed in a batch mixing vessel via a batch blending process. During facility installation, the owner had bypassed the engineering process for the chemical processing area, instead contracting with a local mechanical installation company to install four mixing tanks and the associated transfer lines without a true design.

After facility start-up, the chemical preparation area was found to produce off-specification and inconsistent chemical blends. An investigation of the preparation area uncovered a few design errors, including misapplication and installation errors for the flowmeters. In this case turbine meters had been used for the flow measurements. While turbine meters are high-accuracy meters, they, like all flow measurement equipment, need to be properly applied and installed to work correctly. In this case, the meter size was too large for the flow rates and the installation did not provide enough straight pipe length on either side of the meter. Additionally, the meters were used for multiple fluids - for high accuracy, turbine meters must be calibrated at process conditions with the process fluid.

Eventually, the installation was replaced with an engineered system that included Coriolis mass flow meters, which have fewer installation constraints than turbine meters. The chemical preparation area immediately produced in-specification and consistent chemical feed for delivery to the textile finishing lines.

Summary

Accurate flow measurements are crucial in both reaction processes and blending processes. Accurate flow measurements enable tight control of raw material flows so target values may be closer to specification limits. High-accuracy flow provides greater raw material yield and reduces the amount of off-specification product, thus reducing manufacturing costs for the facility.

The ability of Coriolis mass flow meters to work accurately with difficult fluids and in tight physical locations increases process robustness.

High-accuracy flow metering, with its accompanying tightened specifications and control, offers a significant financial opportunity to blending operations.

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Micro Motion, Inc. USA
Worldwide Headquarters
7070 Winchester Circle
Boulder, Colorado 80301
T (303) 527-5200
(800) 522-6277
F (303) 530-8459
www.micromotion.com

Micro Motion Europe
Emerson Process Management
Wiltonstraat 30
3905 KW Veenendaal
The Netherlands
T +31 (0) 318 549 549
F +31 (0) 318 549 559

Micro Motion Japan
Emerson Process Management
Shinagawa NF Bldg. 5F
1-2-5, Higashi Shinagawa
Shinagawa-ku
Tokyo 140-0002 Japan
T (81) 3 5769-6803
F (81) 3 5769-6843

Micro Motion Asia
Emerson Process Management
1 Pandan Crescent
Singapore 128461
Republic of Singapore
T (65) 6 777-8211
F (65) 6 770-8003

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