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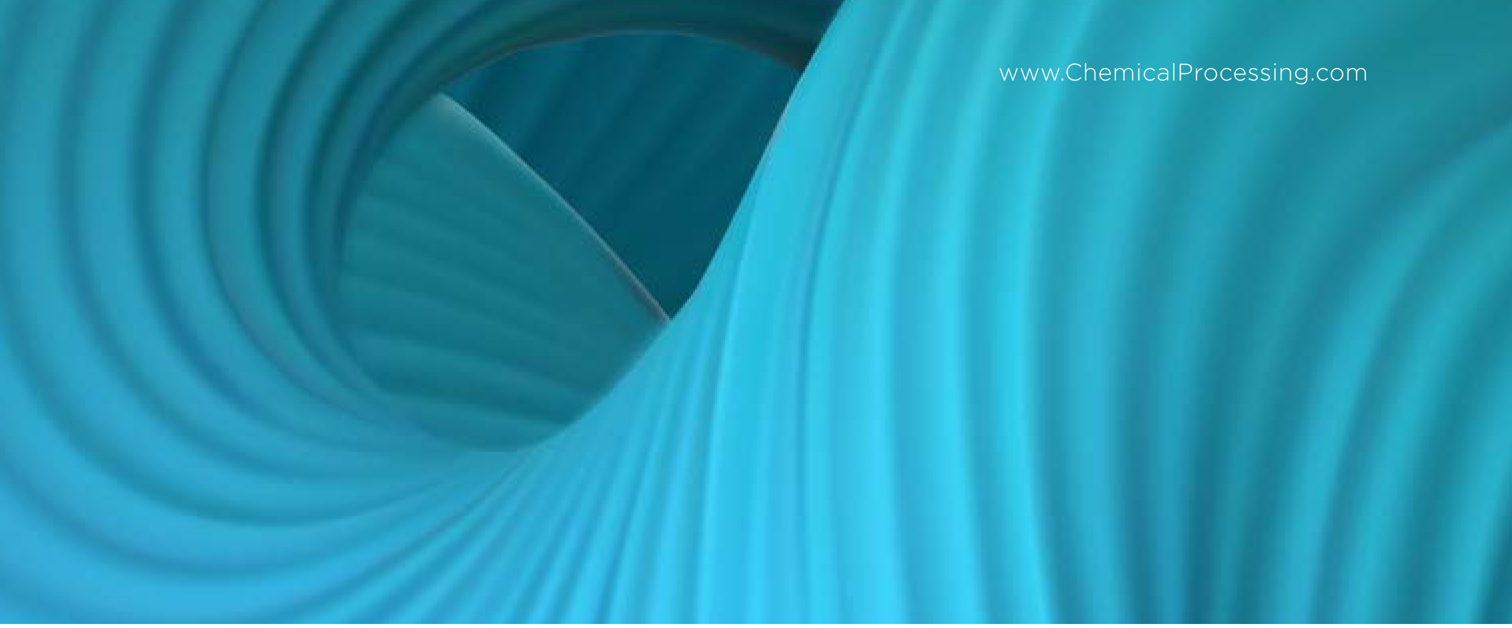

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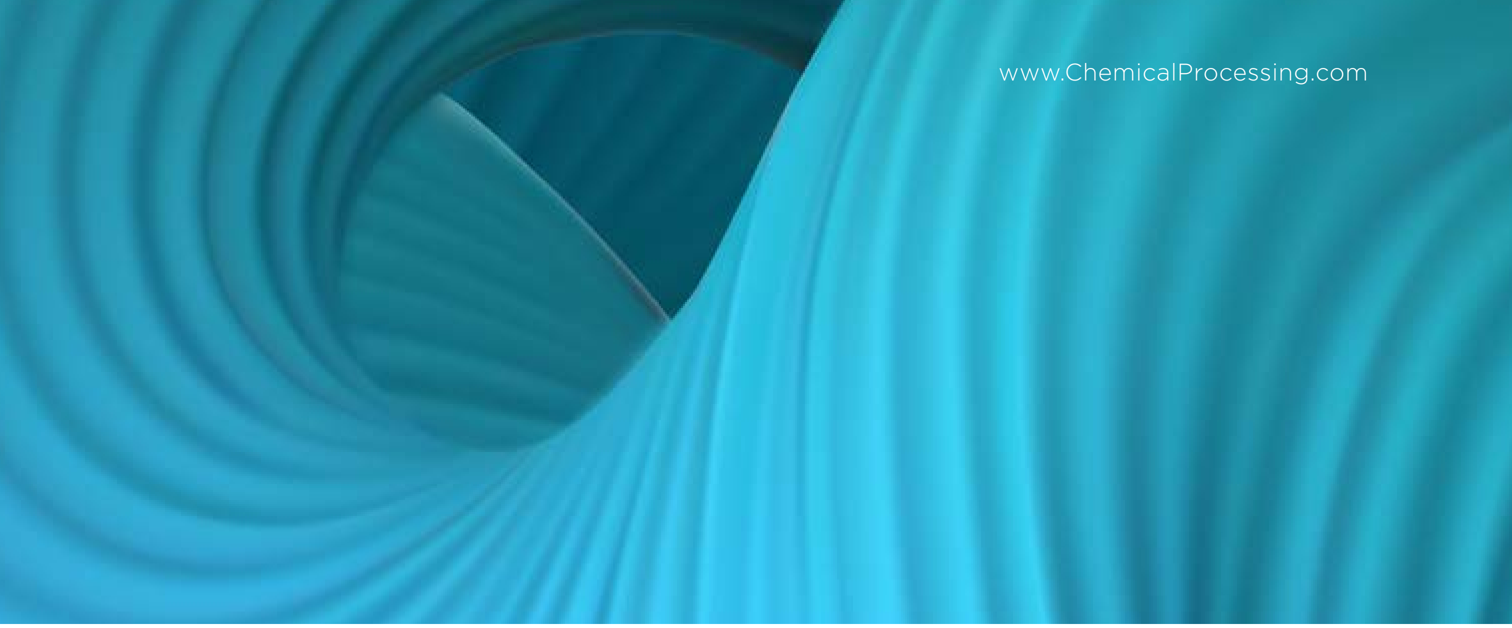

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Don't Let Baffles Baffle You

Understand the role of baffles and best practices for them

By Gail Pogal and Richard O. Kehn, SPX Flow — Lightnin

Baffles are internals, generally flat plates, used in agitated vessels to optimize and stabilize the mixing flow pattern and minimize variation in agitator power draw. Baffle recommendations are part of the agitator vendor's scope although the baffles are designed and fabricated by others. Proper baffle implementation dramatically impacts process results.

Low viscosity fluids in agitated vessels *without* baffles swirl and have surface vortices with little top-to-bottom vessel turnover. Velocity gradients are minimal. Particle tracing within a horizontal plane shows circular motion almost like the horses on a carousel — rotation but not interaction. Particle traces in a vertical plane show minimal motion, a poor configuration for blending or solid suspension.

As Figure 1 illustrates, baffles provide advantages with such fluids. Baffles establish an axial flow pattern, minimizing the tangential or swirl component imparted by the rotation of mixing impellers. The baffled flow pattern facilitates top-to-bottom bulk motion, increasing the velocity across heat transfer surfaces and facilitating blending and solid suspension. However, top entry on-center-mounted agitators on a properly baffled vessel draw more power than on an unbaffled vessel because the impeller pumps more fluid in a given amount of time.

In mass transfer reactions, where power draw is a critical parameter, proper baffling increases impeller power draw and improves blending, which increases the mass transfer capabilities of the mixer.

For vertical cylindrical vessels, “standard” baffles — defined as four flat plates of 1/12 vessel diameter, installed radially along the vessel straight side and spaced at 90° — are common for top entry agitators mounted on center. They are recommended based upon “standard” assumptions about the agitator, vessel, fluids and mixing requirements. Many processes frequently deviate from these assumptions! We will discuss frequently encountered deviations.

A common misconception is that the number of baffles must equal the number of impeller blades. This arose from the change in baffle recommendations that occurred when high efficiency impellers came into the market, replacing many pitched blade turbines. More accurately, the optimum number of baffles is a function of the ability of an impeller to generate axial flow in the process fluids.

When processing low viscosity fluids with high efficiency axial flow impellers, performance differences between three and four equally spaced baffles are barely discernable. In these fluids, four bladed pitched blade turbines and six bladed radial flow impellers require four baffles.

FASTER BLENDING

Relative Blending Comparison (150 mm A310 @ 130 RPM)

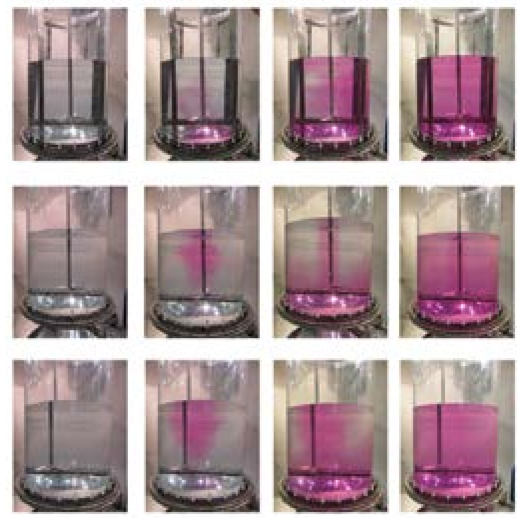

Figure 1. Use of baffles dramatically decreases blend time.

BAFFLE ADJUSTMENTS

Practical considerations or vessel internals often rule out spacing baffles equidistant around the vessel circumference. Redistributing baffles within a few degrees of equal spacing is fine. However, removing a baffle without respacing the remaining baffles is problematic. In other words, it’s much better to have three baffles at 0°, 120° and 240° than three at 0°, 90° and 180°.

When you must reduce the number of baffles, adjustment of baffle width can maintain power draw and facilitate an axial flow pattern. For a low viscosity fluid, an installation with two baffles at widths of 0.1 × vessel diameter will draw approximately the same power as three baffles at 0.062 × vessel diameter.

As seen in Figure 1, off-center mounting in an unbaffled vertical cylindrical vessel will create an axial flow pattern and less swirl than an on-center mounting in the unbaffled vessel. For small vessels, an angle mounted agitator, often called a portable agitator, may make sense. These asymmetric options usually are impractical in large mixers from a mechanical design point of view.

The need for sanitary processing or the handling of fluids with a tendency to foul surfaces creates demand for alternative installation locations and baffle designs.

The Lightnin Mixing Technology Laboratory recently studied triangular baffles. Tests using A510 high efficiency axial and Rushton (radial) impellers evaluated power and flow for the same operation in water for unbaffled, standard plate baffle and triangular baffle configurations. As shown in Figure 2, with the axial flow impeller, the performance of the triangular cross-section baffle essentially equals that of the standard plate baffle. However, with the radial impeller, both flow and power draw decline. With both impellers, lack of baffles results in a marked performance decline.

Another study, summarized in a presentation at the Mixing XIII conference of the North American Mixing Forum (NAMF), looked at the power draw of an A310 high efficiency axial flow impeller in water in an off-center unbaffled configuration. As expected, at constant speed, removing the baffles reduced measured power draw approximately 40% [1].

When fouling or contamination between batches is a concern, installing baffles at ⅓ width off-wall promotes flow between the baffles and vessel wall. At higher viscosities, opt for ½ width off-wall.

Canted baffles, angled in the direction of flow, often are used for cleanliness or when the baffles are heat transfer surfaces. The width of the baffle is calculated to provide the recommended radial component. For example, if a 7-in. baffle width is desired, a 45° canted baffle of 10 in. is suggested because the radial component is (sin 45°) × 10 in. = 7 in.

Triangular baffles with a radial component equivalent to the suggested baffle width are nearly as effective as baffle plates for axial impellers. A typical triangular baffle would have a vertex pointing toward the vessel center with a 45° angle made from two plates. To replace a 4-in. baffle with a 45° triangle, the side plates joining at the vertex would each be 4.33 in. The leading face of the baffle is 4 in./sin 67.5°.

Baffles often are helpful when vessels have bottom cones or dishes. Cone bottoms have a small inherent baffling effect. If an impeller is in the cone, use one or two baffles scaled to the cone diameter at the impeller elevation if installation clearances allow.

At power levels above 1 hp/1,000 gal, opt for baffles extending into a dish if an impeller is at or below the vessel tangent line. Without baffles in a dished bottom, an axial impeller at the tangent line exhibits swirl.

With radial flow impellers, particularly in gassed applications, extended baffles are essential for promoting a useful flow pattern to improve gas dispersion.

Raising the position of a lower impeller up into the baffled straight side of a dished or cone bottom vessel can dramatically improve the mixing flow pattern.

IMPORTANT FACTORS

Baffle recommendations vary with fluid properties and geometry. Common factors influencing baffle recommendations include:

- solids wet-out;
- higher viscosity or non-Newtonian (e.g., pseudoplastic) fluids;
- unusually high or low power intensities;
- glassed vessels;
- internal coils, jackets, vertical tubes and flat plate heat transfer surfaces;
- rectangular, horizontal or asymmetric vessels;
- side-entry mixers; and
- dip pipes, thermowells, probes and other vessel internals.

Solids wet-out. A common requirement is to add solids at the liquid surface. Solids can take many forms. Some have a tendency to float; others are difficult to wet-out, forming air-filled clumps. Fine solids also may trap air. Typically, the mixer/baffle interaction is designed to facilitate drawdown, either through vortex creation or a recirculation loop.

Usually, when solids must be drawn down, a vortex is created with a down-pumping axial flow impeller and baffles cut off at the height of the impeller. Reference 2 provides general recommendations for impeller submergence and baffle width. Installations with cut-back baffles at 2% of tank diameter have proven

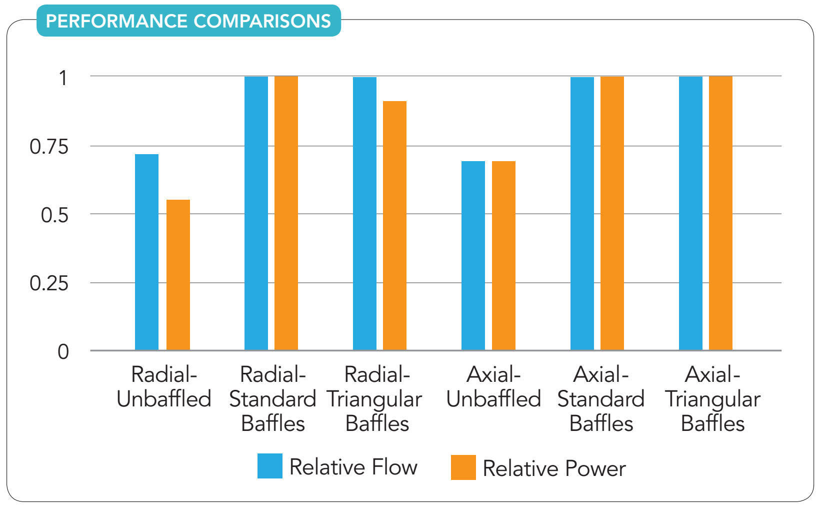

Figure 2. Standard and triangular baffles offer nearly identical performance with axial flow impellers.

more effective than unbaffled ones. Fluctuating liquid levels during solids addition present challenges that must be considered.

For solids drawdown, we cannot over-emphasize the value of small scale experimentation and scaleup correlations using the Froude number:

Fr = N2D/g

where *N* is the rotational speed of the agitator, *D* is impeller diameter, and *g* is gravitational acceleration, which in imperial units is 1.39×10^6 when rotation is in rpm and diameter is in inches.

During process design, characterizing the behavior of process solids in process liquids is vital. Small scale, even bench scale, experiments often demonstrate that drawing down solids from the liquid surface impacts mixer design more than the need to suspend the same solids once incorporated into the process fluid. This requirement for solids drawdown may suggest a larger mixer than the that used for suspension of the same solids.

Sometimes, you can create a recirculation loop for drawing down solids in a baffled vessel with an up-pumping axial flow impeller. Instead of going into a central vortex, solids will be pumped outward along the surface and drawn down along the walls.

An alternative and highly efficient method for introducing solids is below the liquid surface. This doesn't require modifications to baffle recommendations based upon the mixer and vessel geometry.

Higher viscosity fluids. A common statement is: "As viscosity increases, baffle size decreases." Figure 3, which charts the ratio of baffle width to tank diameter against viscosity, enables determining baffle width for full scale applications.

However, a more accurate baffle width statement is: "As Reynolds number decreases, baffle size

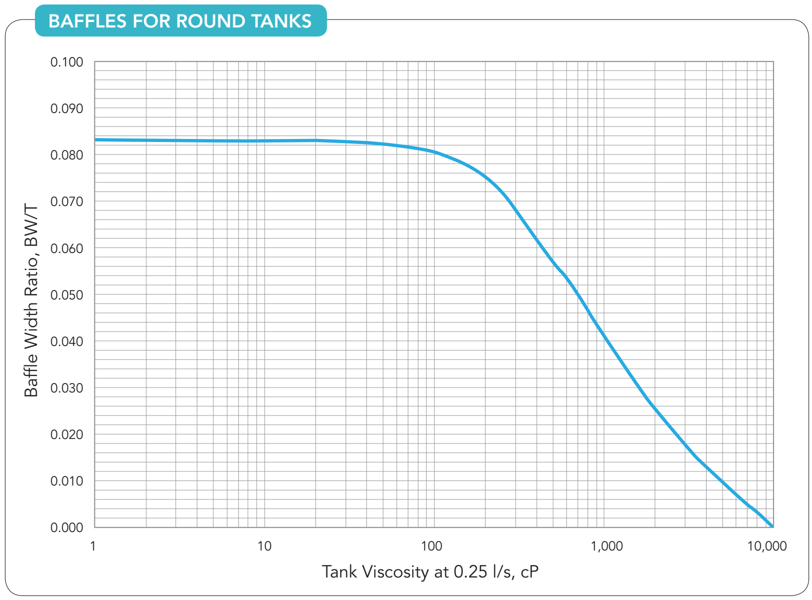

Figure 3. Recommended baffle width depends upon viscosity.

HORIZONTAL REACTOR OPTIMIZATION

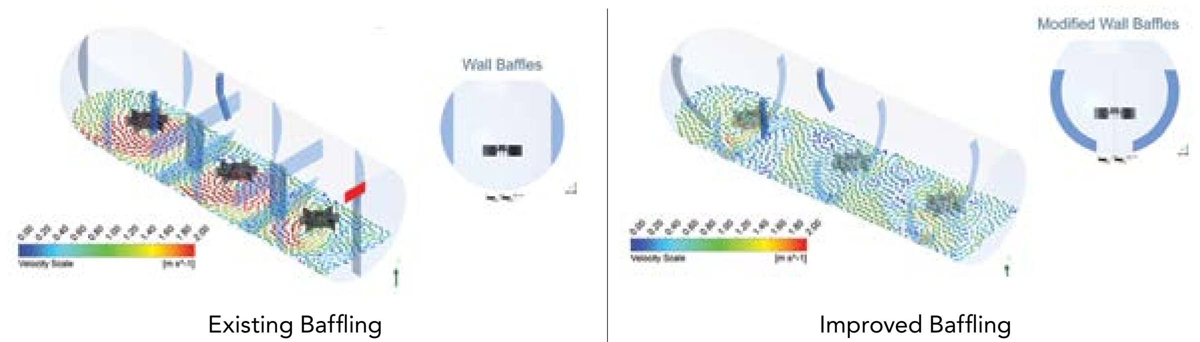

Figure 4. Removal of walls and new baffles reduced swirl and improved mixing.

decreases." Reynolds number, *Re*, which correlates well with mixing requirements, is a function of both the fluid and the mixer/vessel size:

$Re = 10.75\ \rho ND2/\mu$

where ρ is density, μ is viscosity, and imperial units are used.

Baffle recommendations for mixing non-Newtonian fluids — such as many food ingredients, personal care products, resins, latexes, pulps, clay slurries, etc. — require consideration of the viscosity at an appropriately selected shear rate.

As scale increases from bench, to lab, to pilot, to production, flow patterns and the need for baffling may change. Use caution when scaling up bench mixing studies to larger scales because geometric similarity is relevant only in similar fluid regimes. For the same fluids, full scale installations always have higher Reynolds numbers and are likely to be turbulent even when the lab installation isn't. Fluid regimes in the lab often are laminar or transitional due to the small vessel sizes. For this reason, effective small-scale mixing studies frequently require simulant fluids to mimic the expected full-scale Reynolds number.

Unusually high or low power intensities. For higher power intensity reactor agitators, use four baffles. At low power intensities, opting for one or two baffles is better than doing without baffling. With two baffles, spacing at 180° is important. Two baffles in the same quadrant provide no better results than a single baffle.

Glassed vessels. Such units traditionally were fitted with one "beavertail" baffle, resulting in an under-baffled situation. Advances in glassing technology have enabled use of multiple baffles similar to those found in metal vessels.

Internal coils, jackets, vertical tubes and flat plate heat transfer surfaces. Coil supports and the turns of the coils themselves can act as baffles. To prevent swirling, reduce baffling as the number of coil banks increases. It is best to put baffles on the outside of the coils to maximize flow through the coils.

With jacketed vessels, use off-wall baffle installation.

Vertical tubes and flat plate heat transfer surfaces behave as baffles. Once you've calculated the appropriate heat-transfer area, you may need to cant the surfaces to avoid over-baffling the vessel.

In general, optimizing the flow patterns over heat transfer surfaces in agitated vessels necessitates designing a system where these surfaces, impellers and baffles work together. Three-dimensional computational fluid dynamics (3D CFD) can be quite helpful.

Rectangular, horizontal or asymmetric vessels. Rectangular vessels are partially self-baffling. Azdditional baffling occasionally is recommended. Horizontal and asymmetric vessels pose unique challenges. For example, a recent horizontal reactor optimization improved mixing with minor changes to the agitator itself but with a new baffle configuration, as shown in the 3D-CFD model depicted in Figure 4. (This model comes from a study that utilized 3D CFD not only to model flow patterns but also to predict baffles forces for use by the vessel designer [3].)

Side-entry mixers. Don't use baffles with side-entry mixers. Many applications can benefit from offsets or angle-mounting configurations.

Dip pipes, thermowells, probes and other vessel internals. It's tempting to use baffles as the structural support for vessel internals. However, careful consideration of the flow patterns around the baffles is necessary because the flow patterns in the vicinity of the baffles are atypical of the bulk motion. Flow velocities on the trailing sides of baffles often are the lowest velocities in the vessel. Recommendations from agitator vendors, often supported by 3D CFD, can be helpful in locating these internals.

MECHANICAL CONCERNS

Baffles allow for a stable flow pattern in the vessel, which leads to lower variability mechanical loads on the agitator itself as well as the vessel nozzle and mixing mounting structure.

Forces developed by the agitation system determine baffle thickness and mounting hardware. The agitator vendor should provide the force data necessary to specify baffle thickness. Many years ago, Dr. James Oldshue presented the relationship for baffle design load, L_d, as follows:

$$L_d = (10{,}500\ P_m \times DF)/(B \times T_f \times N)$$

where L_d is baffle force in lb, P_m is motor horsepower, DF is the dynamic load factor (normally 2.0), B is the number of baffles, T_f is the tank diameter in ft, and N is in rpm [4].

This formula assumes the baffle force is a constant force perpendicular to the baffle acting in the direction of impeller rotation and is the same on each baffle. The forces are greater on the leading (higher velocity) side of the baffle than on the trailing side.

Generally, in low pressure or open vessels, make baffles the same thickness as the vessel shell, but never less than ¼ in. Always place wall supports on the trailing side of the baffle and uniformly space them along the baffle height.

Baffle force varies with baffle height and time. The force is concentrated at impeller(s) elevation(s). 3D-CFD plots enable visualizing timed-average pressure distributions on both sides of the baffles. Using 3D-CFD analysis for baffle design is most useful when baffle costs are substantial.

Recent studies presented at AIChE [5] used 3D CFD to characterize baffle loads based upon impeller design. The predicted loads then were experimentally validated in the laboratory. This work showed the classic baffle load correlation to be conservative, particularly for axial flow impellers. Specifically, based upon actual power draw, for the radial flow impeller, CFD predicted a maximum baffle force of 9.3 N (versus 15.2 N calculated); for the pitched blade turbine, CFD predicted 4.6 N (versus 14.4 N calculated). Both conditions were at equal agitator power.

A key take-away is that axial flow impellers impart less force on the baffles than radial flow impellers do.

Pressure profiles along baffles can be predicted with 3D CFD. This information is useful in locating baffles supports, troubleshooting or when the costs of high alloy baffles and mounting structures are significant.

In addition to promoting an effective mixing flow pattern, the proper installation of baffles reduces forces on the agitator. An agitator is designed assuming that baffle recommendations have been followed. This is critical because at equal power input, the removal of baffles in a vertical cylindrical vessel will increase fluid force 1.5–2.0 × the initial force on the agitator. Even if the agitator is moved off-center to improve the mixing flow pattern, fluid forces rise similarly [1].

When circumstances require, operating without baffles can result in a stable, but not necessarily optimal, flow pattern as long as vortexing down to the impellers doesn't occur. Due to the losses in mixing efficiency and increased forces on the agitator itself, operation without baffles requires forethought and rarely is an appropriate retrofit.

FINAL THOUGHTS

Baffle recommendations are a critical part of the agitation system design. Because baffles aren't part of the agitator vendor's scope, coordination is important — yet frequently overlooked.

When there is uncertainty about the need for baffles or the potential for process change, include baffle clips in the vessel design. This enables the addition of baffles later. ●

GAIL POGAL is an applications engineer at SPX Flow — Lightnin, Rochester, N.Y. **RICHARD O. KEHN** is director of engineering and R & D for SPX Flow, Rochester, N.Y. Email them at Gail.pogal@spxflow.com and Richard.kehn@spxflow.com.

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Can Particle Size Predict Powder Flow Behavior?

Understanding particle behavior and measurement methods can help improve flow operations

By Bob McGregor, AMETEK Brookfield

The general rule of thumb in gravity discharge from bins and silos states that, as powder particles become smaller, flow behavior may become more difficult. Increasingly cohesive is the term used to describe what happens. For powder mixtures with particle sizes of variable diameter, general observation is that large particles go along for the ride with the fines. The bottom line is smaller-size particles determine flow behavior.

What is the correct method to measure flow behavior? Can a particle size analyzer get the job done all by itself? Not necessarily. It certainly can tell you the makeup of your powder mixture in terms of size distribution from below 1 μ up to more than 1 mm.

If you have prior processing experience, you may be able to make an educated guess on how well the powder will flow during manufacturing. Actual flow behavior is more directly related to interparticle friction within the powder and sliding friction of the powder against the wall of the hopper.

TYPES OF FLOW BEHAVIOR

Mass flow and core flow (also known as funnel flow) are the two ways in which a powder discharges from a bin. The desired preference for flow behavior is mass flow in which particles flow uniformly relative to one another. First in, first out characterizes this type of flow. More common, however, in most powder processing operations is core flow in which particles at the top of the bin cascade into the middle and flow down through a central core (like a funnel).

Particle size definitely is a contributing factor in both situations. However, particle shape, moisture content, electrostatic charge and other possible factors also play a role. Given this reality, the particle size analyzer by itself cannot predict flow behavior reliably.

FLODEX CUPS

A popular tool used in the powder processing industry for measuring flowability is the Flodex cup. A disc in the cup's bottom has a hole in its center. If this hole is at least 10 times the diameter of the largest particle, the expectation is that powder will flow out the bottom. When making a flow measurement, trial and error is used by inserting discs with different hole diameters to see which works best. This test might be used to estimate the opening size for the bin's hopper outlet.

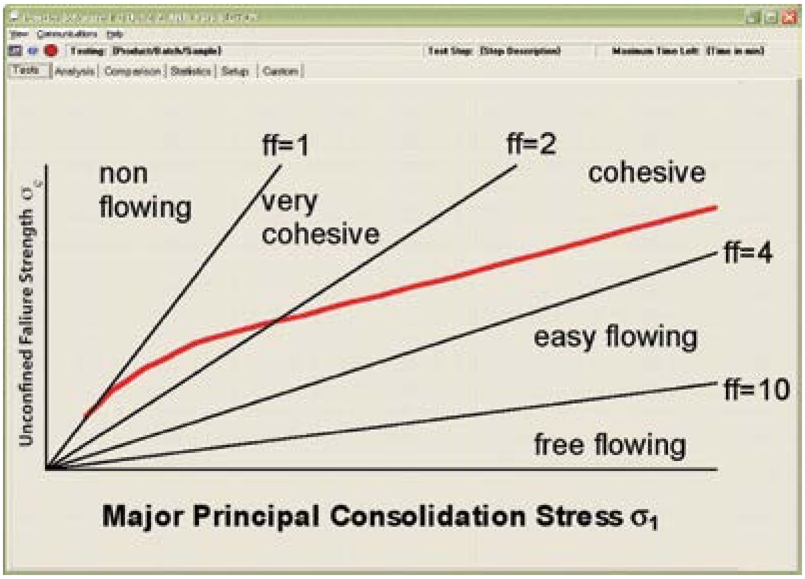
One of the Flodex cup's limitations is that the hole diameter is a correlation to flow behavior out of a bin, not a direct measurement. A second limitation is that the powder in the Flodex cup is loosely consolidated in contrast to the powder in the bin, which begins packing together starting the moment the powder fills the bin. This packing phenomenon turns out to be the critical factor in determining flowability because the powder's self-weight becomes the engine that overcomes the interparticle friction.

SHEAR CELL TEST
Figure 1. A shear cell test shows the correlation between the compressive force acting on a powder and powder strength to measure interparticle friction.

SHEAR CELLS

A test device that measures the interparticle friction directly is the shear cell (Figure 1). The test technician places the powder sample in a container (called the trough, which is shaped like an annular ring) and compresses it with a special lid that has pockets.

The compressed powder experiences consolidation, which causes the particles to move closer to each other. The powder in the trough then is sheared against the powder in the lid pockets to determine the sliding friction between particles. This process is repeated multiple times, and the compressive force increases each time.



FLOW FUNCTION GRAPH
Figure 2: Powder exhibits cohesive behavior at most consolidation stresses but transitions to very cohesive at low consolidation stress.

The data graph from a shear cell test is known as the flow function (Figure 2). The x-axis indicates the compressive force acting on the powder, called consolidation stress. This value correlates with the powder's fill level in the bin. The powder's self-weight is what forces the powder in the hopper to flow downward through the outlet. The y-axis indicates the powder strength, called unconfined failure strength, which is a measure of interparticle friction that must be overcome so the powder can flow.

Industry has agreed on regimes of flow behavior. Powder exhibits cohesive behavior at most consolidation stresses but transitions to very cohesive at low consolidation stress. This suggests that, as the powder level in the bin reduces, flow behavior has a tendency to become more difficult.

A BETTER PICTURE OF FLOW BEHAVIOR

Flow behavior is a physical property that should be measured for its own value using an instrument such as the shear cell. The particle analyzer can work in conjunction with the shear cell to determine whether variations in particle size and distribution will affect the flow behavior. For example, reducing the grind size on flour and starch particles may enable improved flow behavior during processing. The shear cell gives a direct means for making this type of evaluation.

Industry has used both instruments for many years. Recent advances in shear cell design have significantly reduced the investment cost and the time per test, which now is less than an hour. Automatic operation enables the shear cell to produce test results with minimal technician involvement. These new developments help to guarantee success for R&D and QC when introducing new formulations to manufacturing.

BOB MCGREGOR is global marketing director at AMETEK Brookfield. He can be reached at bob.mcgregor@ametek.com.

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Set Your Sights on Better Flow

Use this primer to determine the right sight flow indicator for the application

By Mike Curnutte, L.J. Star

The ability to see what is happening inside a pipe can be invaluable to process operators. Despite technological advances, no sensor can equal the human eye, which has more than 94 million photo receptors.

A sight flow indicator is a device installed in a pipe to provide a visual means of verifying liquid flow for direction and approximate rate. Simple and low-cost, it also allows operators to observe the color and clarity of process fluids through a window.

The basic description of a sight flow indicator is a body with one or more viewing windows, usually with gaskets, and a way to mount the indicator to the pipeline, such as flanged (Figure 1), threaded or sanitary clamp connections. Depending on the manufacturer, sight flow indicators are available to fit standard pipe sizes ranging from ¼ to 16 in. and carry ANSI pressure ratings.

FLANGED MOUNT
Figure 1. Sight flow indicators offer a variety of mounting options, including flanged.

FULL VIEW FLOW INDICATOR
Figure 2. A full-view flow indicator is visible from all angles and allows ambient light to illuminate the flow.

TYPES OF SIGHT FLOW INDICATORS

Unlike sight glass windows that don't have indicating mechanisms, sight flow indicators might have passive components that are set in motion by the flow to indicate flow direction or intensity. If the flow indicator has indication components, a certain level of flow is required to set them in motion. Flow indicators without indication components are used when observing a process fluid's characteristics is more important than verifying flow. Because indication components complicate cleaning in hygienic systems, they rarely are used in sanitary applications.

360° view flow indicator. Also called a full-view, cylindrical-style or tube-style flow indicator, this type of flow indicator passes fluid through a glass cylinder that is visible from all angles (Figure 2). This allows ample ambient light to illuminate the flow. It is ideal for observation of process fluid for clarity, color, foam and other conditions and for the presence of moisture. Designs often feature impact-deterrent shields or sheaths made of plastic. This style of flow indicator is suited for lower-pressure systems with moderate flow rates. These indicators must be installed on pipes with minimal mechanical strain.

An alternative design has a metal shield or sheath with windows. This strengthens the indicator and protects it from moderate mechanical strain.

Note that 360° view flow indicators might be fitted with glass marked with a calibrated scale and used for level indication.

View-through flow indicator. This type of flow indicator has two opposing windows so that an operator can see the intervening flow of fluid lighted from behind, either by ambient light or with an attached luminaire. Unlike 360° full-view flow indicators, this design is suited for ANSI pressure classes, high temperatures and harsh fluid applications. This type can be ordered with a Teflon®-lined metal body for corrosive media (Figure 3).

Mount types include flange, threaded, butt-weld, socket-weld and clamp. Sizes depend on the manufacturer but generally range from ¼- to 16-in. diameters, with larger units

VIEW-THROUGH FLOW INDICATOR
Figure 3. A view-through flow indicator's windows enable operators to see fluid lighted from behind and can come with a Teflon lining for increased corrosion protection.

available as special order. Stock models come in pressure ratings ranging from 20 to 3,000 psi.

Flapper flow indicator. Flow indicators can be fitted with a hinged flapper or flag visible through the sight glass. The flapper is deflected toward the flow direction. Because the flapper's position changes in relation to flow force, it provides operators with an approximate gauge of flow. This style is best applied on horizontal pipelines, but it also can be used in vertical pipelines with upward flow. It is ideal for use with transparent solutions and gases, which cannot be observed directly, and for dark, nearly opaque fluids in which flow is difficult to observe.

Visual flow meters. Flapper-style sight flow indicators are available in which the flapper has a reset spring. The process fluid's relative flow overcomes the spring's force. A graduated scale is marked on the glass to indicate the flow volume. In simple applications this can be used as an alternative to an expensive flowmeter.

Some sight flow indicators use a weighted flapper or flag that indicates flow volume by its position on a calibrated scale marked on the sight glass. These flowmeters are factory-set for a specific flow of water at 20°C for a given pipe diameter. Therefore they are not useful for non-water applications.

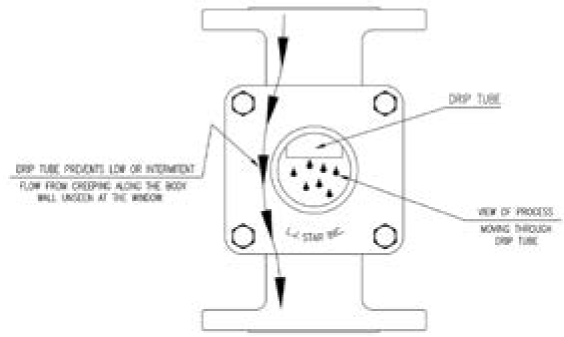
Visual flowmeters work with one direction flow only.

Rotary flow indicator. Flow indicators might be fitted with rotors or impellers that are turned by liquid or gas flow. The rotors are mounted in the window view so operators can observe the direction and approximate speed of flow. This is particularly useful for clear gases and fluids, but the rotor is visible with dark fluids as well. This indicator operates in any position and with any direction of flow. Rotor-style flow indicators should not be used if the flow rate is very low because the rotating device or propeller might not turn.

Drip indicator. Drip indicators can be designed for drip observation or conventional flow indicators installed with a drip tube (Figure 4). Drips and low-volume intermittent flows might be observed in applications such as distillation. Because gravity is used, drip indicators normally are applied in vertical pipes with a downward flow. Nevertheless horizonal installation is possible in some applications.

Ball flow indicator. Flow moves a ball from the bottom of the indicator housing to a position at the top of the sight window. The ball is visible through the window so that flow is observed easily at a glance. The ball's suspension by the fluid indicates flow's presence. Because gravity returns the ball to its rest position, this style of indicator must be applied in vertical pipes with upward flow. Generally this is used with slow-moving fluids or gases and not with high-rate or turbulent flows.

Flutter indicator. The mechanisms for standard flappers and rotors cannot be Teflon-coated, so a flutter style indicator is a good choice for observing gases and liquids in Teflon-lined flow indicators. The movement of a thin ribbon of tough, nonreactive material such as Teflon might be observed though the sight glass window. Flutter's intensity indicates the flow's relative speed. Usually it is mounted inside the sight flow indicator so that it can be used for flows in a single direction only. Because the ribbon has so little mass, it is moved easily; therefore flutter indicators are ideal for low-speed process flow and light process media.



DRIP TUBES
Figure 4. Drip tubes normally are used in vertical pipes with a downward flow and are good for distillation-type applications.

ADDITIONAL OPTIONS TO CONSIDER

Steam-heated jackets. These are available to cover view-through flow indicators. Only the sight glass window is not covered. The jackets prevent cool spots in a process and increase fluid viscosity.

Cameras. Sight ports can be fitted with video cameras that allow remote monitoring as well as recording. For hazardous environments, explosion-proof versions are available.

Lighting. Lights, also called luminaires, can be added to view-through and full-view style sight flow indicators. Generally these lights mount externally using a bracket, or the luminaire fits directly into a sanitary fitting for one-piece mounting right onto the ferrule or cover flange.

CONSTRUCTION MATERIALS TO CONSIDER

Metal. View-through flow indicators usually have cast-metal bodies. Commonly used body materials include carbon steel, iron, bronze and stainless steel. Stainless steel formulas offered might be 316, 304, Alloy 20, Hastelloy®, Inconel and Monel. PVC also is used, although for industrial and chemical processing it rarely is used. Not all styles and models are available in all materials.

Linings. In situations in which the process medium will react with metal, the indicator body can be made corrosion-resistant by adding a lining of Teflon, FRP or other non-reactive material. In addition, lower-cost body materials such as carbon steel can be made suitable for an application by adding such a lining. This approach most often is used to achieve cost savings compared to using indicator bodies made of more expensive alloys.

Gaskets. Gaskets are available in a range of materials, and their selection should be matched to an application's requirements, including operating temperature and compatibility with the medium handled. Common material choices include neoprene, Gylon® (PTFE), Teflon with an elastomer insert, butyl, Buna-N, silicone, fluorocarbon and graphite.

For hygienic applications, sight flow indicator O-ring seals are available. They often mount to the pipe ferrule using clamps. The sight glass windows are attached to the body in a similar fashion.

Glass. Soda lime glass and borosilicate glass commonly are used in sight flow indicators. Quartz glass, also known as fused silica, and sapphire are used only for special applications. Although acrylic and Lexan lenses are available, they rarely are used in industrial applications because of their limited corrosion resistance and temperature range.

In addition to the type of glass (its chemical composition) used, any glass can be strengthened by annealing or tempering.

Soda lime glass. Soda lime glass is common glass dating back to the ancient Egyptians. It is usable in operating temperatures up to 300˚F (150˚C), although in the case of alkaline media up to only 212˚F (100˚C).

Borosilicate glass. Borosilicate glass differs from soda lime glass in that some of the silica is replaced by boron oxide. It was developed in 1893 by a German scientist who found that adding boron salt improved glass' resistance to thermal shock and chemical corrosion and provided higher temperature capabilities (600˚F). "Pyrex," a trademark of Corning, is a brand of borosilicate glass.

Fused silica. Fused silica is made from fusing quartz crystals at high heat. Because no doping agents are added, this pure form of glass has superior temperature and thermal shock capabilities. It is specified for operating temperatures up to 1,000˚C. It is more expensive than other types of glass and not as strong or durable as annealed borosilicate glass. Kel-F or PFA shields can be used to protect the glass from materials that could erode or etch it.

Sight glass lenses are available as plain glass disks that are bolted to the indicator body with intervening gaskets, or as sight glass windows in which the glass is fused to a metal frame during manufacture. Such fused designs are polished so there is no crevice between the glass and metal.

Fused-glass sight glass windows offer many advantages. The metal frame prevents overtorque or uneven bolt compression from affecting the sight glass. Fused sight glasses can be reused, but plain glass should be replaced after maintenance because it is exposed to mounting stresses that can chip or weaken it.

The biggest advantage of fused sight glass is strength. The metal ring holds the glass in concentric compression that overcomes the tensile forces that otherwise could break the glass. Like cement, glass is strong under compression but fragile under tensile stress. Compression gives glass amazing strength. In fact, under high compression the glass become slightly elastic, able to flex under pressure and continue service when it is chipped or scratched. Glass strength is critical for worker safety because glass fails catastrophically with explosive force.

Some people request sight flow indicators with dual glasses for safety and reliability reasons. Depending on the manufacturer, such designs involve either a lens made of multiple layers of glass or independent lenses that are sealed separately. Such designs offer redundancy and reduce the effect of thermal gradients across the glass. However, the glass strength should be calculated only on the inner glass lens, not on the combination of glass lenses. Hydrostatic testing can verify inner glass strength only, so the pressure rating is based on that strength.

A safer and more reliable sight flow indicator is achieved by using a single fused-glass sight glass. Because the metal frame holds the glass in compression, the glass will have more strength and safety than a dual- or double-glass design. If the fused-glass window is made with borosilicate glass, then it also will be more resistant to thermal shock. Moreover, because it has fewer components than a double-glass design, it is less costly and easier to maintain.

MIKE CURNUTTE is the director of business development at L.J. Star. He can be reached at Mcurnutte@ljstar.com.

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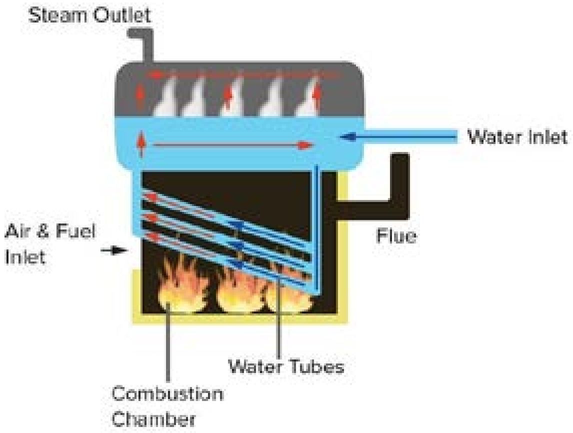
Improve Boiler Efficiency

Know your options when selecting the appropriate flowmeter technology to measure natural gas, water and steam in power generation

By Scott A. Rouse, Sierra Instruments

In many chemical plants, the electricity the plant uses is derived from a natural gas power plant or a co-generation plant burning waste gas streams. In large boilers (Figure 1), power plants bring together air and fuel (natural gas, waste gas, oil or coal) for combustion, which creates heat. The heat boils the water, creating steam. The steam runs through a turbine, which causes the turbine to spin, thus generating electricity.

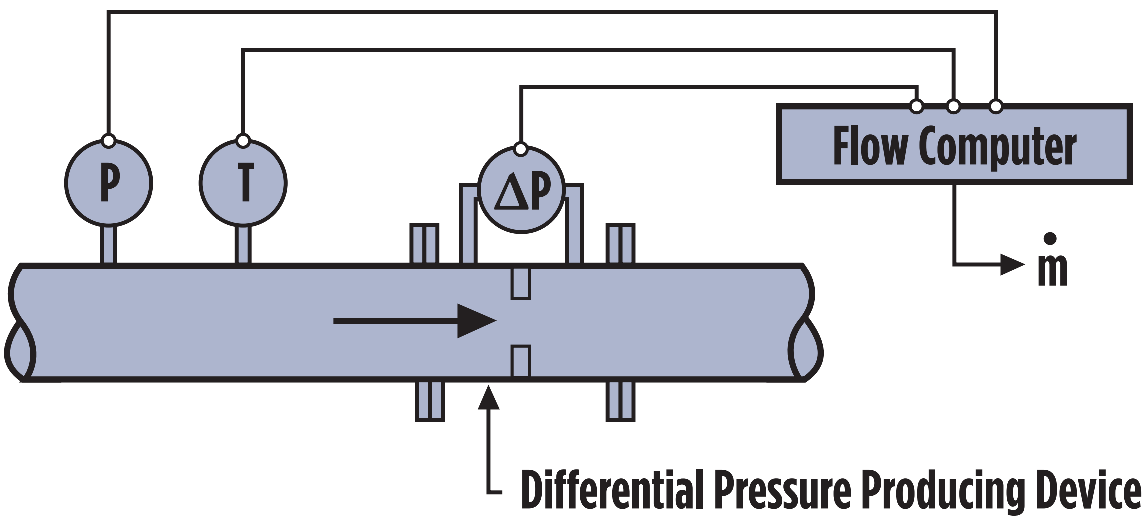
Measuring the flow energy — flows that cost money such as natural gas, waste gas, water and steam — in these boiler applications it is critical for improving energy efficiency, identifying waste and minimizing the greenhouse gases going into atmosphere. Only with accurate flow measurement can you make informed decisions to improve energy efficiency.



BOILER DIAGRAM
Figure 1. Typical boilers follow this process to generate electricity: Air and fuel are combined, combust and create heat, which then boils the water, creating steam. The steam causes a turbine to spin, generating electricity.

BOILER EFFICIENCY CONSIDERATIONS

How do you decide which flowmeter technology is best to measure the gas, water



DIFFERENTIAL PRESSURE PRODUCING DEVICE
Figure 2. This is a typical differential pressure flow meter set up with additional pressure, temperature and differential sensors to infer mass flow.

and steam for boiler applications? Choosing the right flowmeters depends on the fluid being measured. When discussing boiler efficiency improvements, three primary applications are involved:

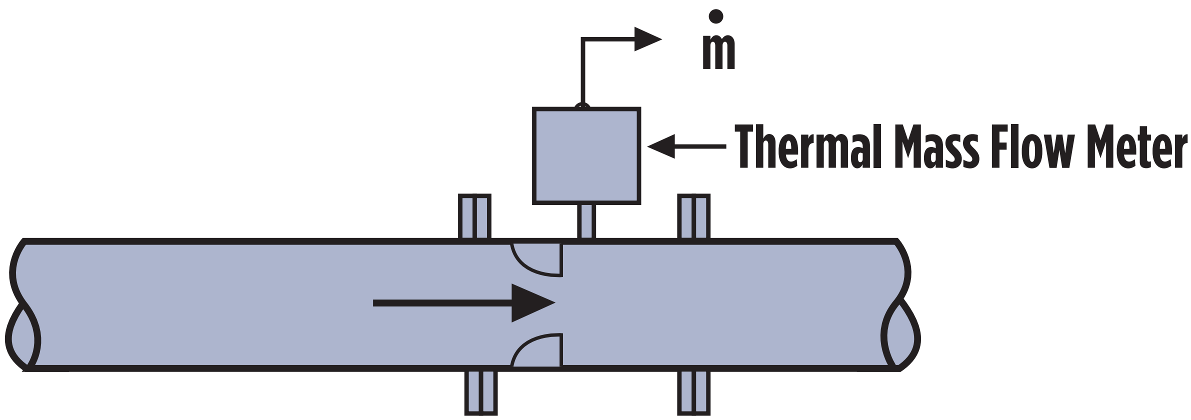
1. Accurate inlet air and fuel (natural gas, waste gas, oil or coal) measurement for efficient combustion;
2. Inlet feed water measurement to determine steam production efficiency and identify waste; and,
3. Measurement of outlet steam production.

INCREASE COMBUSTION WITH OPTIMAL FUEL-TO-AIR RATIO

Power generation requires inlet air and fuel (natural gas, waste gas, oil or coal) for combustion. Engineers must measure the air and gas ratio accurately for efficient combustion in the boilers. Too much gas is wasteful, dangerous and costly, and too little will create insufficient flame to boil the water efficiently.

Orifice and turbine meters. Monitoring fuel gas to boiler units traditionally is accomplished with an orifice or turbine meter. However, these are not the best measuring devices for this application because they both are subject to failure and require frequent skilled maintenance to provide an accurate and reliable measurement.

Constrained piping conditions also can give engineers headaches. For example, an orifice meter requires 10 to 50 diameters of upstream piping to eliminate the effect of flow disturbances. Because long straight pipe runs are hard to find, most flow measurement



THERMAL MASS FLOWMETERS
Figure 3. This diagram demonstrates direct mass flow measurement using thermal mass flowmeters.

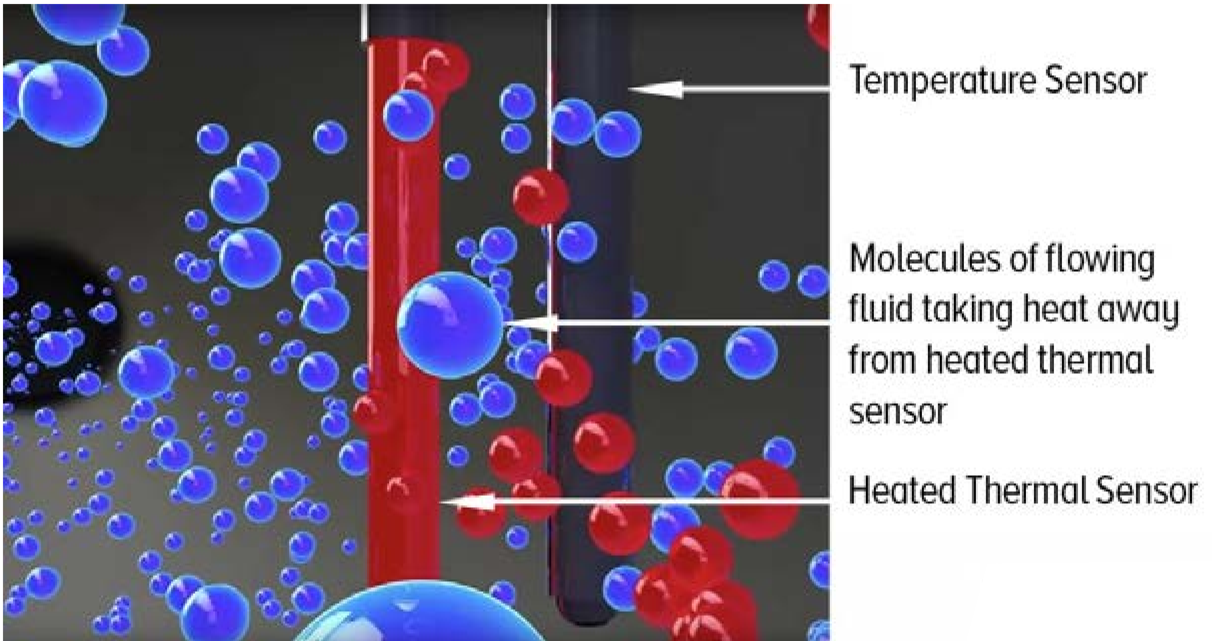
systems are affected adversely by varying flow profiles within the pipe.

The biggest cause for concern, however, is that orifice and turbine meters measure volumetric flow. Additional pressure, temperature and differential pressure sensors, as well as a flow computer, are required to calculate or infer mass flow (Figure 2). This not only degrades the flow measurement accuracy, but the installation and maintenance costs with this type of compensated measurement increase the cost of ownership.

Thermal mass flowmeters. In contrast, thermal mass flowmeters are suitable for the direct mass flow measurement of gases, not volumetric flow. Because thermal mass flowmeters count the gas molecules, they are immune to changes in inlet temperature and pressure and measure mass flow directly without compensation. In inlet air and gas flow boiler applications, thermal flowmeters perform well because the optimal fuel-to-air ratio for efficient combustion in boilers is calculated on a mass basis, not volumetric (Figure 3).

In a thermal flowmeter's simplest working configuration, fluid flows pass a heated thermal sensor and a temperature sensor. As the fluid's molecules flow past the heated thermal sensor, heat is lost to the flowing fluid. The thermal sensor cools down, while the temperature sensor continues to measure the flowing fluid's relatively constant temperature. The amount of heat lost depends on the fluid's thermal properties and its flowrate. Thus, by measuring the temperature difference between the thermal and temperature sensors, the flowrate can be determined (Figure 4).

New developments in four-sensor thermal technology coupled with stable "dry sense" sensor technology as well as advanced



SENSING TEMPERATURE
Figure 4. A thermal flowmeter determines flowrate by measuring the temperature difference between the thermal and temperature sensors.

thermodynamic modeling algorithms enable some thermal flowmeters to attain ±0.5% reading accuracy, rivaling Coriolis flowmeter accuracy at less cost. On-board software apps also enable gas-mixing capability, in-situ validation, and dial-a-pipe.

MEASURE INLET FEED WATER ACCURATELY

Water also is an expensive flow energy and limited resource. In boiler applications, it's important to measure the inlet feed water flow to the boiler accurately because you need to measure the efficiency at which the boiler turns this feed water into steam (Figure 1).

Clamp-on ultrasonic flowmeters. While you could measure inlet water with a volumetric vortex flowmeter, clamp-on ultrasonic flowmeters are ideal for water flow applications due to their ease of use and application flexibility. They achieve high accuracy at low and high flows, save time with no pipe cutting or process shutdown and are not affected by external noise (Figure 5). Advancements in ultrasonic technology now have on-board software and apps that make the meter easy to install, providing a visual signal that it has been done correctly.

OPTIMIZE STEAM PRODUCTION

The boiler's steam must be measured accurately to determine whether your boiler is producing the expected amount of steam or needs to be tuned for increased efficiency (Figure 1). Traditionally, steam flow has been measured with a differential pressure

METER INSTALLATION
Figure 5. Ease of use and flexibility make clamp-on ultrasonic flowmeters suitable for water and liquid flow applications, and easy to install.

METER APPLICATION
Figure 6. Sierra Instruments' Steel-Mass 640S thermal mass flowmeter was installed at a PTA chemical plant in China to measure methane waste gas.

device. This typically is an orifice plate.

However, such devices are inherently volumetric flow measurements. Changes in pressure and temperature will change the steam's mass flowrate. Even a "small" change of 10% in steam pressure will result in a 10% error in non-compensated mass flow. This means that, in a typical differential pressure measurement installation, the volumetric flowrate must be compensated by measuring temperature and pressure. These three measurements (ΔP, T and P) then are integrated with a flow computer to calculate mass flow.

Insertion multivariable vortex flowmeters. Insertion multivariable vortex flowmeters measure steam output production from boilers more accurately. One insertion vortex flowmeter with one process connection measure mass flowrate, temperature, pressure, volumetric flowrate and fluid density simultaneously. Saturated steam's density varies with either temperature or pressure, while superheated steam varies with temperature and pressure, so multivariable vortex flowmeters assure the flowmeter's density calculations are correct, and therefore, the mass steam flow measurements are correct.

Multivariable vortex flowmeters provide steam accuracy of ±1% of reading, 30:1 turndown as well as pressure and temperature compensation. In addition, recent technology and sensor advancements account for external vibration, making the vortex flowmeter even more accurate and enhancing low flow measurement. New on-board software apps also allow easy setup, tuning, trouble shooting, in-situ calibration validation and data logging.

CASE STUDY: THERMAL FLOWMETERS IMPROVE BOILER EFFICIENCY AT A PURIFIED TEREPHTHALIC ACID CHEMICAL PLANT IN CHINA

Purified terephthalic acid (PTA) is the precursor to polyethylene terephthalate (PET), the ubiquitous material used worldwide in plastic bottles, textiles and elsewhere. A PTA chemical plant in China generated steam and electricity from its on-site power plant using coal as a fuel. It also had a wastewater treatment station that produced methane, which then was flared off. Both processes are major greenhouse gas emitters.

New government regulations required the company to reduce its CO2 emissions. The plant decided to modify its four boilers to burn both coal and the previously flared-off waste gas (methane), estimating a savings of approximately $0.5 million in coal each year. Working with a single-source supplier, engineers reworked the boilers' designs and installed Sierra Instruments' industrial insertion thermal flowmeters to measure its combustion air and waste gas fuel, ensuring optimal combustion (Figure 6).

One thermal flowmeter measures the waste gas flow, while the other four thermal flowmeters provide sub-metering of this gas stream to each boiler. Another four meters measure pre-heated (200°C, 392°F) combustion air to each boiler, allowing the boiler control system to optimize the fuel-to-air ratio. The Sierra flowmeters provided both precision flow data for complying with government regulations and helped the company reduce waste while increasing efficiency.

Other potential metering applications are under review, including:

- *Feed water to the boilers using clamp-on ultrasonic flow.* Because this is a pre-existing feed piping system, a clamp-on ultrasonic meter provides a flexible solution.
- *Steam flow measurement.* Measurement of steam flow delivered from the boilers to the turbine generator and sub-metering to the other plant processes.

SCOTT A. ROUSE is vice president of product management at Sierra Instruments. He can be reached at s_rouse@sierrainstruments.com.

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50 Years of Training Yields Revelations

Process veteran offers some valuable tips to understanding process analyzer sampling systems

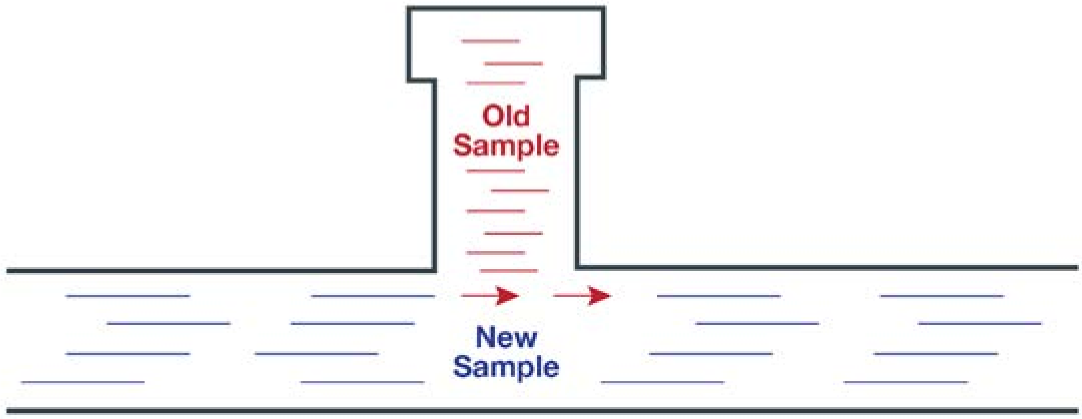
By Tony Waters, Swagelok

A process analyzer sampling system is one of the most challenging systems in your plant. It's challenging to design, and it's challenging to operate accurately. Make a minor adjustment here, and you may have to make a major one elsewhere. No wonder I get so many good questions during my sampling system training courses, as well as such attentive trainees. Over the 50 years I have been teaching, I have observed participants experiencing many epiphanies. Here are some of those "aha" moments.

TIME DELAY OFTEN LONGER THAN EXPECTED

Most trainees haven't considered the importance of addressing time delay in a sampling system and often are amazed at how late some analyzer measurements can be. The industry standard is a one-minute response time from pulling a sample to obtaining a reading. This short time frame provides near real-time readings of process conditions, so you can make immediate adjustments and minimize wasted product. However, the time to obtain a reading could be extraordinary, even with the analyzer mounted a few feet away from the process tap.

The only way to reduce time delay is by adjusting your system design. We do a fun, practical exercise in our training courses in which we calculate the time delay in a typical sampling system. Our initial design has an enormous delay of more than five hours. After making some quick system modifications, we bring that delay down to the one-minute industry standard. Trainees



SAMPLE CONTAMINATION
Figure 1. In this deadleg configuration, old sample trapped in the tee formation leaks into the main fluid stream, contaminating the new sample. ***Source: "Industrial Sampling Systems."***

are amazed and can't wait to try the exercise at their own facilities.

SAMPLE MAY NOT BE REPRESENTATIVE OF THE PROCESS CONDITIONS

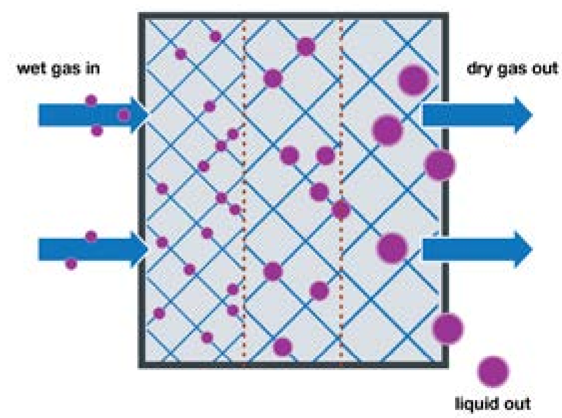
Time delay is such a critical issue to correct because it affects the "representativeness" of your sample reading (i.e., how representative the sample is of the fluid in the process line at the time you obtain your analyzer reading). Say, for example, a system has a more than five-hour delay like the training course exercise. If a bad reading shows up, the system operator quickly will correct the quality issue, thinking the problem is fixed. However, the operator likely doesn't know the reading was delayed more than five hours. During that time, a lot of inferior product went through the system that may have been shipped to a customer.

Even when you take a proper sample and limit time delay, it may still become unrepresentative due to the system's design. For example, deadlegs (Figure 1) or dead spaces in the sampling system may trap old samples that can bleed into the new sample, creating a mixed sample that isn't true to real-time process conditions.

Or, to take another example, your sample may become contaminated because of leaks — not leaks from the sampling system but leaks into the sampling system from the ambient air around it. For instance, oxygen can leak into a system containing 100% nitrogen at 100 psia because the partial pressure of oxygen outside the system is greater than its partial pressure inside the system.

PAY ATTENTION TO COALESCERS

In sample conditioning training, most attendees think a coalescer is a device used to separate and remove liquids from a gas sample. That's partly true, but only for liquids suspended in aerosol form. Aerosol is present in many gas samples because acceleration devices such as cyclones or gravity separators are unable to separate the tiny droplets. A coalescer installed in the sampling system will allow small liquid droplets to come together and combine into large drops that more easily separate by gravity (Figure 2).



COALESCER
Figure 2. Inside a coalescer, droplets from aerosol in a wet gas sample cling to elements inside the coalescer and then form into large drops that fall out as a result of gravity. The gas on the downstream side then is dry. *Source: "Industrial Sampling Systems"; Adapted from Wines, Lakhani, and Miles (2003).*

Trainees are surprised to learn two conditions will typically render a coalescer useless. First, free liquid (i.e., liquid that is not aerosol) will flow right through a coalescer with hardly any separation because of the liquid droplets' large size. In addition, when the flow rate through a coalescer is too high, the fine aerosol droplets get pushed past the coalescer elements and don't drip out of the flow path. Both scenarios increase the potential of aerosol droplets — the very element you were attempting to remove — reaching the analyzer and reducing the reliability of your readings.

VAPORIZING A LIQUID CAN BE VERY DIFFICULT

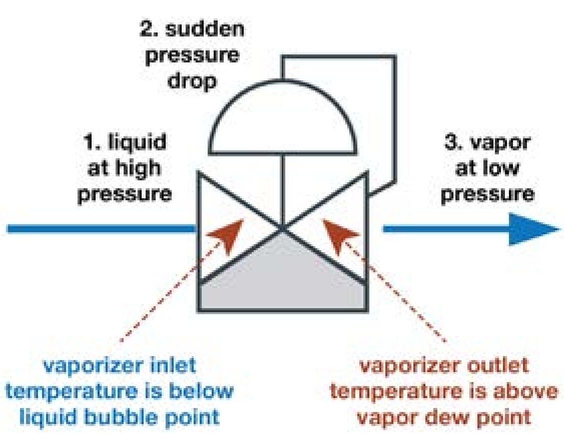
Many trainees think vaporizing a liquid sample is easy — but a lot can go wrong. The goal is to convert the liquid to all vapor instantly by dropping the liquid's pressure rapidly (Figure 3). However, instead of flashing the whole sample into a vapor, you could unintentionally create a fractionated sample through a combination of vaporization and evaporation. In this case, lighter gas molecules that evaporate first move downstream to the analyzer, while heavier liquid molecules remain behind.

As a result, the sample reaching the analyzer no longer accurately represents the product taken from the process line. After a sample fractionates, it no is longer of the same chemical composition. By understanding what occurs during vaporization and learning how to adjust settings for temperature, pressure and flow, you can prevent this scenario.

CONDENSATION CHALLENGES CAN BE AN EASY FIX

Condensation perhaps is the most common issue experienced with gas samples. Trainees are surprised to learn how quickly gases cool down (and how slowly liquids do). However, they're also happy to learn that it's easy to predict when condensation will occur, as well as what temperature is required to stop it.

Consider a system that reduces the pressure of a gas sample in a field station, which should be located as close to the tap as possible. Remember, almost all gases lose heat when their pressure drops (a phenomenon known as the Joule-Thomson effect). If your pressure drop is small, you likely can use a simple pressure-reducing regulator without worry of producing condensation.



VAPORIZATION PROCESS
Figure 3. During the three-stage vaporization process, high-pressure liquid vaporizes to low-pressure gas following a sudden pressure drop. *Source: "Industrial Sampling Systems.*

However, a significant gas pressure drop will cause condensation because of the significant heat loss. This is even more likely when the gas is close to its dew point temperature. In such cases, you may need to use a heated regulator to keep the gas temperature above its dew point. To optimize your energy consumption, you can calculate the number of watts required from the heater cartridge based on the Joule-Thomson coefficient of the gas, as well as the pressure drop and flow rate in the system.

CONTINUING YOUR JOURNEY OF DISCOVERY

Analytical sampling system design is a lifelong journey of discovery. You'll never have everything figured out. After 50 years of experience with sampling systems, I'm still learning myself — and even achieve an "aha" moment of my own now and then. Training is key to enhancing your skills and discovering what you don't know. Then, when you're out in the field you'll likely experience some "aha" moments at your own plant that can lead to more accurate and reliable sampling system readings.

TONY WATERS is an industry consultant and expert for Swagelok. For more information related to fluid system training, visit http://bit.ly/Swagelok_Training.

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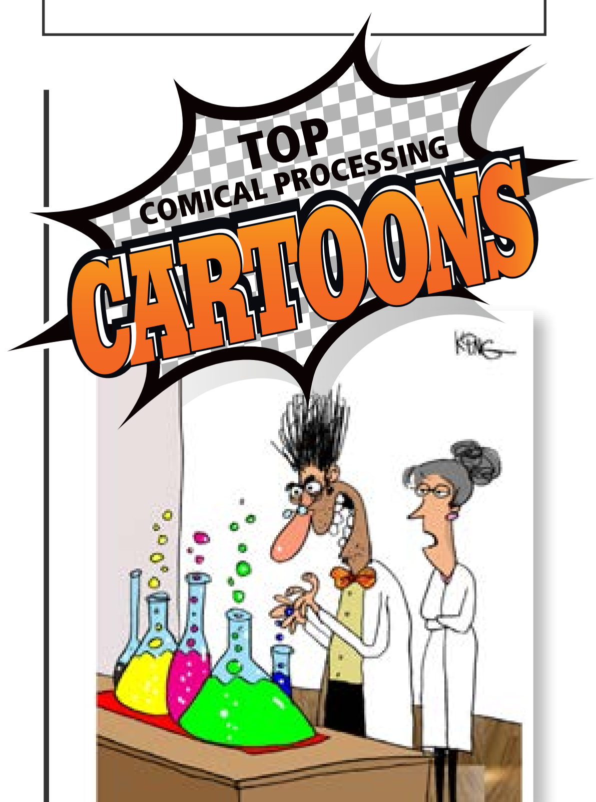

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