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Flow Measurement Part II





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How to select a flowmeter

Multiple flow conditions, scenarios and technologies evaluated at ISA Will-DuPage chapter meeting in January

by Eric Loffland, Zachry Group

Flow is the basis of material balance—what’s coming into a process and what’s going out. There are several ways to quantify flow: mass (units mass/time), volumetric (units volume/time) and velocity (units linear distance/time). These variables interrelate with one another, and by using other known process variables, flow rate can be calculated through several means.

For example, if velocity is known, and the pipe schematics are known, volume can be derived from $Q = vAcs$, where Q = volumetric flow (m^3/s), v = velocity of the fluid (m/s), and Acs is the cross-sectional area of the pipe (m^2). From there, if density is known, mass flow can be calculated from the equation $M = Q\rho$, where M is mass flow (kg/s) and ρ is the density of the fluid (kg/m^3).

The concept of developed flow is also important when selecting flowmeters. In process industry settings, fluids pass through obstructions or around bends, and chaotically swirl, disrupting their velocity profiles and creating bias. This chaotic flow takes time to return to equilibrium, leading to a uniform velocity profile called “developed flow” that includes upstream and downstream requirements based on velocity in industrial applications.

BASIC MEASUREMENTS, PARTS AND PRINCIPLES

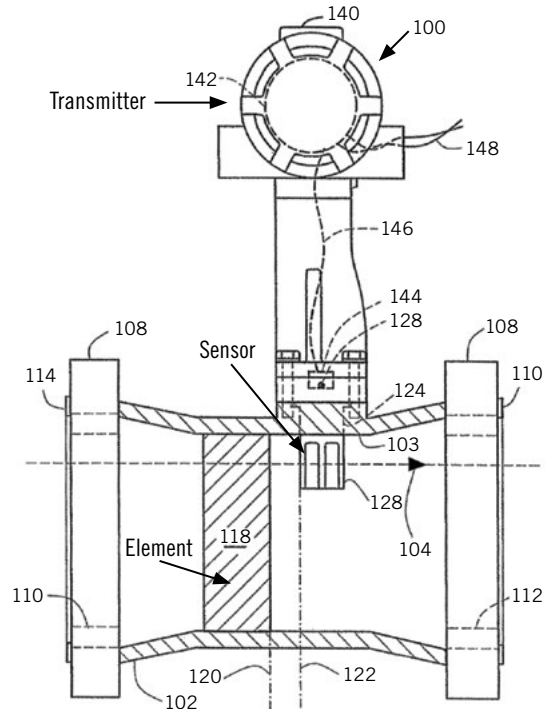
There are many flowmeter technologies available, but many have common anatomical elements and work in similar ways. A typical flowmeter works by altering the stream and measuring how it changes to find the flow value.

Flowmeters typically have three basic parts (Figure 1) that can be assembled in different ways:

- Element that's responsible for altering the flow;
- Sensor that measures the change in the stream, and translates that measurement into a value that can be associated with flow; and
- Transmitter that translates a measurement into a protocol that the control system can understand.

Flowmeters are available in insertion- or spool-type designs. Insertion flowmeters are inserted into a nozzle, and scale more economically with line sizes. However, insertion flowmeters don't allow control of the environment surrounding the probe, which necessitates added calibration. Spool flowmeters serve as part of a pipe spool that includes a line of pipe. While they allow more control of the environment around the sensor, spool flowmeters are often quite expensive for larger lines.

When choosing a flowmeter, it's important



BASIC FLOWMETER ANATOMY

Figure 1: Most flowmeters have three primary parts: element that's responsible for altering the flow; sensor that measures the change in the stream, and translates that measurement into a value that can be associated with flow; and transmitter that translates a measurement into a protocol that the control system can understand. Source: Zachry Group

to keep some key engineering principals in mind. Every measurement comes with a cost, and the best solution will do the required job for the lowest total installed cost. Even if a flow technology and its installation were free of charge, there are still operating costs, such as pump heads that contribute costs of the measurement. In addition, know your priorities by asking what can be sacrificed and what's truly needed for the process application. Also, repeatability is often more important than accuracy because consistency creates a more efficient process.

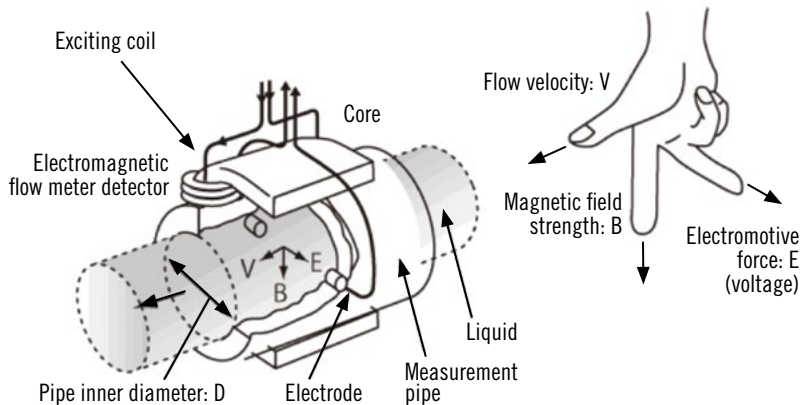
STRENGTHS AND WEAKNESSES

Because every flow device has limits, the strengths and limitations of each must be evaluated to find the most appropriate choice.

Mechanical flowmeters

measure flow as a process flow moves mechanical parts within them. Typically, a mechanical part with a fixed volume is rotated by the stream, and its rotations are counted to infer a volumetric flow rate. Strengths of mechanical flowmeters include low upfront costs, the ability to be manufactured in small sizes, and suitability for extremely low-flow applications. However, mechanical meters may have higher total installed costs, as well as mechanical parts that will degrade over time.

Differential pressure (DP) flowmeters typically introduce a velocity increase and corresponding pressure drop to the system, which pulls some of the pressure (or potential energy) into



ATTRACTIVE PRINCIPLES

Figure 2: Magnetic flowmeters use the $E=vBD$ equation to find flow by generating a magnetic field, and measuring the generated voltage to find velocity. In the equation, E is voltage generated, v is the velocity of the fluid, B is the strength of the magnetic field and D is the distance between electrodes for conductive fluids travels through a magnetic field. Source: Zachry Group

kinetic energy or velocity.

By measuring the pressure drop, velocity can be calculated to find flow.

DP meters are available in many sizes and styles, including orifice plate, pitot tube, venturi, v-cone and wedge. Not only do DP meters offer low upfront costs, but they're also well understood. However, impulse lines are prone to plugging, and wear and tear on the elements can "invisibly" alter measurement accuracy. Another important limit of DP flowmeters is that flow rate is proportional to the

square root of the differential pressure, which limits turndown.

Vortex flowmeters rely on a turbulent flow. When a fluid contacts the shedder bar of a vortex meter, piezoelectronics count the vortices and translate them into flow rate. Vortex flowmeters have low upfront costs, can measure liquids or vapors, are tolerant of droplets in vapor service, and have no stagnant zones. Limitations of vortex meters include the need for a turbulent flow along with a minimum flow requirement to provide any

measurement at all. Vortex flowmeters are also generally limited in size to between 0.5 and 12 inches and tend to increase in price with size.

Magnetic flowmeters determine flow by generating a magnetic field, and measuring the generated voltage to find velocity (Figure 2). Magnetic flowmeters are generally moderate in cost for their size, have an unrestricted flow path, good turndown and are offered with various electrode designs for different services. However, they can only measure conductive liquids, and metallic solutions can generate magnetic fields that can cause inaccurate measurements.

Coriolis flowmeters use the Coriolis force to find mass flow. Most Coriolis flowmeters vibrate two tubes at a natural frequency, and measure the change in vibration when the flow stream is introduced. Coriolis flowmeters offer extremely high precision, accuracy and turndown; they measure mass directly; provide a density measurement even without flow; and are insensitive to solids. However, Coriolis meters contain precisely machined elements that are sensitive to corrosive or abrasive surfaces. Other drawbacks include a high permanent pressure loss, relatively low maximum temperature, difficulty with low-pressure gases, and larger sizes that are very expensive.

Ultrasonic flowmeters use ultrasonic beam pulses to measure fluid flow. They're avail-

able in two primary types: transit-time and doppler. Transit-time flowmeters use multiple sensor/transmitter elements upstream and downstream on the outside of a line. Because the fluid moves with one beam and against the other, the difference in time for the two beams to travel between the elements is used to calculate the flow rate. It should be noted that transit-time ultrasonic flowmeters require clean service, as particles and bubbles will alter the pulse, and create noise and a loss of signal.

Doppler ultrasonic flowmeters use one sensor/transmitter, which shoots an ultrasonic pulse into the line that reflects off particles and bubbles, and uses the Doppler effect to measure shifts in pulse frequency to infer the flow rate. Doppler ultrasonic flowmeters require particles or bubbles in the stream to function. Ultrasonic flowmeters generally are high precision and turndown, don't restrict flow path, are available in clamp-on type, and are often low-cost. However, when using an ultrasonic flowmeter, again, particulate content must be known. These meters also have significant upstream and downstream requirements, and their sensors must be precisely positioned to be effective.

Optical flowmeters use two lights and corresponding detectors to measure how long it takes for a shape to pass, and employ the equation $v = d/t$ where v is the velocity of the fluid, d is the distance between probes, and t is the time interval between sensor

detection. There are two basic types of optical flowmeters: laser two-focus (L2F), which measures the velocity of particles and bubbles moving in the fluid, and scintillating, which measures the velocity of shadows and irregularities caused by turbulent flow. Scintillating meters measure a cross-section area of the flow, capturing the entire 3-D shape of the shadows or irregularities. This makes them relatively insensitive to velocity irregularities, but they do require minimum turbulence (Figure 3). Strengths of optical flowmeters include high precision and turndown, unrestricted flow path, low cost for line size, and they're ideal for changing fluids. However, optical flowmeters are often overlooked by the industry as a relatively new technology.

Thermal mass flowmeters rely on the $\Delta H = mCP(T_2 - T_1)$ equation, where ΔH is enthalpy change/unit time, m is mass flow rate, CP is specific heat, T_2 is downstream temperature and T_1 is upstream temperature. As a result, heat dispersion between two points in a stream is proportional to mass flow, and by heating an element and placing it upstream of a temperature sensor, mass flow can be measured. Strengths of thermal mass flowmeter are their ability to directly measure mass, availability in insertion type, and high accuracy and precision. However, it should be noted that thermal mass flowmeters require consistent fluid composition of known properties, and typically are only used to measure vapor flow.

BASELINES AND WARNING SIGNS

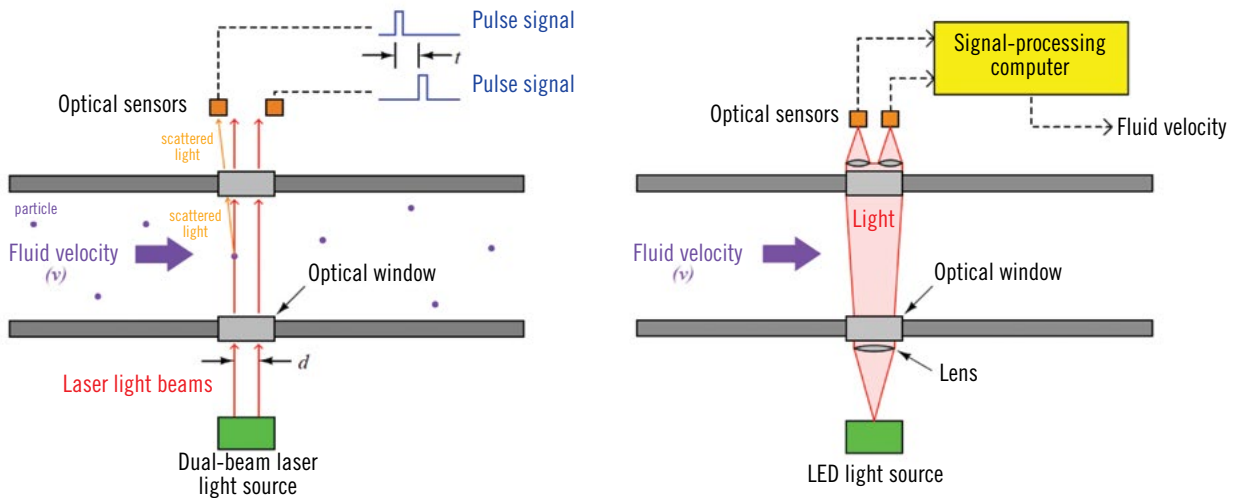
By understanding the available technologies, users can consider which flowmeter is the most appropriate for an application. A good practice is to start with a baseline technology that's inexpensive, and will blanket the majority of the facility's applications. Differential pressure (orifice plate), vortex and magnetic flowmeters are common baseline solutions. Once a baseline technology is selected, more expensive solutions can be considered for applications that diverge from the facility's norm. This strategy will help keep maintenance and training costs down.

After an application is defined, if the baseline technology isn't a good enough fit, then other, potentially more expensive options can be considered. The following are some of the warning signs that a specialized flow technology might be necessary:

- High accuracy or turndown requirements,
- Extremely low flow,
- Large line size,
- Variable/unknown composition,
- Dirty/erosive surface,
- Multiphase flow,
- Short upstream/downstream straight pipe runs,
- Low available pressure drop,
- Bidirectional flow, and
- Crystallization concerns.

RIGHT CHOICES FOR THE REAL WORLD

So which flow technologies are the best



SEEING AND BELIEVING

Figure 3: The two basic types of optical flowmeters are laser two-focus (L2F) that measures the velocity of particles and bubbles moving in the fluid, and scintillating that measures the velocity of shadows and irregularities caused by turbulent flow. Scintillating meters measure a cross-section area of the flow, capturing the entire 3-D shape of the shadows or irregularities, which makes them relatively insensitive to velocity irregularities, but they do require minimum turbulence. Source: www.InstrumentationTools.com

options for which process applications? It depends on the operating characteristics and goals of those processes.

For instance, the aim of **custody transfer** is to track how much important chemicals, products or other fluids are leaving or entering an area, which could be for mass balance or point of sale. Inaccuracy means lost revenue, so accuracy is more important, and turndown is a plus.

Options include:

- Turbine/positive displacement flowmeters have high accuracy and turndown, but moving parts mean more maintenance, so they're used less now.
- Coriolis flowmeters are the most accurate, but even though they're pricey for big

lines, they're often the first choice for lines less than 8 inches in diameter.

- Ultrasonic flowmeters also have high accuracy and turndown, so they're economical for large lines, and are used more often lately for such applications.
- Scintillating optical flowmeters have high accuracy and turndown, and they're economical for large lines, too. They aren't a standard yet, but may become one soon.

Injection quills add tiny flows of costly, commodity chemicals to larger streams, or are used in labs with low flows and small pipes. At extremely low flows, the regimes are laminar, but there's variance across profiles. This makes injection quills and other low-flow applications difficult for velocity-

based flow measurement, especially as flow approaches zero. Options include:

- Positive displacement because their mechanical rotation isn't very sensitive to flow profiles.
- Coriolis that comes in small sizes, has very high turndown, and measures mass, so velocity isn't very important.

Large air duct processes typically involve intakes to large compressors, operate at low pressures that favor instruments with minimal pressure drops such as insertion or no flow obstructions; have huge line sizes, often with square profiles that favor insertion types or external sensors; and are exposed to particles in the air such as dust solids and condensates that favor devices that are resistant to plugging. Options include:

- Insertion-type DP pitot tube (purged) flowmeter, which measures velocity at a representative point that may be difficult to obtain. Purge devices may protect the unit from plugging, but they also require a constant expense for air pressure.
- Low-pressure loss DP venturi (purged) flowmeters, which deal with condensate well, are often used on suction of compressors, but are costly at large line sizes, and also require a constant operating cost.
- Clip-on ultrasonic is inexpensive for most line sizes; non-contact, so there's no pressure loss, so they may seem attractive, but they have high upstream-downstream straight pipe run requirements and may be difficult to place on a square duct.

- Insertion-type thermal mass flowmeter is also inexpensive for most line sizes, less sensitive to turbulence, and benefits from air's well-known properties.

As the vapor garbage disposals for refineries, **flares** can have a huge range of compositions, environmental requirements that require accuracy, and need premium turndowns to cover flows from a trickle to the whole plant venting at once. Big lines for flaring mean they favor devices that scale well with line size, while handling many vapor densities and properties means they also need technologies that are insensitive to those vapor properties. Options include:

- Ultrasonic flowmeters scale well with size, have great turndown and accuracy, and aren't heavily influenced by fluid properties if the stream is relatively clean.
- Optical flowmeters scale well, have great turndown and accuracy, and aren't heavily influenced by fluid properties.

Wastewater/high solids feeds are only mostly liquid, so plugging is a concern that favors open flow paths and no stagnant zones, while erosivity is a concern that favors hardened flow elements or no element in the stream. Options include:

- Magnetic flowmeters are great for conductive liquids, work with straight paths, and have erosion-resistant electrodes.
- Doppler ultrasonic flowmeters thrive in areas with particulates, and also work with straight flow paths.

- DP wedge flowmeters with hardened, indirect impact surfaces for maximum erosivity resistance also feature the ability to handle non-conductive fluids.
- Optical (L2F) flowmeters thrive in areas with particulates, and also work with straight flow paths.

Brownfield process applications typically need to add a flow sensor to an existing line, can't take up much space, and have tight piping with very short upstream and/or downstream lengths. Options include:

- Mechanical flowmeters that count volumes directly, but have moving parts requiring more maintenance.


- DP V-Cone flowmeters designed to condition flows as a part of measurement, and are resistant to entrained particles.
- Coriolis flowmeters that measures mass directly, and are insensitive to flow profiles.

REFERENCES

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Sizing and installing vortex meters

Accuracy depends on observing diameter and straight pipe run requirements.

by Béla Lipták

Q: I'm purchasing vortex flowmeters and having doubts. In one application, we have a 3-in. line and I selected a 3-in. flowmeter. However, due to a change in wall thickness of the pipe, its inner diameter (ID) isn't aligned with vendor offerings—the meter tube diameters don't have a pure line of contact with pipe inner diameter. When we requested that the vendor provide the same meter tube ID as pipe ID, they deviated and offered some tolerance gap between pipe ID and meter ID. Is this an acceptable practice? If we do it, will there be any impact on the performance of the meter by creating additional pressure loss across the meter (in the case of larger size)? Could you please explain in brief?

A second application involves a 2-in. pipeline. Per the vendor manual, the vortex flowmeter requires a straight run of 30 pipe diameters (D) upstream and five D downstream, and the two inner diameters are slightly different (54 mm for the pipe and 51 mm for the meter). My question is, which ID should I use when determining the lengths of the upstream and downstream straight runs?

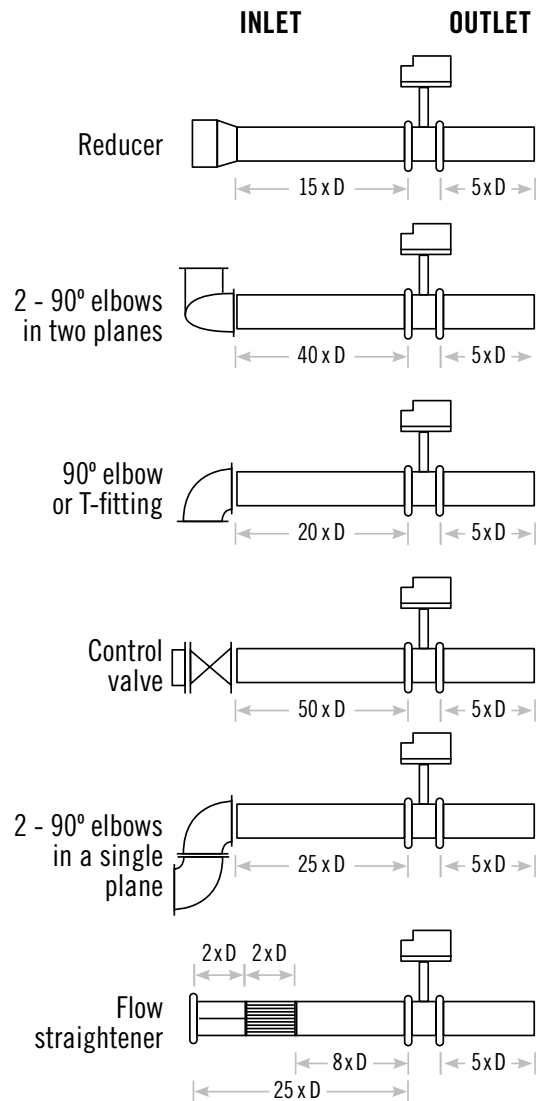
M. Ulaganathan
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A: Dr. Tódor von Kármán was fishing in beautiful Hungarian Transylvania when he noticed that the vortices formed by rocks in the stream were floating equal distances from each other, no matter how fast or slow the water was moving. This discovery became the basis

of not only vortex flow metering, but also contributed to the advance of modern aviation and space technology. Simply stated, as long as the velocity profile is fully formed (the Reynolds number is over 20,000), the distance between the shed vortices is constant. This phenomenon is the same as the one that keeps the wavelength of the fluttering of flags a simple function of the diameter of the pole, unchanged by wind velocity.

Now coming to your questions: as to the IDs of the pipe and the meter, your sizing may be wrong because (in my experience) the meter ID, if properly sized, is usually at least one size smaller than the ID of the pipe. In any case, the K factors of vortex flowmeters are calibrated in schedule 40 pipe. There's a small K-factor shift if the pipe ID is different because of the slight change in the velocity at the inlet, but these changes have been programmed into the electronics, and will be corrected for automatically when the user's pipe ID is other than schedule 40. The units are also tested for process fluid temperature variation and for upstream and downstream disturbances. As a result of this testing, compensation factors are included in the vortex meter software. This allows the output of the vortex meter to be adjusted for the actual process temperature and process piping being used.

Now, coming to the question on straight runs, the meter accuracy increases (the shift



STRAIGHTEN THE FLOW

Figure 1: Typical straight run recommendations in pipe diameters (D) for vortex shedding flowmeters vary depending on the piping configuration.

in the K factor drops) as the length of the straight run increases because that helps to fully form the velocity profile. Rosemount recommends 35 diameters upstream of straight run, but that's just an average. As shown in Figure 1, these requirements vary with the type of installation.

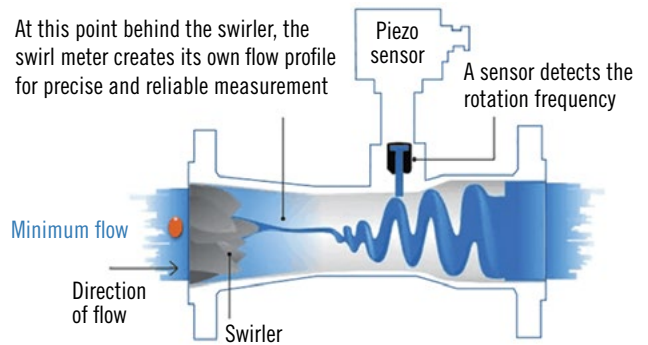
If you have a tight piping situation, remember that there are two types of vortex meters, and only the vortex shedding design requires long straight runs to form its uniform velocity profile—the vortex precession (also called swirl) meter does not. This design combines the characteristics of turbine and vortex meters in the sense that helical vanes at the entrance introduce a spinning (swirling) motion, resulting in the vortex precession. Thus, the meter speeds up the incoming flow and creates its own velocity profile (Figure 2).

Because it speeds up the incoming flow, it can be pipe-size, can operate at lower Reynolds numbers (10,000 instead of 20,000 minimum for the shedding design), higher viscosity (30 cp instead of 10 cp), higher rangeability (30:1 instead of 20:1) and shorter straight runs (3-5 D upstream and to 1-3 D downstream). Its accuracy is also claimed to be slightly better: 0.75% of rate instead of 1% for the shedding version.

Béla Lipták

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A: Excessive pressure drop is rarely an issue, and only for certain very specific process fluid conditions (e.g., marginal flashing or degassing service). It's highly unusual to select a vortex meter the same as the line size. Usually, it's one line size smaller (sometimes two line sizes). This should be checked using the vendor sizing software (most vendors have online versions you can



SWIRL REPLACES STRAIGHT RUNS

Figure 2: In a vortex precession flowmeter, the frequency of swirl precession is proportional to flow. Source: ABB

use). Having too large a vortex meter can result in not being able to measure low-range flows.

Vendors now have inbuilt reducers. As an example, a 2-in. vortex can have 3-in. flanges to bolt directly to a 3-in. pipe.

When you order a vortex meter, you need to specify pipe size and schedule. The vendors have different vortex IDs for the same pipe size and different schedules.

The mismatch between pipe and meter ID can cause noise interference for the vortex, giving faulty readings. The worst arrangement is when the vortex ID is smaller than the pipe ID. You should clarify with the vendor that their meter software can compensate for this (by filtering).

You only need to calculate straight runs using nominal pipe sizes. You're wasting time

and effort calculating to two decimal points. You won't be able to measure any significant difference. Use the pipe size because you're trying to establish the ideal flow profile before it reaches the vortex flowmeter—this is based on the pipe size, not the vortex size.

Upstream and, to a lesser extent, downstream obstructions disturb the ideal flow profile (e.g., an elbow). These flow profile disturbances give +ve or -ve flow measurement offsets. The amount and polarity depend on the type of physical obstruction and distance between the obstruction and the vortex.

The errors are offset and not inaccuracy measured as +/- tolerance of the measurement. Modern vortex meters can be configured to take these offsets into account. With this offset compensation done in the configuration of the vortex, you can install them with 5 D upstream and downstream piping straight runs in many instances (if I remember correctly). The vendors have detailed information in their manuals.

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A: Normally, the inside diameter of most flow transmitters as well as the flanges will comply with the pipe schedule for the operating pressures. For example, a 3-in. pipe that's 3.5-in. OD in schedule 40 has the ID 3.1 in., while in schedule 80, the ID is 2.9 in. Small variations in ID should not impact the equipment operation. The vendor will have to indicate the expected pressure drop across his instrument, and you need to consider it in the pipeline dynamic.

I prefer to use the OD of the pipe or the nominal size of the line since the ID will always be smaller depending on the pipe schedule. For example, a 2-in. pipe will have an OD 2.38 in. and nominal size of 2 in., while the ID will be much smaller, so the optimal design condition would be to use 2.38 in., which would result in the 30 D recommended by the manufacturer of the equipment being 71.25 in. and 5 D would be 11.9 in. In this way, you're sure to maintain sufficient upstream and downstream dimensions. And, always round up to the nearest whole inch.

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Ultrasonic flowmeters for flare flow metering

Why and how to use ultrasonic flowmeters for this demanding application.

by Fawaz ALSahan, Saudi Aramco

Accurate flare flow metering is important to account for production and energy loss, closing the gaps in the plant mass balance, and in reducing emissions and protecting the environment.

Existing industry regulations and standards provide helpful guidelines by defining the acceptable accuracy limits for flare flowmeters. The challenge has always been how to reveal the flowmeter inaccuracy, and minimize errors in flare flow measurement. We've found practical tools to properly select, configure, install, test and maintain flowmeters in flare applications, and how to determine the flaring source using the built-in features provided by these flowmeter technologies.

Each of the different flowmeters used for flare applications has limitations. For example, dif-

USING CLAMP-ON ULTRASONIC FLOWMETERS FOR FLARE

Clamp-on ultrasonic flowmeters can't measure a low-pressure flared gas in a metallic pipe because the flared gas has lower acoustic impedance than metallic pipes. This causes the acoustic signal to travel in the pipe and not to the second transducer across the pipe.

To address this limitation, there are two solutions. One option is to increase the flared gas pressure, which is difficult to accomplish. The other is to install a clamp-on flowmeter on a nonmetallic pipe. This will lower the acoustic impedance of the pipe, and increase the possibility of acoustic signals traveling across the pipe and measuring the flow. Using a non-metallic pipe in the flare header is also a challenging option, and will require a very comprehensive assessment before implementation.

TABLE I: ERRORS RELATED TO USING A FIXED COMPOSITION*

	Actual volume	Standard volume	Mass
Case 1—Propane increased			
Differential pressure meter	34%	34%	25%
Thermal flowmeter	2-15%	2-15%	35-45%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	0%
Case 2—Hydrogen added			
Differential pressure meter	31%	31%	45%
Thermal flowmeter	100-300%	100-300%	300-700%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	112%
Case 3—CO₂ increased			
Differential pressure meter	9%	9%	8%
Thermal flowmeter	2-5%	2-5%	15-20%
Velocity meter (optical, ultrasonic, vortex)	0%	0%	15%

* The approximate measurement error under constant flow conditions when using a fixed composition of 1% CO₂, 0.9% H₂S, 97% methane, 1% ethane and 0.1% propane and the flare composition changes to:

Case 1: 0.53% CO₂, 0.47% H₂S, 51.08% methane, 0.53% ethane, 47.39% propane

Case 2: 0.4% CO₂, 0.36% H₂S, 38.8% methane, 0.4% ethane, 0.04% propane, 60% hydrogen

Case 3: 12% CO₂, 0.8% H₂S, 86.22% methane, 0.89% ethane, 0.09% propane

Source: API MPMS 14.10

ferential pressure (DP) flowmeters such as orifice plates and pitot tubes are sensitive to fouling and composition changes, and will require frequent calibration. Conventional thermal flowmeters are also sensitive to fouling, liquid and composition changes, and will require frequent calibration unless they have automatic composition measurement and correction. Vortex flowmeters also have limitations in sensitivity to fouling and liquid, maximum flow capacity and maintenance difficulties.

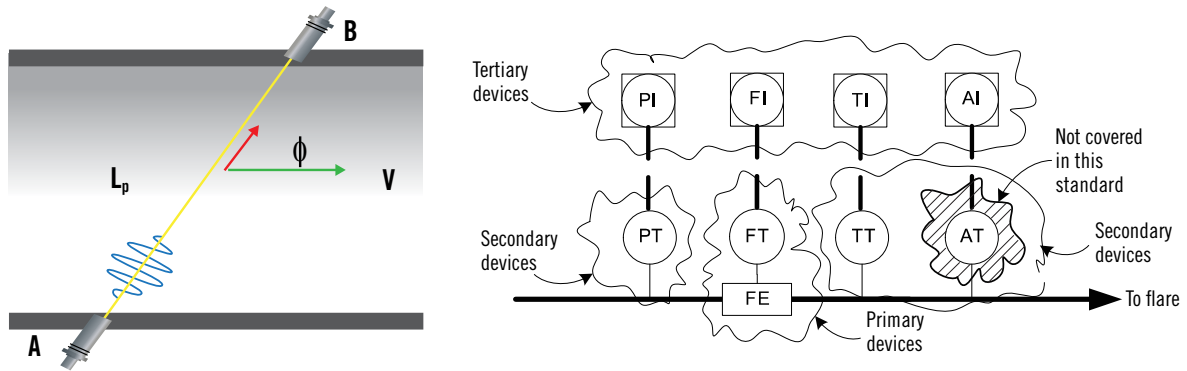
An experiment (Table I) was carried out to demonstrate the possible errors in flare flow measurement using different types of flowmeters with different gas compositions. Because of the accuracies demonstrated in

Table I and the above considerations, this article focuses on the use of ultrasonic flowmeters for flare applications.

FLARE FLOWMETER CHALLENGES

Flare applications introduce many challenges on flow measurement and flowmeters, the major ones being:

- Flare can have a very low flow (0.01 m/sec) and a low pressure drop across the meter (typically 0.5 psig) is required.
- The flow can be non-axial and asymmetric. Laminar-turbulent transition flow introduces inaccuracy, and stratification (by sun or wind) can happen and affect the flow profile. Pulsating flow is also possible as the gas entry to the flare header is not continuous.
- High flow may causing low signal-to-noise



ULTRASONIC ESSENTIALS

Figure 1: Ultrasonic flowmeters determine the flow velocity by measuring the difference in the travel time ($t_{ab} - t_{ba}$) for a pulse moving from one transducer at one side of the pipe to another one at the other side (t_{ab}) and vice versa (t_{ba}). Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. Source: API MPMS 14.10, ISO 17089-2

ratio and probably liquid carry-over. High CO_2 , H_2S , N_2 and H_2 can cause attenuation to the signal.

- Flare flow has a large turndown (2,000-4,000:1) and the gas composition is variable.
- Primary flow elements have uncertainties due to electronics drift, metrological (pipe diameter, alignment) and process buildup. Secondary instruments (temperature and pressure) have uncertainty due to electronics drift, mounting location and process buildup.
- The application might require a dual-path ultrasonic flowmeter (i.e., two sets of transducers) to either improve accuracy, cover very low flow conditions, or reduce the straight piping requirement.

ULTRASONIC PRINCIPLE OF OPERATION

Ultrasonic flowmeters (UFM) can be either insertion or cross-pipe. Both types are in-

stalled as single- or dual-path. These flowmeters (Figure 1) determine the flow velocity and speed of sound by measuring the difference in the travel time ($t_{ab} - t_{ba}$) for a pulse moving from one transducer at one side of the pipe to another one at the other side (t_{ab}) and vice versa (t_{ba}). The transducers are inserted through the pipe wall, either by hot tapping or as an inline flowmeter (installed on a spool pipe). The flowmeter calculates the flared gas velocity (V), volumetric flow at operating conditions (Q_{act}) and volumetric flow at standard conditions (Q_{std}).

Sound velocity (C) is also calculated by this flowmeter. The value of sound velocity is used to estimate the molecular weight (MW) of the flare gas mixture. A mathematical or graphical correlation is experimentally extracted by testing many gas mixtures and defining their sound velocity and MW relationship. MW measurement helps in calculating the density and therefore the mass

flow. Secondary instruments for pressure and temperature are required to calculate the volumetric flow at standard conditions. The setup of these secondary instruments is shown in Figure 1 or as advised by the flowmeter's manufacturer.

Referring to Figure 1, the main equations are:

- $V = [L / (2\cos\theta)] \times [1/t_{ab} - 1/t_{ba}]$
- $C = [L/2] \times [1/t_{ab} + 1/t_{ba}]$
- $Q_{act} = V \times \text{pipe area}$
- $Q_{std} = Q_{act} \times P/P_s \times T_s/T$

Where:

V: flow velocity

C: sound velocity

Q_{act} : volumetric flow at actual flow conditions

Q_{std} : volumetric flow at standard flow conditions

L: distance between transducers

t_{ab} : time for signal travel from transducer a to transducer b (and vice versa for t_{ba})

T, P: operating temperature, pressure

T_s, P_s : standard temperature, pressure

SPECIFICATION AND TESTING

ISO 17089-2 and BS 7965 define the required flowmeter uncertainty in flare application to be $\leq 10\%$ for the flow above a certain minimum limit. This uncertainty can increase by 5% due to flowmeter installation effects. The flare flowmeter needs to be tested at the factory or at a third-party calibration shop. The main testing requirements are:

- Air is usually the testing media. A Reynolds number is used to account for differ-

ences in densities (between air and flared gas composition).

- Expansion of the flowmeter shall be considered in high velocity.
- Testing shall cover 0.03 m/s to the maximum design velocity. The flowmeter shall be tested at velocities 0.03, 0.15, 0.30, 0.61, 1.5, 3.0, 6.1, 15, 30 and 15 m/s increments up to the maximum operating velocity.
- The flowmeter shall be tested with the same pipe size and upstream/downstream straight piping.
- Pressure transmitter accuracy shall be maximum ± 0.67 kpa.
- Temperature transmitter accuracy shall be maximum ± 2 °C.
- The testing facility shall be traceable to NIST or equivalent national or international standard, and shall be accredited by ISO/IEC 17025.
- The factory and testing facility shall provide all the testing data and records of the installation, configuration and diagnostics data at the test bench.
- The manufacturer shall provide the flowmeter uncertainty and the installation effects.
- Testing shall be done at a low pressure and at ramping up and down.

INSTALLATION AND COMMISSIONING

Requirements stated in API MPMS 14.10 and 22.3, ISO 17089-2 and BS 7965 will help users reach an accurate flare flow measure-

ment. The major points to follow are:

- Manufacturer or manufacturer-certified entity shall be responsible to install and commission the flare flowmeter and all secondary instruments. This will eliminate critical problems, like transducer misalignment.
- The end user shall decide early on the installation approach (i.e., hot tapping, cold tapping or a complete spool piece). Definitely, the last option is the best option as it will eliminate all installation errors.
- Transducers shall be retractable to allow online removal for testing and replacement.
- Recommended piping straight run is generally 20 diameters (20D) upstream and 10D downstream. This requirement can be relaxed based on the specific flowmeter installation and manufacturer recommendations, which must be verified.
- The end user shall consider accessibility for flowmeter maintenance and gas manual or automatic sampling.
- Pressure and temperature sensor mounting locations shall follow the flowmeter manufacturer's recommendations.
- Vibration shall be avoided by selecting the right location for the flowmeter and its associated panel.
- Any control valve with noise attenuation or fittings up or downstream shall be checked, as this can produce interference with the transducer pulses.
- The installation shall avoid liquid accumulation.
- Rapid pressurization or depressurization

when removing or installing transducers shall be avoided.

- Manufacturer shall provide the accuracy impact when replacing any part or software of the flowmeter system.
- The hardware serial numbers, firmware and testing shall be submitted by the vendor.
- All data and software configuration in electronics are saved as a backup. After commissioning, management of change (MOC) is required.

FIELD VERIFICATION

To verify the reading of an installed ultrasonic flare flowmeter, there are many techniques. The steps and tools below can be used:

- The flowmeter manufacturer shall be requested to provide a written procedure for functionality testing and verification, inspection intervals and dimensional verification. Also, uncertainties and speed of sound calculations shall be provided.
- Wall thickness, inclination angle of transducers, length of acoustic path, the pipe internal diameter and pipe cleanliness shall be verified.
- Installed meter specifications and current operating conditions shall be checked to match the flowmeter's specification sheets and drawings.
- The installed flowmeter configuration and serial number shall be verified with the manufacturer requirements.
- Straight piping and installation of the me-

ter, pressure and temperature transmitters shall be verified.

- Wiring shall be inspected for signs of moisture or physical damage.
- Performance of the flowmeter using the same transducers model and the same installation setup at a calibration shop can be checked. This is to verify the accuracy of the installed flowmeter, considering the same straight piping and mounting of the current field installation.
- The ultrasonic flowmeter reading can be verified using a secondary device such as:
 - 1) A second insertion flowmeter (such as a pitot tube).
 - 2) Optical method (laser doppler anemometer tracer), which requires a steady velocity.
 - 3) Tracer dilution technique: injecting a gas (like SF6 or helium) and measuring the flow rate increase using a secondary flowmeter.
 - 4) Radioactive tracer: introducing a gaseous radioactive tracer and inserting two detectors to detect the passage (based on transit time). BS-5857-2 can be referenced for details.
- The transducers and the electronics can be verified using a zero flow box. This will provide zero calibration of transducers, and will also check speed of sound measurement for air compared to the estimated value (performed by the manufacturer software). Also, zero testing can be done for the electronics and cabling using dummy transducers and checking the signals.
- Absolute speed of sound (C) comparison, like injecting N2 and determining C.
- Verification of the ultrasonic flowmeter can be also done by taking a sample of the flared gas and measuring SOS, and then comparing the measured value to the flowmeter estimated SOS. Difference shall be less than 0.25%.
- Another verification tool is comparing C and the velocity reading of one path, and comparing it to the second path. This is only applicable for dual path measurement (i.e., when two sets of transducers are installed).
- Flaring volume could be estimated by conducting mass balance or using process simulation, and the result can be compared to the flowmeter reading.
- Computational fluid dynamics (CFD). This is a modeling and verification technique, which is a cost-effective solution and helps to reveal installation errors. Also, it provides a correction for the flow profile and the missing straight piping run. The flow is modelled in 3-D coordinates considering turbulence and wall roughness. Manufacturers of flare flowmeters or some flow calibration labs can provide this service.

ONLINE PERFORMANCE MONITORING

Ultrasonic flowmeters have the advantage of providing online diagnostics. Diagnostics can be used to check the health, performance and the accuracy of the flowmeter without the need to remove and physically

DETERMINING FLARING SOURCE

Observing flared gas and not being able to determine which operating flare branch it's coming from is very frustrating for operating facilities. In many circumstances, the source of the flared gas is a leaking valve. However, identifying which valve and from which operating unit is difficult and time consuming.

An ultrasonic flowmeter offers a solution to this problem because the most valuable advantage of the technology is the sound velocity measurement. There's a determined sound velocity value for every type of gas and for every mixture of gases. Knowing the sound velocity will determine the molecular weight and composition of the flared gas. Knowing the composition will help the operating facility identify the potential sources of flaring. This is a unique feature of ultrasonic flowmeters.

check, calibrate or replace any part. Once the flowmeter is proven to be correctly selected, installed and commissioned, diagnostic parameters can be collected and used as a baseline for future online performance monitoring.

The flare flowmeter manufacturer shall be requested to provide detailed diagnostics parameters along with their acceptable limits. Having these diagnostics parameters in the local display and also reflected in the remote workstation (i.e. distributed control system) is crucial for online performance monitoring. The main diagnostics parameters to be displayed and monitored are:

- System diagnostics: Transducers and electronics functionality check, flow profile. This diagnostic parameter helps with the recalibration decision.
- Speed of sound (C): The measured C and the actual C can be compared to check the health of the flowmeter. Actual C is

calculated using a gas sample and the flowmeter manufacturer software. Also, compare the initial flowmeter C reading and the current C.

- Signal strength/quality indicator: Signal-to-noise ratio (SNR) indicates the quality of ultrasonic signals. Distribution of SNR among transducers might indicate a source of a problem such as noise.
- Automatic gain control (AGC) level: As meter performance deteriorates, AGC level increases and a fault happens.
- Flow profile: A change in flow profile indicates viscosity changes and/or changes to pipe wall roughness.
- Axial velocity through the flowmeter.
- Meter performance: The ratio of transducers good pulses received to rejected pulses received. As the flow rate increases, meter performance decreases. Performance also decreases with a decrease in pressure.
- Temperature: Can indicate stratification in the gas flow.

Following the above steps will assist end users in evaluating their installed flare flowmeters and could also result in modifying or even replacing existing flowmeters to fix the system performance and installation errors.

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Optimize your calibration plan

Establishing ideal calibration intervals based on key regulatory, criticality, safety and quality considerations is only the first step in achieving optimal instrument performance. There are other factors to consider when it comes to developing a plan and executing against it. First, since you're looking to optimize calibration operations and not just keep records, a software application designed specifically to help manage and keep track of your instrumentation is a good first investment.

In a new plant, setting initial calibration frequencies relies on the criticality of the measurement, the maximum permissible error (MPE), the use of self-diagnostics and verification, as well as advice from the instrument manufacturer and qualified calibration team. But in an existing plant, determining calibration intervals based on established work practices and actual historical experience often yields better results.

Indeed, once a calibration plan has been in effect for a few years, the instrument/asset management software takes on an even bigger role. When each calibration is completed, new data is recorded, including the status of the flowmeter before and after calibration. Analysis of these records may very well indicate that the instrument does not require calibration as often as expected, helping to justify longer intervals.



This portable flowmeter calibration rig can be brought onsite to compare flowmeter performance against a standards-traceable reference meter, avoiding the delays and potential damage inherent in transporting the meter to a laboratory.

Other advantages of today's instrument/asset management packages include the support of mobile access to an instrument's history and supporting documentation. From the field, a technician can pull up real-time diagnostics, calibration history, troubleshooting instructions and other information needed to properly address issues as they arise. In many cases, modern instruments equipped with advanced diagnostics can determine if a problem exists, and automatically notify the maintenance department.

IN-HOUSE, AT A LAB, OR ONSITE?

Once the need for a calibration is established, a number of other decisions come into play. First, do you have—or can you afford—the necessary equipment to do it in house? And, do you have the properly trained technicians on staff to perform it properly?

Standard maintenance shops are not equipped for some calibrations. Flowmeters, for example, are far more complicated to calibrate than other measurement instruments, such as for temperature or pressure.

Professional calibration labs use pipe-clamp measurement sections to accommodate different diameters. The sections tend to be large, making them cost-prohibitive for many asset owner-operators. Calibrating in-house also necessitates the purchase of one or more costly flow-reference devices—these devices require calibration with traceability, adding further costs and complexity to processes. In such cases, the help of an outside services organization is called for—preferably one accredited to the ISO/IEC 17025 Standard for Testing and Calibration Laboratories.

Flowmeters are often removed from systems for the purpose of calibration and sent to a calibration laboratory. The commonly held belief is that the necessary calibration accuracy can be guaranteed only under laboratory conditions. However, this is only partially true.

Flowmeters and many other measuring devices can also be calibrated directly on-site by an accredited calibration provider. There are several advantages to this:

- Plant availability improves as the device is calibrated near-line or in-line.
- Sources of error can be detected and eliminated on-site, while the ability to achieve the same result in a calibration lab is limited. Calibration technicians on-site can detect errors during installation and identify blockages or contamination in the pipes directly in the system.

- Cost savings increase due to the speed of completion, reduced downtime and the elimination of an inventory of replacement parts.
- There is no need to disassemble and ship contaminated devices, and costly decontamination measures can be avoided.

Endress+Hauser, for example, has both high-end regional calibration centers across the world as well as fleets of portable rigs—supported by highly trained engineers—that can be brought directly to plant sites. Convenient and cost-effective, this approach removes the need to send instruments offsite. Coordinating an onsite visit with a plant outage also allows multiple instruments to be quickly calibrated and returned to service.

These mobile rigs (see photo) compare a flowmeter's performance against another reference meter with traceability. But for those applications requiring even higher accuracy, or to address especially large meter sizes, one's choices are limited to dedicated calibration facilities such as Endress+Hauser's regional calibration centers in Europe, Asia and North America, where a new Gulf Coast campus will open later this year. These dedicated facilities offer traceable, highest-accuracy calibration of even high flow-rate flowmeters.

Even with the budget to purchase the most sophisticated calibration and reference



Calibration traceability should follow an unbroken chain of calibrations, so that the highest-level calibration can be traced back to a national calibration standard, or equivalent.

equipment currently available, there is no substitute for a properly trained technician. Not only do they need to be trained on the mechanics of the calibration process, they also need to be equally qualified in completing and maintaining the documentation. Accuracy, repeatability and reproducibility are key and in the world of calibration, if it isn't properly documented, it didn't happen.

Truly professional calibration needs highly trained experts. While it is perfectly feasible to calibrate some measuring points yourself, other points present a challenge that it is not to be underestimated, even by experts. In cases involving a large number of flowmeters, calibration requires project planning. The staff conducting these calibrations needs to consider the minimization of plant

downtime, the removal and reinstallation of devices, technical knowledge of calibration, as well as the operation and handling of tools and equipment. Additionally, staff must always know the current applicable regulations to ensure that the correct calibration intervals are being observed and can complete the documentation in compliance with the regulations. After all, calibration provides proof and documentation of compliance with the permitted measurement error and plays an important role in audits and certifications.

Furthermore, taking on internal or in-house calibrations can raise questions from an audit standpoint as to what the company's core competence may be. Is it to produce a product or perform calibrations?

INSIST ON TRACEABILITY, ACCREDITATION

Traceability means that the reference standards used when executing a calibration have also been calibrated using an even higher-level standard. That traceability should follow an unbroken chain of calibrations, so that the highest-level calibration has been traced back to a national calibration standard, or equivalent.

So, for example, you may calibrate your process measurement instrument with a portable process calibrator. The portable process calibrator you used, should have been calibrated using a more accurate reference calibrator. The reference calibrator should be calibrated with an even higher-level standard or sent out to an accredited or national calibration center for calibration. If the traceability chain is broken at any point, any measurement “below” that point cannot be considered the true representation of the measurement. Comparisons between devices under testing, testing equipment and the country’s

highest national standard are the only way of establishing end-to-end traceability of measured values.

Just as traceability ensures the integrity of calibration standards, accreditation ensures that providers of calibration services have the necessary technical expertise, and that the calibration infrastructure (operating procedures, methods, calculations) and quality management systems meets industry best practices. Endress+Hauser’s calibration capabilities, for example, are accredited in the U.S. by the American Association for Laboratory Accreditation (A2LA, www.a2la.org).

Your organization’s competitive edge depends on accurate instrumentation. Optimize calibration in line with your needs to enhance productivity, ensure compliance and maintain quality. Schedule calibration of critical instruments, monitor KPIs for process improvement and call on the expertise of accredited calibration service providers when it makes sense to augment your in-house capabilities.