The Big 6 flowmeter technologies
Where to use them and why

Flow measurement is one of the most important aspects of process control and is found in a wide variety of industry sectors, including upstream, midstream, and downstream oil and gas; chemicals; power generation; pulp and paper; food and beverage; mining; water and wastewater.

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Flow measurement typically relates to media moving through a closed pipe, although sometimes open-channel flow is measured in a flume or weir. It is one of the most frequently measured process variables throughout industry.

There are a wide range of flow applications and a broad variety of flowing media to measure, including liquids, gases, and steam. It can be a very challenging measurement because the process can be complicated by high pressures and temperatures, suspended solids within the fluid, and entrained air. So, it’s not surprising that no single flowmeter technology can accurately measure all types of media or meet all application needs.

Instead, process owners are faced with selecting the optimum meter from the diverse array of flow-measurement technologies available. Some are uniquely qualified to meet the needs of certain applications. In most cases, though, there is application overlap, because the same technologies can be used in multiple applications.

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Technology considerations

Selecting the right flowmeter requires you to first take a look at what media you're measuring, the application process parameters, the level of accuracy required, and finally, your budget for this application.

Measurement purpose and application

First, narrow your search by examining what media you are measuring and the specific application parameters, which may include:

- Flowing media such as liquid, gas, or steam
- Media properties like viscosity, density, specific gravity, operating temperature, etc.
- Controlling a process via a pump or valve
- Monitoring flow from one pipe section to another
- Measuring flow in order to bill a customer through custody transfer that's going to require more-sophisticated, more-precise technology
- Ensuring quality to achieve a precise mix or a blend of materials
- Maintaining safety by triggering alerts/alarms in the event of leaks or spills

To further narrow the field, consider some of the more-specific application details:

- Flowrate and pipe particulars: Flanged, wafer style, material, etc.
- Display requirements: Rate, total flow, etc.
- Output required: Analog or digital, local or remote display
- Device location: Hazardous area, harsh environment, etc.
- Additional information/features: Enhanced diagnostics, conductivity, gas bubbles in the stream, etc.

Accuracy level

Next, keep in mind what level of accuracy you will need. Different flow-measurement technologies deliver different levels of accuracy. You must consider the application requirement (e.g., how accurate MUST the measurement be) and your budget (accuracy that fits budget) as you evaluate the technologies available. Some measurement-data and accuracy variables to consider are:

- System accuracy
- Repeatability
- Response time
- Upstream & downstream straight piping length requirements
- Permanent pressure loss

Total cost for application

The final evaluation to keep in mind is your budget. When looking at the price, a simple, mechanical design will initially be very attractive. The total of cost ownership is likely to be higher, though, when you consider that in a few years you are likely to be replacing parts due to wear and tear. In some applications, energy usage may also be a consideration as some flowmeters require more power than others to operate correctly (pump power and/or direct power).

The Big 6 flowmeter technologies

There are six flowmeter technologies used in the majority of applications. Understanding how each technology works and the advantages and drawbacks of each will provide a good foundation for selecting the right flowmeter.

Figure 1 shows the primary technologies available. The Other category includes thermal mass, positive displacement, and turbine technology. This paper won't cover those. Instead, we will focus on the six major flowmeter technologies beginning with differential pressure.

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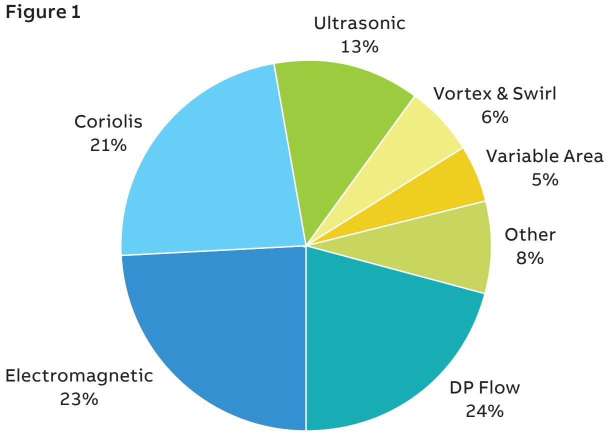
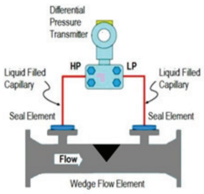
Figure 1





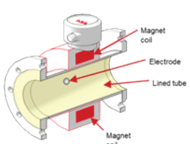
Differential Pressure
This is the most widely used meter, consisting of a flow element, sensors up and downstream from the element, and a differential-pressure transmitter. The primary elements could be orifice plates or venturis, wedges, pitot tubes, nozzles, or other devices.

A common design uses a wedge-shaped flow element that creates a restriction within the pipe to create a pressure drop from one side to the other. As the medium flows from left to right, the higher pressure ahead of the constriction is compared to the lower downstream pressure to derive the differential pressure. The difference between the two is proportional to the medium velocity. The higher the flow velocity, the larger the differential pressure you're going to have.

Regardless of the type of primary element or sensor, the restriction is integrated into the measuring tube. Different flow elements are appropriate for different application conditions. If you have a simple orifice plate with suspended solids in that stream, that creates a lot of turbulence, resulting in a large pressure drop across that restriction. That makes an orifice a poor choice as the flow element in this case. A flow nozzle, for example, will minimize turbulence and reduce the pressure loss.

Advantages
- Suitable for liquid, gas, and steam
- Tolerates extreme process conditions
- Transmitter can be replaced without shutting down the process
- Entirely electronic with no moving parts
- Approved for custody transfer
- Well understood way to measure flow

Limitations
- Limited rangeability due to non-linear discharge coefficient
- Inferior accuracy compared to other technologies
- Accuracy may deteriorate with wear and clogging
- Affected by changes in density, pressure, and viscosity
- Maintenance intensive (orifice plate)

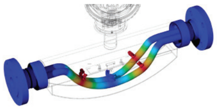


Electromagnetic (Mag Flow)
This technology relies on a magnetic coil that may be integrated with a primary transmitter, or may have a secondary sensor assembly connected to a remotely mounted transmitter. The coils are typically mounted on the top and the bottom of the meter tube. A pair of electrodes is arranged opposite one another, positioned outside of a metal tube that has an inert liner like PTFE (Teflon ™), elastomers, ceramics, or any one of a multitude of different plastic materials. Liner choice depends on the application.

Current from the transmitter is applied to the coil package, creating a magnetic field across the metering pipe. As liquid flows through the field, it essentially forces the negatively and positively charged particles in solution to separate. That separation causes an induced voltage between the two electrodes that is proportional to the flow velocity. The beauty of mag flowmeters is that they have no flow obstructions. They are open pipes with electrodes flush to the liner walls. The technology has been around for decades and is prevalent in many industries because of its simplicity and accuracy with conductive fluids.

Advantages
- Can measure electrical conductivity down to 5 micro siemens
- Typically doesn’t require much upstream (3-5D) or downstream (0-3D) straight piping
- Independent of pressure, temperature, and viscosity
- Works with entrained solids
- Diameter range from 1/10″ to 96″
- Straight-through tube with no moving parts
- No pressure losses

Limitations
- Only conductive liquids can be measured
- Measurement less accurate and more difficult with weakly conductive fluids, e.g. demineralized water
- Deposits inside measuring tube or on electrodes can cause errors



Coriolis Mass

The concept for this technology has been around for a couple of hundred years, but as a practical flow-measurement tool, it has been widely adopted only over the last 10-to-15 years.

These meters actually measure direct mass of the medium using tubes inside a sensor. An exciter imposes a "twisting" motion in the medium that creates a uniform oscillation as the medium flows through measuring tubes. The higher the flow velocity, the greater the deflection of these oscillating tubes. Sensors on the inlet and outlet of the element measure the time of the oscillation, in a one-to-one and a half-second time window, which is the phase shift and is proportional to the mass-flow rate. This provides a direct measurement of the volume of the liquid or gas flowing in the pipe.

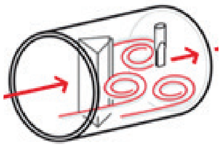
This technology can simultaneously provide density measurement, which can be useful when doing mass-flow calculations. In addition to the frequency of the oscillation, the sensors also measure the amplitude. A denser medium oscillates more slowly.

While the cost of this technology is typically much higher than others, it does provide data that others don't, including temperature.

A major benefit is that measurement is unaffected by density changes. You can measure large pressure drops across the flowmeter at high flow rates and viscosities. Because they are insensitive to density, they are a good choice in applications where the physical properties of the medium are not well known or variable.

Advantages
- Measurement unaffected by fluid density changes, making it appropriate in applications where physical properties of the fluid are not well known or variable
- Suitable for liquid, gas, and steam
- Highest accuracy
- Direct mass measurement with density and temperature
- Applicable to sanitary applications
- Approved for liquid and gas custody transfer
- Highly reliable / low maintenance
- Unaffected by flow-profile disturbances
- Easy installation; no inlet or outlet sections required
- Excellent verification and diagnostic capability

Limitations
- Expensive, especially for sizes above 4"
- Pressure drop can be a considerably higher for older "U-shaped" tube designs and high viscosity fluids
- Limited wetted material selection
- Limited and/or expensive for corrosive fluids
- Limited line size



Vortex and Swirl

Vortex technology is based on a principle that was first identified in the mid-1600s related to the vortices discovered in flowing water. Three hundred years later, physicist Theodore von Karman explored applications of this principle as it related to fluid dynamics. He identified a repeating pattern of swirling vortices that is responsible for the unsteady separation of flow of a fluid around blunt bodies. This effect, known as the Kármán vortex street, causes things like the “singing” of suspended telephone or power lines and the vibration of a car antenna at certain speeds.

Flowmeters based on this principle have an obstruction referred to as a bluff body inside a pipe, usually in the middle of the pipe. The bluff body disturbs the medium flow, causing recurring vortices on each side of that body. A mechanical sensing element measures the frequency of the oscillations between consecutive vortices, which corresponds directly to the flow velocity.

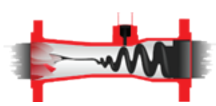
The major advantages of this technology are that it works with all media, and it has no moving parts inside the meter. By adding pressure and temperature, you can look at mass-flow measurement. The most significant drawback is that it doesn’t perform very well with low flow rates.

Advantages

- Suitable for liquid, gas, and steam over wide measurement ranges:
  - 30:1 gas/steam
  - 20:1 liquids
- Available from ½” to 16” diameters.
- Adding pressure and temperature can be used for mass flow measurement
- Good accuracy:
  - ±0.75% Liquid
  - ±1.0% Gas/Steam
- Low pressure loss (typically 0.44 psi)

Limitations

- Pulsating flow reduces accuracy
- Requires long inlet and outlet runs
- Cannot be used for high viscous fluids
- Inferior accuracy compared to other technologies at low end of range
- Not ideal for dirty or abrasive fluids



Swirl technology is very similar in measurement principle to vortex (see below) but with some subtle differences. Swirl meters also measure pressure variation in flow when interrupted by an obstruction, but the bluff body is quite different. The swirl meter has a stationary turbine rotor at the inlet. It creates a small, thread-like rotating or spiral flow of the medium that enlarges and stabilizes as it moves toward the outlet. Sensors at the outlet use the speed of the rotation to calculate the flow rate.

The major benefit of this approach is that, of all flowmeters, it has the least requirement for upstream and downstream straight piping which makes it ideal for tight spaces. In fact, no special piping is usually required.

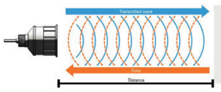
Since there are no moving parts inside the flowmeter, there’s nothing to wear out, making it virtually maintenance free. As with the vortex meter, you can do mass measurement if you incorporate pressure and temperature with it. It’s available with two- and four-wire designs for a wide variety of communication protocols. But, like the vortex technology, it doesn’t perform well with pulsating flows.

Advantages

- Least requirements for upstream and downstream piping
- Excellent accuracy of ±0.5% of rate for liquids, gases, and steam
- Volumetric measurement of liquids, gases, and steam
- Mass flow measurement possible with pressure and temperature sensing
- Low installation costs due to 2-wire technology
- Lower pressure loss than even vortex technology
- Dual & triple-sensor design with redundant analog loops

Limitations

- Pulsating flow reduces accuracy
- Cannot be used for high viscous fluids
- Inferior ability to read at low end of range compared to other technologies
- Not ideal for dirty, corrosive, or abrasive fluids



Ultrasonic

Ultrasonic flowmeters have been around for quite a number of years. The early designs were based on Doppler measurement; the current technology instead relies on ultrasonic transit time. Ultrasonic signals are transmitted both upstream and downstream. Sensors measure the differences in the transit times between the two signals. That data, combined with pipe diameter, are used to calculate the flow rate.

Ultrasonic technology is best suited to measuring liquids – like water, cryogenic liquids, and chemicals – but can also measure gases and vapor. It is commonly used to measure the velocity of liquids that allow ultrasonic waves to pass: water, molten sulfur, cryogenic liquids, chemicals, etc. Slurries, on the other hand, can interfere with the ultrasonic signal.

The major advantages of ultrasonic include the facts that there's really no pressure loss and that the technology can be used with corrosive fluids. The major drawback is you have to be cautious about sludge deposits on the pipe walls that can interfere with the ultrasonic signals. However, more sensors can help overcome that issue.

Advantages
- Can be used in a wide range of pipe sizes
- Able to measure highly corrosive fluids
- No pressure loss
- Can be retrofitted by mounting or welding to a pipe
- Measurement principal independent of physical properties

Limitations
- Measurement results depend on flow profile
- Medium-to-low accuracy, depending on acoustic transparency of fluid
- Deposits on pipe/sensor reduce measurement accuracy
- Doppler method only applicable to certain applications – flow monitoring

Variable Area

The final technology discussed in this paper is variable area (VA). This technology has also been around for many years. It relies on a very simple measurement principle that works well with many different liquids. Commonly used as cost-effective local indication of small liquid or gas flows, it consists of a vertical, conical column, narrow at the bottom and wider at the top, with a specialized float that moves freely up and down.

Flowing fluid enters the bottom of the meter, passes upward through a metering tube, around the float and exits at the top. Flow rate is read by noting the position of the float against the calibrated scale etched on a sight glass. Remote measurements are also possible using sensors that measure the height of the float. This is an inferential type of measurement appropriate for relatively clean liquids and gases. The medium must be clear and clean enough to see the float level.

There are different ways of connecting the float that can be selected to adapt to the application requirements. Some use a spring-opposed vane that moves in relation to the flow rate, others use a spring-opposed piston. The latter is less sensitive to viscosity differences.

Advantages
- Able to measure liquids, gases, or steam
- Low cost
- No power supply needed
- Sight glass designs provide easy, dependable on-site flow monitoring
- Low pressure loss
- Able to handle high pressures

Limitations
- Measuring accuracy depends on process conditions and fluid properties
- Not suited to media that could coat the measuring tube or float or interfere with sight glass
- Requires fluid-specific calibration
- Limited turndown (10:1)
- Affected by entrained matter; not suitable for liquids containing solids
- No totalizing function

Selecting your flowmeter

This table provides a summary of how well each of the six major flowmeter technologies meet the most common application requirements.

Liquids	Differential Pressure	Electromagnetic (Mag Flow)	Coriolis Mass	Vortex & Swirl	Ultrasonic	Variable Area
Clean	***	***	***	***	***	***
Dirty	**	***	***	**	***	**
Conductive	***	***	***	***	***	***
Viscous	**	**	***	*	***	**
Slurries	**	***	***	*	**	*
Corrosive	**	***	**	**	***	**
Reverse flow	**	***	***	*	***	**
Pulsating flow	*	***	***	**	**	*
Gases	**Differential Pressure**	**Electromagnetic (Mag Flow)**	**Coriolis Mass**	**Vortex & Swirl**	**Ultrasonic**	**Variable Area**
Steam	***	*	**	***	*	***
Clean	***	*	***	***	***	***
Wet	**	*	**	*	**	**
Contaminated	**	*	**	**	**	*
Corrosive	**	*	**	**	**	**

*** Performs well, ** Can be used, * Performs poorly

With a better understanding of the different flowmeter technologies and how each can be applied, you can now go back to the three qualifying factors – media and application, level of accuracy, and cost (budget) – that we initially discussed. Evaluate each of those factors with the new knowledge learned about the technology and where to best use that technology. You will find the optimum technology to meet your needs.

As always, we suggest engaging vendors that provide such technologies to gain further insight into their specific product capabilities, measurement accuracies, pricing, etc. to ensure you have all the facts as you make your decisions.

Click here for a pre-recorded webinar on this topic.

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