PendoTECH Flowmeter Offerings and Suggested Applications

1. Introduction

The ability to accurately measure flow is an essential part of being able to control critical aspects of bioprocesses. Flow meters can be used to provide feedback in order to control a process or simply be inline as a passive monitoring device ensuring that that the flowrate does not exceed defined process limits. In either case, the flowmeter must be able to reliably read flow. In order to achieve accurate flow measurements, the proper type of sensor must be selected for each step of the process. PendoTECH offers numerous types of flowmeters to fulfill any process requirement. The following technical note discusses the fundamentals of each flow measuring technology and which meter is best suited for different types of applications.

2. Available Technology

This section will provide a brief overview of how each type of sensor technology works. This not a comprehensive list of all sensor technologies and is limited to those types of sensors sold by PendoTECH.

- **Ultrasonic**

Ultrasonic flowmeters use sound waves to determine the velocity of a fluid flowing in a pipe. At no flow conditions, the frequencies of an ultrasonic wave transmitted into a pipe and its reflections from the fluid are the same. Under flowing conditions, the frequency of the reflected wave is different due to the Doppler effect. When the fluid moves faster, the frequency shift increases linearly. The transmitter processes signals from the transmitted wave and its reflections to determine the flow rate.

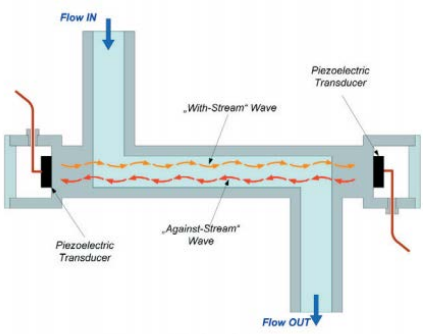
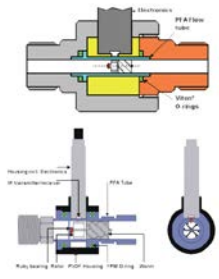


Figure 1: Operating principle of ultrasonic single-use sensor

This technology can be very accurate and has high turndown (can read low as a percentage of the full scale as well as full-scale flow), handles high pressures, is repeatable (consistent), handles extreme temperatures, is low maintenance, highly reliable and self –diagnosing. Disadvantages can include high cost, sensitivity to stray process vibrations, problems with pipe diameter change due to buildup, and clamp-on units have lower accuracy. Additionally, ultrasonic flowmeters do not accurately measure fluids with changing properties, such as viscosity.

- **Rotary (Impeller) Flowmeter**



Rotary flow sensors work by measuring the rotations of the rotor that is in the flow path. The rotor rotates on a ruby bearing and is the only moving part. The rotor blades reflect an infrared light beam and each rotation measured is converted to an electrical pulse that is received by the flow monitor which has a “pulse accumulator” that counts the pulses. The rotations per second are converted to volume/minute by a factor called the pulse constant (k-factor). The nominal pulse constant is different for each rotor size and pre-calibrated pulse constants for each rotor are available for units purchased from PendoTECH. For best accuracy, with fluids of viscosity much different than water, the pulse constant can be easily calculated by measuring a known volume and setting the monitor to count the pulses. The pulse constant is then calculated by the pulses counted divided by the volume.

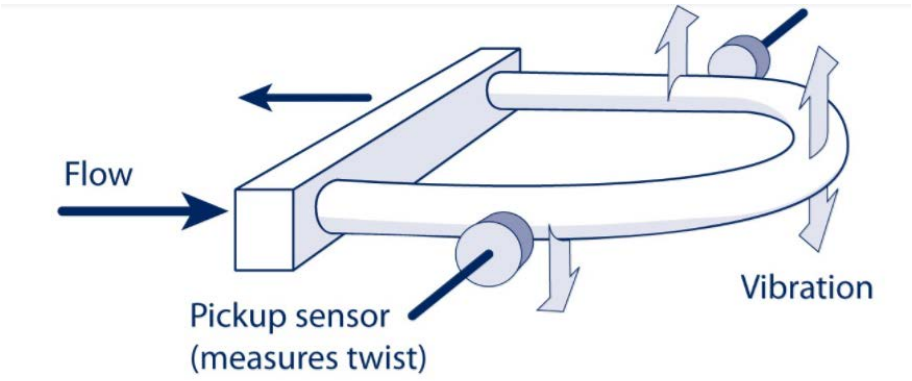
The main advantage of rotary flowmeters is their low cost which makes them amenable to single use applications. Disadvantages include comparatively poor accuracy. Also, rotary flowmeters are not recommended for solutions where there are changes in viscosity or density, or where particles and debris are present.

- **Coriolis**

  Coriolis mass flowmeters measure the force resulting from the acceleration caused by mass moving toward (or away from) a center of rotation. With flowmeters, water is flowing toward and away from the center of rotation, opposite forces are generated and cause the hose to twist. The amount of twist is proportional to the mass flow rate of fluid passing through the tube(s). Sensors and a Coriolis mass flowmeter transmitter are used to measure the twist and generate a linear flow signal.

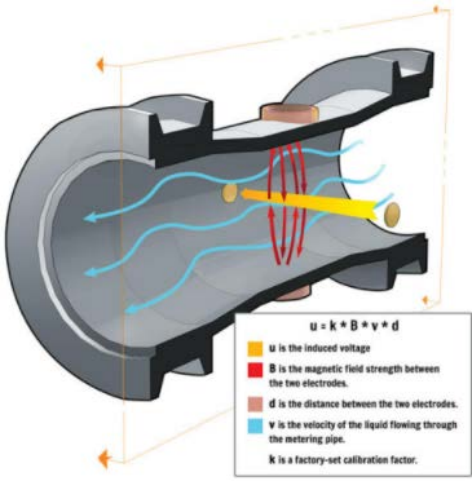
  This technology has high accuracy, can handle sanitary applications, and is highly reliable and low maintenance. Mass flowmeters are also ideal for situations when the characteristics of a fluid will be changing throughout the duration of an experiment as they are not dependent on a constant fluid density or viscosity. This is particularly important for TFF experiments when the concentration of a solution will be changing significantly throughout the run. Coriolis flowmeters are recommended on the retentate line for accurate measurements due the changing fluid properties previously mentioned.

  The cost for Coriolis flowmeters are high and are not generally available in a low cost single-use format. Pressure drop and hold-up volume should be a consideration for “U” shaped tube designs and high viscosity fluids.



- **Magnetic Flow Meter**

  An electromagnetic flow meter, commonly referred to as a mag flow meter, is a volumetric flow meter with no moving parts and ideal for applications where low-pressure drop and low maintenance are required. These meters measure fluid velocity using electromagnetic induction. A fluid passes through the metering tube where a magnetic field is applied. This results in a potential difference proportional to the flow velocity which the meter then converts to a linear flow measurement.

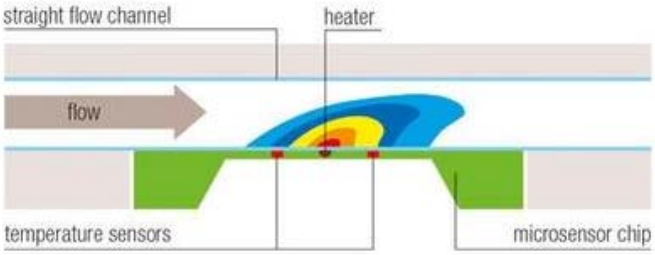


  Mag flow meters provide reliable accuracy and minimal maintenance as there are no moving parts. They can be adapted for sanitary uses and work on dirty liquids and slurries. This results in a meter that can be used in a wide range of applications however, they do not work on nonconductive fluids and cannot be used to measure steam or gas flows.

- **Thermal Flow Measurement**

  Thermal mass flow meters are ideal for measuring very low fluid flow rates. They operate by introducing a known amount of heat into a flowing stream and measuring the associated temperature change. Thermal mass flowmeters are unaffected by changes in viscosity, density, temperature, or pressure. The components of a basic thermal mass flow meter include two temperature sensors and a heating element between them.

  Standard thermal mass flow measurements use coils wrapped around a steel capillary in order to measure flowrate.



3. PendoTECH Offerings

Product/Technology	Description	Flow Range/ Typical Accuracy	Single Use?	Application
Coriolis  *This flow measurement technology is needed if a change in viscosity/density is expected, or if particles in the fluid are present*	**PendoTECH Coriolis Flow Meter:** Advantages: Highly accurate and can measure fluids with changing properties. Disadvantages: Cost, generally not available as low cost for single-use applications.	Available in different sizes: PCFM-31: 12-1500 ml/min PCFM-32: 12-4000 ml/min Accuracy: 1% of reading + Z.O.S. (Z.O.S. varies by model)	Only where the high cost of disposable can be tolerated	Applications where viscosity of liquid is changing. Often used on retentate line of TFF processes.
Rotary  *Small turbine located in line of the fluid path.*	**PendoTECH Rotary Flow Meter:** Advantages: Cost effective and single use. Disadvantages: Cannot handle change in viscosity/density, comparatively poor accuracy, particles and debris in fluid will diminish performance.	Available in different sizes, 0.1-2 L/min and 0.3- 20L/min Accuracy: ± 5% of reading	Yes	Processes with constant flow regime and density/viscosity of solution. Works best with filtered materials. Processes where costs must be kept low. Often used on TFF permeate lines.

Product/Technology	Description	Flow Range/ Typical Accuracy	Single Use?	Application
UltraSonic  *Uses sound waves to non-invasively measure very low flows*	**PendoTECH Low-Flow Ultrasonic Flow Meter** Advantages: Accurate and non-invasive. Ideal choice for low flow experiments. Disadvantages: Generates back pressure at high end of operating range. Cannot handle change in viscosity/density.	Flow rate: 2-200 mL/min Accuracy: ± 2% of the reading for flow rates over 100 mL/min, ± 2% ± 0.2 mL/min for flow rates under 100 mL/min	No	High accuracy ultrasonic flowmeter for low flow applications. Ideal for small normal flow filtration applications or on TFF permeate lines.
Single-Use Ultrasonic 	**Leviflow Single Use Flowmeters** Advantages: Highly accurate and a range of models to cover large flow range. Designed for single-use applications. Disadvantages: Must be calibrated to specific liquid being processed. Single-use component cost. Cannot handle change in fluids viscosity.	FM-LFS-03SU = 0-0.8 L/min FM-LFS-06SU = 0-8 L/min FM-LFS-10SU = 0-20 L/min FM-LFS-20SU = 0-80 L/min Accuracy ~3% of reading. Depends on model	Yes	High accuracy ultrasonic flowmeter for low flow applications. Various models for any flow requirements. Ideal for normal flow filtration applications or on TFF permeate lines.

Product/Technology	**Description**	**Flow Range/ Typical Accuracy**	**Single Use?**	**Application**
Clamp-on Ultrasonic 	**Leviflow Clamp-on Flowmeters** Advantages: Non-invasive and reusable. Disadvantages: Must be calibrated to specific tubing. Accuracy	Four models available covering flows up to 160 l/min Accuracy ~3% of reading. Depends on model	Yes	Various models for any flow requirements. Ideal for normal flow filtration applications or on TFF permeate lines.
Electro-magnetic *No obstructions in fluid path.* 	**Endress+Hausser PROMAG** Advantages: No pressure loss. Very accurate, wide flow rate range. Non-invasive. Works with changing viscosity. Disadvantages: Liquid MUST have some conductivity to read and not available in single-use format.	Flow rate: 2-98 L/min (smallest size) Accuracy: ±0.2 %	No	Applications where viscosity of liquid is changing. Often used on retentate line of TFF processes/

4. Conclusions:

- The accuracy required for a specific application plays a large role in determining what type of sensor is required. Highly precise measurements require more expensive sensors such as a Coriolis or ultrasonic meter. Sensors used for general trending or information collection only can use more basic technology like the rotary flowmeter mentioned above.
- Single-use flowmeters are available and can be integrated into tubing sets.
- Mass flowmeters provide the most accurate/reliable measurements and remain effective even when the fluid properties are constantly changing.
- Particulates in the fluid can dramatically affect measurements.