Advances in Flowmeter Technologies

ISA Los Angeles Section – 3/9/2021

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Agenda

1	Introduction
2	Basics
3	dP Flow Measurement
4	Vortex Flowmeters
5	Electromagnetic Flowmeters
6	Coriolis Flowmeters
7	Sizing Tool

Introduction

Qualifications

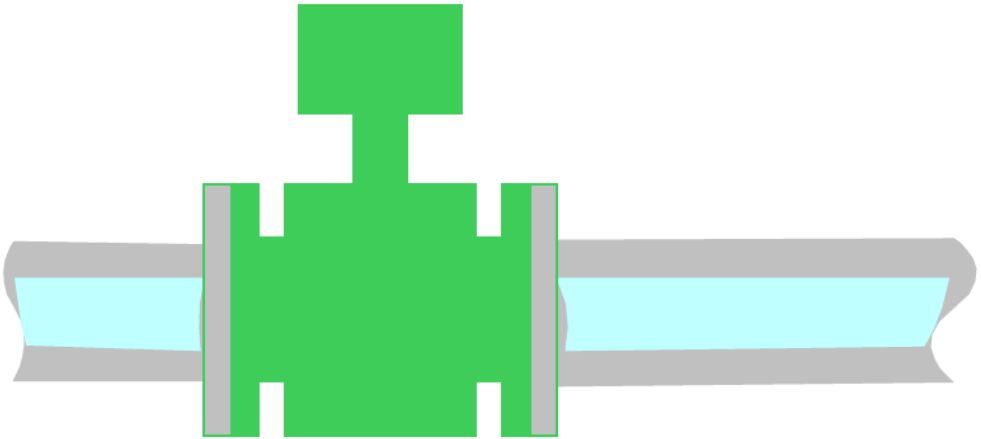
- Leandro “Leo” Massaro
  - Business Development Manager – North America
  - Bachelor of Science Engineering – Mechatronic Engineer
  - Master of Science – Systems Engineer (Advanced Control and System Identification)
  - 6 Years as Control Systems and Instrument Engineer at an EPC company
  - 2014 – Technical Sales Consultant - Brazil
  - 2016 – Business Development Manager – Latin America
  - 2017 – Business Development Manager – North America
  - 2020/2021 – ISA Houston Section Treasurer
  - linkedin.com/in/leandromassaro

Basics

Why do we measure flow?

Why do we measure Flow?

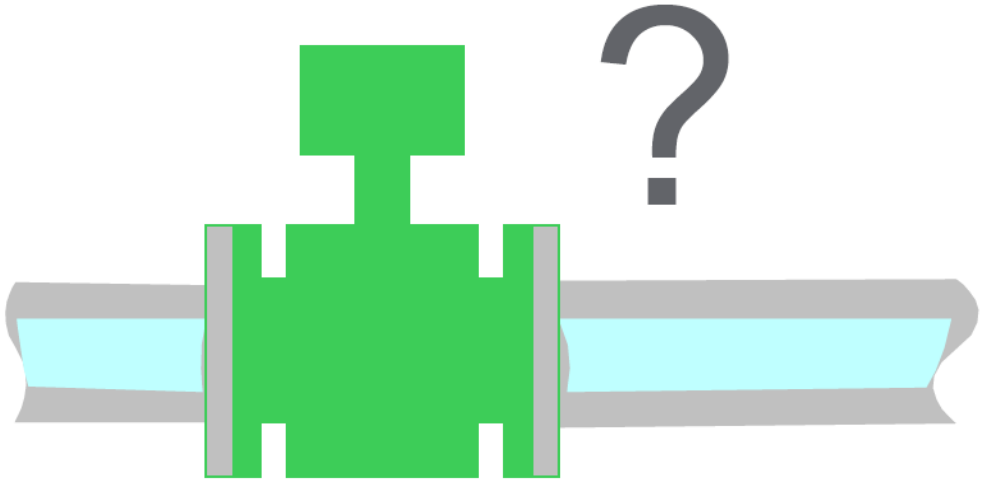
- Control a process
- Billing (Custody Transfer)
- Blending
- Efficiency (mass balance)
- Boiler water feed
- Burner fuel feed
- Leak detection
- …
- Answer – “How much”



Basics

Complex task

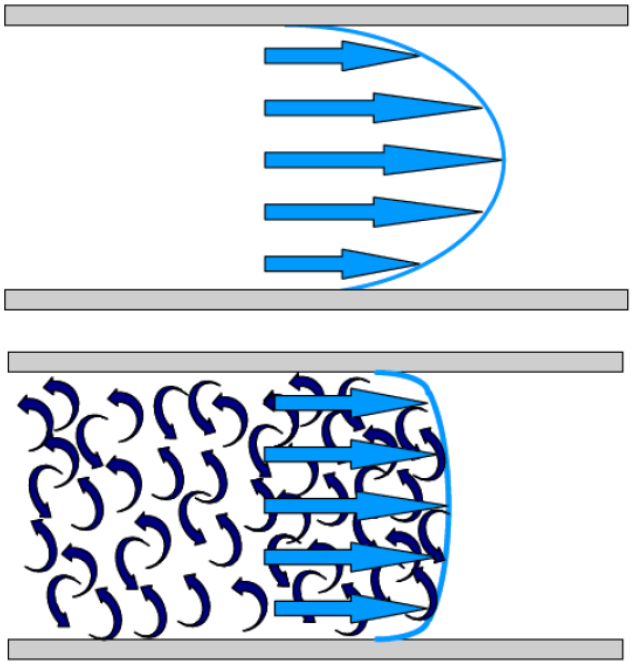
- Mass or volume?
- Viscosity?
- Abrasive?
- Corrosive?
- Price?
- Pressure drop?
- Straight pipe run?
- Accuracy?
- Density?
- …



Basics

Reynolds Number

- **Reynolds number defines the state of the flow regime in a pipe!**
- Reynolds number (Re) is a dimensionless number
- Laminar profile – Re < 2,000
- Turbulent profile – Re > 8,000
- The higher the viscosity, lower the Reynolds number
- The higher the density, higher the Reynolds number
- The higher the velocity, higher the Reynolds number
- The technology you will choose depends heavily on your flow regime

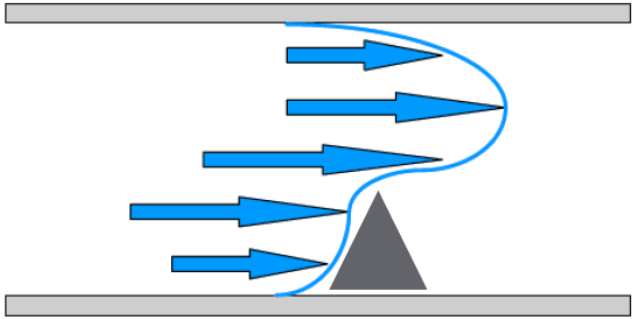


$$Re = \frac{\rho \cdot v \cdot d}{\mu}$$

Basics

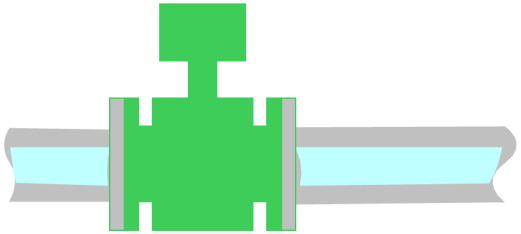
Disturbed flow profiles

- **Flow profile can severely affect measurement accuracy!**
- What affects the flow provide?
  - Bends
  - Elbows
  - Reducers
  - Expanders
  - Etc.
- Flow profile will be restored by the natural mixing action of the fluid particles as the fluid moves through the pipe
- Straight pipe runs - pipe diameters upstream and downstream of the flowmeter



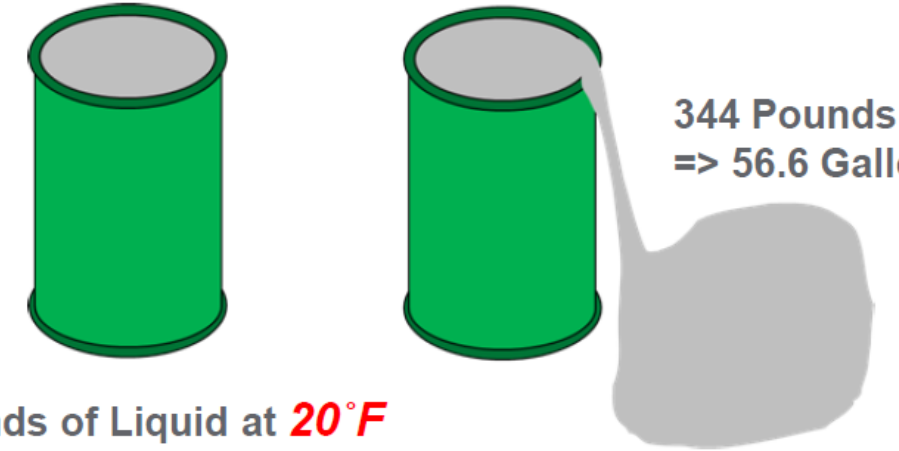
Basics

What do you need to measure?



- Mass with the symbol m measured in kg or g, Pounds (lb) or Tons
- Volume with the symbol V measured in m^3, dm^3 or cm^3, $feet^3$, U.S. gallons or $inch^3$

Mass versus Volume



Basics

What do you need to measure?

- Volume can be measured as:
  - Actual Volume
  - Standard or Normal Volume
- Liquids – usually Actual Volume
- Gases – Normal or Standard Volume
  - Volume compensated to specific pressures and temperatures
  - How are you going to compensate it?
  - To which conditions?

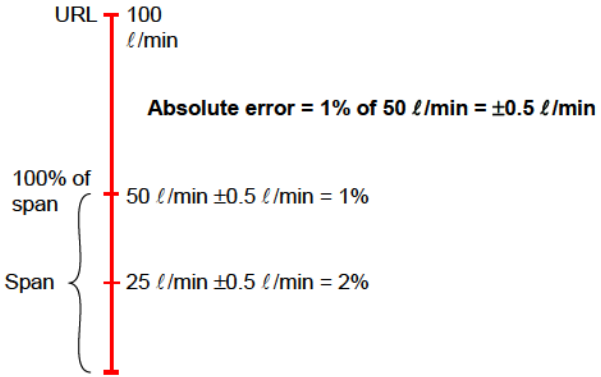
Standard reference conditions in current use

Temperature	Absolute pressure	Relative humidity	Publishing or establishing entity
°C	kPa	%	
0	100.000		IUPAC (STP)[1]
0	101.325		NIST,[7] ISO 10780,[8] formerly IUPAC[1]
15	101.325	0[2][9]	ICAO's ISA,[9] ISO 13443,[2] EEA,[10] EGIA[11]
20	101.325		EPA,[12] NIST.[13] This is also called NTP, Normal Temperature and Pressure.[14]
22	101.325	20-80	American Association of Physicists in Medicine[15]
25	100.000		IUPAC (SATP)[1]
25	101.325		EPA[16]
20	100.000	0	CAGI[17]
15	100.000		SPE[18]
20	101.3	50	ISO 5011[19]
°C	mmHg	%	
20	760.0	0	GOST 2939-63
°F	psi	%	
60	14.696		SPE,[18] U.S. OSHA,[20] SCAQMD[21]
60	14.73		EGIA,[11] OPEC,[22] U.S. EIA[23]
59	14.503	78	U.S. Army Standard Metro[24][a]
59	14.696	60	ISO 2314,[25] ISO 3977-2[26]
°F	inHg	%	
70	29.92	0	AMCA,[27][b] air density = 0.075 lbm/ft³. This AMCA standard applies only to air.
59	29.92		Federal Aviation Administration (FAA)[28]

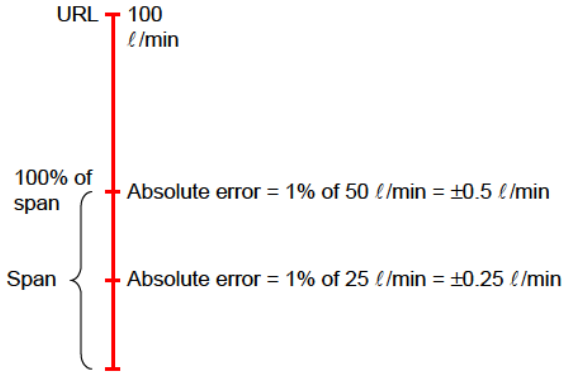
Basics

Accuracy

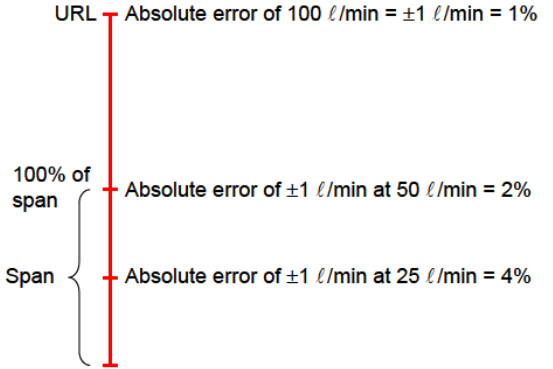
- Flowmeter 1
  - URL = 100ℓ/min
  - Calibrated Span = 0 – 50 ℓ/min
  - Accuracy = ±1% of Span



- Flowmeter 2
  - URL = 100ℓ/min
  - Calibrated Span = 0 – 50 ℓ/min
  - Accuracy = ±1% of Reading



- Flowmeter 3
- URL = 100ℓ/min
- Calibrated Span = 0 – 50 ℓ/min
- Accuracy = ±1% of URL



Basics

Accuracy vs. Repeatability

- Poor Repeatability
  - Means Poor Accuracy

- Good Accuracy
  - Means Good Repeatability

- Good Repeatability
  - Does Not Necessarily Mean Good Accuracy

Flow Technologies

Trends

- **There is not 1 meter that will meet every application!**
- ±50% by Differential Pressure in combination with primary flow elements, trend stabilizing
- ±20% by Electromagnetic Flowmeters, trend stabilizing
- ±5% by Coriolis Flowmeters, trend strongly rising
- ±5% by Vortex Flowmeters, trend rising
- ±20% by Other Technologies






Flow Technologies

Metering Technology	Clean liquid	Dirty liquid	Corrosive liquid	Low conductivity < 5 µS/cm	High (> 150°C) Temperature	Low (< -40°C) Temperature	Low velocity	High viscosity	Abrasive slurries	Fibrous slurries	Clean Gas	Dirty Gas	Steam	Semi-filled pipe
Coriolis	Good	Good	Limited	Good	Limited	Good	Good	Good	Limited	Good	Limited	Limited	No	Limited
Electro Magnetic	Good	Good	Good	No	Limited	Limited	Good	Good	Good	Good	No	No	No	Limited
Vortex	Good	Limited	Limited	Good	Good	Limited	No	No	No	No	Good	Limited	Good	No
Integral Flow (dP)	Good	Limited	Limited	Good	Good	Limited	No	No	No	No	Good	Limited	Limited	No
Orifice Plate (dP)	Good	Limited	Limited	Good	Good	Limited	No	No	No	No	Good	Limited	Good	No
Averaging Pitot tube (dP)	Good	Limited	Limited	Good	Good	Limited	No	No	No	No	Good	Limited	Good	No
Venturi (dP)	Good	Good	Limited	Good	Good	Limited	No	No	Limited	Limited	Good	Good	Good	No
V-Cone (dP)	Good	Good	Limited	Good	Good	Limited	No	No	Limited	Limited	Good	Good	Good	No
Wedge (dP)	Good	Good	Limited	Good	Good	Limited	No	No	Good	Good	Good	Good	Good	No
Flow Nozzles (dP)	Good	Limited	Limited	Good	Good	Limited	No	No	No	No	Good	Good	Good	No
Thermal Mass	Good	Limited	Limited	Good	Limited	No	Good	Limited	Limited	Limited	Good	Limited	Good	No
Positive Displacement	Good	No	Limited	Good	Limited	Limited	Good	Limited	No	No	Good	Limited	No	No
Turbine	Good	No	Limited	Good	Limited	Limited	No	No	No	No	Good	Limited	Good	No
Ultrasonic (transit time)	Good	Limited	Limited	Good	No	Limited	Limited	Limited	No	No	Good	Limited	No	No
Ultrasonic (doppler)	No	Good	Limited	Good	No	Limited	Limited	Limited	Limited	Limited	No	Limited	No	No
Ultrasonic (multibeam)	Good	Limited	Limited	Good	No	Limited	Limited	Limited	No	No	Good	Good	Limited	No
Variable Area	Good	No	Limited	Good	Limited	No	No	No	No	No	Good	No	No	No

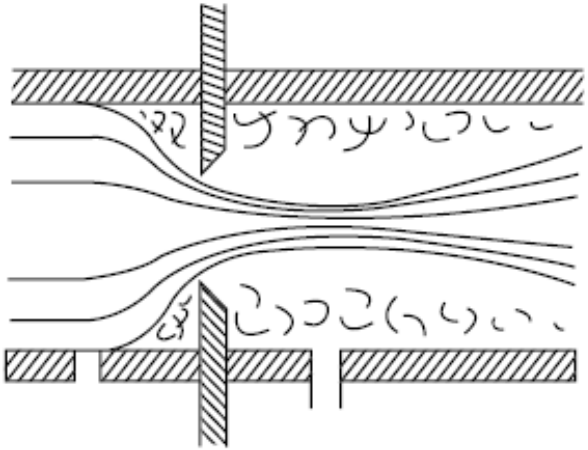
dP Flowmeters

The most common technology

dP Flowmeters

How it works

- Differential Pressure Flowmeters are based on a physical phenomenon in which a **restriction in the flow line creates a pressure drop that bears a relationship to the flow rate**
- The pressure decrease that results from a flowing stream passing through a restriction is **proportional to the flow rate and to fluid density**
  - The Equation of Continuity and the Bernoulli's equation
- If the **density is constant** (or if it is measured and we correct for its variations), the flow rate is the **square root extraction of the differential pressure**



$$Q(\text{flow}) = K(\text{constant})\sqrt{\frac{h(\text{differential head})}{d(\text{fluid density})}}$$

dP Flowmeters

Advantages vs. Disadvantages

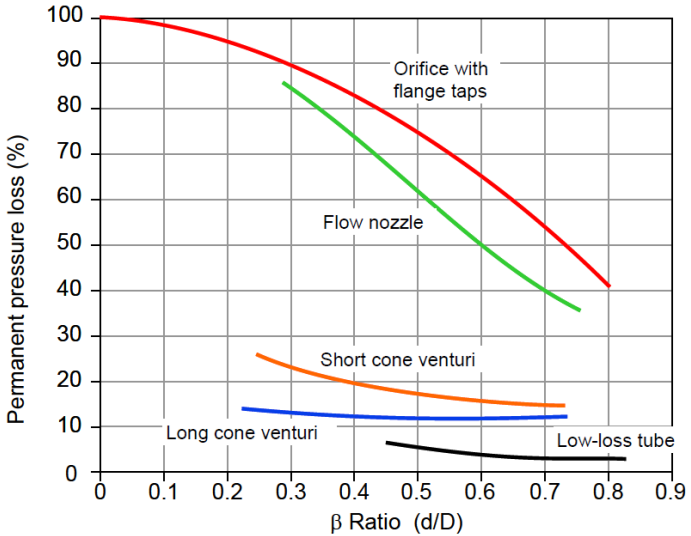
- Advantages:
  - The most familiar meter type – **Well known and well accepted** (multiple standards)
  - They are widely used to measure flow of both gases and liquids, including viscous and corrosive fluids
  - Suitability for practically all flow rates in a wide variety of pipes and tubes
  - No moving parts
  - **Loop-powered devices (2-wire)**
  - **Relatively low cost**
  - **Easy to prove (dP Transmitter)**

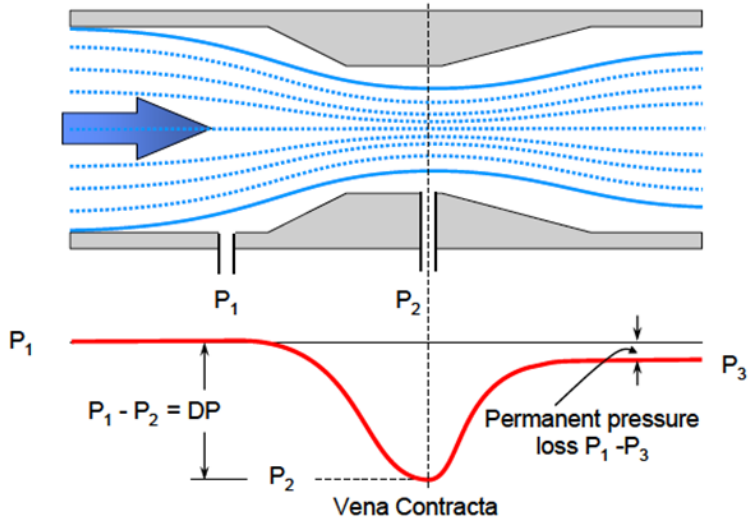
- Disadvantages:
  - **Permanent pressure head loss**
  - Often long straight pipe runs are required
  - There are many potential leakage points
  - **Rangeability is limited (typically 3:1)**
  - The output is not linearly related to flow rate, thus entailing square root extraction
  - **If density is not constant, it must be known or measured (gas)**

dP Flowmeters

Permanent Pressure Loss

- **Differential pressure measurement creates a permanent pressure loss**

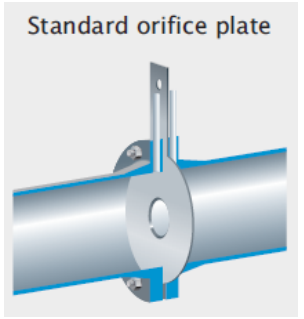


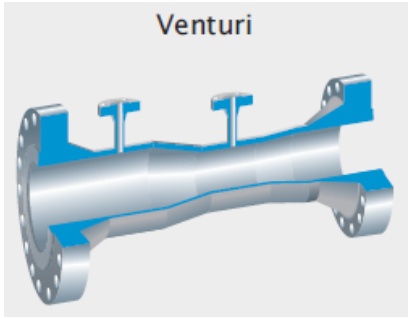


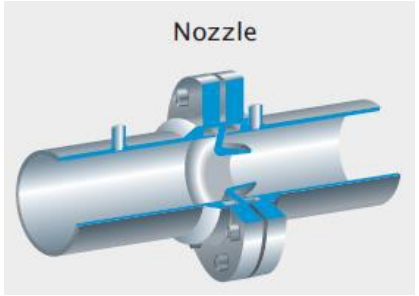
dP Flowmeters

Primary Flow Elements

- Several primary flow elements available:
  - Orifice Plate:
    - Simplest and most widely used (inexpensive)
    - Price does not increase dramatically with size
    - Highest pressure drop
  - Venturi
    - Less significant pressure drop across restriction
    - Less unrecoverable pressure loss
    - Requires fewer straight pipe runs
  - Nozzle:
    - Adaptation of the standard venturi
    - Higher pressure drop than Venturi, but cheaper



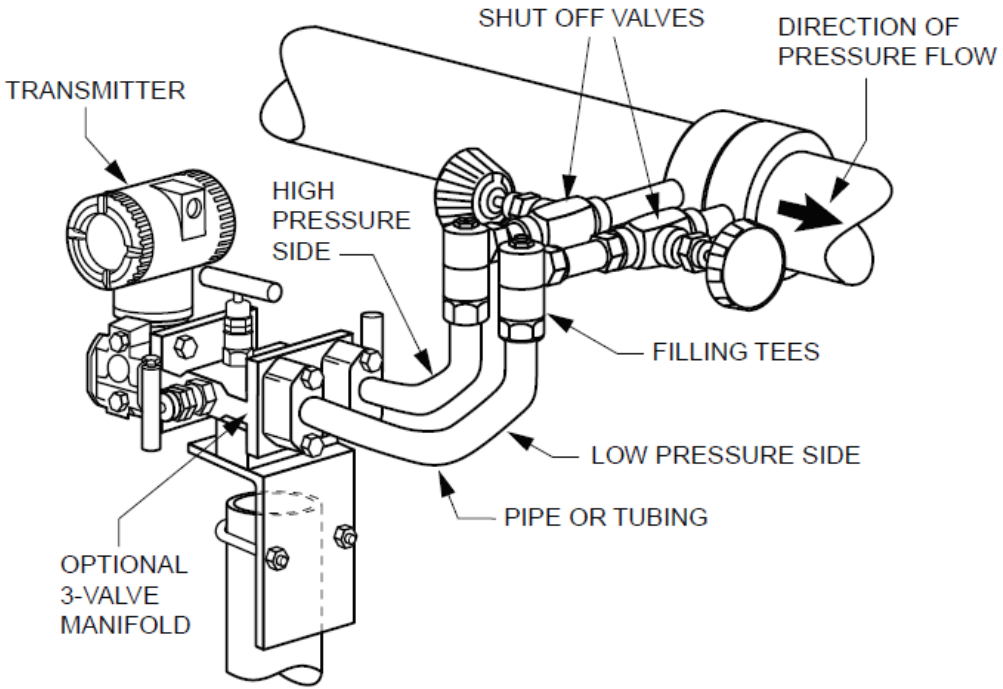




dP Flowmeters

Leak Points

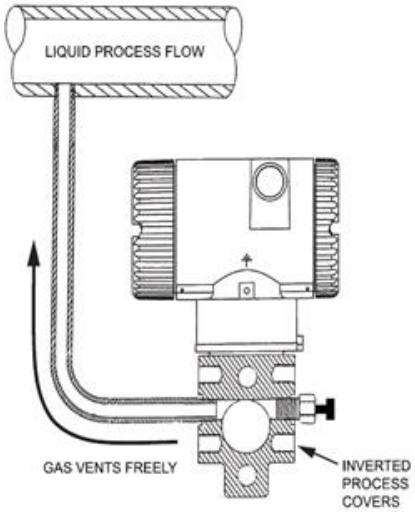
- **Leakage Points could be a concern**



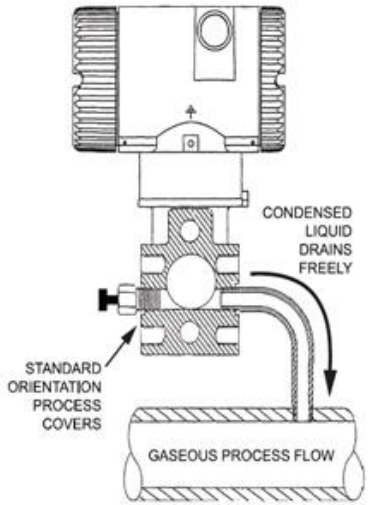
dP Flowmeters

Installation

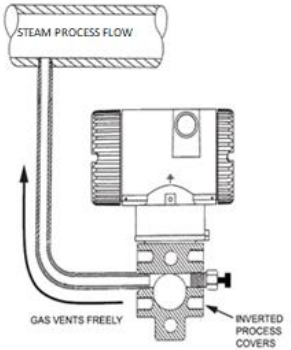
- Liquid Flow:
  - Process connection on the bottom or side or the process piping
  - Transmitter under process line



- Gas Flow (without seal liquid):
  - Process connection on top of the process piping
  - Transmitter above process line



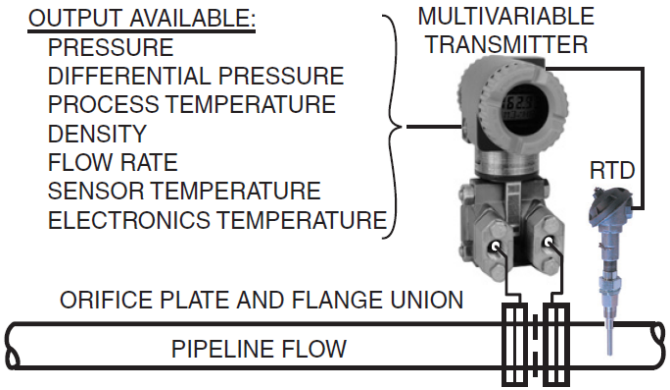
- Steam Flow or Gas Flow with Seal Liquid:
  - Seal Liquid to protect transmitters
  - Process connection on the bottom or side or the process piping
  - Transmitter under process line

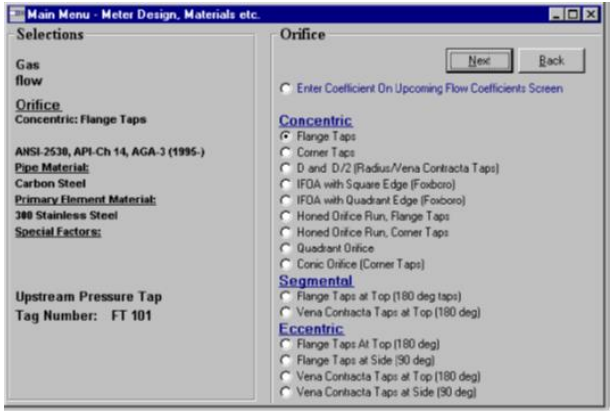


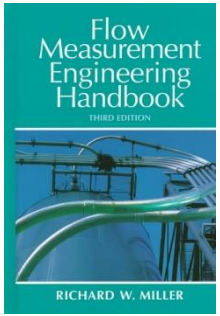
dP Flowmeters

Multivariables

- **If density is not constant, it must be known or measured**
- This is of the upmost important to gas measurement
- Several equations available
- Compensation can be done in a flow computer, PLC, DCS, or in a multivariable dP







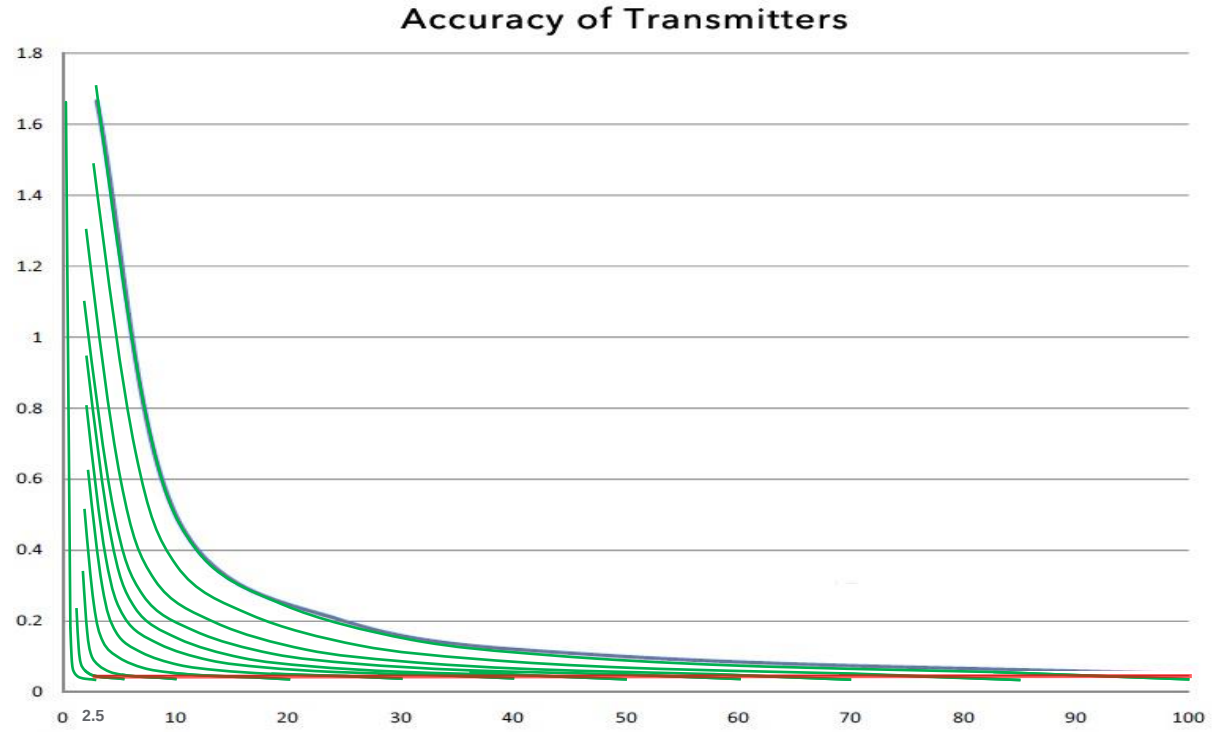
dP Flowmeters

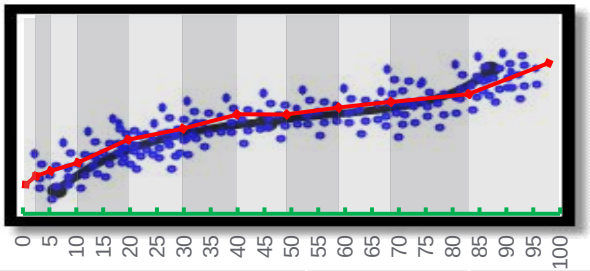
S Series - Adaptive Sensing Technology

- **1 Transmitter that does it all**
- Same IGP part number, for 50, 500 and 2,000 psi
- Same IDP part number, for 25, 100 and 1,000 inH2O
- Up to 400:1 Turndown Ratio (Max Span/Min Span)
- Adaptive Sensing Technology – FoxCal
- 11 calibration curves included in 1 transmitter
- Automatic transition

dP Flowmeters

S Series - Adaptive Sensing Technology





IGP10S		max. 2000 psi	max. 138 bar
FoxCal Curves (0 to X% URL)	FoxCal Points (X% URL)	psi	bar
Calibration 1	100	2000	137.9
Calibration 2	85	1700	117.2
Calibration 3	70	1400	96.5
Calibration 4	60	1200	82.7
Calibration 5	50	1000	68.9
Calibration 6	40	800	55.2
Calibration 7	30	600	41.4
Calibration 8	20	400	27.6
Calibration 9	10	200	13.8
Calibration 10	5	100	6.9
Calibration 11	2.5	50	3.4

dP Flowmeters

Accuracy – New Concept!

- Without FoxCal:
  - URV = 2,000 psig
  - LRV = 0 psig

Process Pressure (psi)	Accuracy (% span)	Accuracy (% reading)	Accuracy (psi)
2,000	0.05%	0.05%	1.0
1,000	0.05%	0.10%	1.0
500	0.05%	0.20%	1.0
200	0.05%	0.50%	1.0
100	0.05%	1.00%	1.0
50	0.05%	2.00%	1.0
20	0.05%	5.00%	1.0

- With FoxCal:
  - URV = 2,000 psig
  - LRV = 0 psig

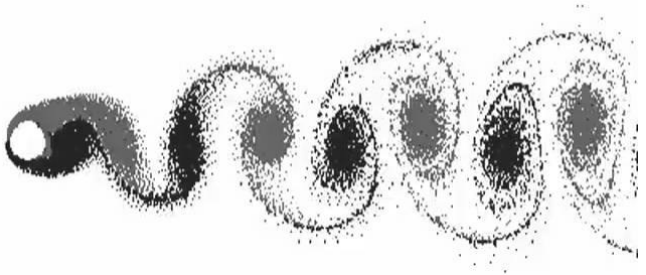
Process Pressure (psi)	Accuracy (% span)	Accuracy (% reading)	Accuracy (psi)
2,000	0.05%	0.05%	1.0
1,000	0.025%	0.05%	0.50
500	0.013%	0.05%	0.25
200	0.005%	0.05%	0.10
100	0.003%	0.05%	0.05
50	0.002%	0.08%	0.04
20	0.002%	0.20%	0.04

Vortex Flowmeters

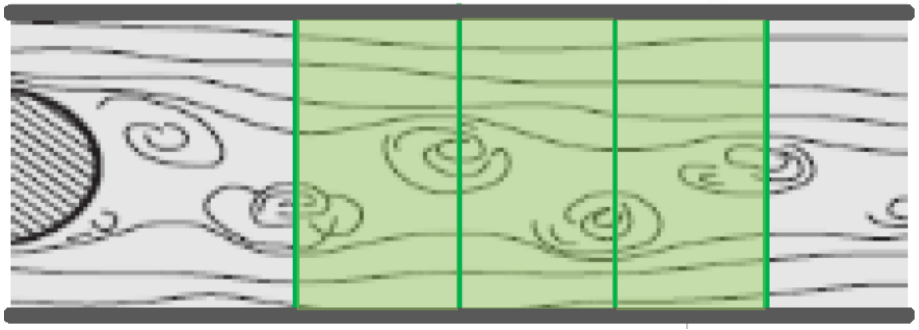
Ideal for Turbulent Flow

Vortex Flowmeters

Basics

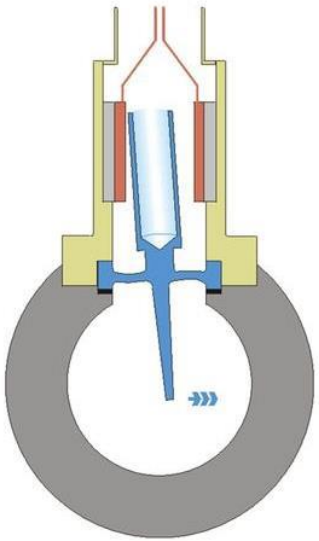


- Theodore von Kármán
- When a body (**bluff body**) is placed in the middle of a **turbulent** media flow **vortices are formed on both sides**, for example a flag waving from a flagpole
- Knowing the pipe diameter … every section between the vortices represents a defined volume, so vortex is a **true volumetric flow measurement**



Vortex Flowmeters

Sensor



- Flowmeter:
  - Bluff Body – Shedder Bar
  - Sensor – Detector
  - Flowmeter body
  - Transmitter
- Several types of detectors
  - Some are mechanical, like flappers
  - Some are based on piezoelectric elements
- Multivariable options available (temperature sensors built-in)
- Built-in mass flow computers (especially for steam)

Vortex Flowmeters

Advantages vs. Disadvantages

- Advantages:
  - Good accuracy (0.5% for gases and 1.0% for liquids – rate)
  - **No drift**
  - No moving parts
  - **It can measure the flow of gas, steam or liquid**
  - High rangeability
  - **Low maintenance**
  - **Economically competitive alternative to orifice plates**

- Disadvantages:
  - **Flow profile needs to be turbulent (not good for low velocities)**
  - Reynolds number usually needs to be more than 10,000
  - Limited to 16”
  - **Not good for high viscosity or dirty process fluids**

Vortex Flowmeters

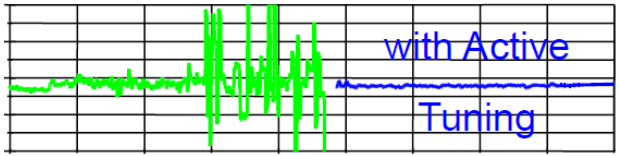
Reliable Measurement with the Best Accuracy and Lowest Cost of Ownership

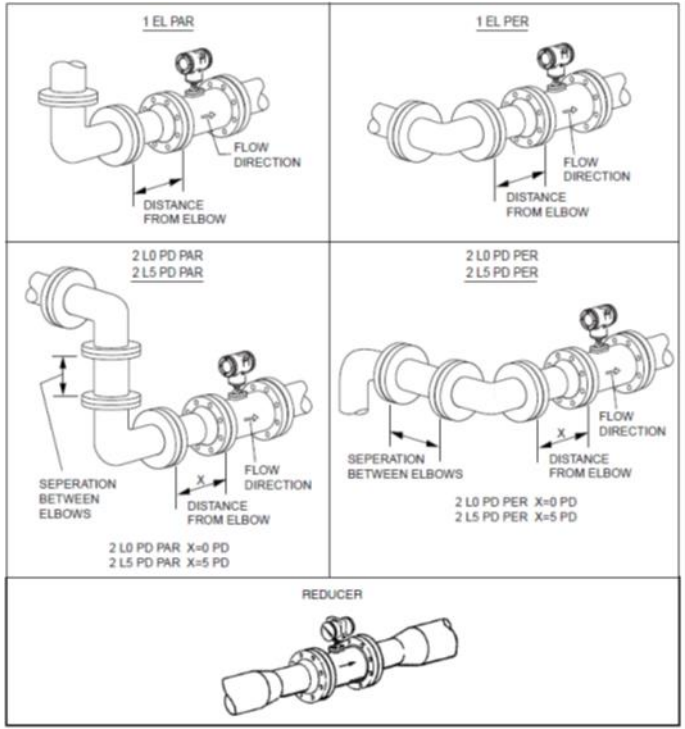
- **Reliable Measurement with the Best Accuracy and Lowest Cost of Ownership!**
- DirectSense Technology
- No Moving Parts
- Widest Rangeability
- Best Accuracy on the market:
  - 0.5% for Liquids
  - 1.0% for Gas and Steam
- Up to 800º F
- Wafer, Flanged or Threaded
- Up to 12” and 1500#

Vortex Flowmeters

ActiveTuning

- **Installation issues and low flow – How to address them?**
- Standard Straight Run Requirements:
  - 30 pipe diameters upstream and 5 pipe diameters downstream
- ActiveTuning:
  - 5 pipe diameters upstream
  - General Recommendation for Reynolds Number is 20,000
  - With ActiveTuning, down to 5,000
  - Adaptive Filtering and Signal Conditioning

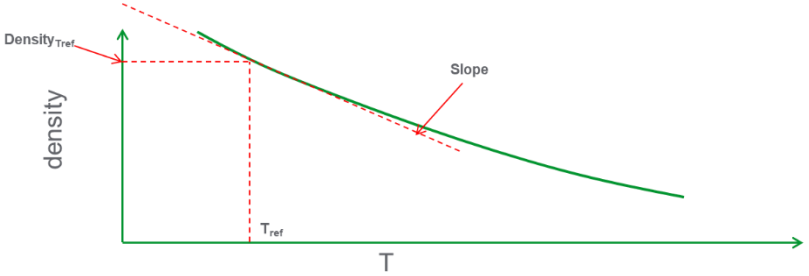




Vortex Flowmeters

Multivariable

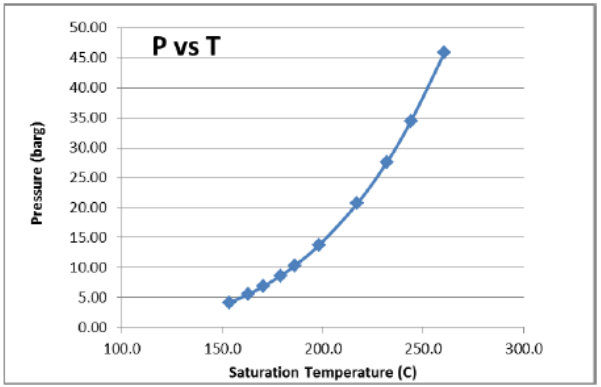
- **Which applications do you usually use a Multivariable Vortex?**
- RTD included for Temperature Compensation
- Saturated Steam Curves are built-in
- Live Pressure Input via HART for Super-heated Steam
- User-defined Liquids

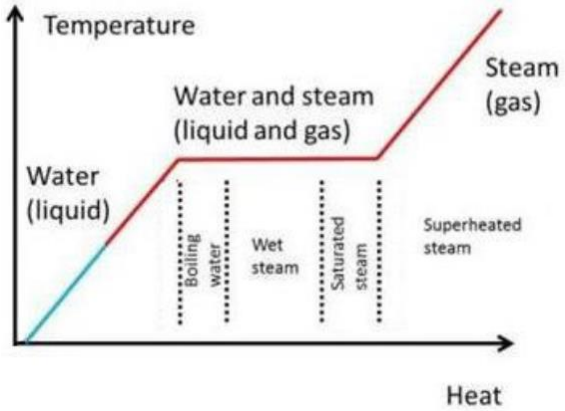


Vortex Flowmeters

Multivariable for Saturated Steam

- **How do you measure your Energy Consumption?**
- Saturated steam has a direct relation between pressure and temperature
- Saturate steam is widely used to transfer energy
- SE Multivariable Vortex Flow Meter = 1.4% accuracy for Energy
- Advantages over other technologies (Mechanical and Orifice Plates):
  - One process penetration
  - Simple commissioning and start up
  - No external compensation required
  - Low up front costs
  - Operational cost savings due to higher accuracy





Vortex Flowmeters

No Calibration Shift…Proven results!

- **No Calibration Shift…Proven results!**
- Client using Vortex for custody transfer of steam
  - Regulatory Requirements:
    - Meter calibration verification every 5 years
    - Returned to the manufacturer
    - Verified using NIST standards
- Database of 1,200+ meters over 23 years
  - Only noticeable shift in K-factor

Serial #	# of Calibrations	Year Mfg	Years in Service (Since most recent recal.)	Year Calibrated	KRef	Max % Change
93421792	2	1993	17	2010	81.28628	0.03%
93421791	2	1993	11	2004	80.5637	0.05%
93421797	2	1993	11	2004	80.6555	0.04%
93421795	2	1993	11	2004	79.8699	0.02%
97211739	2	1997	10	2007	548.94	0.09%
93421757	2	1993	10	2003	258.966	0.01%
97211745	2	1997	9	2006	264.6127	0.03%
93421794	2	1993	9	2002	80.645	0.02%
3200669	2	2003	7	2010	10.01216	0.08%
98121633	3	1998	7	2005	266.9476	0.08%
96080237	2	1996	7	2003	263.1308	0.05%
97211733	2	1997	7	2004	79.5455	0.01%

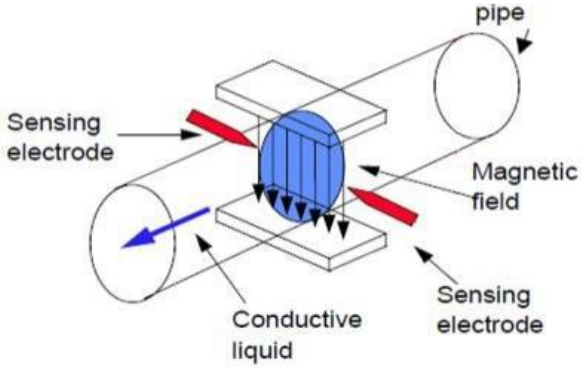
Electromagnetic Flowmeters

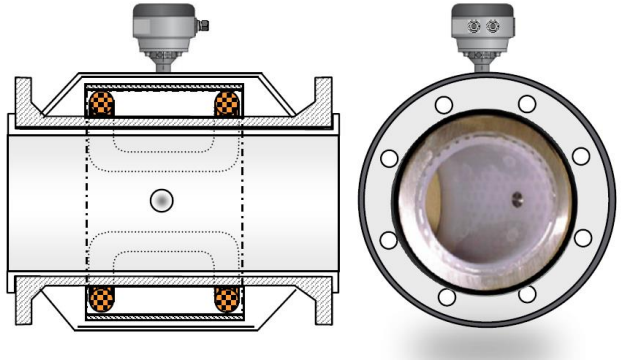
Great for tough applications

Electromagnetic Flowmeters

Basics

- **Faraday's law of induction**
- Any **conductive material** passed through a **magnetic field** will induce a **voltage proportional to the velocity** of the moving conductor
- Flowmeter:
  - Measuring tube with or without flanges
  - Liner or coating (electrical insulation)
  - Pair of electrodes (pick up the signal voltage)
  - Magnet-foil (return circuitry for magnetic field)
  - Coil house (protects the coils)
  - Connection box or transmitter





Electromagnetic Flowmeters

Advantages vs. Disadvantages

- Advantages:
  - **Unobstructed bore (no pressure loss)**
  - No moving parts
  - Excellent accuracy (up to 0.15% of rate)
  - **Chemical compatibility with virtually all liquids**
  - Indifference to viscosity, pressure, temperature and density variations
  - Linear analog outputs
  - Bi-directional flows
  - **Wide range of sizes**
  - Only short inlet and outlet sections required (5D/5D)

- Disadvantages:
  - **It can only be used with electrically conductive fluids**
  - Initial Price
  - External power may be needed (4-wire devices)
  - **May need grounding rings**

Electromagnetic Flowmeters

Overview

MagPLUS

WWW	F&B	Chemical

9500A

9600A

9700A

8400A

8500A

IMT30A

Low tier

IMT31A

Mid tier

IMT33A

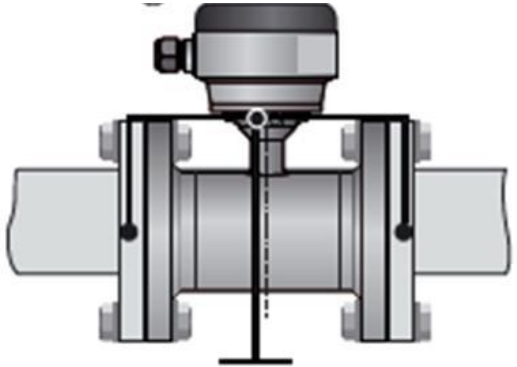
High tier

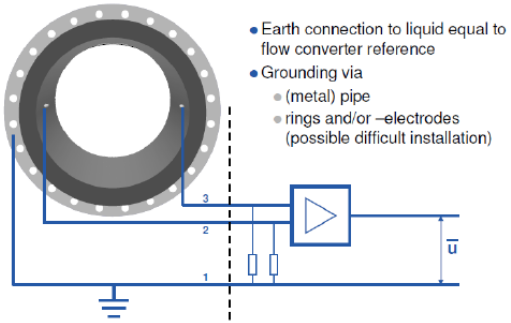
Life Is On Schneider Electric

Electromagnetic Flowmeters

Grounding

- **80% of all issues with Electromagnetic Flowmeters are grounding issues!**
- When the flow tube is mounted between unlined/uncoated metal pipes, the flange bolts provide the electrical connection from the flow tube to the pipeline and, therefore, the fluid
- When the flow tube is mounted between non-metal or lined/coated metal pipe, installation of grounding rings on each pipe flange is required. Continuity is provided by connecting grounding wires from the flow tube to the grounding rings

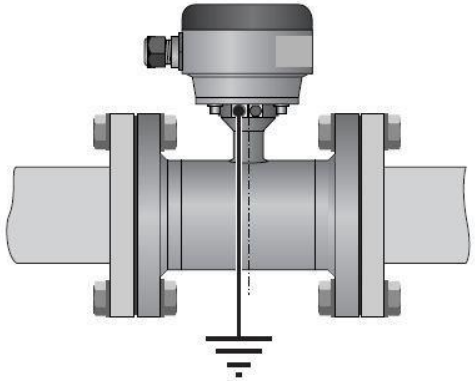


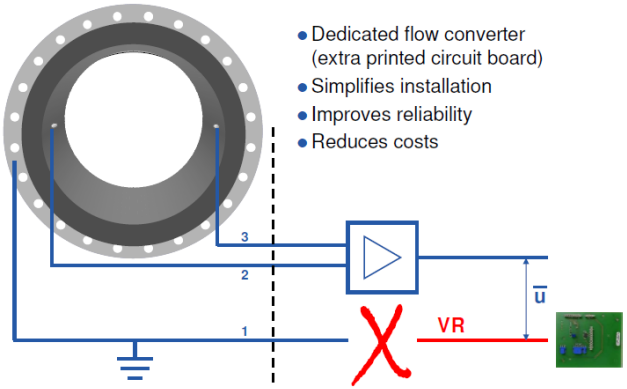


Electromagnetic Flowmeters

Grounding

- **Third grounding electrode:**
  - Internal grounding of the fluid through an optional third electrode
  - Simplifies installation
- **Virtual Grounding or Virtual Reference:**
  - Dedicated flow converter (extra printed circuit board)
  - Simplifies installation
  - Measurement circuit ‘floats’ at liquid’s potential, sensing only induced voltage caused by conductive fluid velocity
  - Eliminates need for grounding of process fluid by providing complete isolation



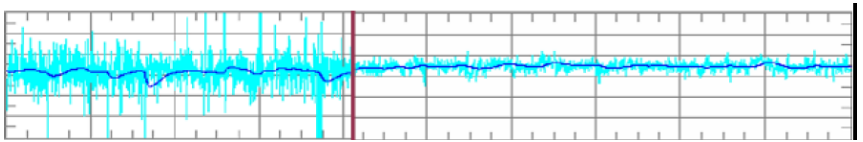


Electromagnetic Flowmeters

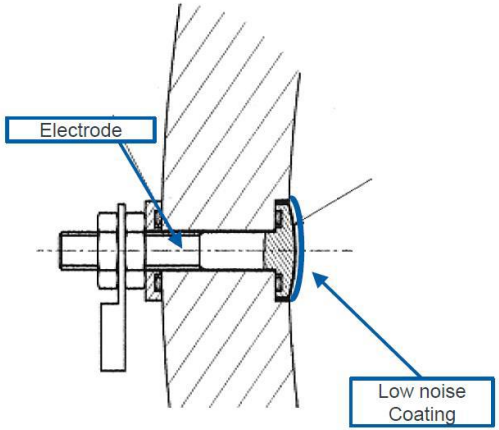
Low noise electrodes

MagPLUS

- **What causes noise?**
  - Metal particles, fibers, particles hitting the electrode
  - Chemical reaction, fast changing pH
  - Coating



- **Solutions:**
  - **Conductive soft rubber electrode:**
    - Reduces mechanical noise when particles hit the electrodes
    - Ideal for drilling, slurries and large particles applications
  - **Ceramic Low noise electrodes:**
    - Porous ceramic coating (aluminum oxide) on a metallic base (Hastelloy or Stainless Steel)
    - Noise reduction at source of measurement – stable flow indication (filter at the source)
    - Provides most value in applications with solids or rapid variation in pH value
  - **Tungsten carbide low noise electrodes:**
    - Special conductive and non-porous coating on the electrode
    - Ideal for pulp & paper, fibers, glass water and black liquor applications



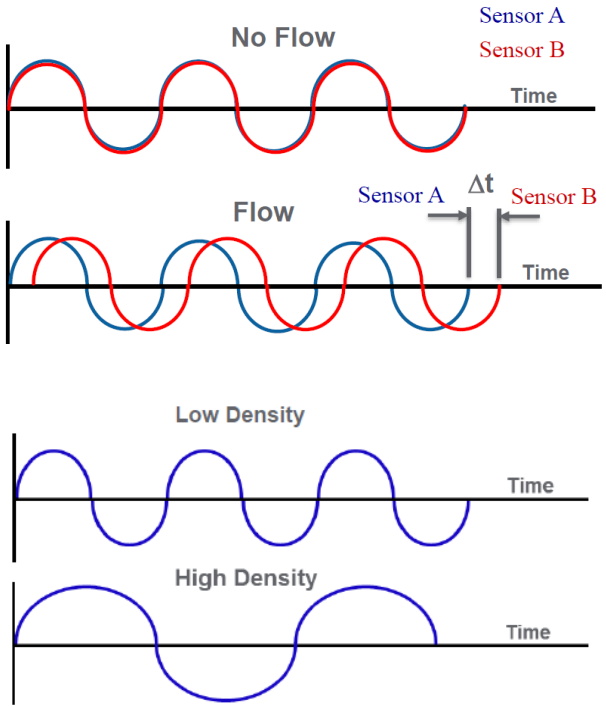
Coriolis Flowmeters

Fits almost all applications

Coriolis Flowmeters

Basics

- When there is mass flowing thru the tubes there is a reactive force which is opposite on each side of the tubes. These forces let the tubes swap out of phase
- **The degree of phase-shift is directly proportional to the mass flow rate of the fluid**
- At the same time, **different densities** (mass per volume) have **different natural oscillation frequencies**
- **Density measurement** is a direct measurement of the **resonance frequency**
- Density **measurement is simultaneously and independent** of the mass flow measurement



Coriolis Flowmeters

Advantages vs. Disadvantages

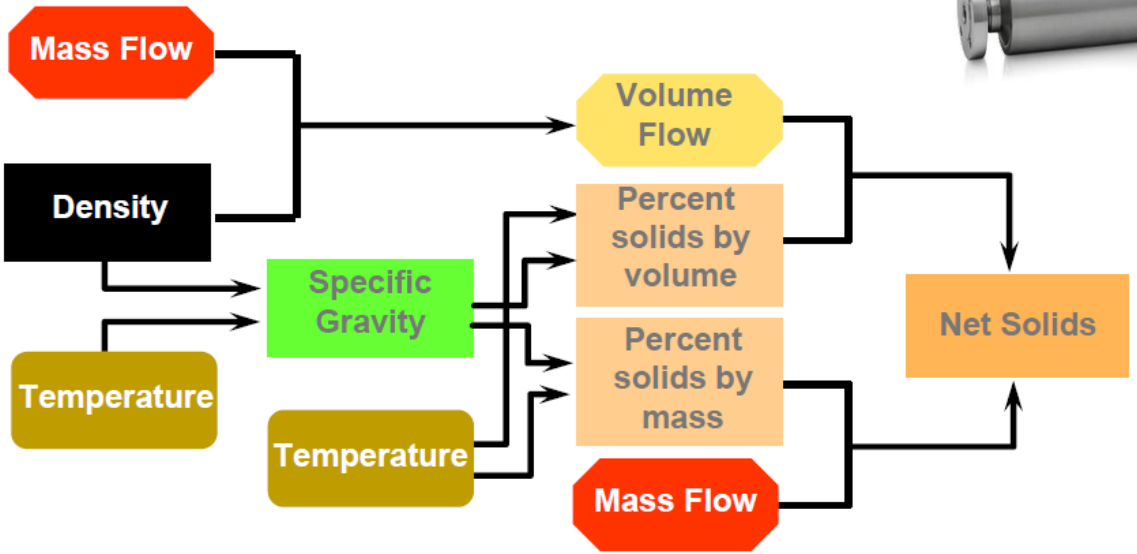
- Advantages:
  - High turndown
  - **High accuracy (0.05% for liquids)**
  - Bi-directional flows
  - No moving parts
  - **No straight pipe runs required**

- Disadvantages:
  - **Initial Price**
  - External power may be needed (4-wire devices)
  - High temperature may be a challenge

Coriolis Flowmeters

Measurements

- Most of them also have a temperature measurement (built-in pt100 temperature sensor)



Coriolis Flowmeters

From ½” to 16”

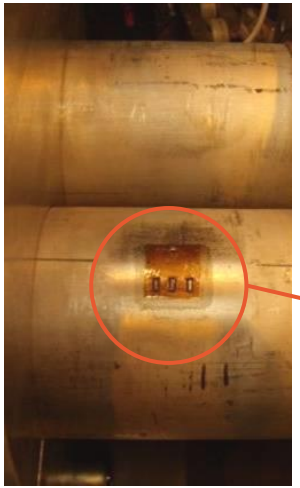
- **General Purpose (CFS300A)**
  - Twin straight tube flowmeter
  - 1/2”, 1”, 1.5”, 2” / SST
  - Accuracy ±0.15% + zero stab.
  - Max pressure 100 bar / 1450 psi
  - Max temperature 130˚C / 266˚F
  - Hazardous area, hygienic, and custody transfer approvals
  - FF, Profibus, Modbus, HART 7
  - Best price / performance ratio

- **Large Sizes (CFS400A)**
  - Twin or quad straight tube
  - 4”, 6”, 10” and 16”
  - Duplex and Super Duplex
  - Accuracy ±0.10% + zero stab.
  - Max pressure 180 bar / 2610 psi
  - Max temperature 130˚C / 266˚F
  - Hazardous area, hygienic and custody transfer approvals

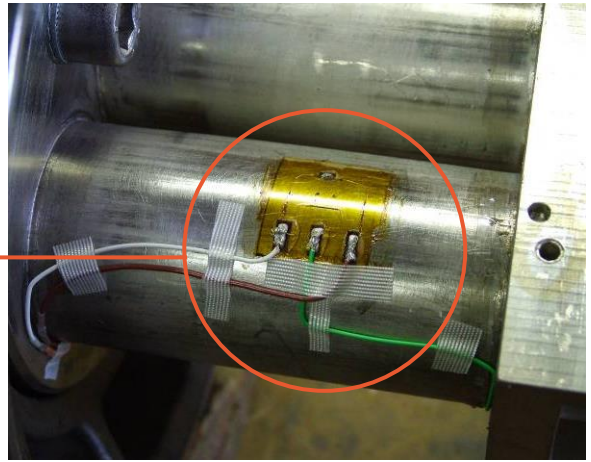
- **Exotic Materials (CFS700A)**
  - Single straight tube flowmeter
  - Duplex, Hastelloy C22, Titanium, Tantalum
  - 1/2”…4”
  - Max pressure 100 bar / 1450 psi
  - Max temperature 150°C / 302°F
  - Accuracy liquid: ±0.10% + zero stab.
  - Accuracy gas: ±0.35% + zero stab
  - Hazardous area, hygienic and custody transfer approvals
  - Best for demanding applications

Coriolis Flowmeters

CFS400 – Integrated Pressure Compensation



strain gauge mounted circumferentially on the tube to compensate pressure effect on density measurement



axially mounted strain gauge for stress compensation

Custody Transfer meter for liquids R117-1 and MI-005

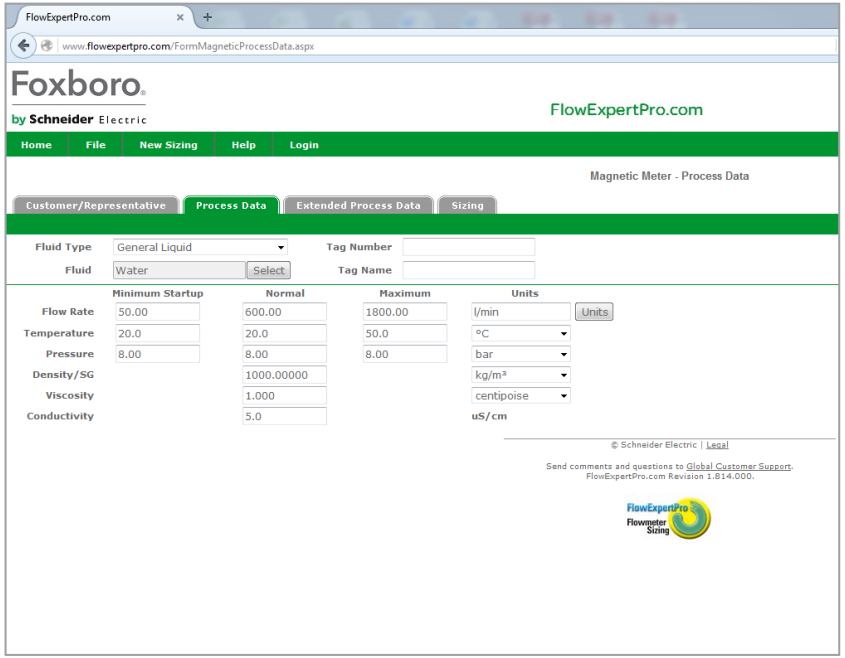
Sizing Tools

Always size your flowmeters

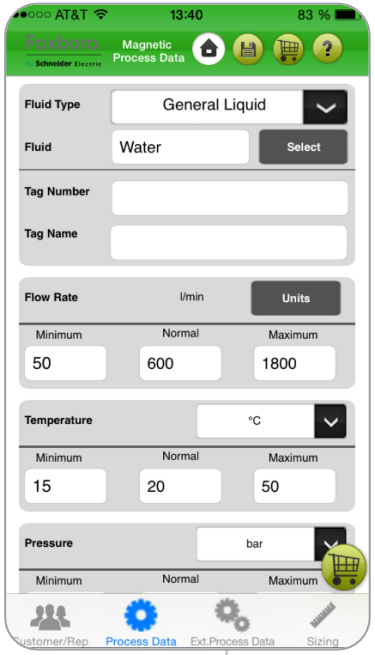
FlowExpertPro

Size your Flow Meters!

- Visit www.flowexpertpro.com



- iPhone or Android App



FlowExpertPro

Size your Flow Meters!

- **Application:**
  - Saturated Steam
  - 100 psig
  - 4” pipeline
  - Better than 2% accuracy
  - Flow rates:
    - Minimum flow: 500 lb/hr
    - Normal flow: 2,000 lb/hr
    - Maximum flow: 6,000 lb/hr
  - www.flowexpertpro.com

References

- Instrument and Automation Engineers' Handbook: Process Measurement and Analysis, Fifth Edition, Volume 1 and Volume 2 - By Béla G. Lipták and Kriszta Venczel
- Industrial Flow Measurement, Third Edition - By David W Spitzer
- Flow of Industrial Fluids - Theory and Equations – By Raymond Mulley
- The Tao of Measurement: A Philosophical View of Flow and Sensors - By Jesse Yoder and Dick Morley
- Flow Measurement Engineering Handbook, Third Edition – By Richard Miller

Final Statement

- We have always done it this way!
- If it is not broken, don't fix it!
- I will not buy from them, I already have X, Y and Z brands here!
- Simply relying on past achievements can lead to stagnation!
- Dare to Disrupt!

Questions?

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