

Confidential – not for distribution

WIN-102-1

Flow Technology: Selection and practice

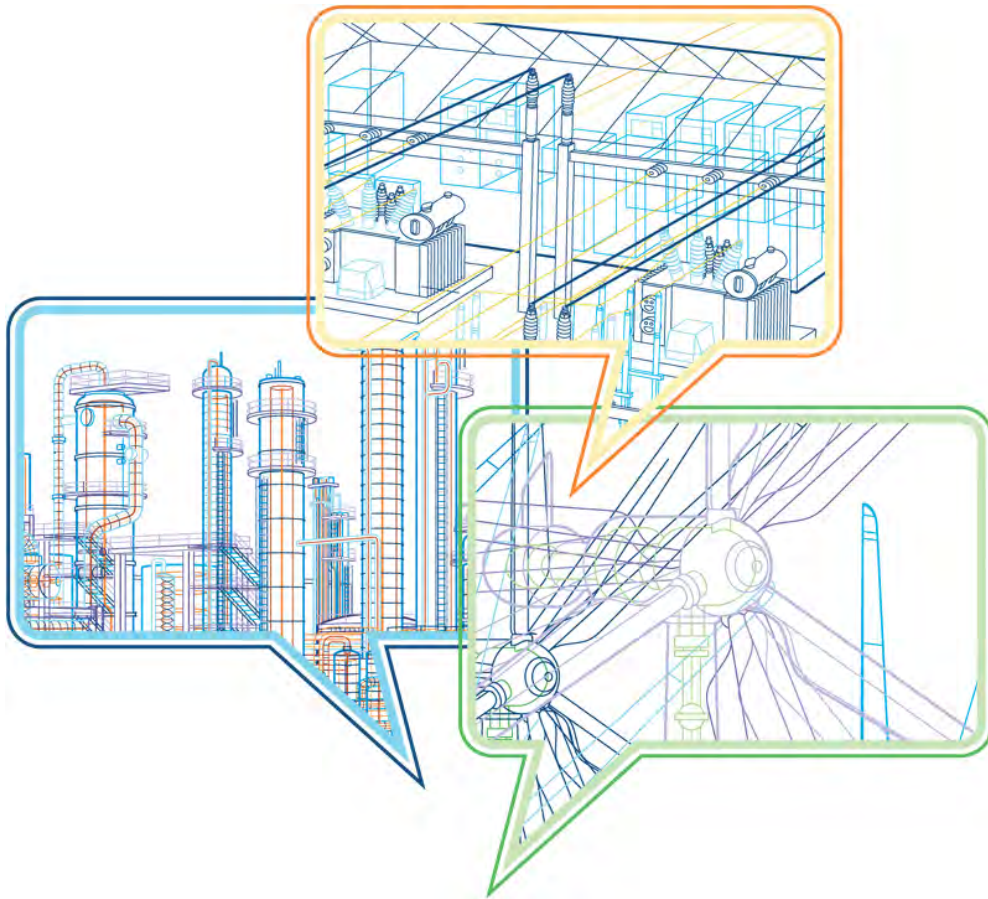
Automation & Power World 2011

April 18-21, 2011 in Orlando, Florida



Automation & Power World 2011

April 18-21, 2011 in Orlando, Florida



- Save the date for this “must attend” event!
- April 18-21, 2011
- Orlando World Center Marriott, Florida
- Over 400 hours of educational training
 - Business forum
 - Customer case studies
 - Hands-on training
 - Panel discussions
 - Technical workshops
- Earn PDHs and CEUs
- Technology & Solution Center
 - Over 70,000 sq. ft. of exhibits
- Network with your peers
- www.abb.com/a&pworld

ABB Automation & Power World

At-a-glance

400+

Educational Workshops

Automation & Power World offers over 400 hours of Educational Workshops specifically designed to make engineers, maintenance and management more valuable to their companies.

70K

Technology & Solution Center

Over 1 ½ acres (70,000 ft²) of with nearly 100 tons of electrical gear and 100's of experts ready to answer any of your questions and share the future of Automation & Power Solutions.

4,000

Connect with Peers

With over 4,000 of your peers in attendance, this is a powerful opportunity to network and learn from the industry. In addition, over 45 customers will be sharing their own case studies.

Educational workshops developed for all audiences

Just a few examples

Roles

Engineering

Management

Maintenance

Company types

Industrials

EPCs

Utilities

OEMs

- The coming wave of process safety system migration
- Implementing an alarm management strategy for a 100,000 I/O system - Case study
- Replacement and retrofit of large motors: Challenges and solutions
- Dynamic studies for large scale renewable energy integration at a Texas CREZ - Case study
- Secure commissioning of your process plant - Case study
- New arc flash mitigation technologies and techniques for a safer working environment
- Robotics 101
- A better approach to non-revenue water loss
- Electric vehicles: Are they real this time?
- Why is SIL more important than architecture?

Past attendees input

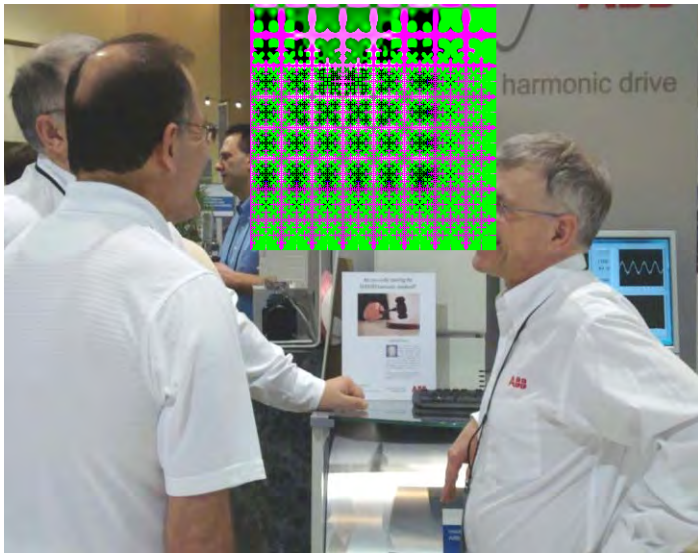


“I am impressed with the different parts of the program, the workshops and also the exhibit set-up... there is a lot of information to pick up.”

Duane Souers, Georgia Pacific

“It’s a great opportunity to get a lot of exposure to people and products in one week.”

Pardeep Gill, Alcoa



“It is well worth the time given the opportunities to: learn from industry experts, network with peers in the same industry, learn about emerging technologies, and build excellent supplier relationships.”

Sanjin Osmancevic, National Grid

WIN-102-1

Flow Technology: Selection and practice

- Ron DiGiacomo
- Business Development Manager, Flow Technologies / North America
- ABB Instrumentation
- Warminster, PA

Agenda

Overview, Terminology and Principle of Operation

Marketing Overview

- Technology by percentage
- Why measure flow?

Flow Terminology

- Accuracy, repeatability, turndown
- Reynolds number (Viscosity; Velocity; Density; Diameter)
- Pressure and temperature affects
- Flow profile: Laminar, transitional & turbulent flow
- Up and downstream piping considerations (elbows etc.)

Flowmeter Types

- Inferential: Differential Pressure
- Velocity: Magnetic; Ultrasonic & Vortex & Swirl
- Volume: Positive Displacement
- Direct Measurement: Coriolis

Why Measure Flow?

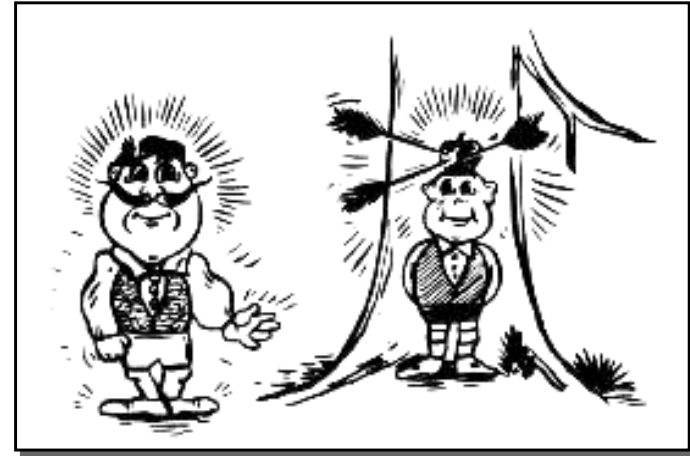
- Custody Transfer
 - Measurement of fluid passing from a supplier to a customer
- Product Integrity
 - Customers expect process control systems to provide the right amount of blended materials
- Efficiency Indication
 - Enables companies to determine the efficiency of their processes (e.g. additives)
- Safety



Accuracy verses Repeatability



Poor Repeatability Means
Poor Accuracy

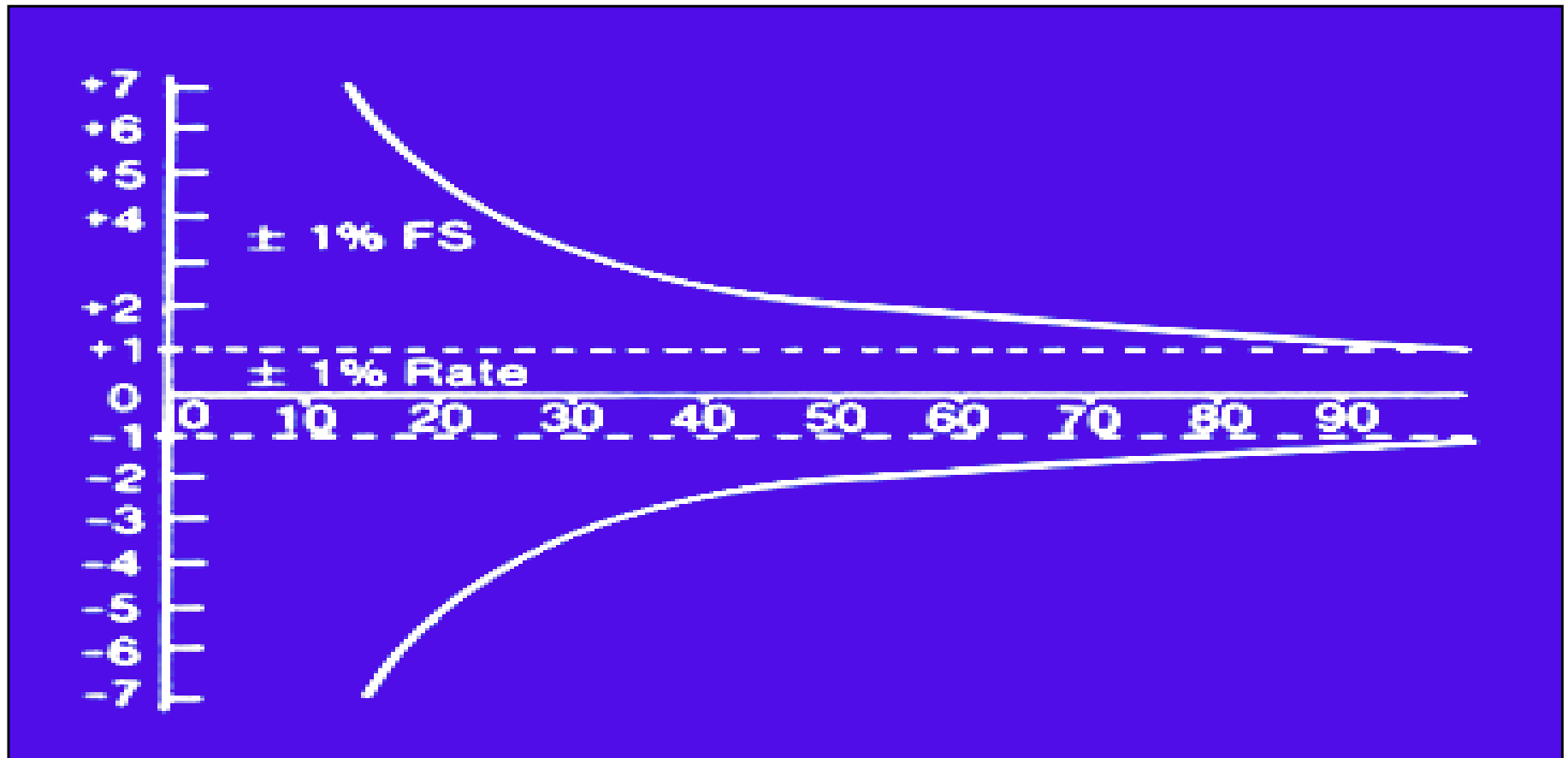


Good Accuracy Means
Good Repeatability

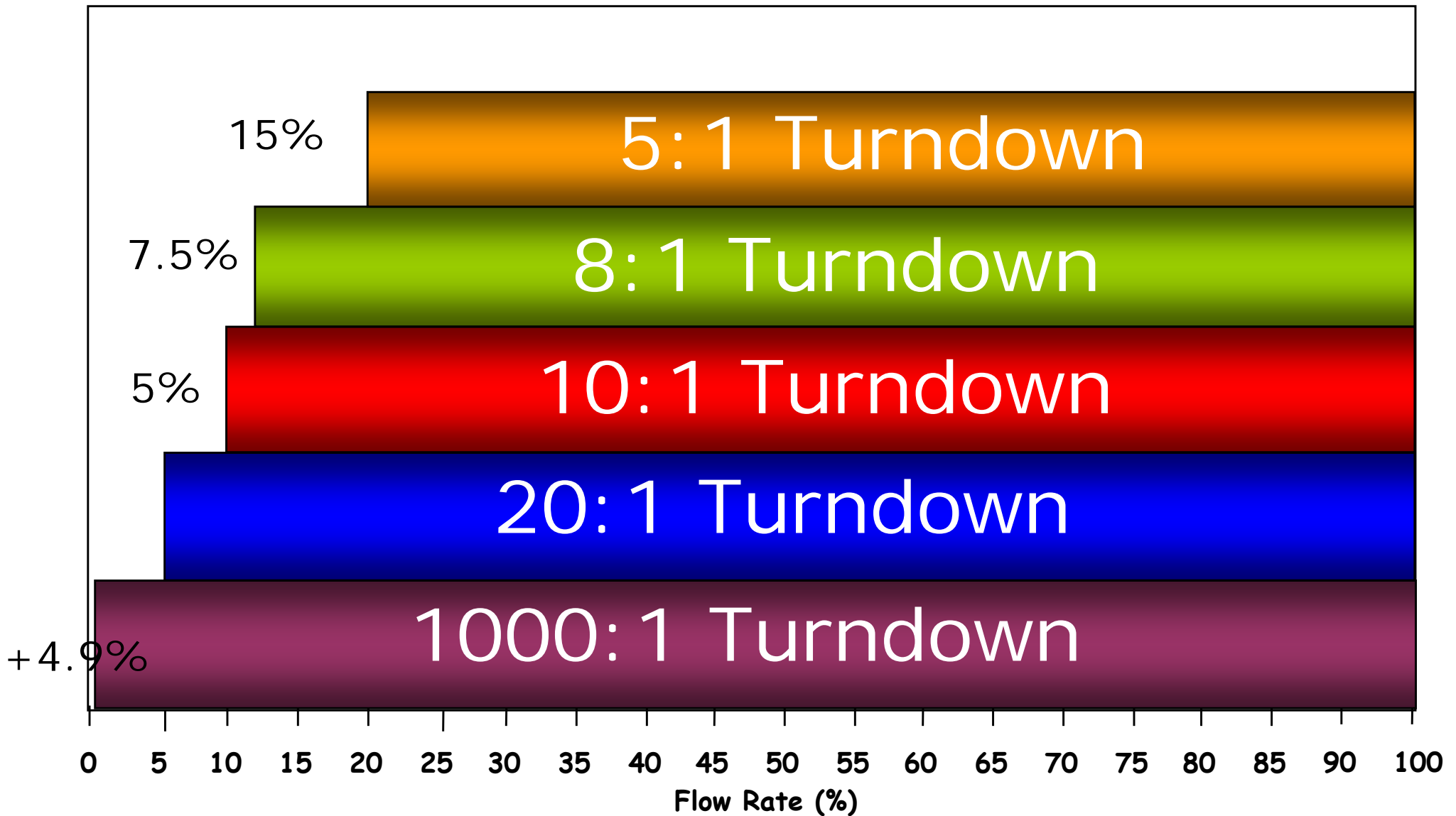


Good Repeatability Does Not Necessarily Mean Good Accuracy

Percent of Rate vs. Percent of Full Scale



“Flow Turndown” can be Misleading



Flow Pioneers – Osborne Reynolds

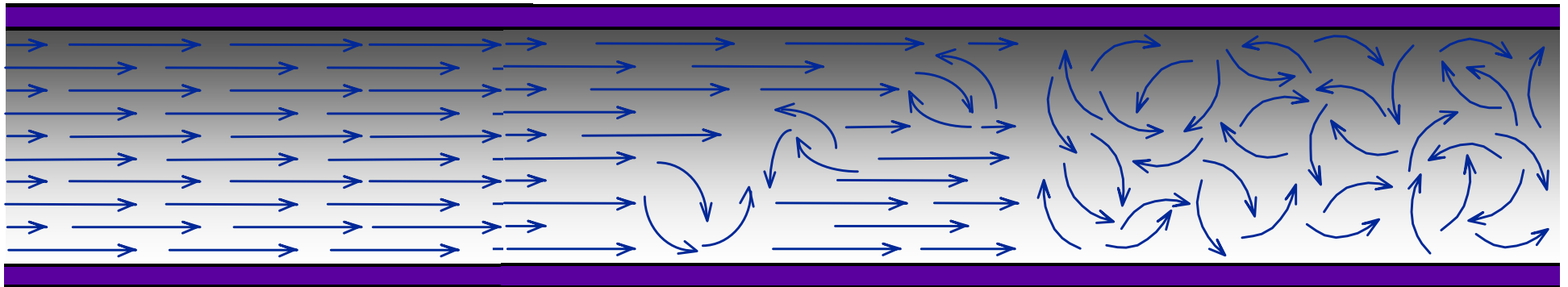


(1842 – 1912)

Publication: *On the dynamical theory of incompressible viscous fluids and the determination of the criterion* (1895)

Concept: Reynolds Number – The dynamic theory of incompressible viscous fluids

Lay-man's: Conditions in which the flow of fluid transitions from laminar to turbulent flow



Laminar
<2,000 R_d

Transitional

Turbulent
>4,000 R_d

Flow Pioneers – Osborne Reynolds

- In 1883, the British mechanical engineer Osborne Reynolds proposed a single, dimensionless ratio to describe the velocity profile of flowing fluids:

$$R_E = \frac{VD\rho}{\mu}$$

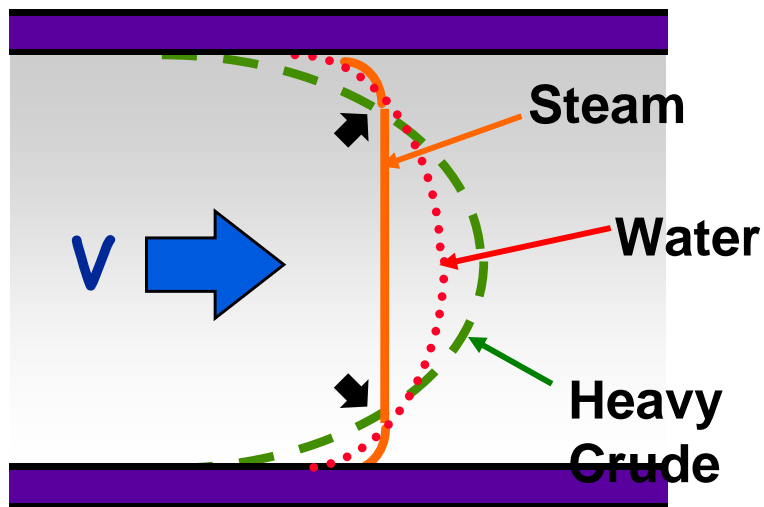
- D is the pipe diameter, V is the fluid velocity, ρ is the fluid density, and μ is the fluid viscosity
- Osborne's findings stated
 - At low Reynolds numbers (below 2,000), flow is dominated by viscous forces and the velocity profile is elongated
 - At high Reynolds numbers (above 20,000), the flow is dominated by inertial forces, resulting in a more uniform flat velocity profile.



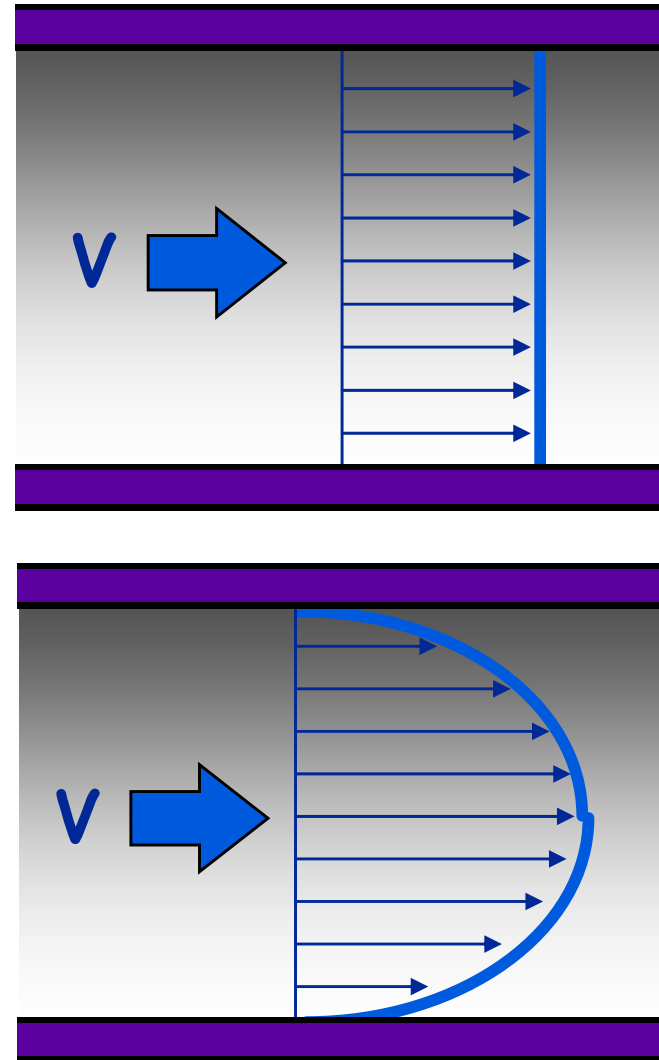
(1842 – 1912)

Velocity Profile

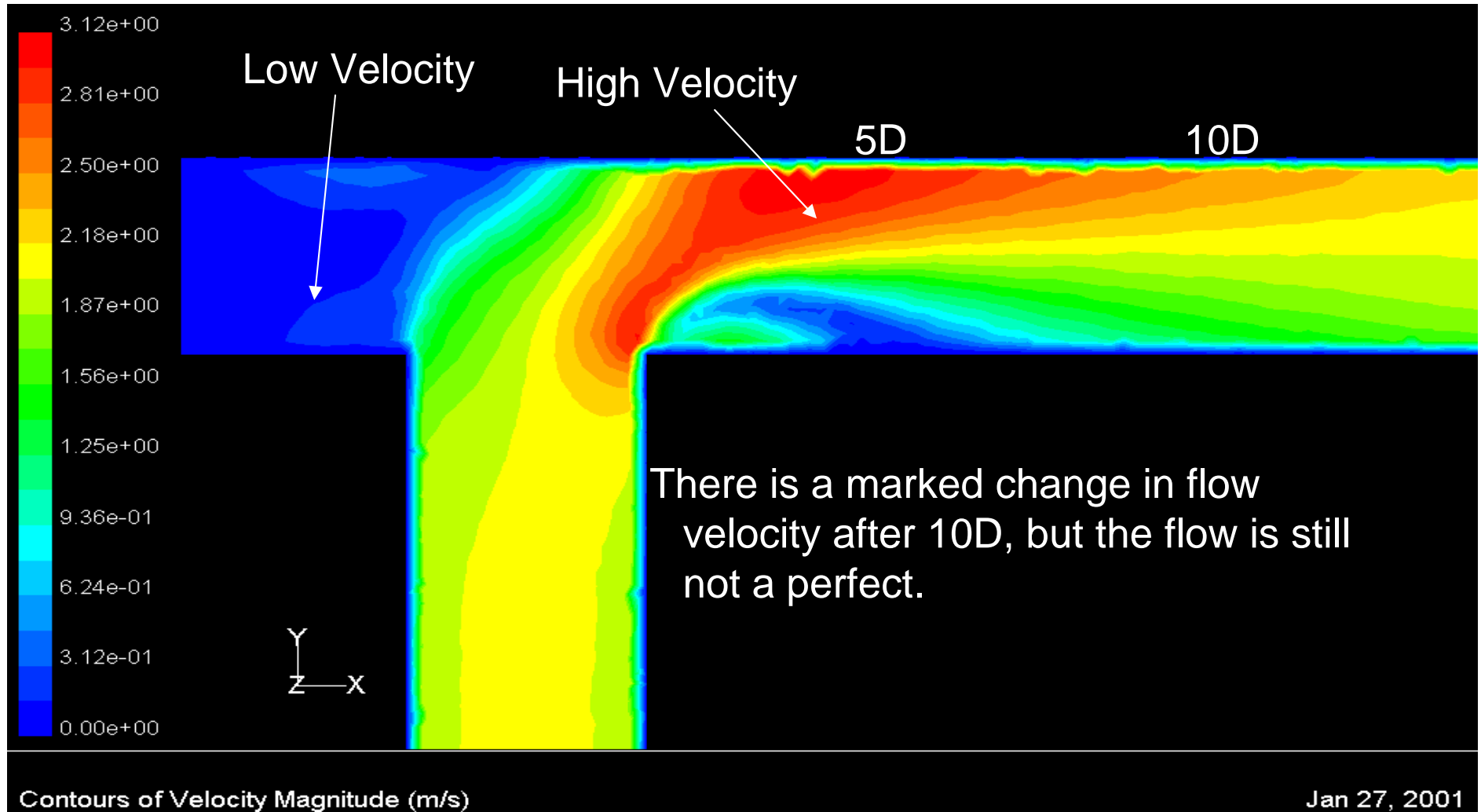
- Velocity profile is a predictable function of Reynolds Number
- Fluids with identical Reynolds Number will have similar velocity profiles



$$R_E = \frac{VD\rho}{\mu}$$



Velocity Contours through a "T"



Fluid Properties – Density

- The mass per unit volume of a fluid
- In most liquid applications, the density is fairly constant
 - Where large temperature variations are present, compensation may be needed
- Gas density is very dependent on both pressure and temperature
- Proportional to pressure and inversely proportional to temperature

| Liquids | Gases |
|--|--|
| ↑ Temperature = ↓ Density ↓ Temperature = ↑ Density | ↑ Temperature = ↓ Density ↓ Temperature = ↑ Density |
| ↑ Pressure = No Change ↓ Pressure = No Change | ↑ Pressure = ↑ Density ↓ Pressure = ↓ Density |

- Common units: lb/ft^3 or kg/m^3
- Density affects each flowmeter in a different way, influences flowmeter selection

Fluid Properties – Specific Gravity

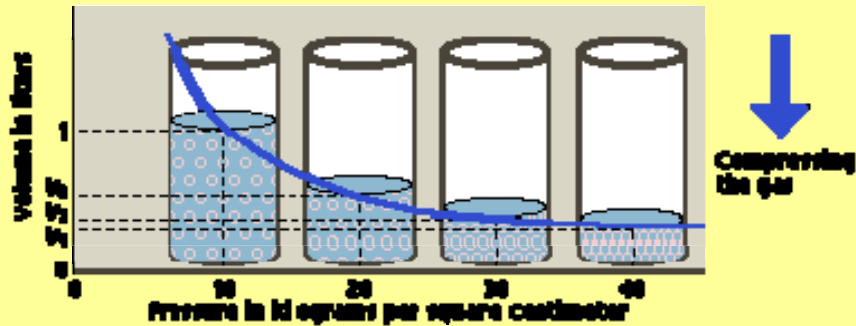
- Also known as relative density
- Equal to the density of the material divided by the density of water for liquids or air for gases
- A unitless measure of density
- For Liquids: ratio of the density of the process liquid at flowing conditions to the density of water at base conditions (60°F [16°C])
- For Gases: ratio of the molecular weight of the process gas to the molecular weight of air. A gas's specific gravity remains constant because the molecular weight of a gas does not change with pressure or temperature

$$SG_{gas} = \frac{MW_{gas}}{MW_{air}} \quad SG_{liquid} = \frac{\rho_{liquid \cdot at \cdot flowing \cdot temperature}}{\rho_{water \cdot at \cdot base \cdot temperature}}$$

Impact of Pressure and Temperature

Boyle's Law

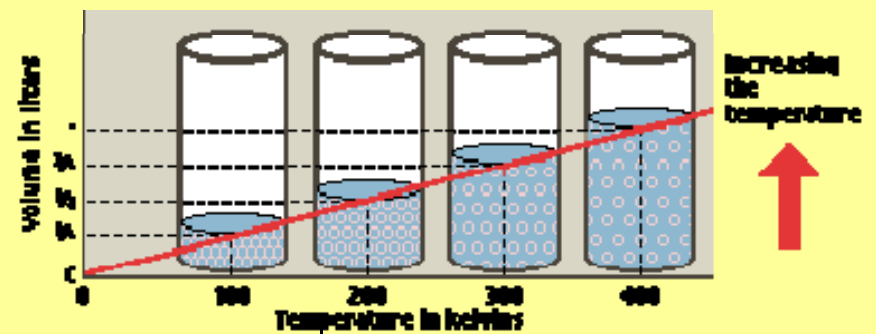
At a constant Temperature, the volume of a gas is inversely proportional to the pressure



Compressing a gas to half of its initial volume doubles the pressure

Charles' Law

At a constant Pressure, the volume of a gas is directly proportional to the temperature



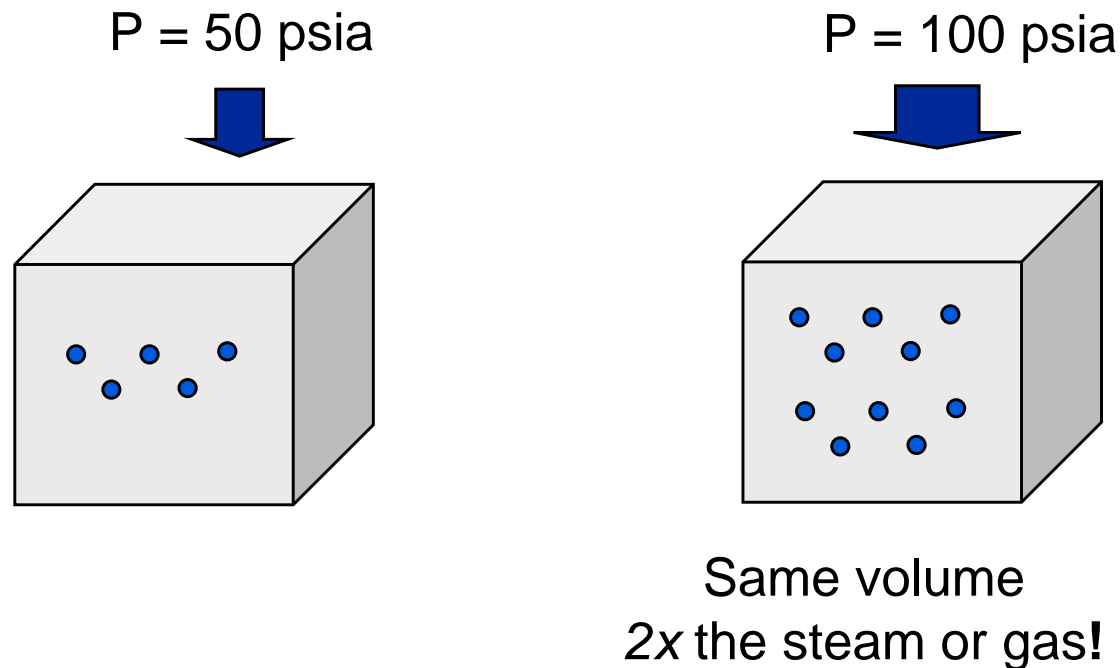
Heating a gas to double its original temperature doubles its volume

Compressible Fluids

Gases & steam are compressible
(Density changes with Pressure and Temperature)

volumetric flow is usually meaningless: acfm

need mass flow: lb/hr, scfm



Flow Meter Types



- Inferential dP Flowmeters

- Orifice plate
- Pitot tube
- Averaging pitot tube
- Wedge flow element



- Velocity Flowmeters

- Magnetic flowmeter
- Vortex flowmeter
- Turbine
- Ultrasonic



- Volumetric Flowmeters: Positive Displacement Meters

- Direct Mass – coriolis



ABB Compact DP-Flow Family

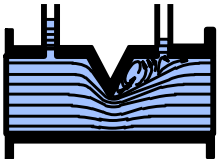
3 technologies; 4 products



OriMaster
FPD500



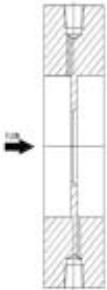
PitotMaster
FPD360



WedgeMaster
FPD560



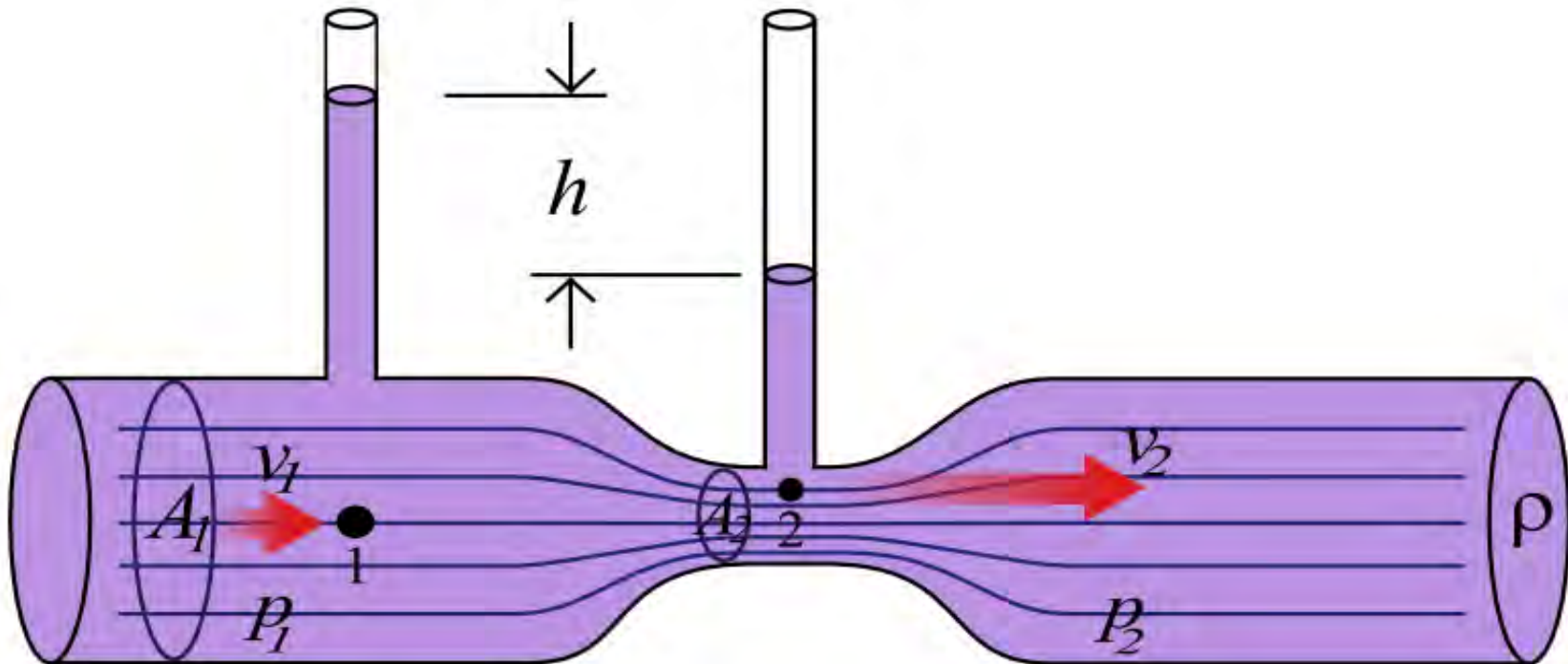
IOMaster
FPD510



Flow Pioneers – Daniel Bernoulli

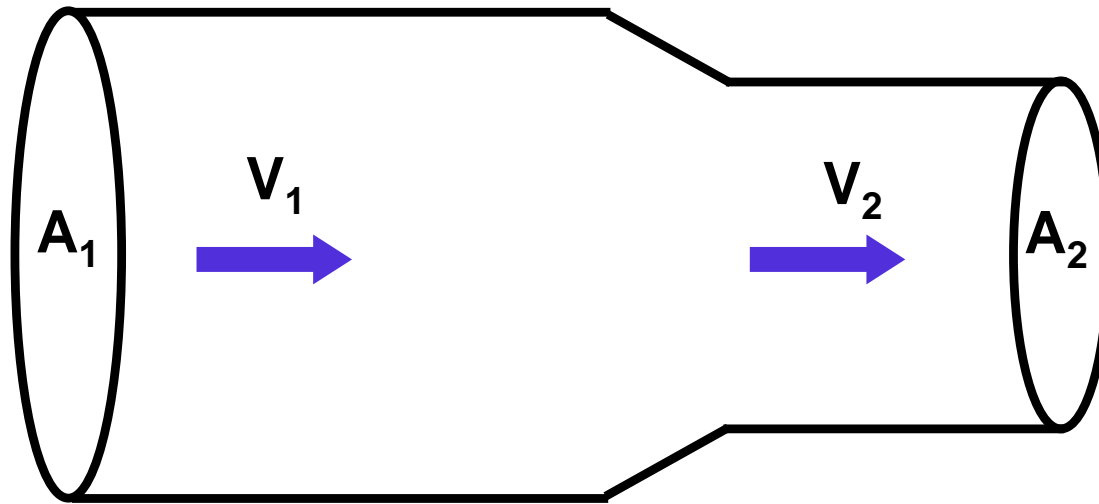


- Publication *Hydrodynamica* (1738)
- Concept: Conservation of energy for fluid flows – As the speed of a moving fluid increases, the pressure will decrease
- Lay-man's: A flow restriction causes an increase in the flowing velocity and also causes a drop in the static pressure of the fluid



How Most DP Flowmeters work

1. Continuity Equation



Actual Volume

$$\text{Flowrate } Q = A_1 V_1 = A_2 V_2$$

e.g. $\text{ft}^3/\text{s} = \text{ft}^2 * \text{ft}/\text{s}$

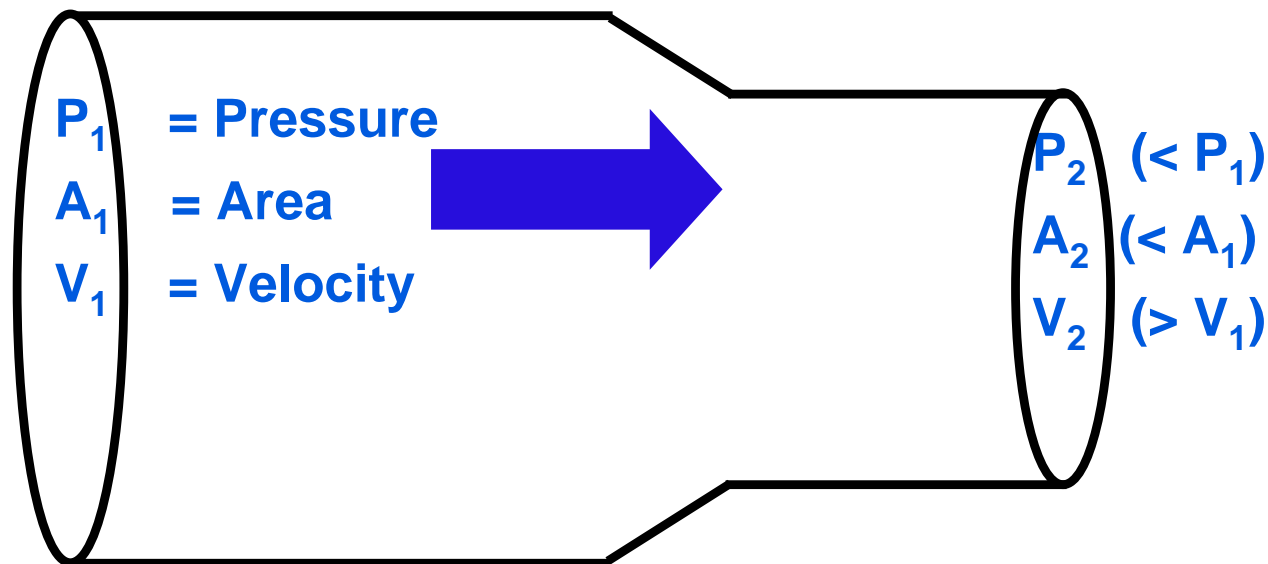
How Most DP Flowmeters work

2. Law of Conservation of Energy

"Energy cannot be created/destroyed, but can only be transferred from one form to another"

3. Bernoulli's Theorem

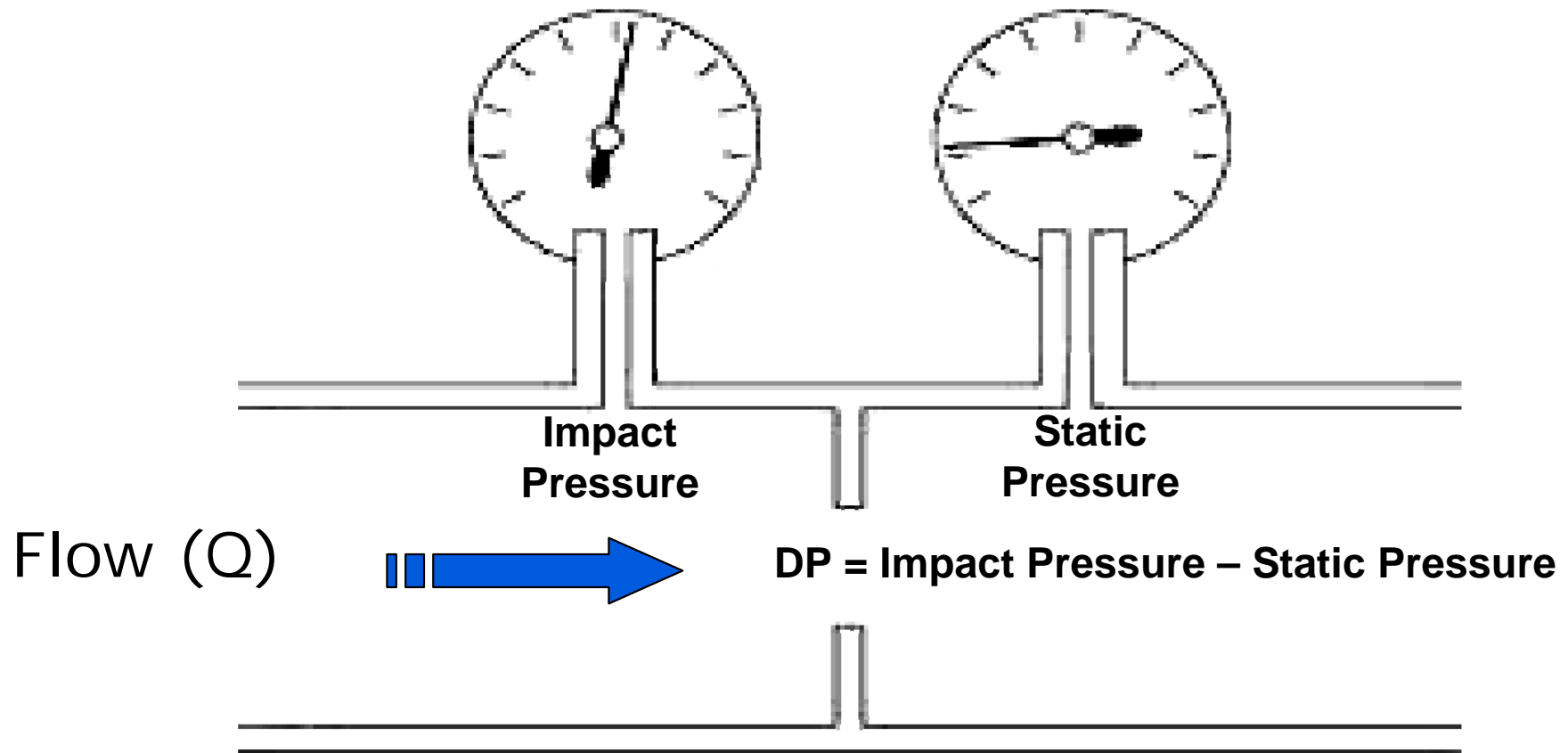
"Total energy (Potential + Kinetic + Pressure) in a flowing system is constant, therefore at a restriction in the flowpath, the fluid pressure will be lower"



How it applies to Flow Measurement

Differential Pressure

DIFFERENTIAL PRESSURE



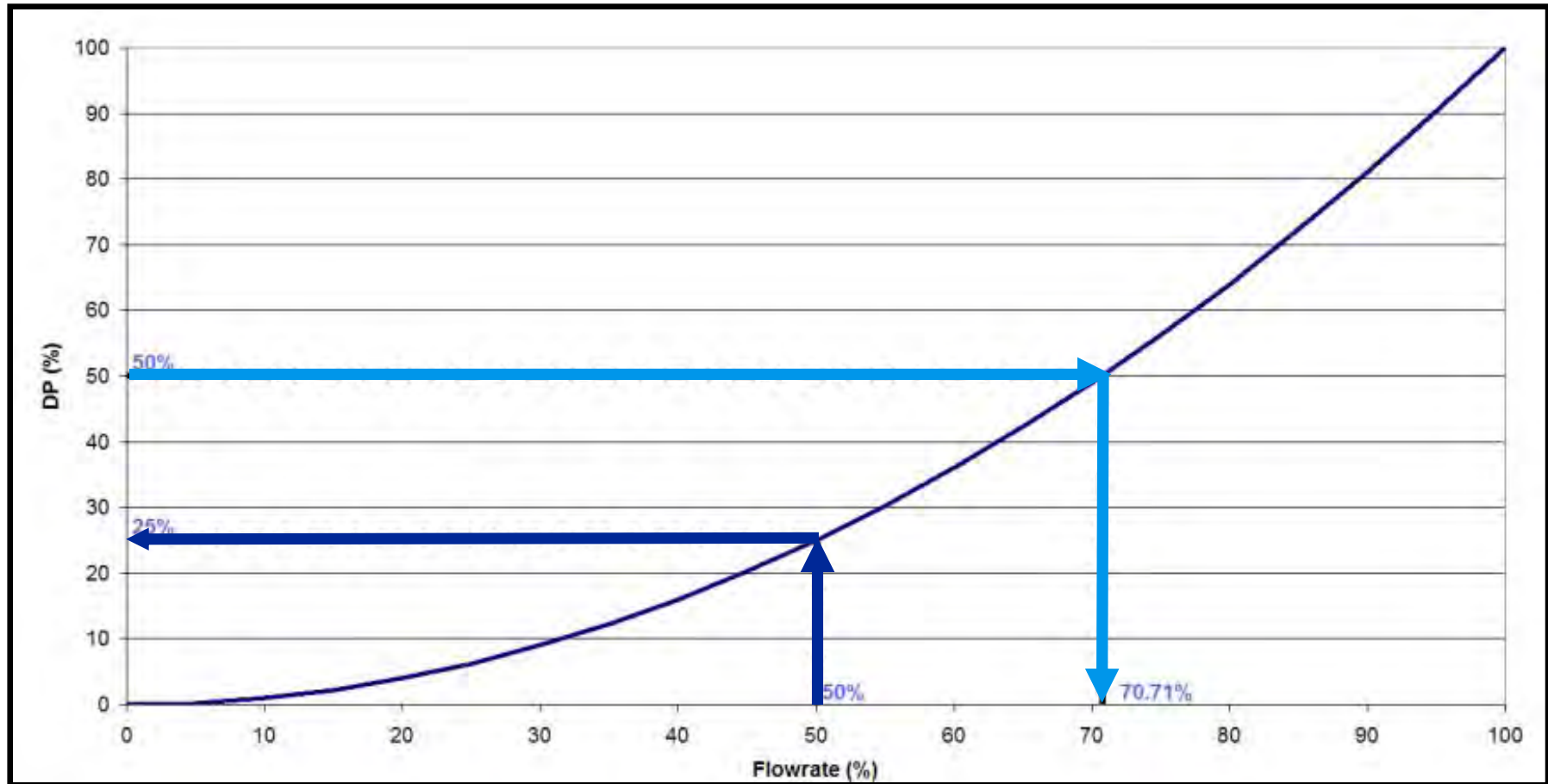
$$Q = K \sqrt{DP}$$

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How DP Flowmeters work

DP proportional to Flowrate squared;

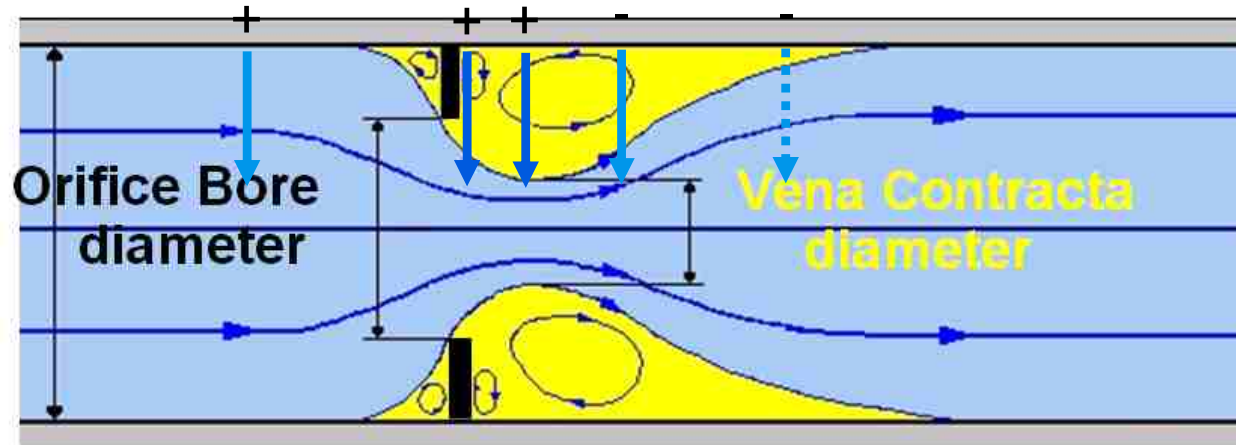
Flowrate proportional to square root of DP



$$DP = k_1 \cdot (\text{Flow})^2$$

$$\text{Flow} = k_2 \cdot \sqrt{DP}$$

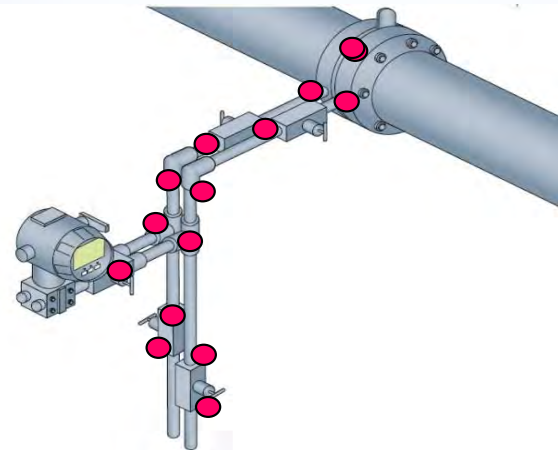
Vena Contracta and Discharge Coefficient



$$Q = K \sqrt{DP}$$

- Where a fluid cannot flow through the contours of the restriction perfectly, the diameter of the narrowest part of the flow jet is less than the diameter of the restriction.
- A smaller diameter gives a higher velocity and hence at the vena contracta there is a lower downstream pressure (so a higher DP than expected from the calculated bore).
- This effect is corrected for by the Discharge Coefficient **C**, which is <1 and whose value varies with the position of the tapping set (more later)

Compact OriMaster



Wedge Meter



ADVANTAGES

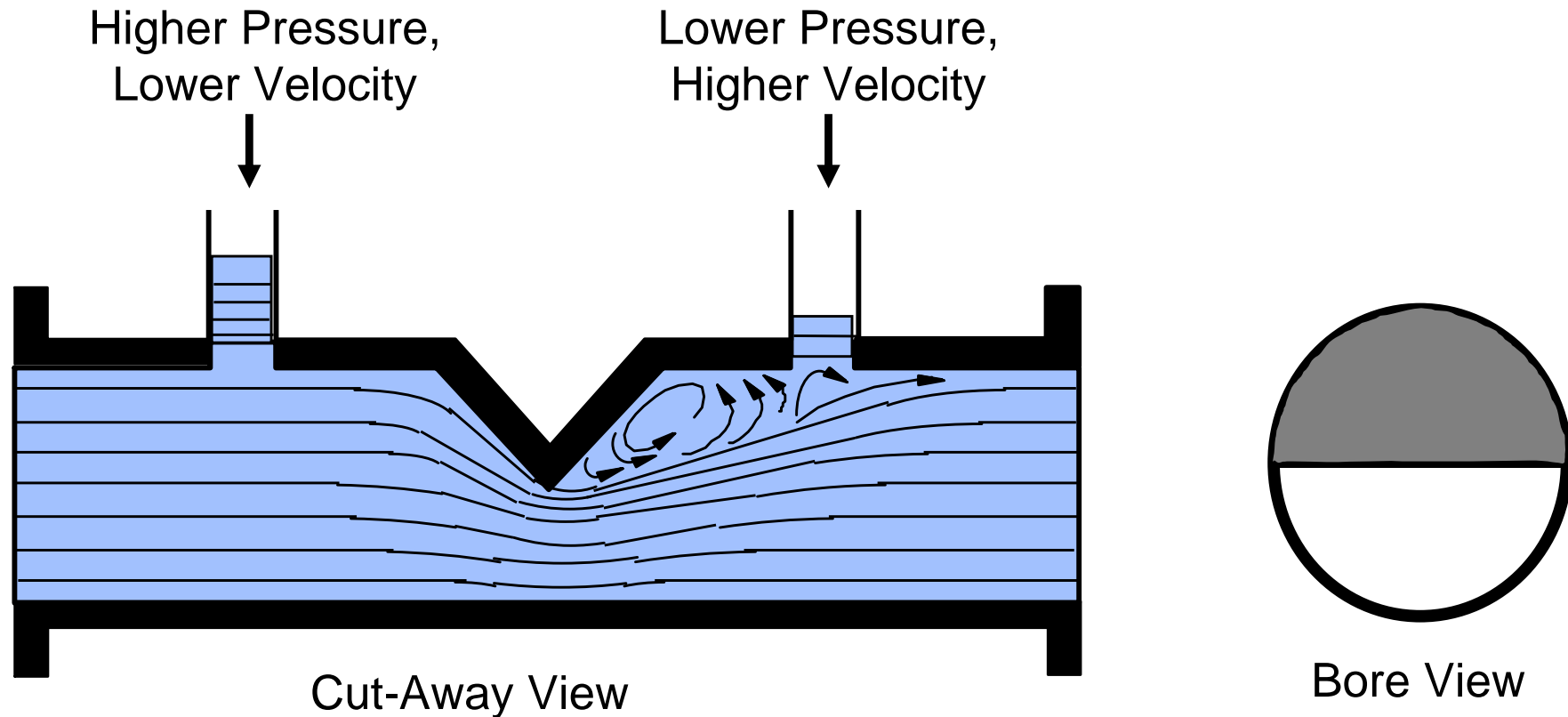
- Use on liquid, gas, and steam
- Generally impervious to dirty liquids
- Reynolds numbers as low as 500
- Improved rangeability 8:1 & accuracy $\pm 0.5\%$ No critical surface dimension
- No places for secondary phase build-up
- Bi-directional
- Only half the pressure loss of an orifice plate
- Available in standard sizes 0.5" to 24"

DISADVANTAGES

- More expensive than orifice
- Not approved by AGA or API
- Limited acceptance in the market

Differential Pressure - Wedge

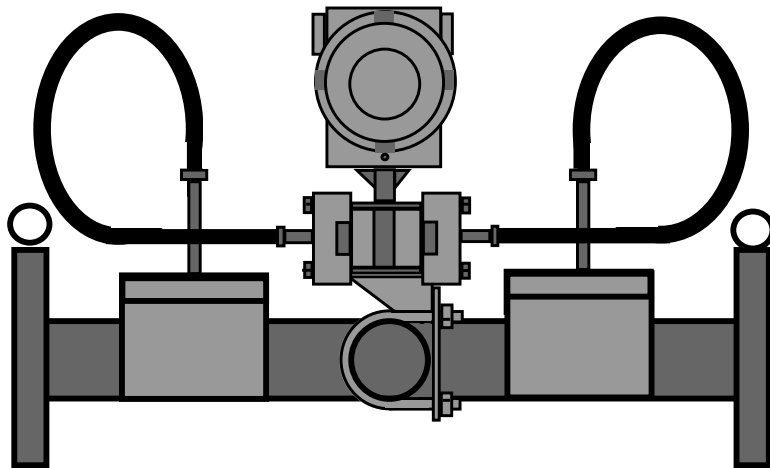
The Wedge element offers a "V-shaped" restriction to flow



Wedge elements have been in use since the 1960's
(initially under Taylor Instruments!)

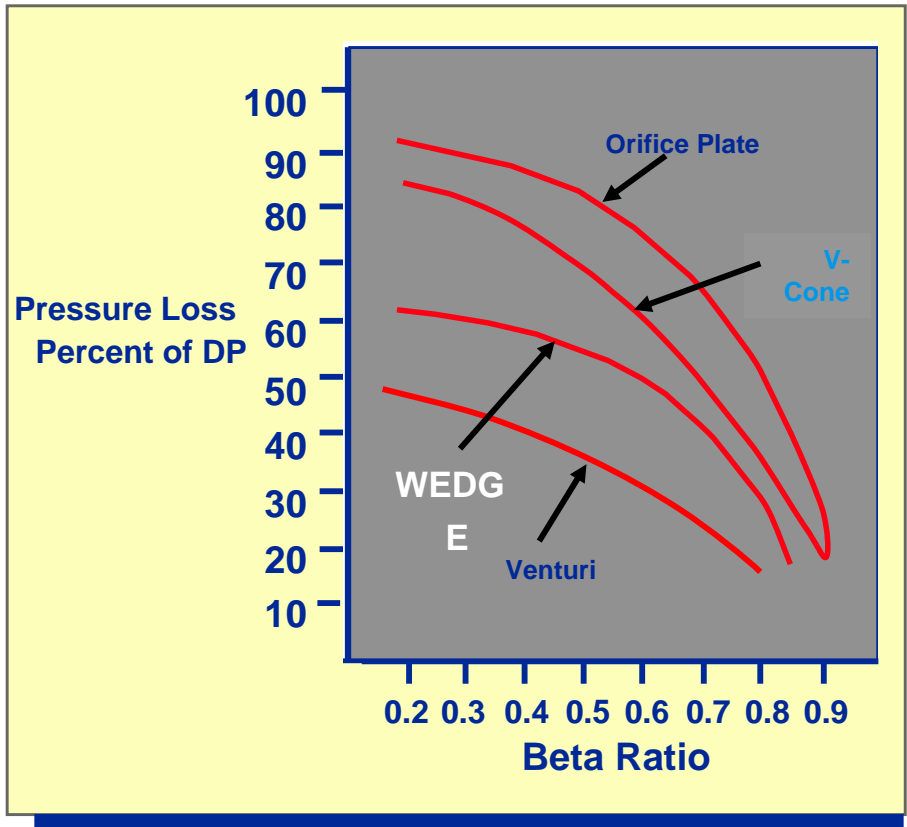
Wedge Distinguishing Features

- No dead zones for a secondary phase to build-up (remote seal element)
- Slanted faces provide "self-scouring" action and minimize damage due to impact
- Ability to use large remote seal diaphragms

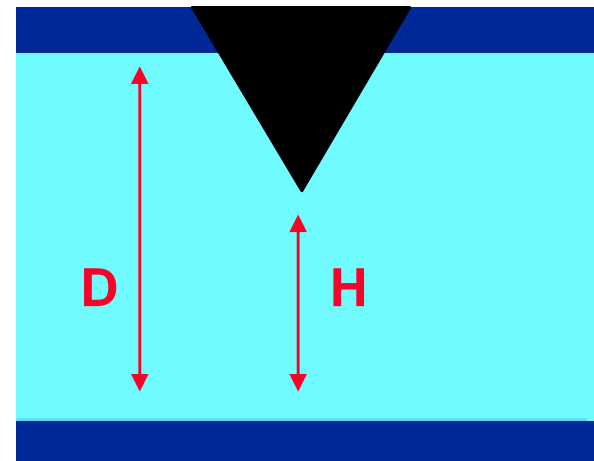


Handles a diverse range of applications!

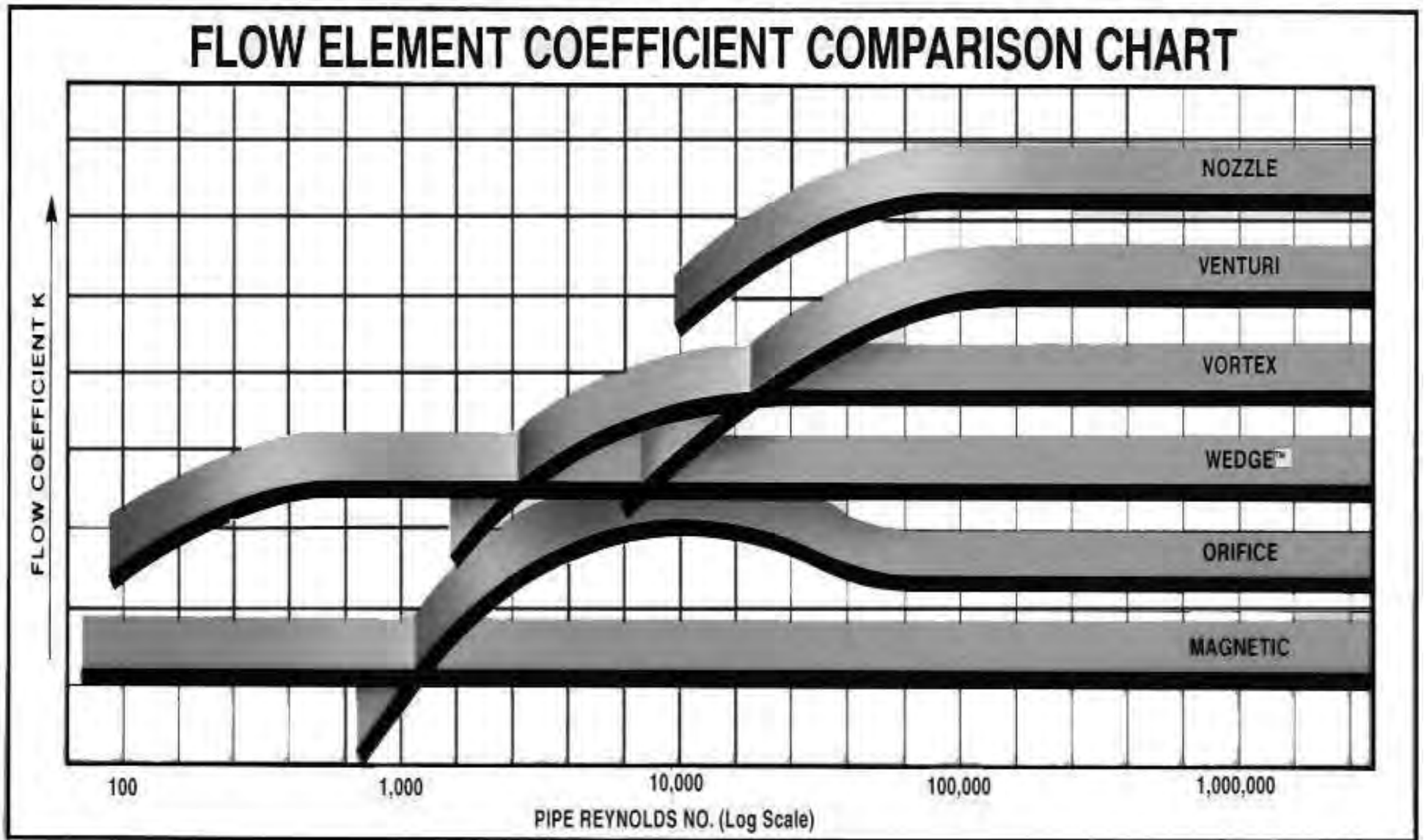
Differential Pressure - Wedge



| <u>H/D Ratio</u> | <u>Beta Ratio</u> |
|------------------|-------------------|
| 0.2 | 0.38 |
| 0.3 | 0.50 |
| 0.4 | 0.61 |
| 0.5 | 0.71 |
| 0.6 | 0.79 |
| 0.7 | 0.86 |



Reynolds Number Limits of Meters



Averaging Pitot Tube



ADVANTAGES

- Use on liquid, gas, and steam
- Can be used in high temperatures and pressures
- Minimal pressure loss
- Low cost
- Insert into existing piping - easy installation
- Averaging unit limits required straight pipe

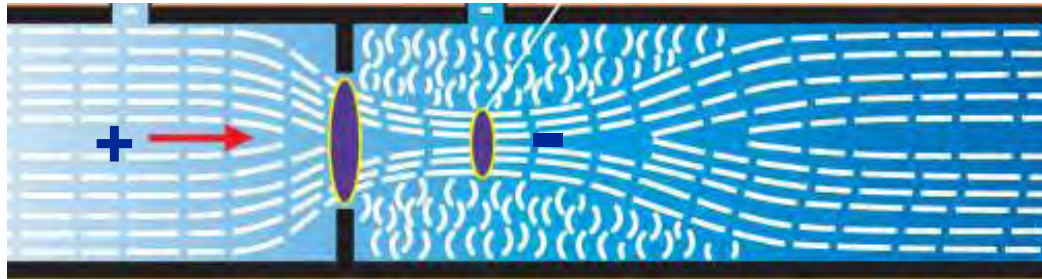
DISADVANTAGES

- Cannot handle dirty flows
- Limited rangeability
- Affected by changes in density, pressure, and viscosity

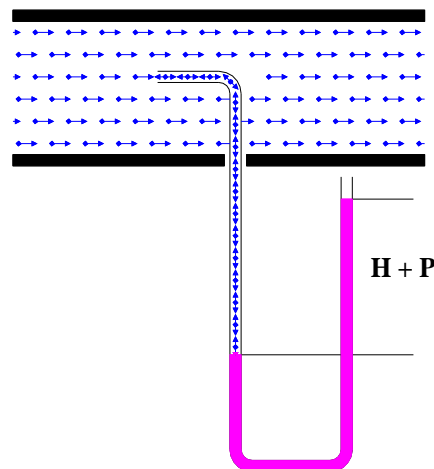
Pitot Tubes work a little differently

Pitot and Mass Accelerating DP devices involve different energy conversions

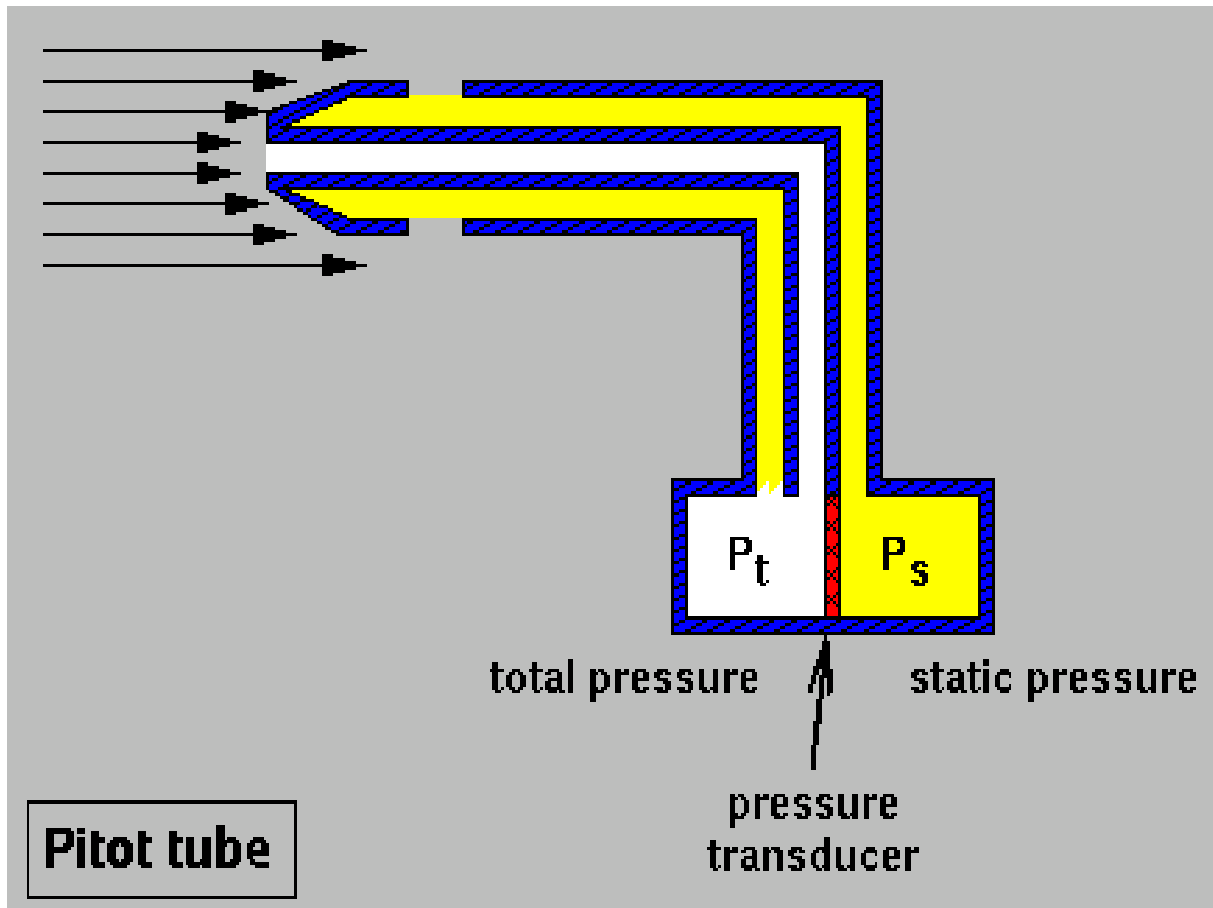
- Mass–accelerators (e.g. Orifice) convert pressure energy to kinetic energy



- Pitots convert kinetic energy (impact) to pressure energy



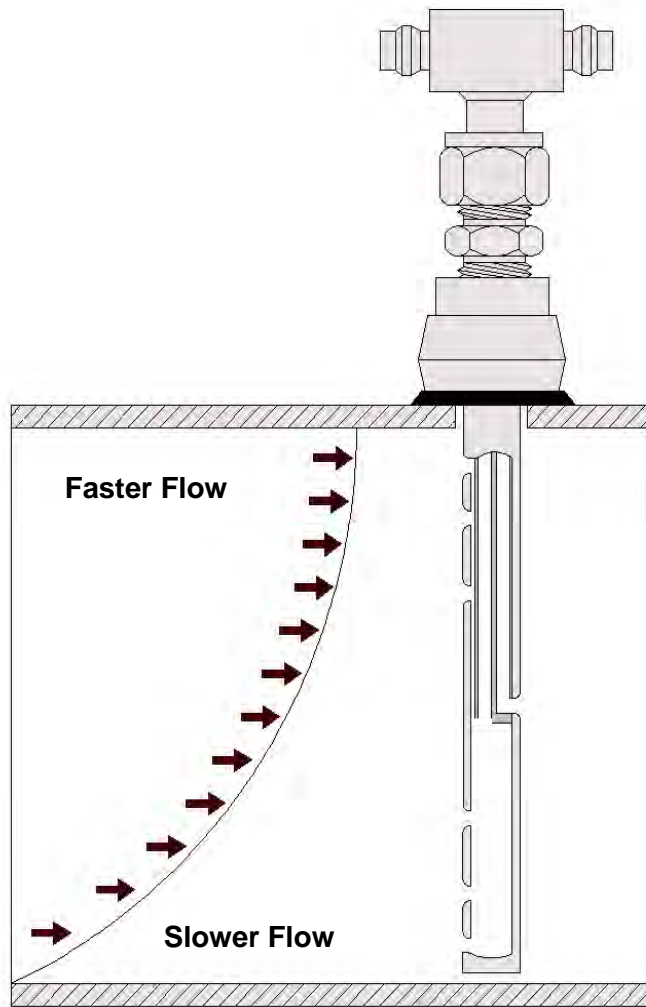
Pitot Tube Principle of Operation



- Kinetic energy is converted to Potential Energy
- Yellow: Measures Static Pressure
- White: Measures Static Pressure (Yellow) PLUS Dynamic Pressure

Averaging Pitot Tubes

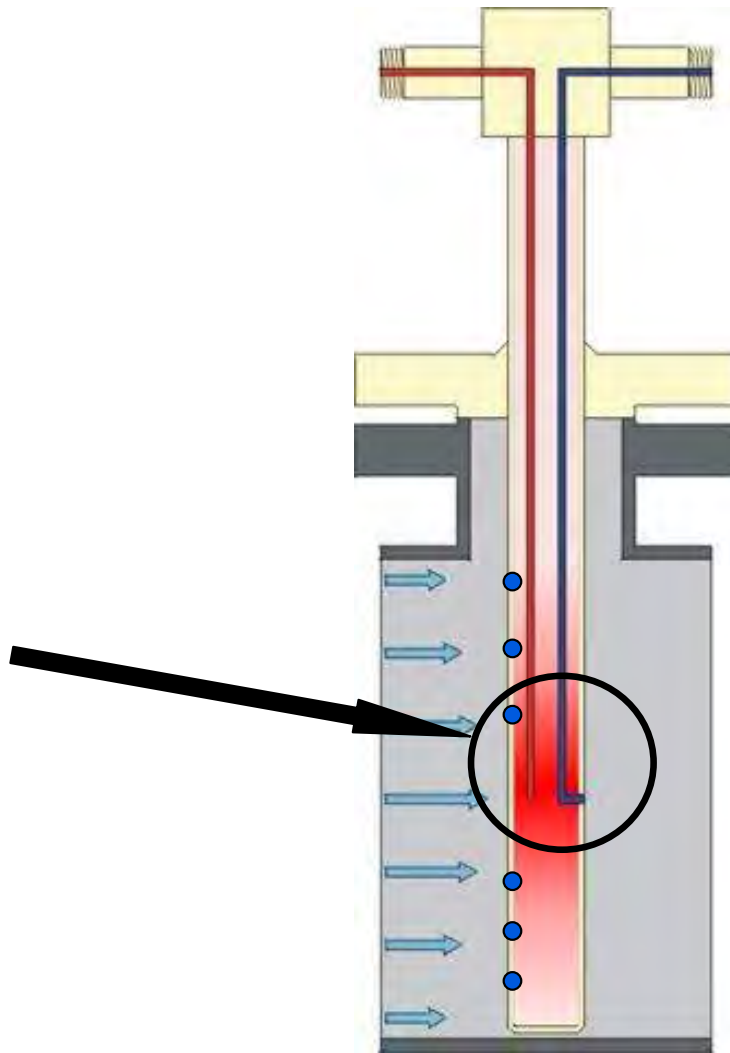
Self Averaging properties



- **Averaging Pitot Tubes** *average* the varying velocities across the diameter of a conduit
- Torbar has **dual averaging** to greatly improve this feature, especially in non-ideal situations

Averaging Pitot Tubes

Secondary Averaging

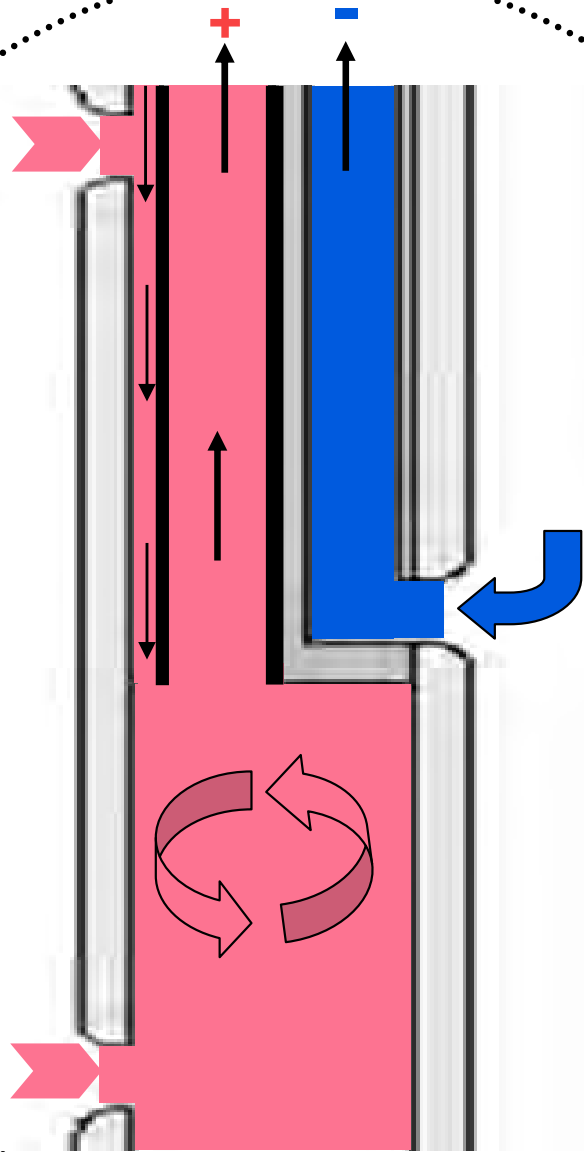


Dynamically achieved by...

- Sensing the pressure at several points
- Bringing the pressures together in a common manifold
- Taking the signal output from the neutral position of the manifold

Averaging Pitot Tubes

Secondary Averaging



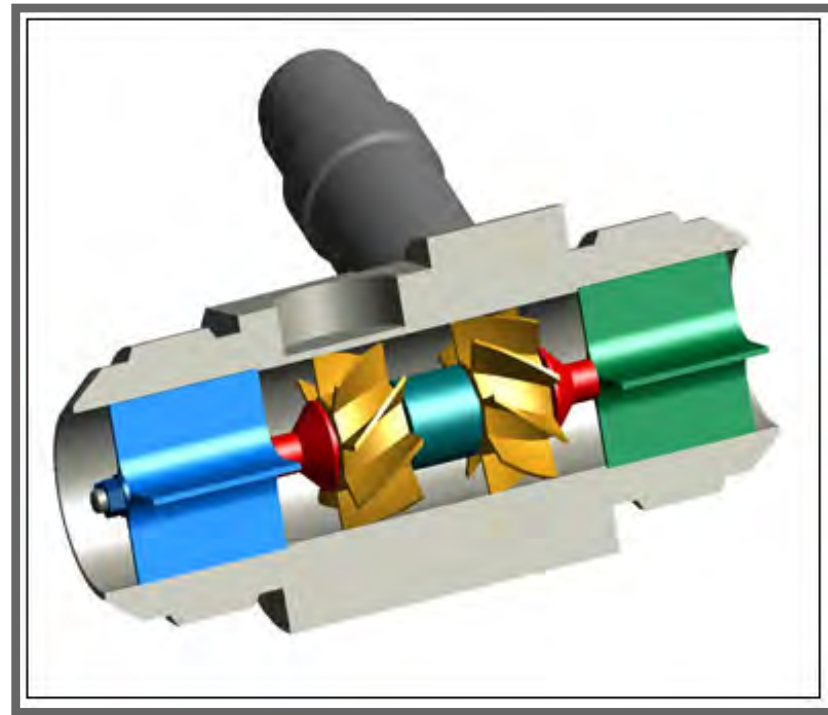
Advantages

- Increased Accuracy
- Better Repeatability
- Suitable for less-than-ideal pipe configurations

Turbine Meter Theory of Operation

An electrical pulse is then generated and converted to a frequency output proportional to the flow rate

As liquid or gas flows through the turbine, it turns an impeller blade that is sensed by infrared beams, photo-electric sensors, or magnets



Turbine Meter



ADVANTAGES

- High accuracy
- Suitable for extreme temperatures and pressures
- Can be used on Gas or Liquid
- Easy installation
- Well accepted in Oil & Gas industry

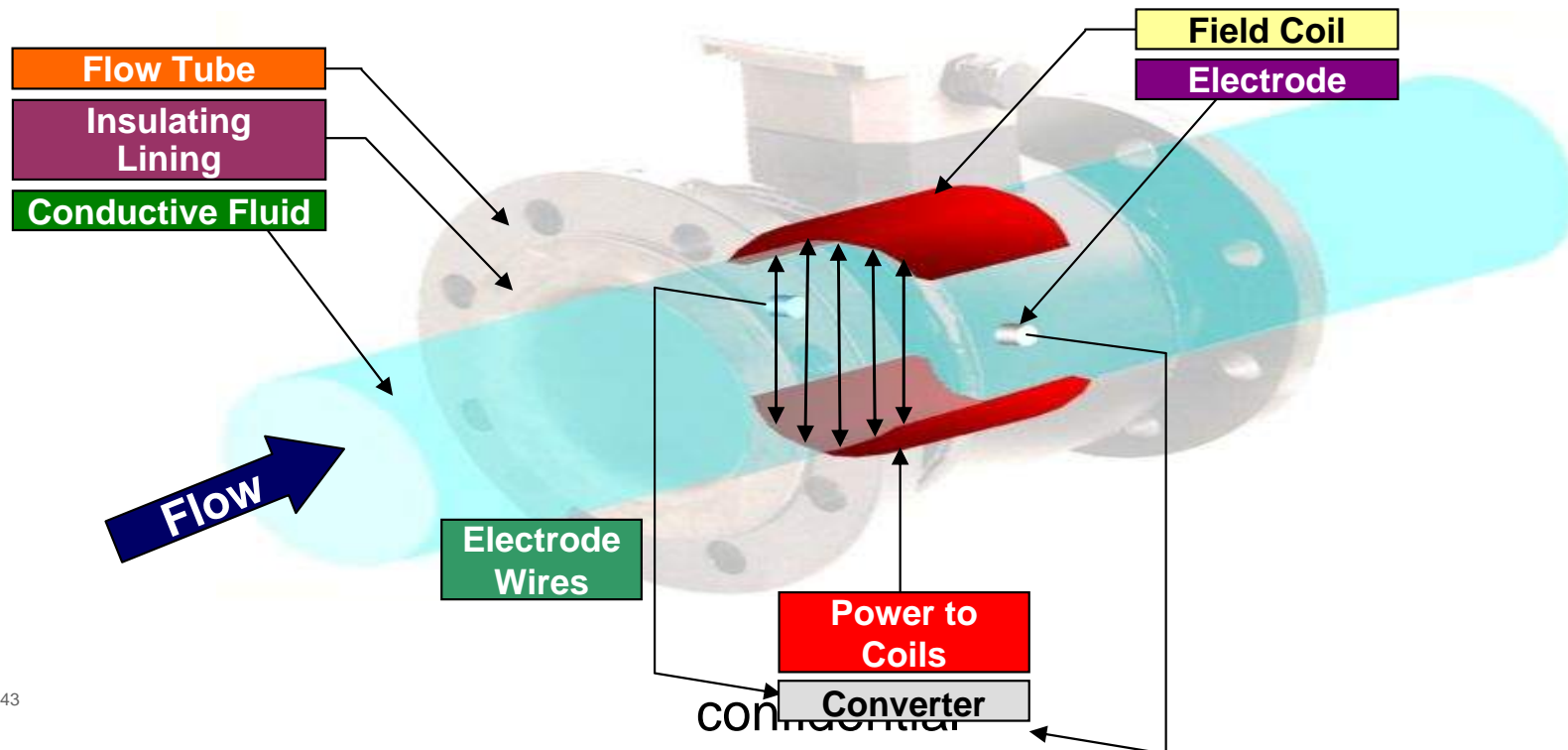
DISADVANTAGES

- Only for low viscosities
- Require upstream and down-stream flow conditioning
- Require frequent calibration Moving parts
- Sensitive to flow profile
- Vibration sensitive

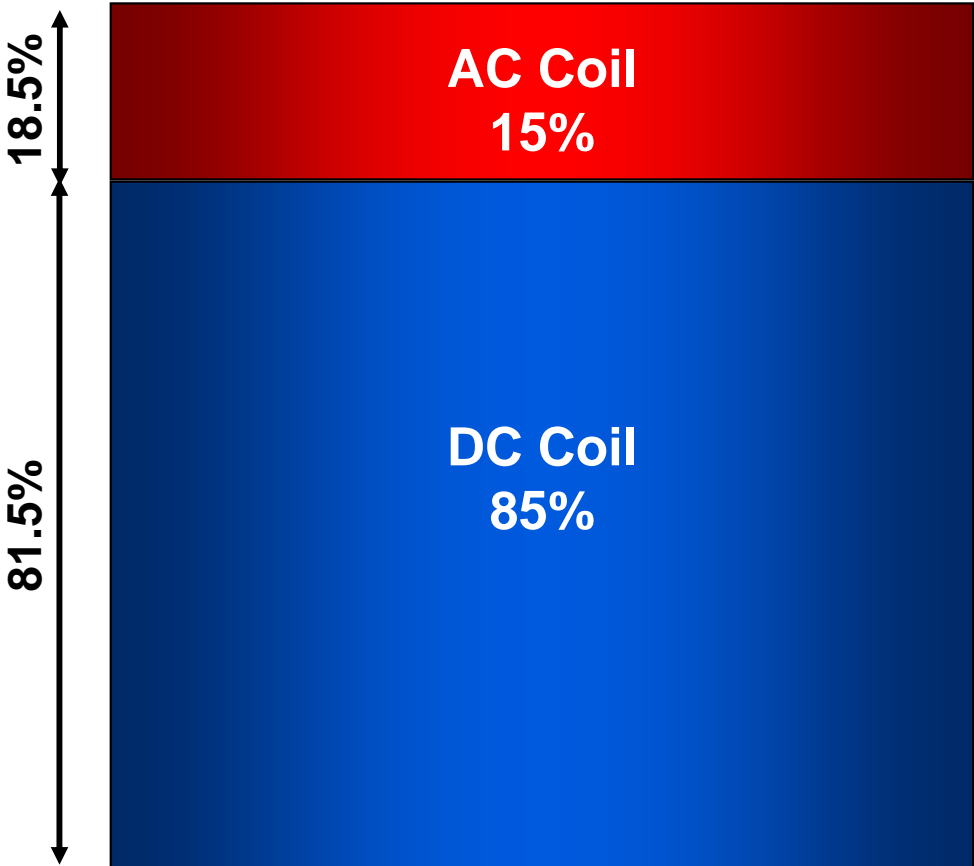
Flow Pioneers – Michael Faraday



- Publication: *Experimental Research in Electricity* (1855)
- Concept: Faraday Effect – An intersection between light & a magnetic field in dielectric media
- Lay-man's: Discovered that if a copper disk is rotated between the poles of a permanent magnet and electric current is generated. The resistance is proportional to the velocity

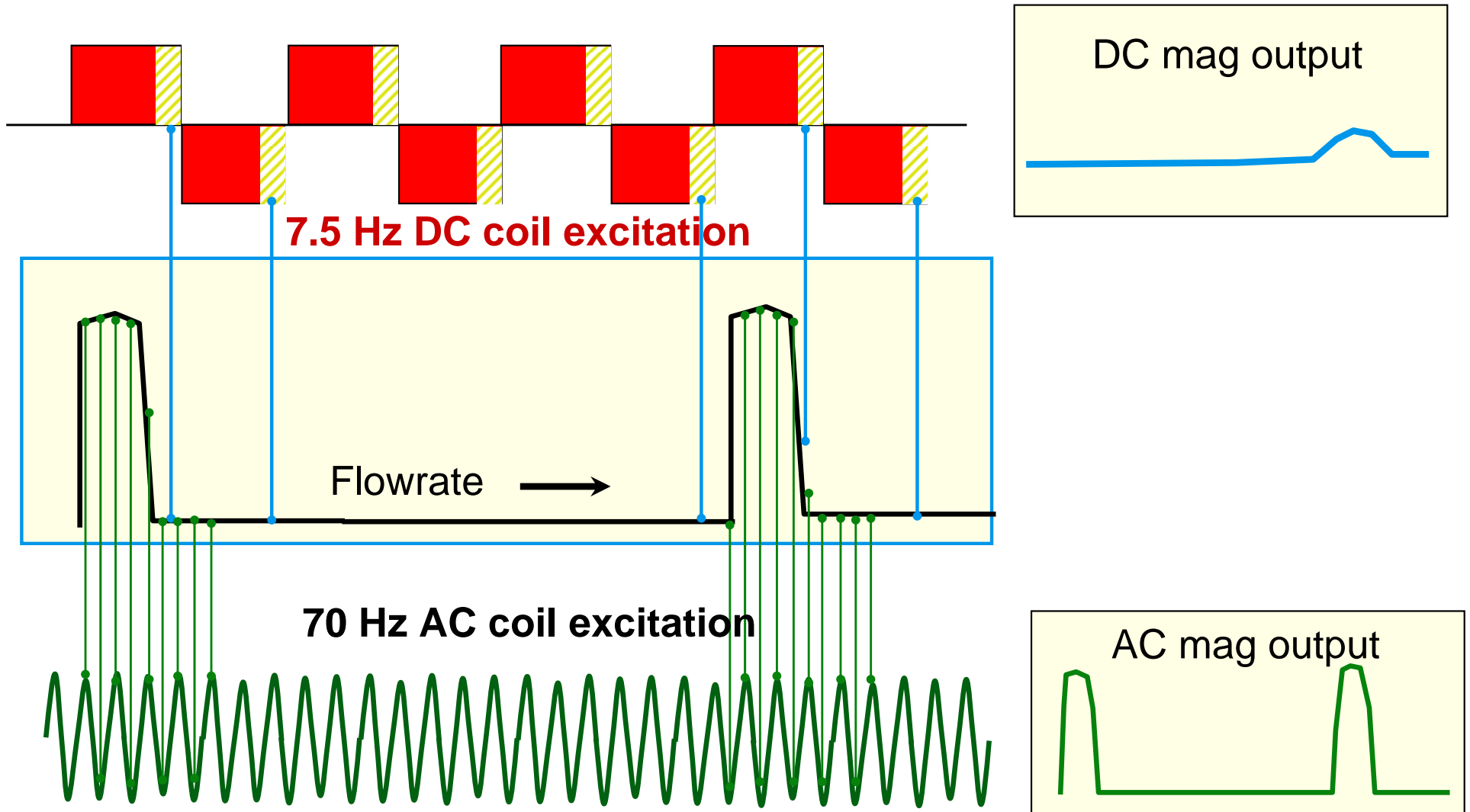


AC & DC MAGMETER SALES COMPARISON



ARC & Flow Research – 2002 Revenues

Magnetic Flowmeters – Pulsating Flows



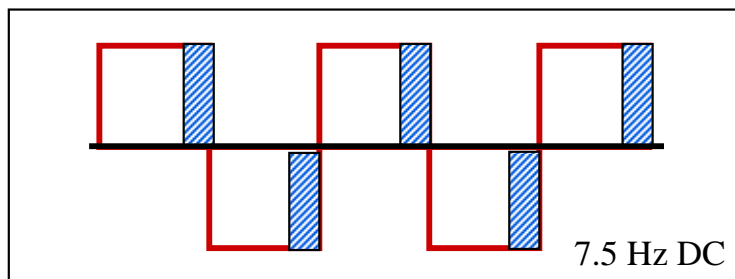
DC vs. AC Excited Magmeters

DC ADVANTAGES

- No Zero Drift
- High accuracy - $\pm 0.2\%$ or 0.4% of rate
- Low power consumption

DC DISADVANTAGES

- Low sample rate
 - Poor for batching or PD pumps
- Unstable output on noisy slurry applications

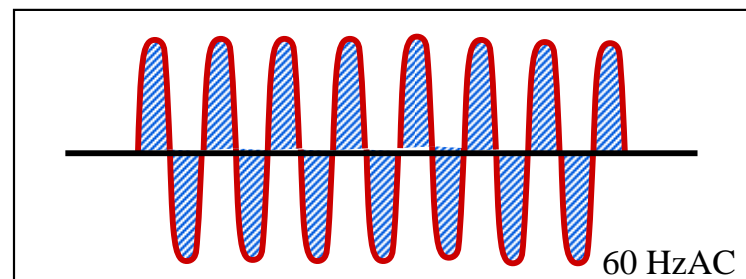


AC ADVANTAGES

- Slurry noise immunity
- Eliminates pulsating pump problems
- Capable of high speed batching

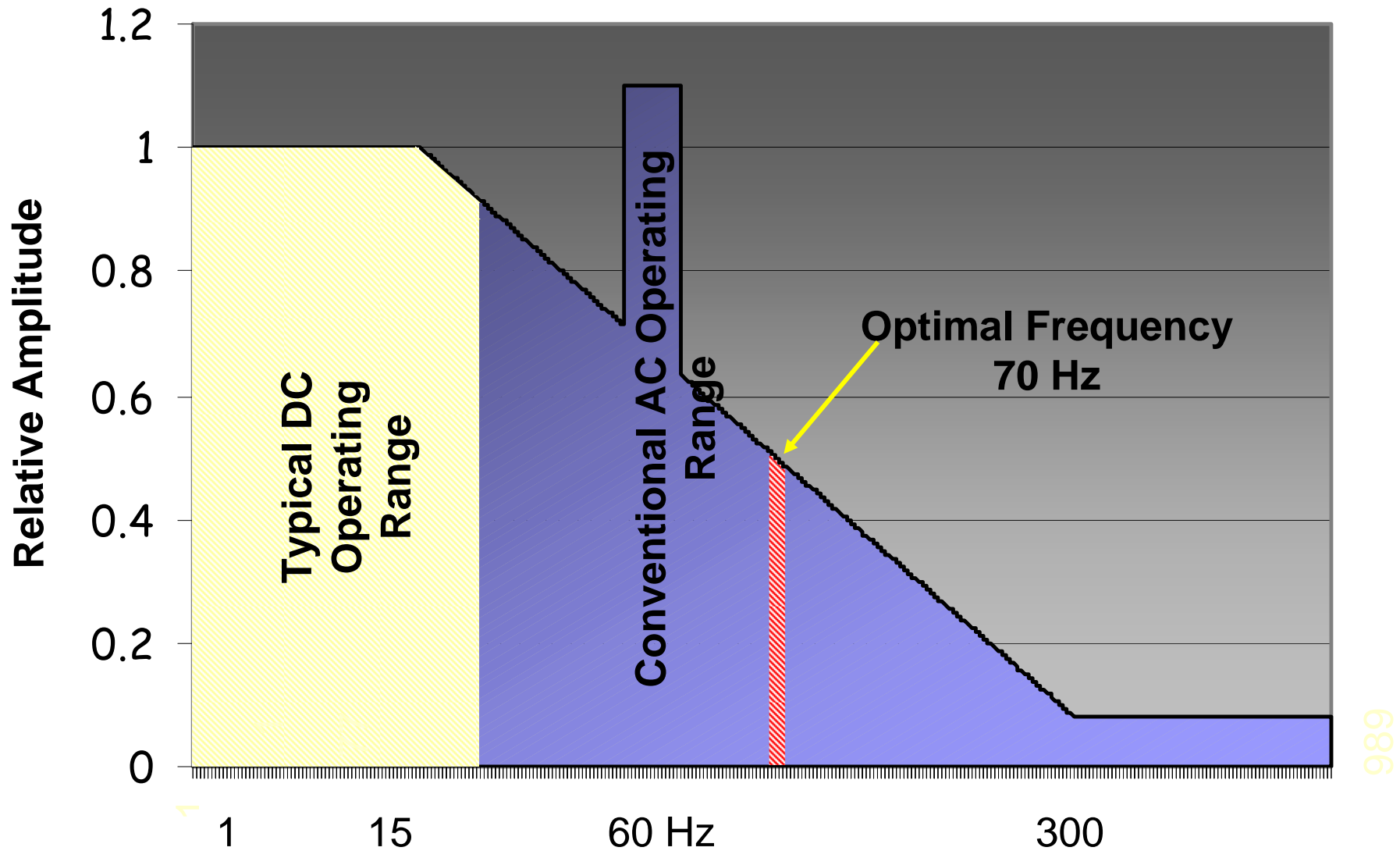
AC DISADVANTAGES

- May require periodic zero adjustment (now stable zero)
- Accuracy $\pm .2\%$
- Higher power consumption than DC



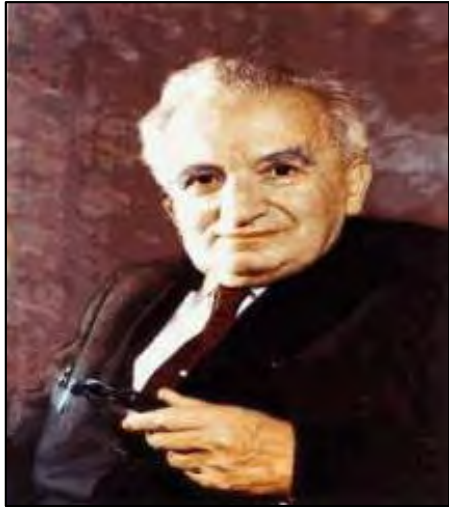
FSM 4000

Optimal Frequency for Noisy Applications – 70 Hz



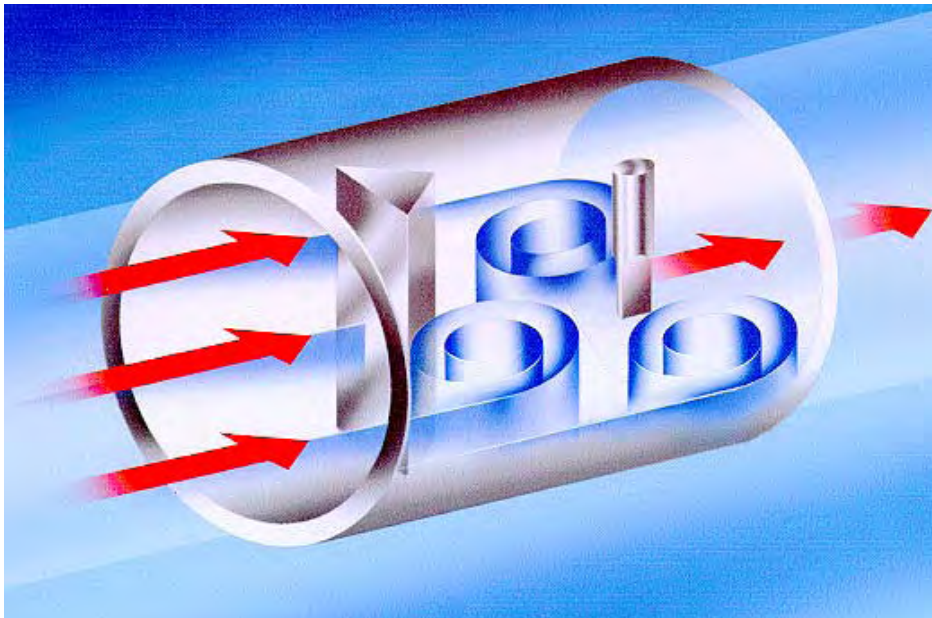
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Flow Pioneers – Theodore von Karman

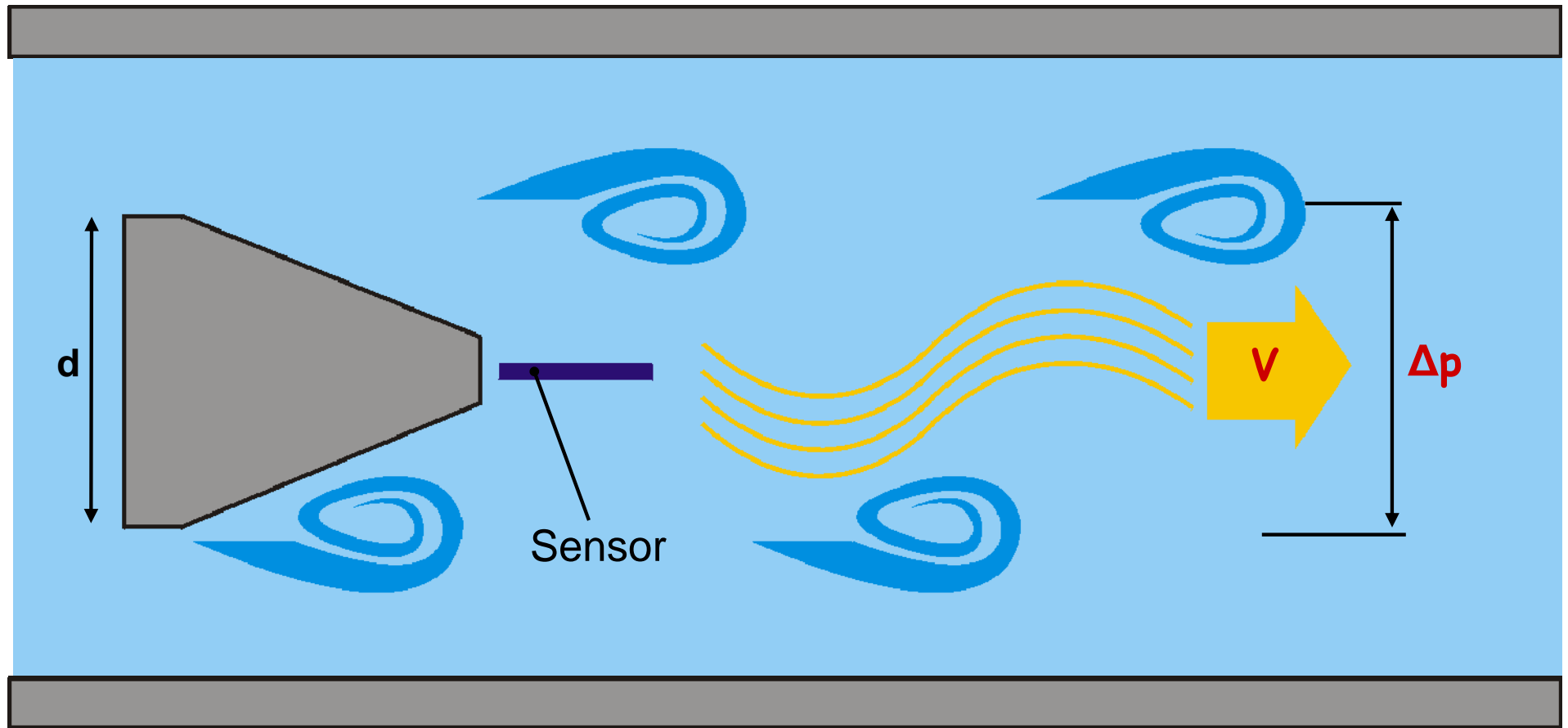


(1881 – 1963)

- Publication: *Aerodynamics* (1954) $Q = V * A$
- Concept: Vortex Effect – pattern of vortices caused by the separation of flow over bluff bodies
- Lay-man's: When a vortex is shed, an unsymmetrical flow patten forms around the body, which changes the pressure distribution

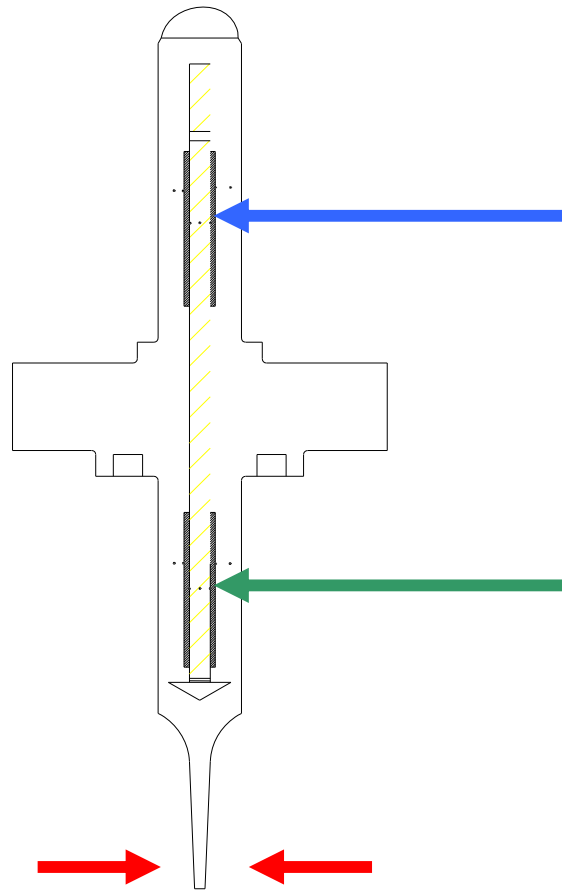


Vortex Meters – How a Vortex Meter Works?



$$Q = V * A$$

Piezo-Electric Sensing

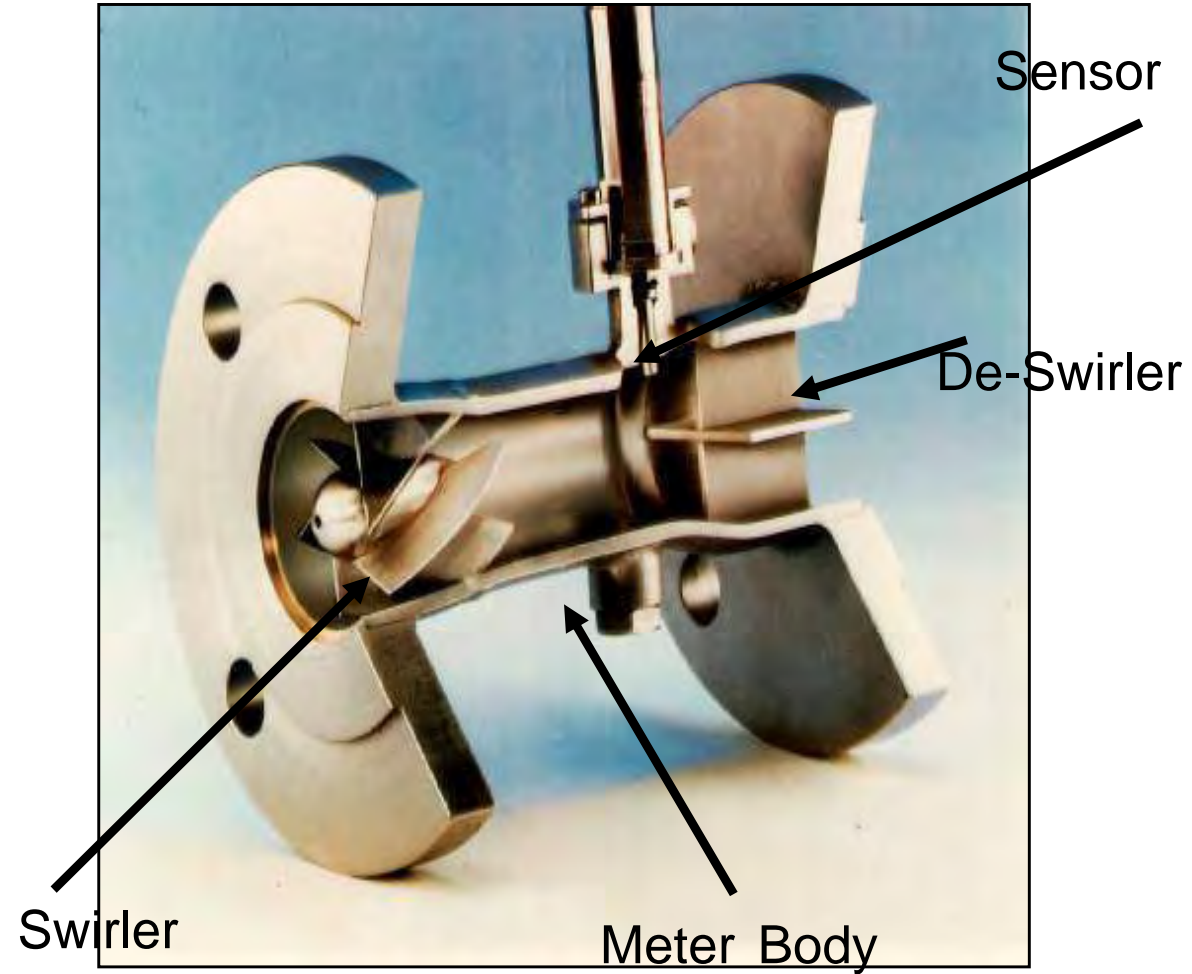
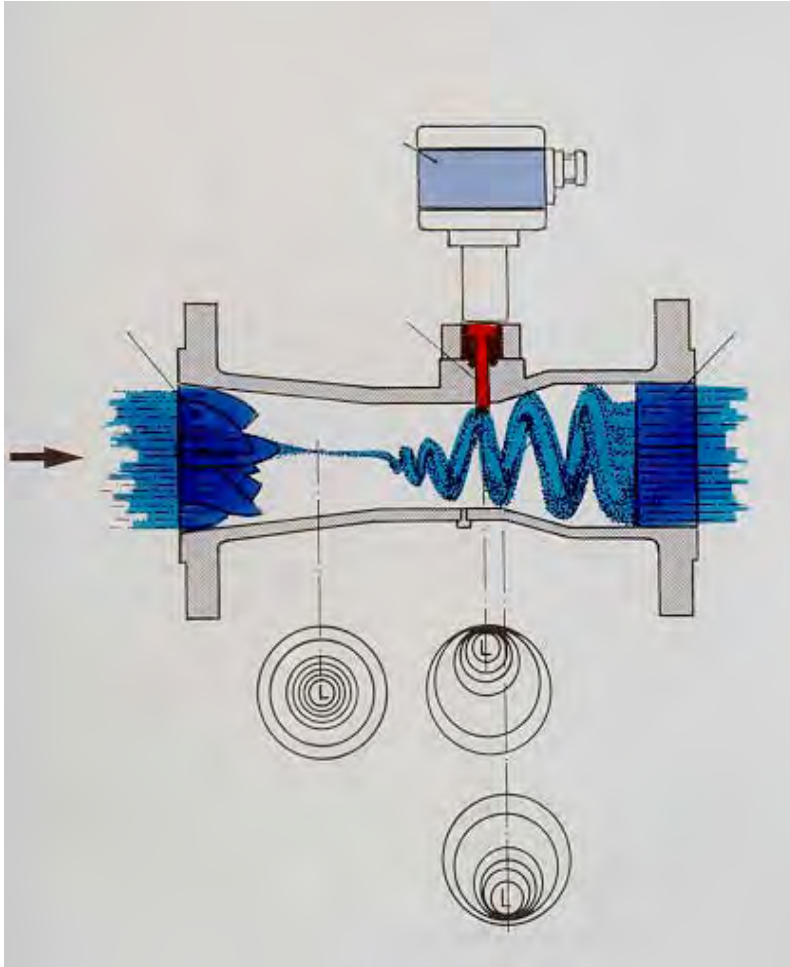


Compensation Piezos are mechanically isolated from the flow Piezos and respond only to vibration

Flow Piezos respond to flow and vibration

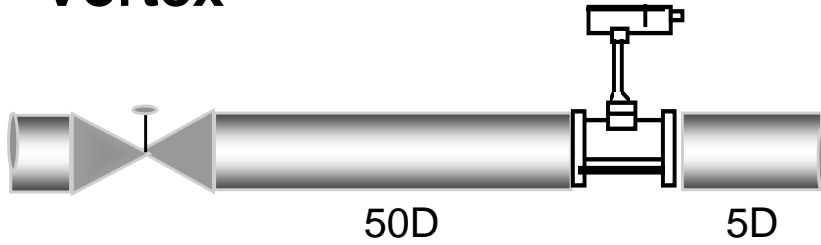
Alternating Pressure Pulses From Vortex Shedding

Swirl Meters – Cut-a-way

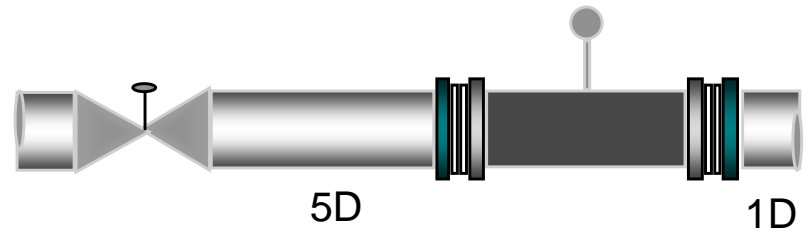


The Swirl Difference

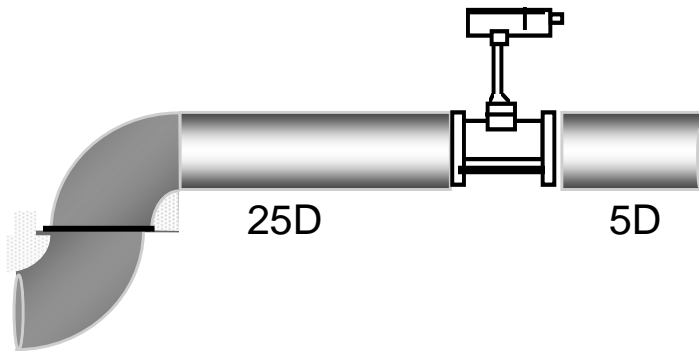
Vortex



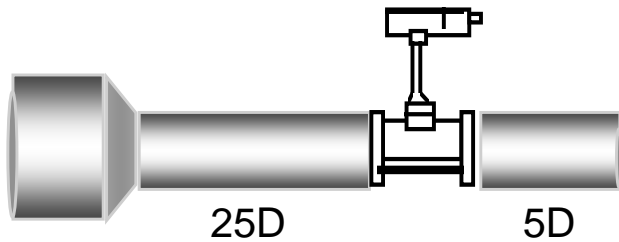
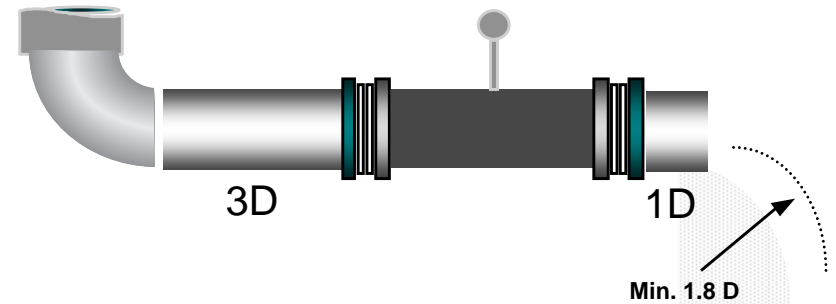
Swirl Meter



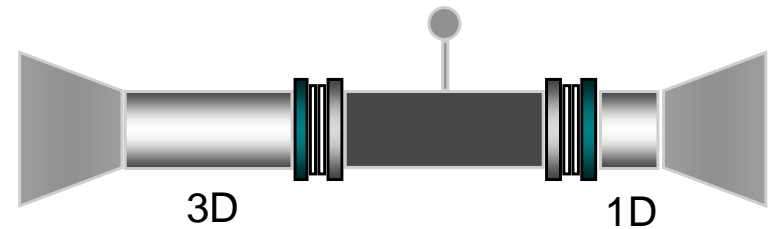
Process Control Valve



90° Elbow



Reduction



Swirl Meters – Vortex vs. Swirl Meters

Vortex

- Lower Cost
- All Cast Construction
- Wafer and Flanged meter bodies
- Higher maximum flow capability
- Measures liquids (viscosity < 8 cp), gases and steam
- Typical Sizes ½” to 12”
- 316L SST or Hastelloy
- ±0.75% of rate for liquids and ±1.0% of rate for gases/steam for volumetric flow
- ANSI 150/300/600

Swirl

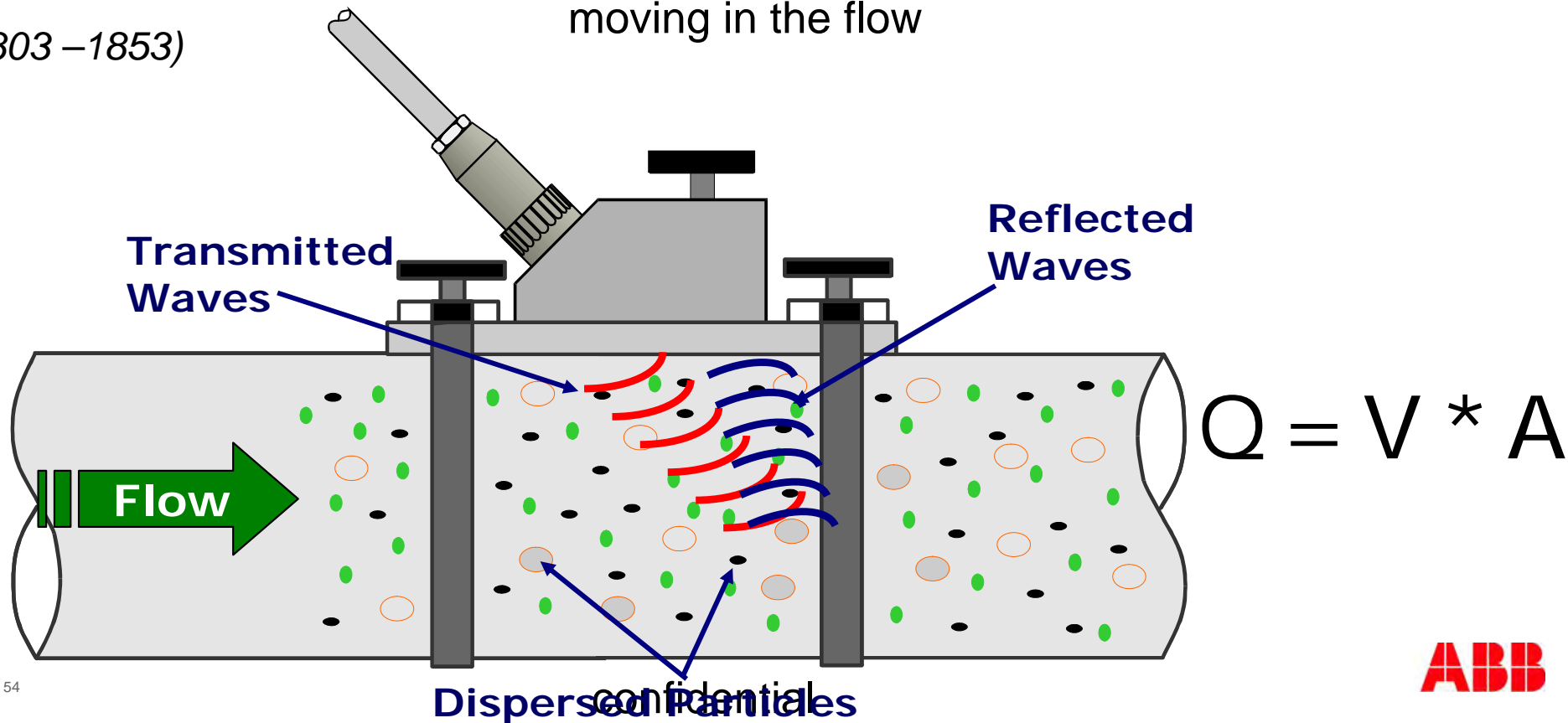
- Minimal inlet/outlet piping (3D)
- Better low flow capability than vortex on liquids and low density gases/steam
- Flanged bodies only
- Gives better rangeability on more viscous liquids
- Lower flow capability
- Higher accuracy: ±0.50% of rate for liquids, gases and steam for volumetric flow
- Measures liquids (viscosity <30 cp) gases and steam
- Sizes 1/2” to 16” flanged
- 316L SST

Flow Pioneers – Johann Christian Doppler



(1803 – 1853)

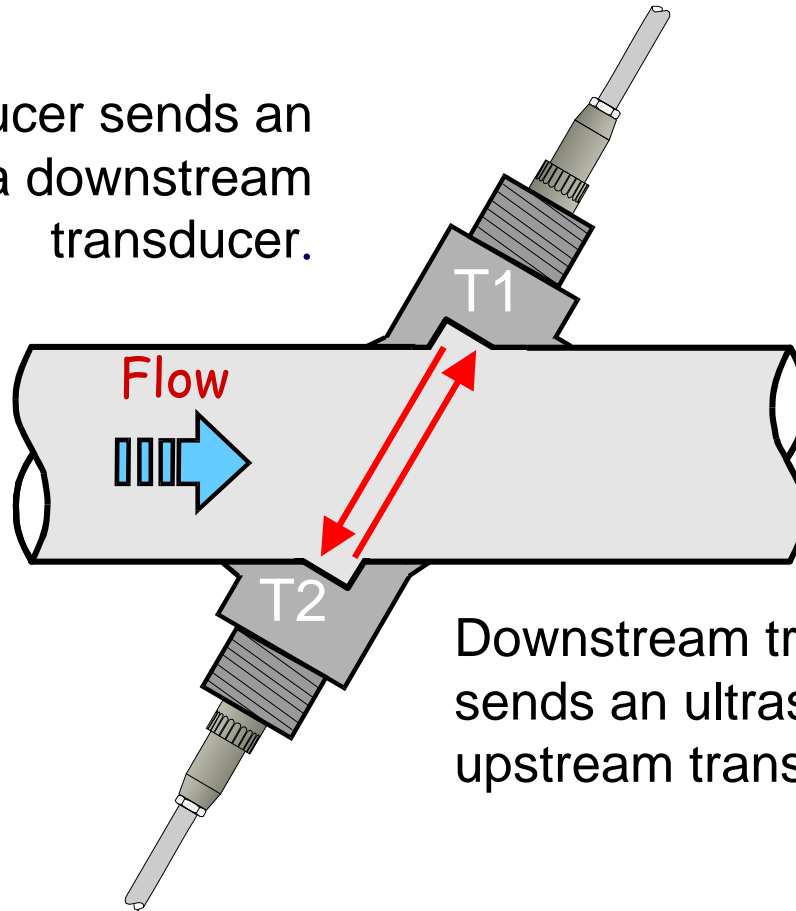
- **Publication:** *Über das farbige Licht der Doppelsterne einige andere Gestirne des Himmels (1842)*
- **Concept:** Doppler Effect – Change in frequency and wavelength perceived by an observer
- **Lay-man's:** A light or acoustic beam measures the shift in wavelengths of reflections from particles moving in the flow



Theory of Operation - “transit time”

Upstream transducer sends an ultrasonic signal to a downstream transducer.

When flow is present it will speed up the upstream to downstream signal and slow down the downstream to upstream signal

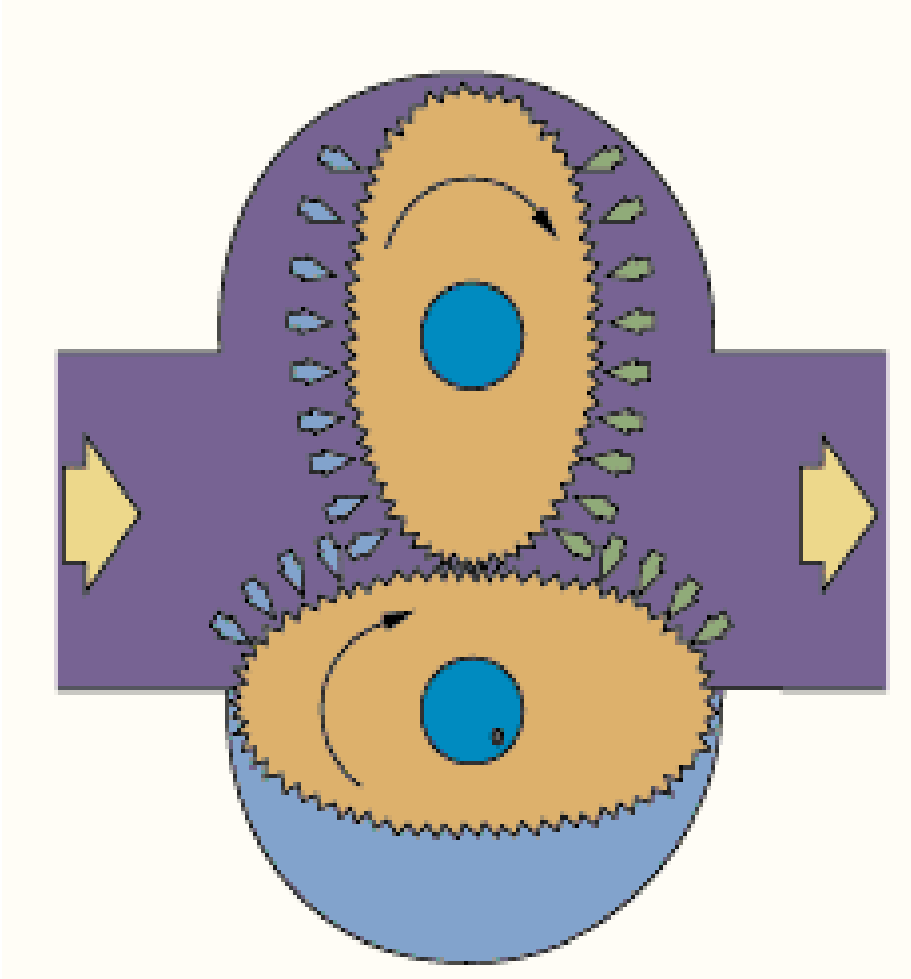


Downstream transducer then sends an ultrasonic signal to the upstream transducer.

Change in time (Transit Time) is proportional to the flow.

Sensors must be in contact with the fluid
Installation interrupts process
Long pipe runs required with single-path configuration

Positive Displacement Meter



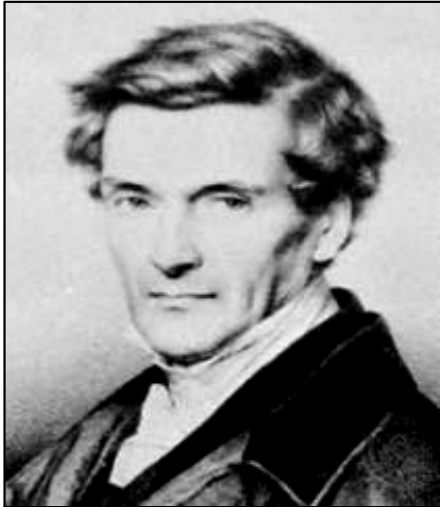
ADVANTAGES

- Good accuracy - $\pm 0.1\%$
- Can be used in high viscosity applications
- Impervious to poor flow profile
- Used for measuring gas and water into your home and gasoline into your car
- Suitable for liquids, gases, and steam
- Direct reading/no power required
- Can handle high pressures

DISADVANTAGES

- Cannot handle solids, entrapped air (in liquids) or liquids (in gas)
- Expensive to install and maintain
- High pressure drop
- Many moving parts

Flow Pioneers – Gaspard Coriolis

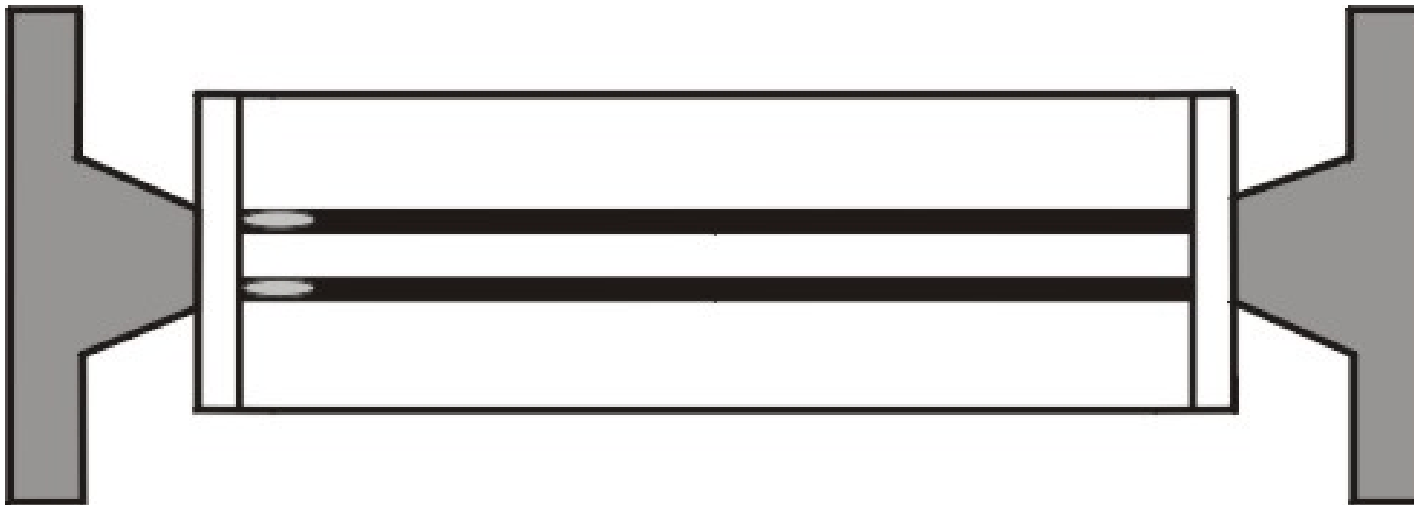


Publication: *Sur les équations du mouvement relatif des systèmes de corps* (1835)

Concept: Coriolis Effect – Energy transfer of moving objects viewed from a rotating frame

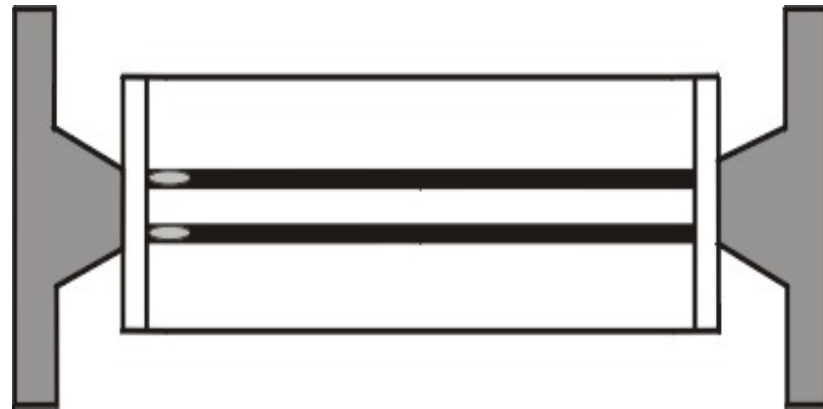
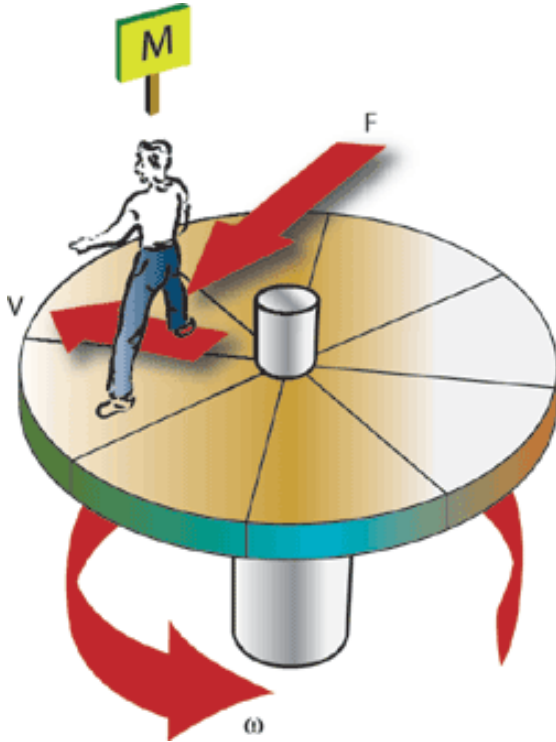
Lay-man's: phase shift represents mass flow

(1792 – 1843)

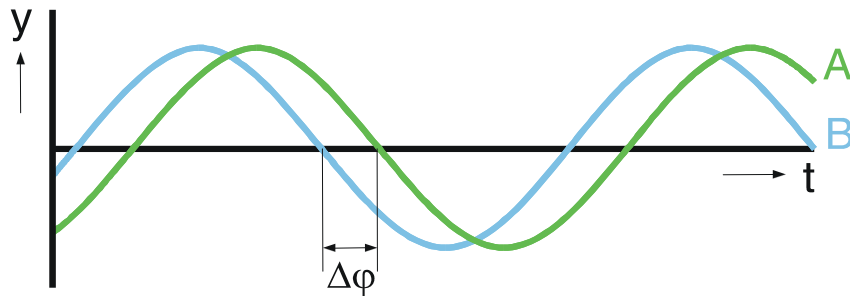
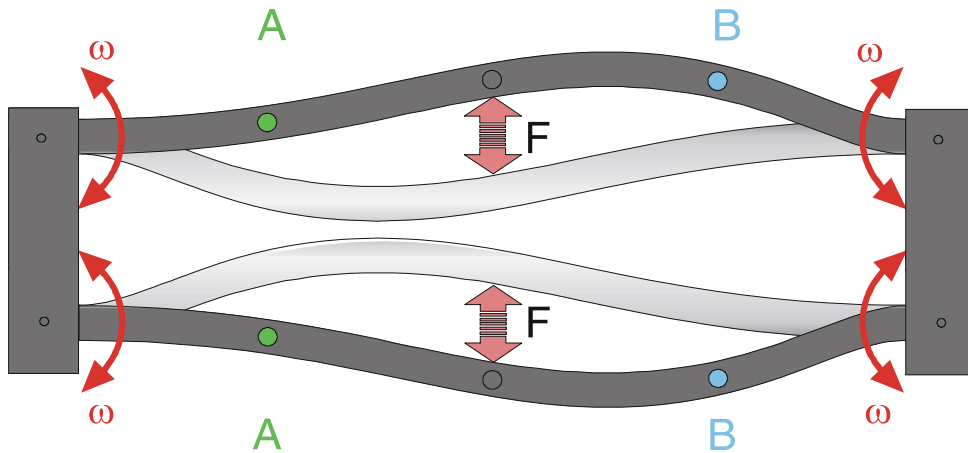


Principle of Operation

- In simple terms, when a mass is moving in a rotating frame of reference, it experiences a tangential acceleration that is proportional to its linear velocity times its angular velocity.



Principle of operation



ω = angular velocity

F_c = Coriolis force

$\Delta \phi$ = Phase shift

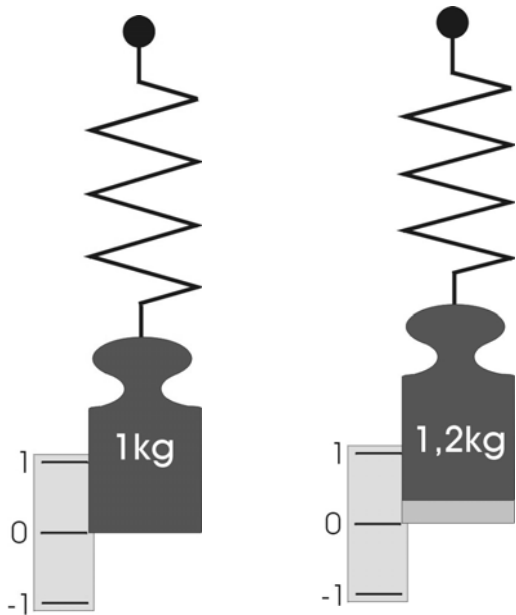
A,B = Sensors

Y = amplitude

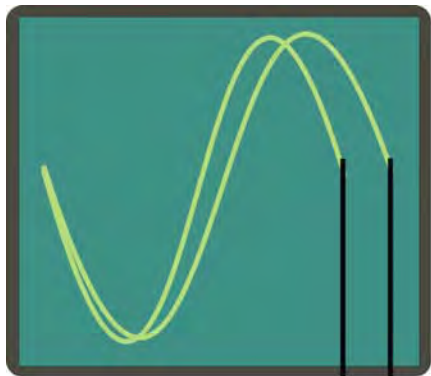
T = time

$$\Delta\phi \sim F_c \sim \dot{m}$$

Principle density measurement

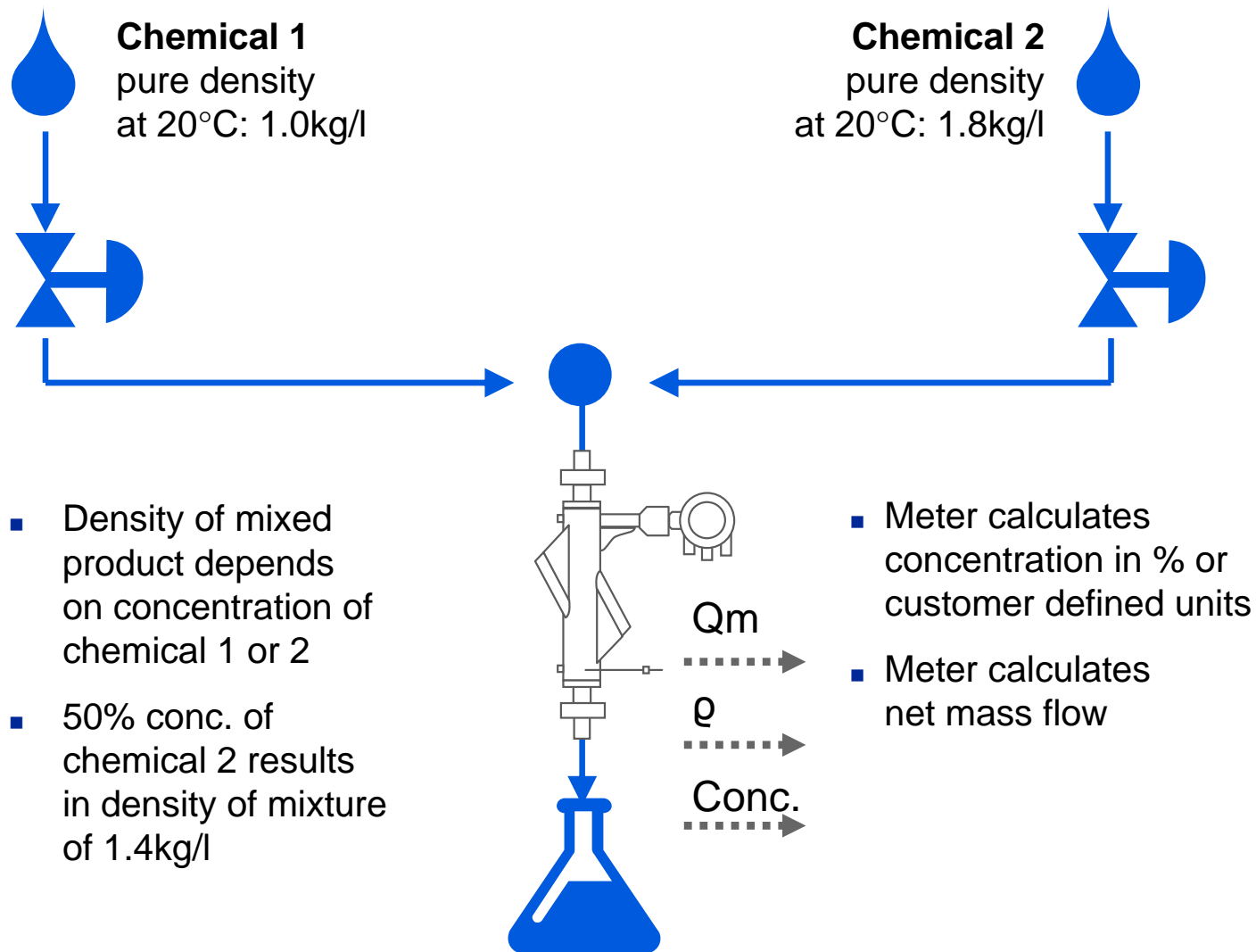


- Higher density @ Lower Natural Frequency
- Conversely, Lower Density @ Higher Natural Frequency
- Calibrate on Water and Air
- % Concentration therefore possible, given, mass rate and temperature



$$\Delta f_R = \frac{1}{2\pi} \cdot \sqrt{\frac{c}{m}} f_{Res} = f(\text{density})$$

ME2 – Concentration computation based on density



ME2 – Concentration computation DensiMass

| | Temp. Concentr. | Temp 1 | Temp 2 | Temp 3 | ... | Temp 10 |
|------|--------------------|---------|---------|---------|---------|---------|
| % 1 | K 1 | density | density | density | density | density |
| % 2 | K 2 | density | density | density | density | density |
| % 3 | K 3 | density | density | density | density | density |
| ... | | density | density | density | density | density |
| % 10 | K 10 | density | density | density | density | density |

- Predefined matrices for alcohol or ethanol, sugar (BRIX and Baumé), sodium hydroxide as well as wheat and corn starch
- Interpolation between the matrix values. Extrapolation up to limits of the meter
- Max. 10 x 10 matrix, 2 matrices can be stored, switching (automatic / manual / contact input / HART)
- All n x m matrices possible when data < 100 values (ex.: 2 x 50)
- Entering of data with communication tool

Questions and Answers

| Question | Answer |
|---|--|
| Q: What about hot-film flow meters? | These are used in the automotive industry and aren't really process meters so they wouldn't have been discussed in the Webinar. |
| Q: Does the number of windings on a magmeter coil matter to the signal to noise ratio? | Windings are certainly relevant, and ABB has proprietary winding practices. Notwithstanding, signal to noise ratio is addressed in the converter and not the sensor. In a word, digital signal processing is what is key to signal to noise ratio, especially in more recent years. |
| Q: DC mag meters are on the majority of filling machines made today how can you say they not good for batching? | I said in the Webinar that DC mags are inferior on pulsating flow, which include unpredictable flow spikes that ought not be confused with *repeatable* fill mag applications. Fill mags work on empirically verifiable assumptions that are based upon time and rate, which cannot be incorporated in non-fill processes that experience *random* spikes in flow, hence the need for AC mags on pulsating flow applications but not on fill mag applications. Finally, FSM4000, an AC mag, will outperform all DC mags (and AC mags). |
| Q: How can we measure the flow if the pipe is not full? | Partial pipe conditions are never a good thing. If the meter is oriented in order for flow to vertically through the meter, then partial pipe issues disappear. However, given partially filled pipes, a calculation must be made with all volume meters since the meter, if it is even able to read under such conditions, will overestimate the flow because the measurement will be off by the "gas void fraction". There are mags that incorporated electrodes around the inside liner that act as level monitors, which in turn can be incorporated into the velocity calculation. With mass meters, if the meter measures without stalling, the measurement will be off not by the volume of gas (or air) in the pipe but rather by the mass of the air which is negligible. |
| Q: What are the main differences between positive displacement meters and turbine meters? | A: Turbine will require more up and downstream piping than PD and can be higher maintenance due to bearing fatigue at higher rates than pd |

Questions and Answers (Continued)

| Question | Answer |
|--|---|
| Q: Up to what size is the wedge meter available | A: Unlimited on size and material due to custom engineering largest to date is 48" |
| Q: Please explain the difference between the permanent pressure loss and DP? | A: Through the restriction there is a pressure loss relative to the flow velocity, downstream of the restriction there will be some recovery of the loss but never to the full static pressure of the upstream side |
| Q: Is the compact orimaster available with diaphragm seals | A: No. ABB Wedge meter would be the device that takes advantage of remote seals |
| Q: 1) why magmeter vs doppler? 2)what errors can one expect from upstream/downstream valves or bends installed closer than recommended limits for mag or dopplers? | A: Mag meter is more economical but is process wetted and could be more on maintenance side, doppler on the other hand more susceptible to solids creating noise etc |
| Q: 1) Why magmeter vs doppler? 2) What errors can one expect from upstream/downstream valves or bends installed closer than recommended limits for mag or dopplers? | A: Errors from up and downstream can be varied based on the installation therefore very difficult to answer in this setting but would advise up to 5 % error at some cases |

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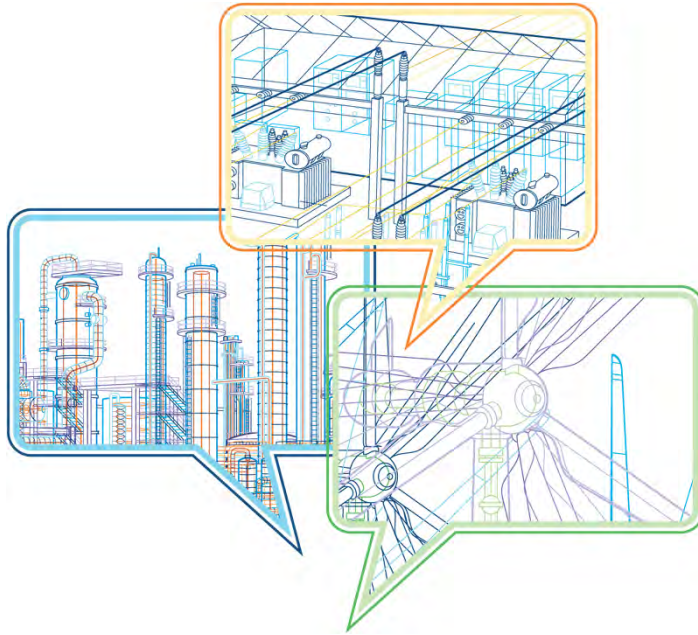
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