Practical Selection and Usage of Coriolis Meters for Gas Measurement

Marc Buttler

Application Innovation Director

Micro Motion Coriolis Flow and Density Products

Agenda

Introduction and Principle of Operation

Industry Standards

Calibration

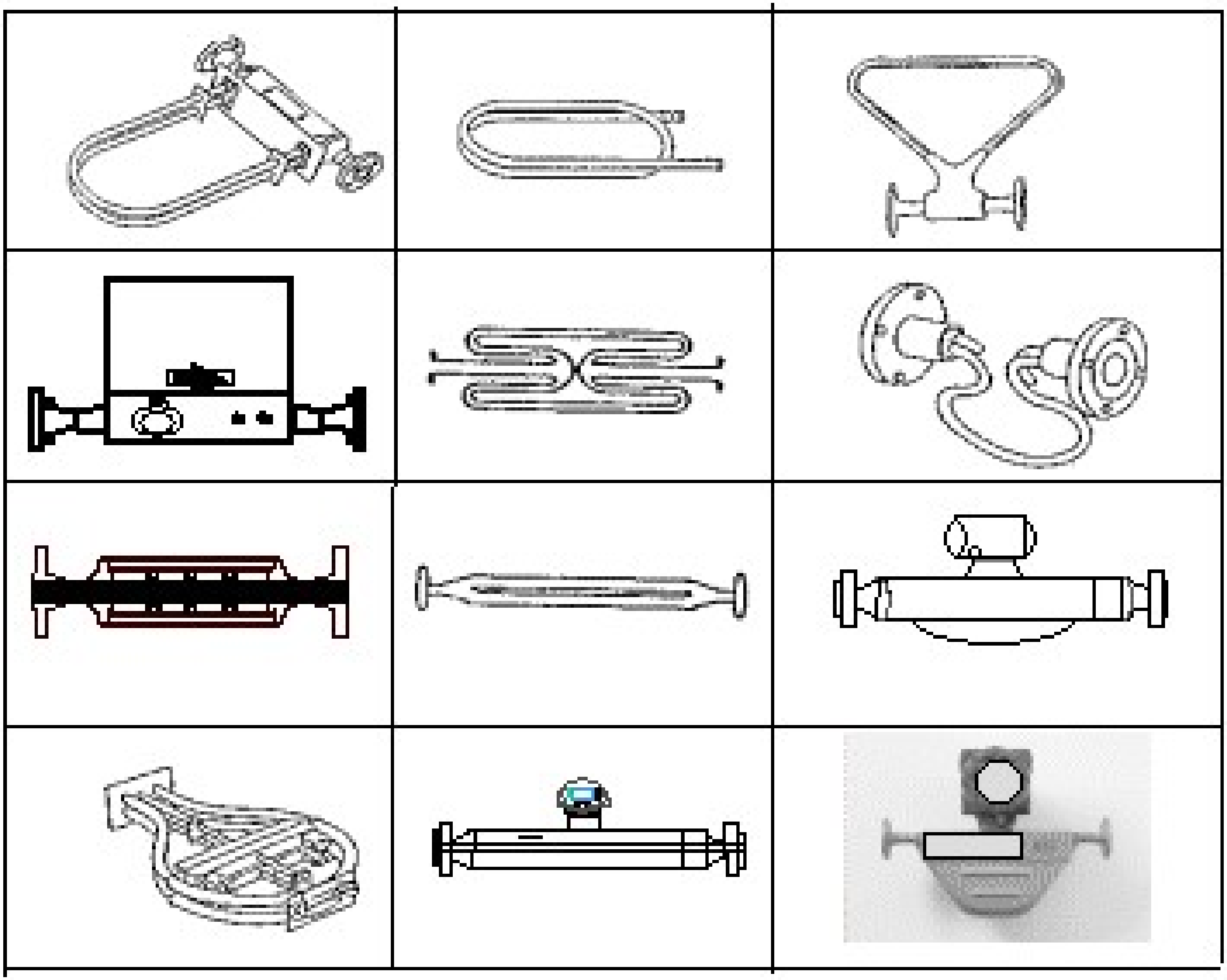
Maintenance Best Practices

Application Selection and Volume Conversion

Meter Sizing and Installation Considerations

Typical Applications

Overview of Coriolis Meters



Coriolis Flowmeter Pros and Cons

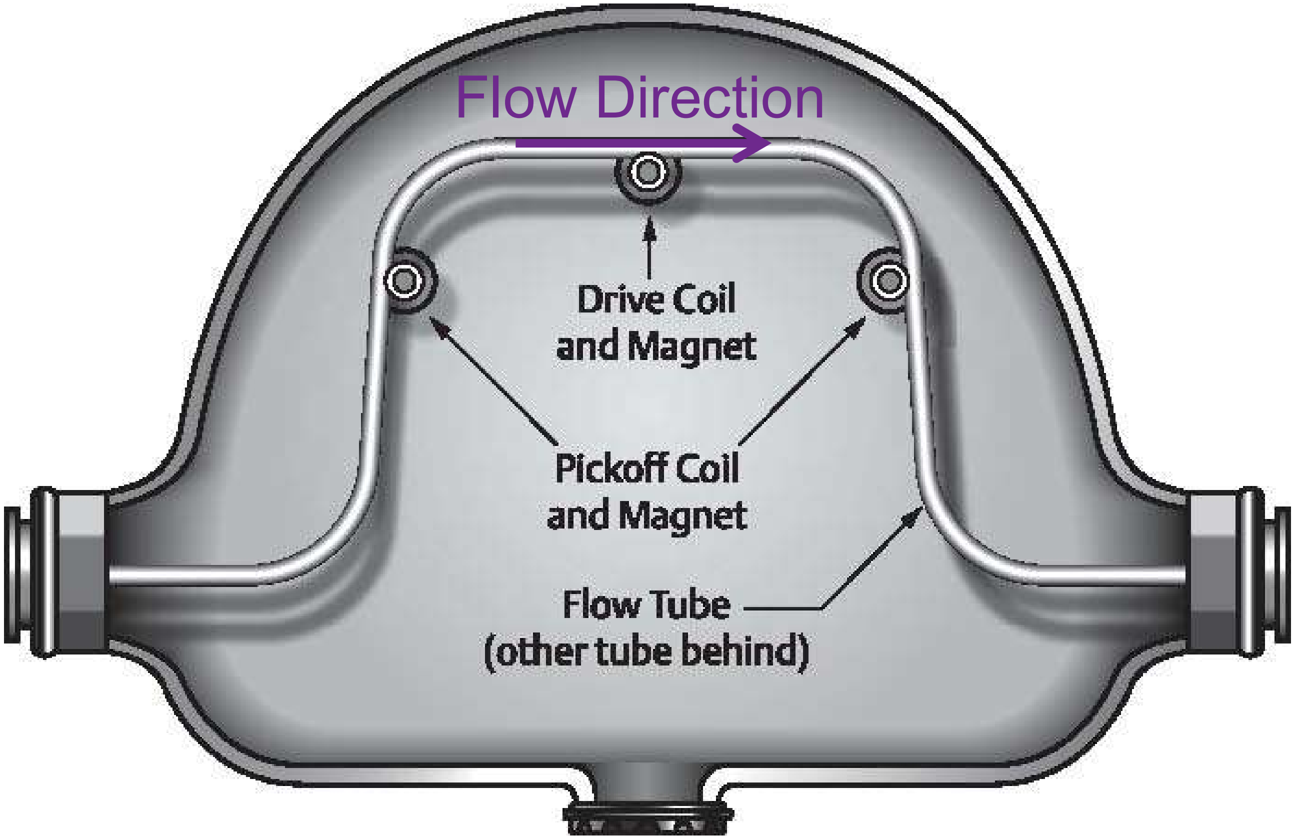
Key Advantages

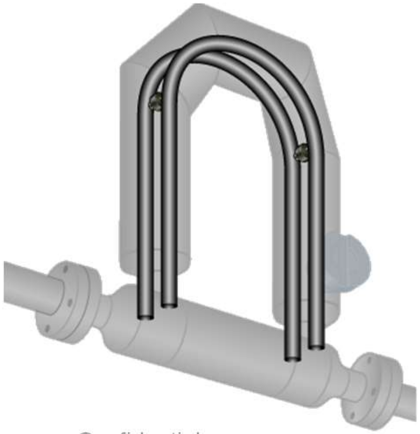
- Best-in-class direct mass flow, volume flow, and/or density measurement
- Non-obstructed flow path
- No moving parts
- Low / No maintenance required
- No flow conditioning or straight runs required
- Can provide limited multiphase flow measurement
- Excellent repeatability and turndown
- Advanced diagnostics to monitor meter AND process health

Some Constraints

- Not for line sizes over 16 inches in diameter
- Large external meter envelope
- Some designs result in high pressure drop at high flowrates
- Not as suitable as a Multi-Phase Flow Meter
  - Wet gas above Lockhart-Martinelli Parameter 0.75
  - Entrained gas in liquid Gas Void Fraction above 15% by volume

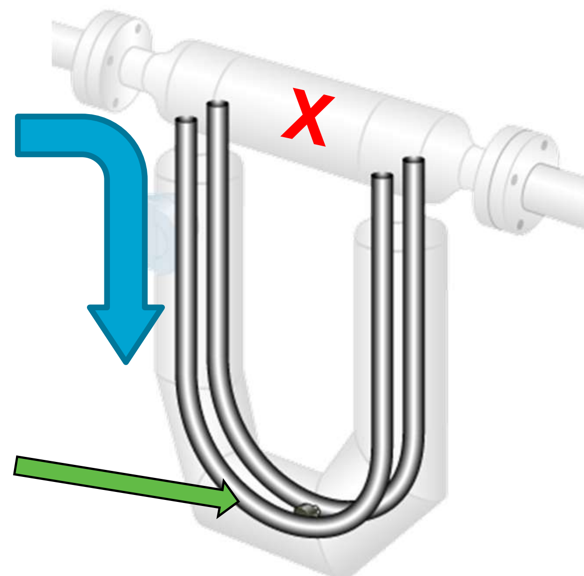
Principle of operation - Bent Tube Meter Design





Principle of Operation

- Process fluid enters the sensor and flow is split with half the flow through each tube

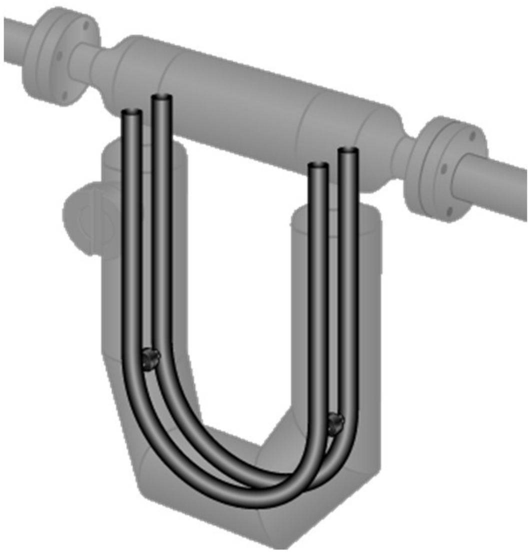


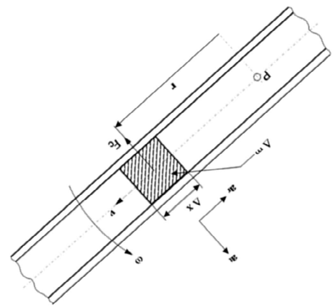
- Drive coil vibrates tubes at natural frequency

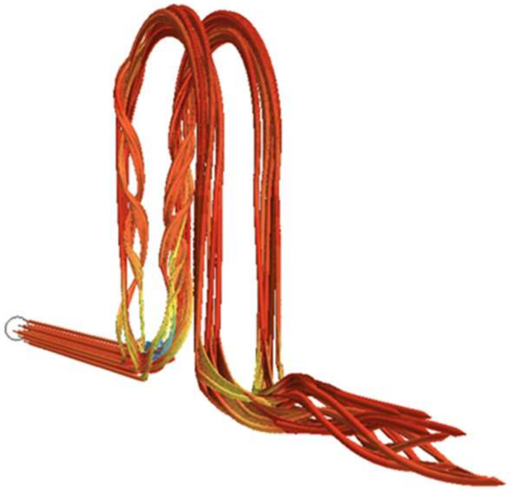
- Pick-off coils on inlet and outlet sides generate raw measurement signals

Coriolis Meter Principle of Operation Physics of Coriolis Force That Creates Twist During Flow

- Coriolis Principle: As a mass moves toward or away from the center of rotation (P) inside a rotating tube, the particle generates inertial forces on the tube.

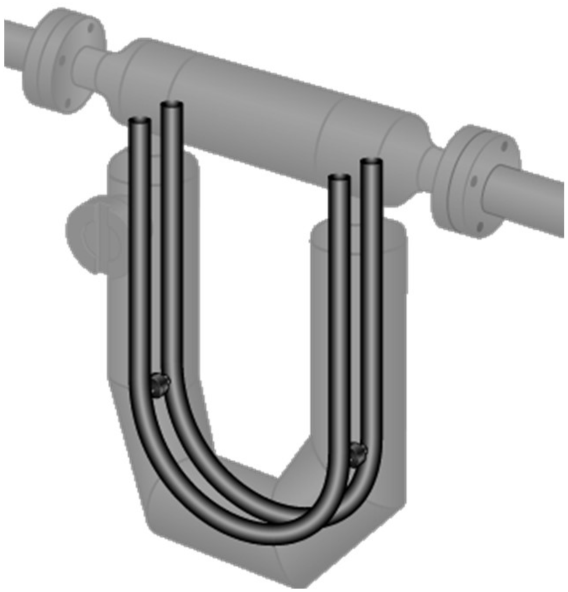




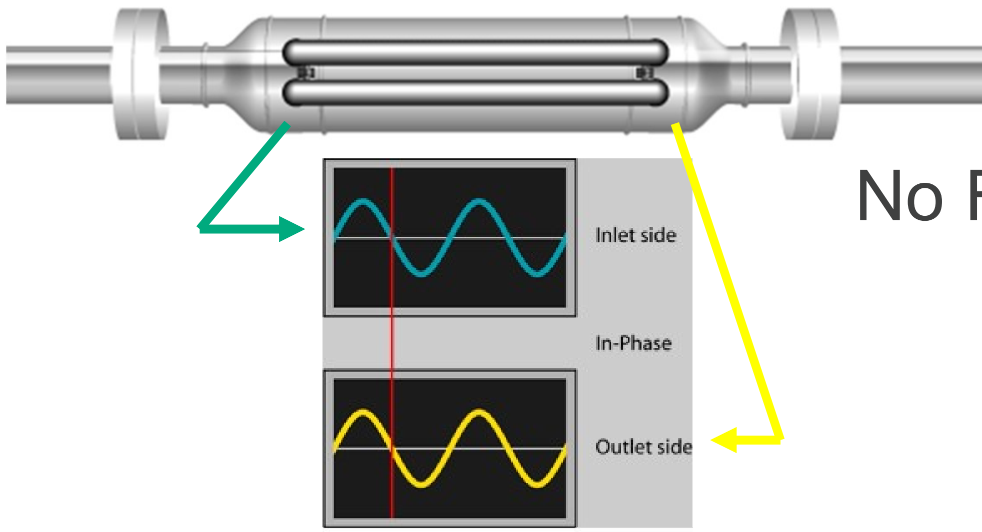


- A Coriolis meter measures mass directly
- Measurement is not affected by changes in fluid properties and velocity profile

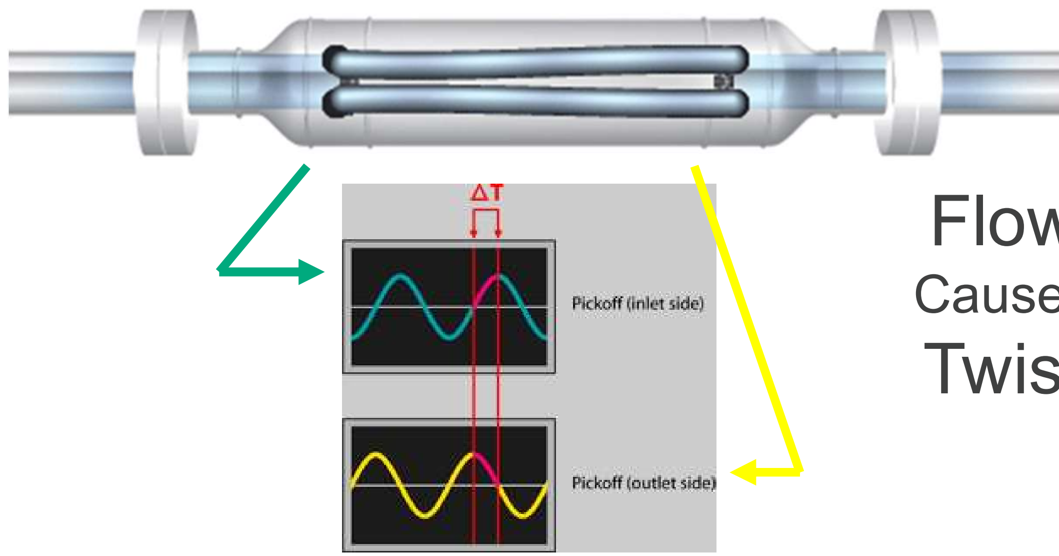
Coriolis Meter Principle of Operation
Signal Processing



Isometric View
At No Flow



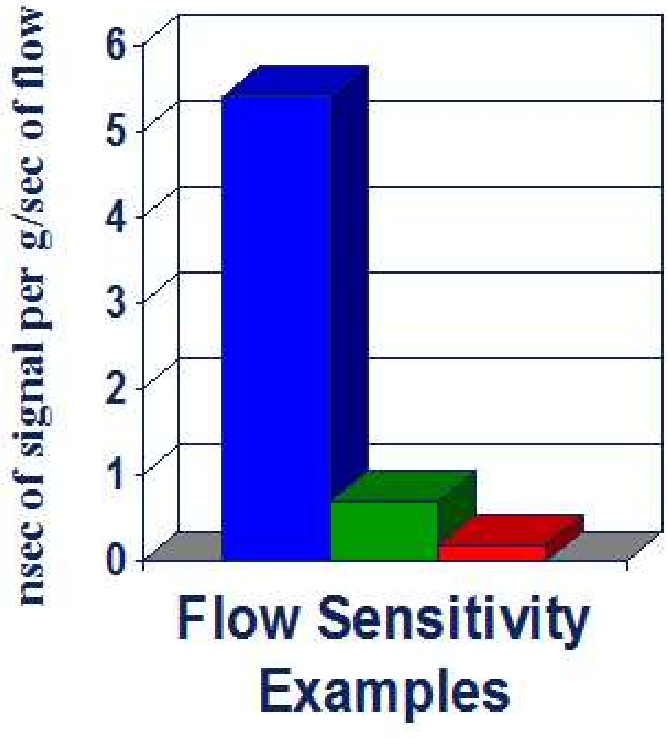
No Flow



Flow
Causes
Twist

Coriolis Meter Raw Sensitivity Varies with Design

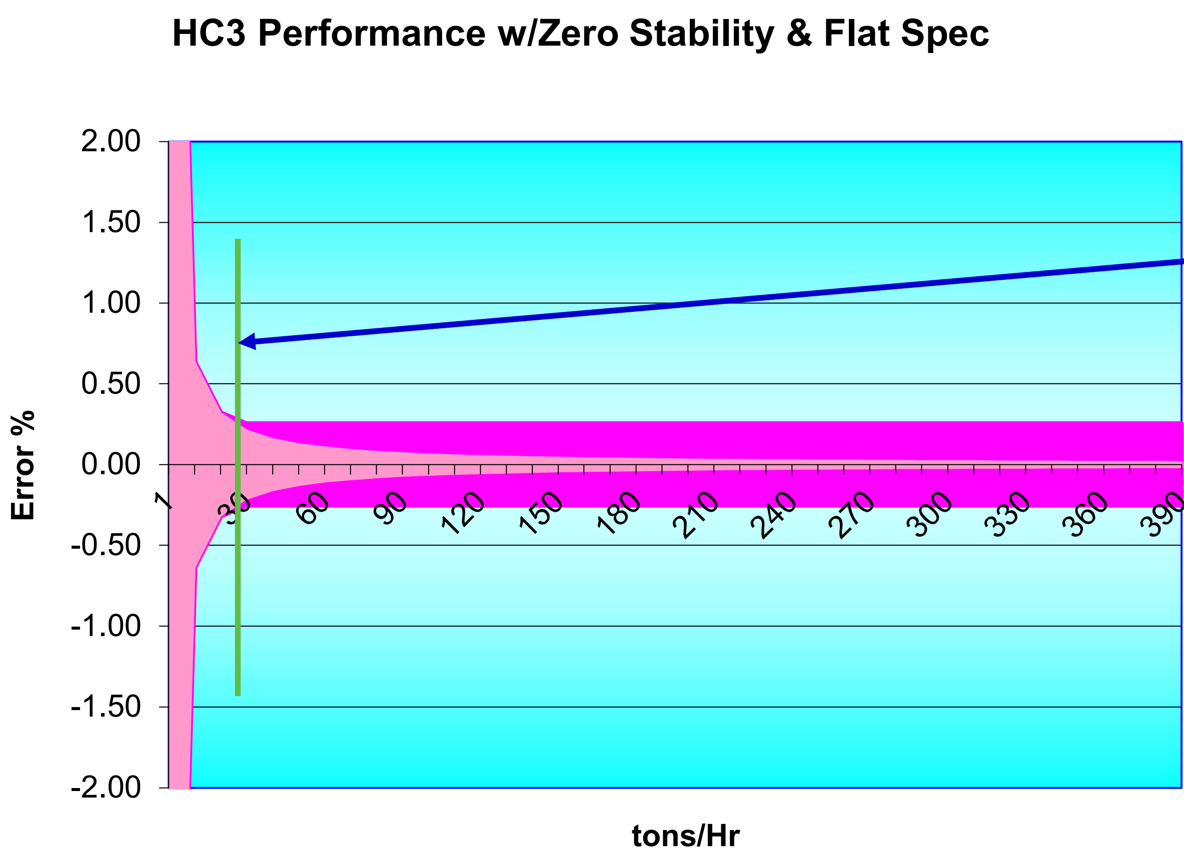
- **Raw Sensitivity Depends on Tube Geometry**
- **Signal to Noise Ratio Depends on Raw Sensitivity and Stability**
- **Calibration Flexibility, Immunity to Secondary Effects, and Diagnostic Capabilities Depend on Signal to Noise Ratio**



Coriolis Flow Performance –
Zero Stability and Flat Spec or rated accuracy

Performance specification	Standard models
Mass flow accuracy [(1)]	±0.25% of rate

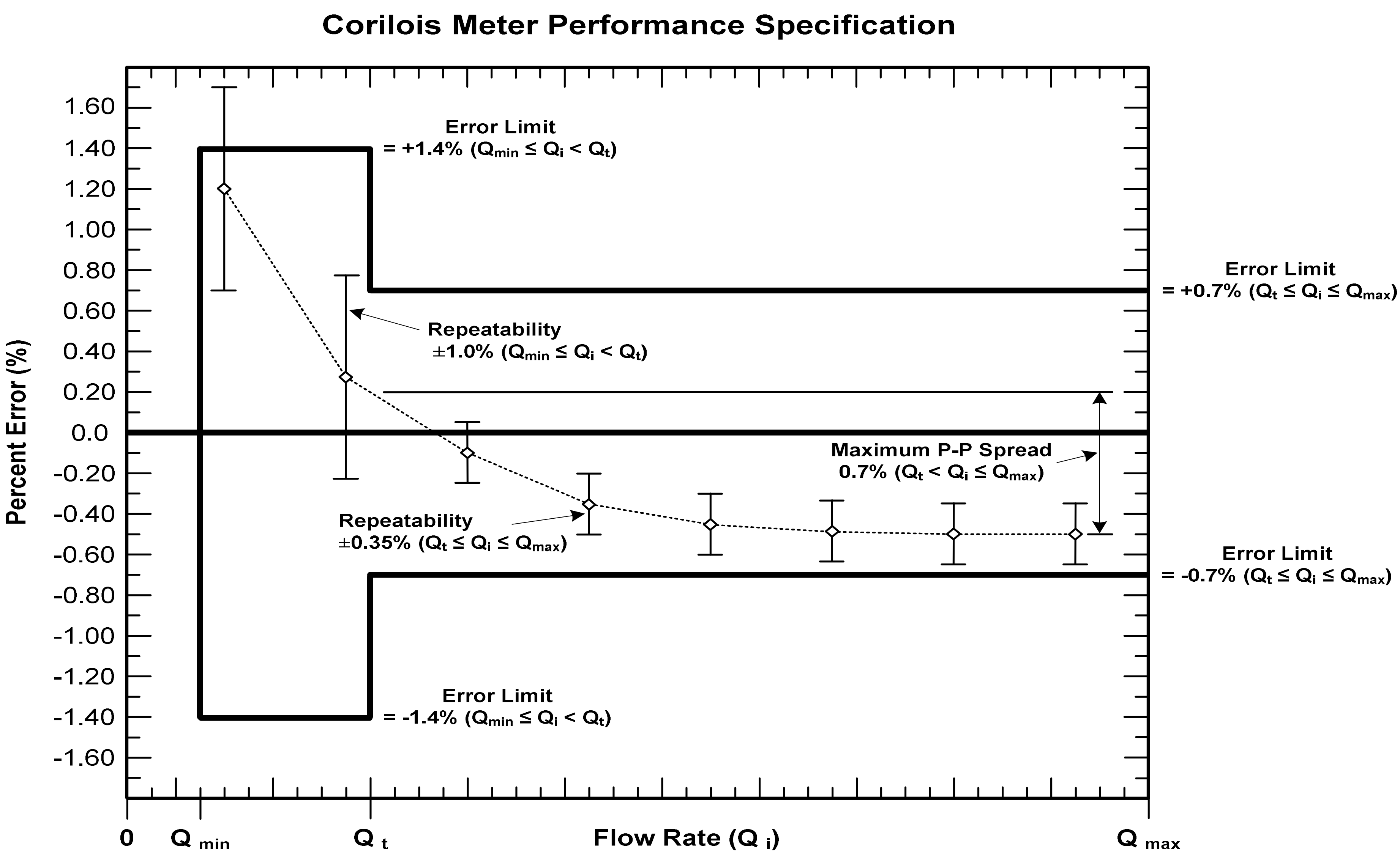
(1) Stated flow accuracy includes the combined effects of repeatability, linearity, hysteresis, orientation and other non-linearities.



Example Calculation of Qt HC3

$$Qt = ZeroStability/FlatSpec$$
$$Qt = 63.56(kg/hr)/0.25\%$$
$$Qt = 0.070(tons/hr)/0.0025$$
$$Qt = 28 tons/hr$$

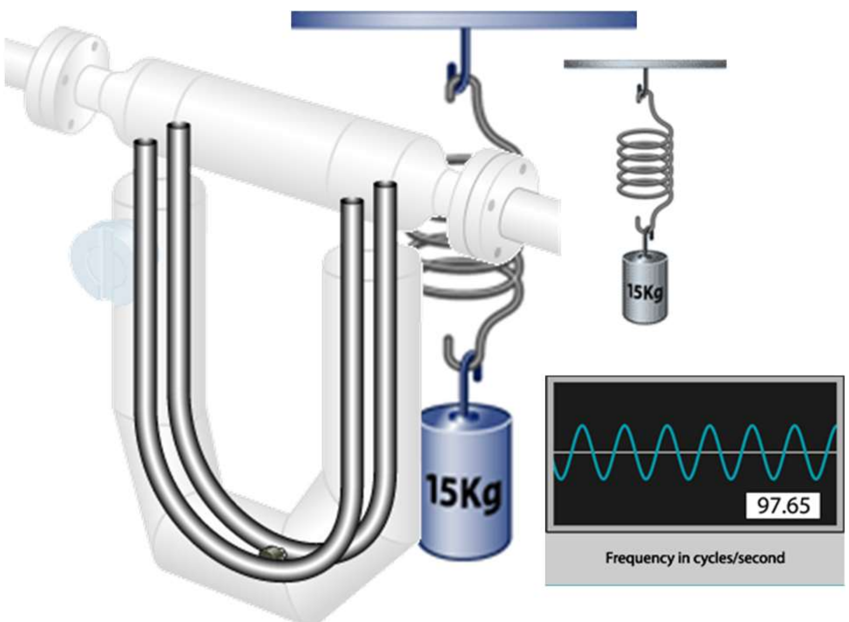
AGA Section 6.1
Minimum Performance Requirements

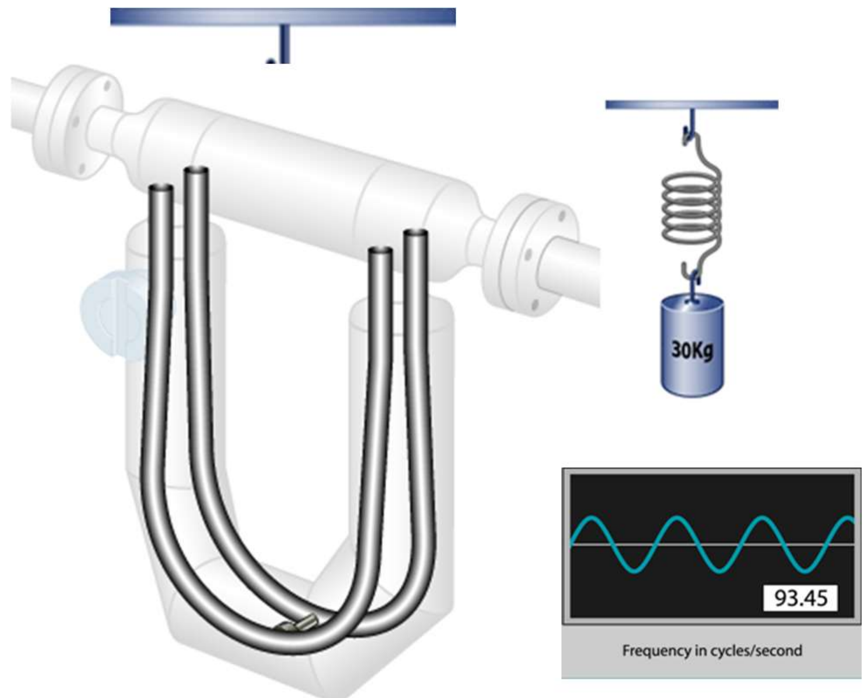


Direct Density Measurement

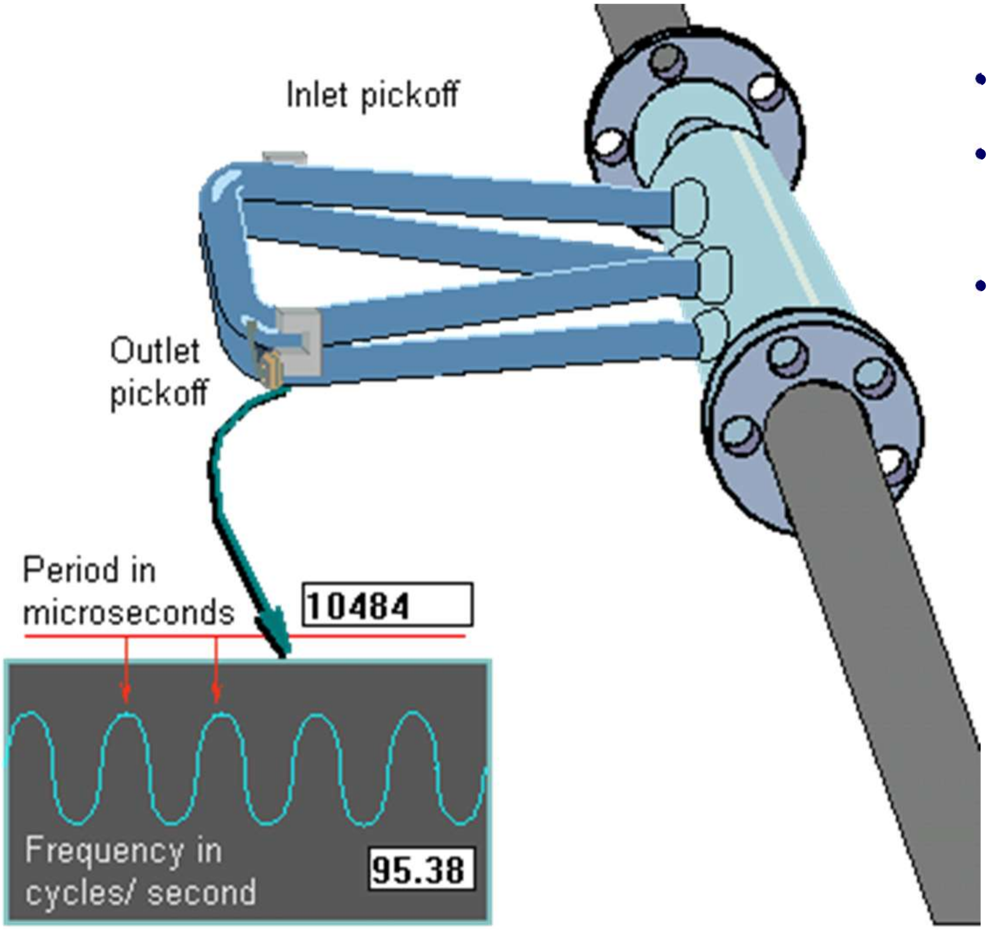
Density measurement is based on the natural frequency

- As the mass *increases*, the natural frequency of the system *decreases*
- As the mass *decreases*, the natural frequency of the system *increases*





Direct Density Measurement - Gas



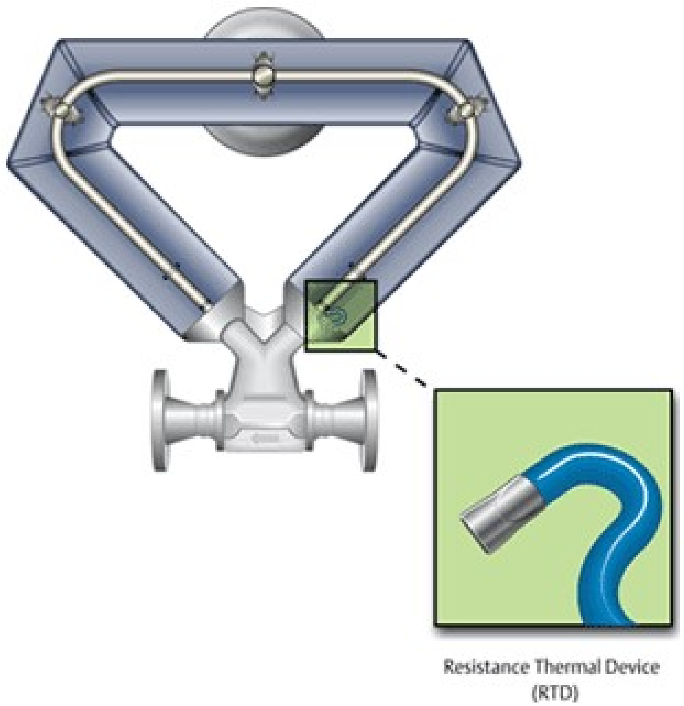
- Density Accuracy +/- 0.0005 gm/cc
- Water Density = 1 gm/cc
  (potential error = 0.05%)
- Natural Gas Density @ 500 psi = 0.0272 gm/cc
  (potential error 1.8%)

Increasing density may indicate coating or liquids

Clean vs. Dirty & Meter Health Diagnostic

Direct Temperature Measurement

- ***Three wire platinum Resistance Temperature Detector (RTD)***
- ***Measures tube temperature on inlet side of sensor***



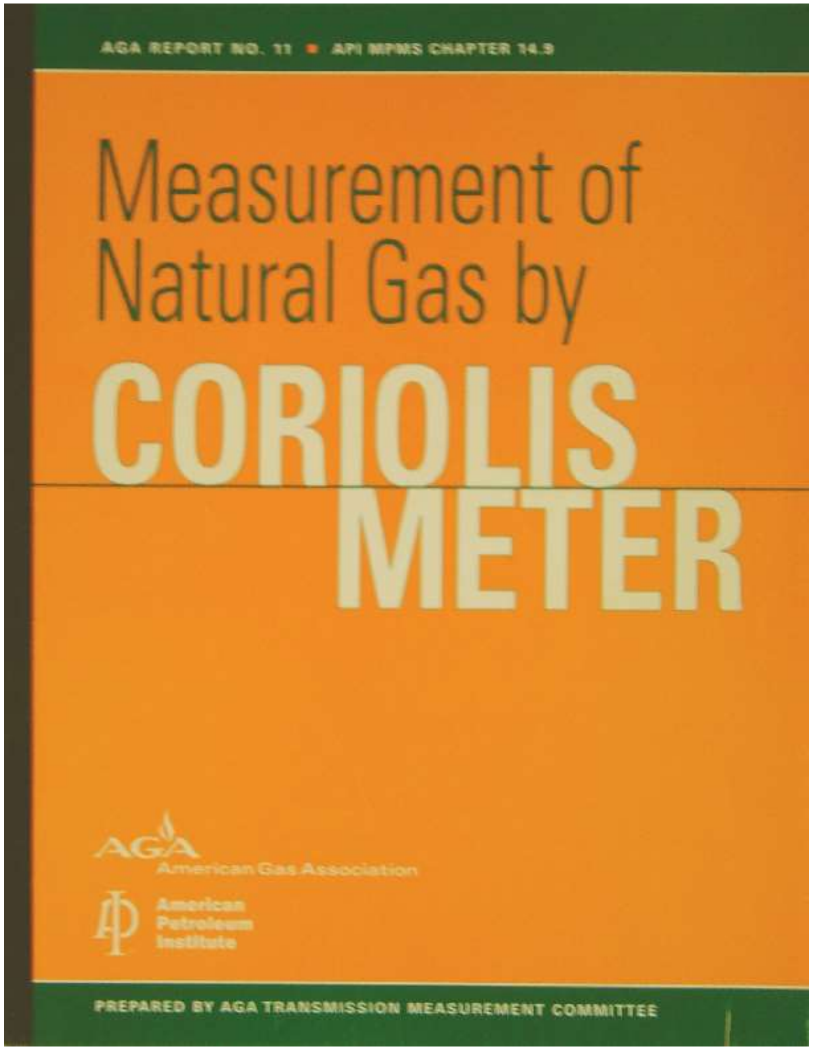
Agenda

- Introduction and Principle of Operation
- **Industry Standards**
- Calibration
- Maintenance Best Practices
- Application Selection and Volume Conversion
- Meter Sizing and Installation Considerations
- Typical Applications

AGA Report Background

AGA Report No. 3	**Orifice Metering of Natural Gas**
AGA Report No. 4A	**Natural Gas Contract Measurement and Quality Clauses**
AGA Report No. 5	**Natural Gas Energy Measurement**
AGA Report No. 6	**Field Proving of Gas Meters Using Transfer Methods**
AGA Report No. 7	**Measurement of Natural Gas by Turbine Meter**
AGA Report No. 8	**Compressibility Factor of Natural Gas and Related Hydrocarbon Gases**
AGA Report No. 9	**Measurement of Gas by Multipath Ultrasonic Meters**
AGA Report No. 10	**Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases**
AGA Report No. 11	**Measurement of Natural Gas by Coriolis Meter**

AGA Report No. 11 / API MPMS Ch. 14.9
Measurement of Natural Gas by Coriolis Meter



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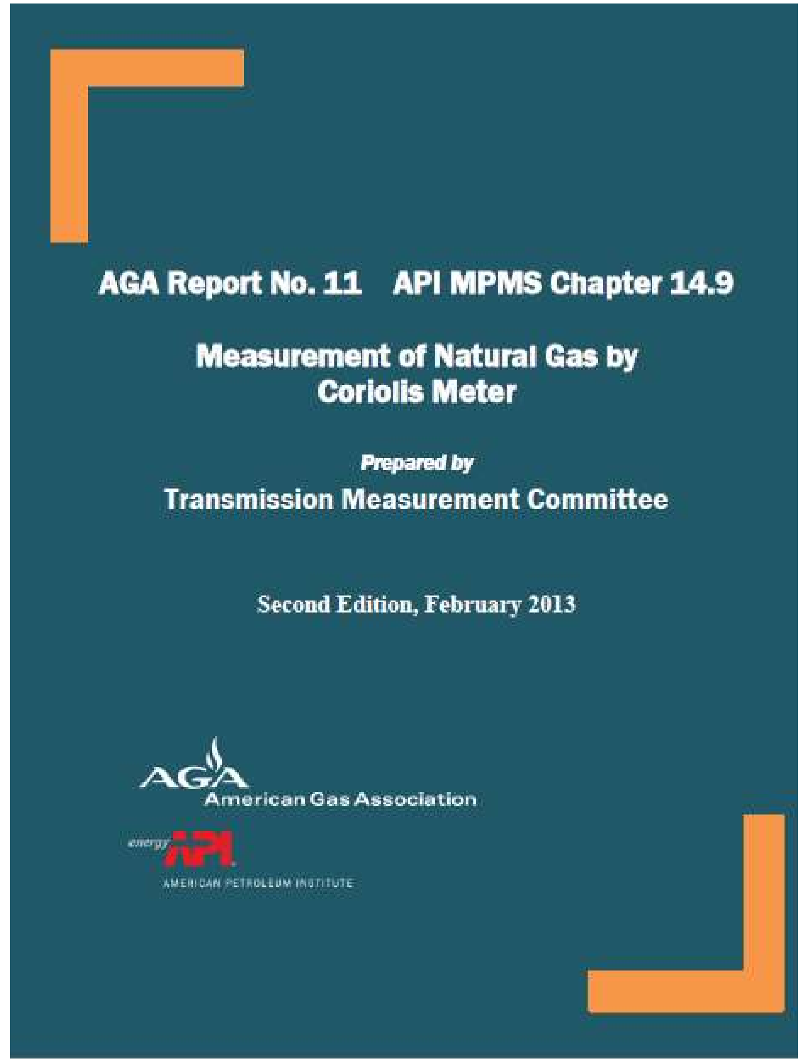

Revised February 2013 (2nd Edition)

Agenda

Introduction and Principle of Operation

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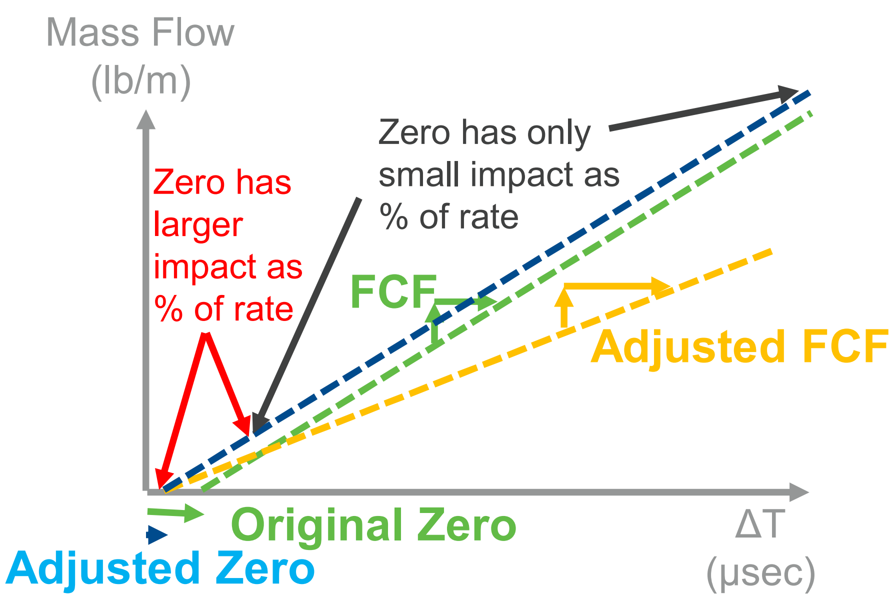
Coriolis Meter Principle of Operation

How Flow Calibration Factor (FCF), Zero, and ΔT Relates to Mass Flow

$$Y = mx + b$$

mass flow rate = FCF (ΔT) + zero



- FCF (Slope) is the relationship between the ΔT signal and mass flow, determined with the initial calibration
- The Zero accounts for offset observed at no-flow conditions
- A change in FCF means the relationship between the flow signal (ΔT) and the actual mass flow rate has changed

Conversion of Mass to Volume at Standard Conditions

$$SCF = \frac{Mass}{\rho_b}$$ ⬌ ***AGA11 Eqn. D.2***

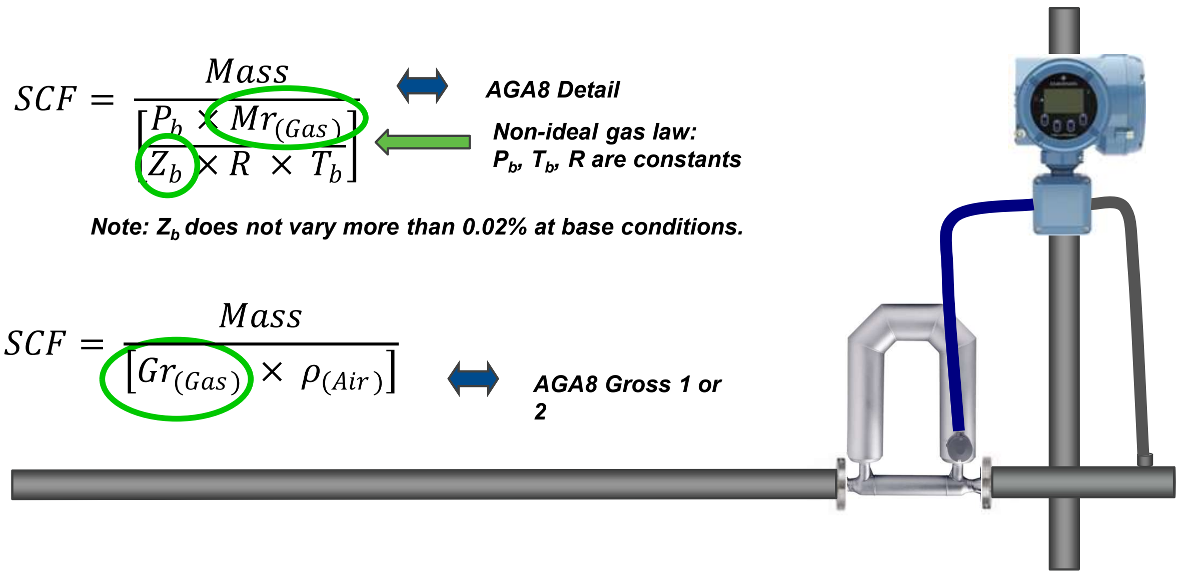
lbs/day ÷ lbs/ft3 = ft3/day

$$SCF = \frac{Mass}{\left[\frac{P_b \times Mr_{(Gas)}}{Z_b \times R \times T_b}\right]}$$ ⬌ ***AGA8 Detail***

Non-ideal gas law:
P_b, T_b, R are constants

Note: Z_b does not vary more than 0.02% at base conditions.

$$SCF = \frac{Mass}{\left[Gr_{(Gas)} \times \rho_{(Air)}\right]}$$ ⬌ ***AGA8 Gross 1 or 2***



No Pressure or Temperature Measurement Required to Convert from Mass to Standard Volume

Base Density, Molar Weight, Base Compressibility, and Specific Gravity Are All Determined by Gas Composition

AGA 11 Sensor Mass Flow Calibration Established on Water

Section 7 – Gas Flow Calibration Requirements

Manufacturers are responsible for initial flow calibration of Coriolis meters prior to delivery. Calibration with an alternative calibration fluid (e.g.. water) is valid with Coriolis sensor designs where the transferability of the alternative calibration fluid, with an added uncertainty relative to gas measurement, has been demonstrated by the manufacturer through tests conducted by an independent flow calibration laboratory. When the transferability of the manufacturer's calibration fluid to gas cannot be verified, the meter shall be flow calibrated on gas as per the requirements in Section 7.1

Calibration Fluid Flexibility

"Calibration fluid flexibility" is a capability that allows a traceable liquid calibration to be used for traceable gas measurements

- Meters may be calibrated for natural gas in liquid laboratories
  - Liquid calibration recognized in AGA Report No. 11 (aka.: API MPMS Ch. 14.9)
  - Must demonstrate acceptable provenance for each Coriolis meter design
  - Advantages of liquid calibration:
    - Meets manufacturers accuracy spec and AGA 11 direct from the meter factory
    - Factory calibration (e.g., water) = Low cost
    - Direct Shipment from meter factory to installation site = Fast project execution
    - Better reference standard uncertainty possible with liquid labs
    - Portable liquid flow calibration rig can be used for traceable onsite calibration at field locations

- Meters may also be calibrated in gas laboratories
  - Piece-Wise Linearization (PWL) Option is available for fine tuning by 3rd - party gas labs
    - Potential to reduce Lost and Unaccounted For (LAUF) gas with improved measurement
    - Similar to practice used by gas ultrasonic flow meters
  - Meter calibration traceability chain tied directly through gas calibration standards

NMi Euroloop Testing of Meters to Prove Liquid Cal is Suitable for Gas Measurement

*Manufacturer Dependent (meter shown as example)

Sensor Calibration Established on Water
3rd Party Testing and Certification

EC type-examination Certificate

Number **T10020** revision 4
Project number 12200340
Page 1 of 1

Issued by	NMi Certin B.V., designated and notified by the Netherlands to perform tasks with respect to conformity modules mentioned in article 9 of Directive 2004/22/EC, after having established that the Measuring instrument meets the applicable requirements of Directive 2004/22/EC, to:
Manufacturer	Emerson Process Management Flow B.V. Neonstraat 1 6718 WX Ede The Netherlands
Measuring instrument	A **Coriolis Gas Meter**

Brand	: Micro Motion
Type	: CMFxxxy (see paragraph 1.2 for the meaning of xxxy), CNG050 and DS600, with MVD electronics (see paragraph 1.1 for details)
Destined for the measurement of	: fuel gases, with an actual density of 4 kg/m^3 and higher, and supercritical ethylene with a density up to 450 kg/m^3
Q_{min} - Q_{max}	: see paragraph 1.2 of the description
Accuracy class	: Class 1,0
Environment classes	: M3 / E3
Q_{min} - Q_{max}	: see paragraph 1.2 of the description
Temperature range gas	: -40 °C / +150 °C for CMF200/300/400/HC2/HC3/HC4/DS600; -10 °C / +50 °C for CMF025/050/100; -25 °C / +55 °C for CNG050.
Ambient temperature range	: -40 °C / +55 °C

Further properties are described in the annexes
– Description T10020 revision 4
– Documentation folder T10020-4

Valid until	8 May 2017
Remarks	This revision replaces the earlier version(s) including its documentation folder.
Issuing Authority	**NMi Certin B.V., Notified Body number 0122** [illegible] 2013

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Head Certification Board

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INSPECTION
RvA I 122

Description

Number **T10020** revision 4
Project number 12200340
Page 2 of 6

1.1.3 Flow transmitter, model 2500
A flow transmitter, model 2500, is connected to the core processor. The flow transmitter is described in the Evaluation Certificate no. TC7057, but with the following aspects:
- markings as described in paragraph 1.3.2;
- only the double pulse output, set to mass, is used for custody transfer purposes and is connected to a remote MID approved indicating device/flow computer;
- indication as described in paragraph 1.5.1;
- settings as described in paragraph 1.5.2.

1.1.4 Flow transmitter, model 3500 or 3700
A flow transmitter, model 3500 or 3700, is connected to the core processor. The flow transmitter is described in the Evaluation Certificate no. TC7057, but with the following aspects:
- markings as described in paragraph 1.3.2;
- only the indication of mass via the "Total" and "Inventory" registers is used for custody transfer purposes;
- indication as described in paragraph 1.5.1;
- settings as described in paragraph 1.5.2.

1.2 Essential characteristics

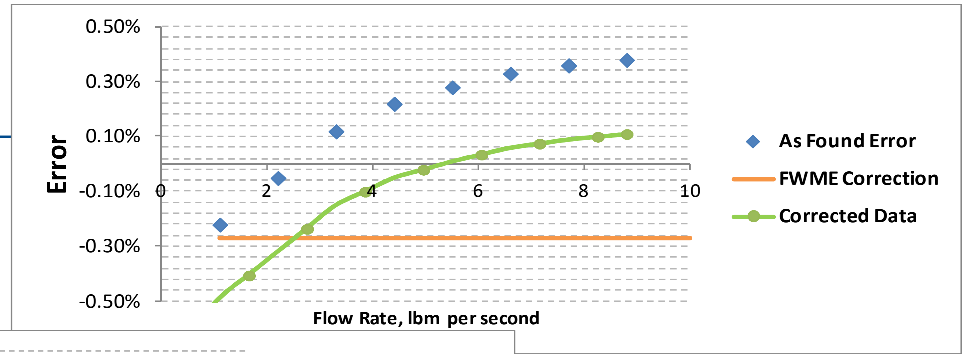
1.2.1 Flow characteristics
The meter has the following flow characteristics:

Model	maximum Q_{max} [kg/h]	Q_t	minimum Q_{min} [kg/h]	diameter (nominal) [mm]	maximum p_{max} [bar] A/A4/L/A (y)	maximum p_{max} [bar] B/C/R/H/W/Y (y)	minimum actual density [kg/m³]
CMF025 y)	19 x actual density (kg/m³)		3	6	103	190	4
CMF050 y)	80 x actual density (kg/m³)		11	12	103	189	5
CMF100 y)	175 x actual density (kg/m³)		60	25	100	170	6,3
CMF200 y)	425 x actual density (kg/m³)		200	50	108	190	5,3
CMF300 y)	1.175 x actual density (kg/m³)		500	80	119	185	8,4
CMF400 y)	3.750 x actual density (kg/m³)	< 1/5 Q_{max}	3.333	100	103	187*)	57,2
DS600 S	5.000 x actual density (kg/m³)		6.500	150	45	N/A	39,6
CNG050	4620		115	12	345		-
CMFHC2 y)	3.571 x actual density (kg/m³)		6.182	200	102	206	34,7
CMFHC3 y)	5.004 x actual density (kg/m³)		12.364	200	102	206	41,6
CMFHC4 y)	8.249 x actual density (kg/m³)		18.545	250	102	206	60,2

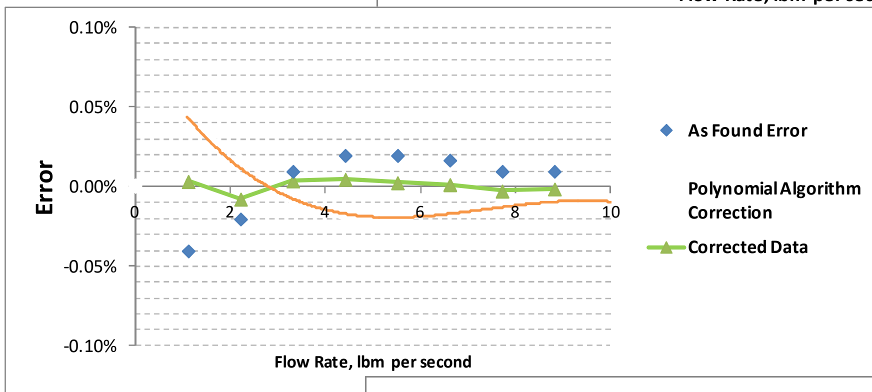
Remarks:
- *) with the exception to the value as indicated in the table the maximum p_{max} value of the CMF400P is 205 bar.
- y) indicates the type of material the meter is build of.

Calibration Adjustment Methods Described in AGA 11

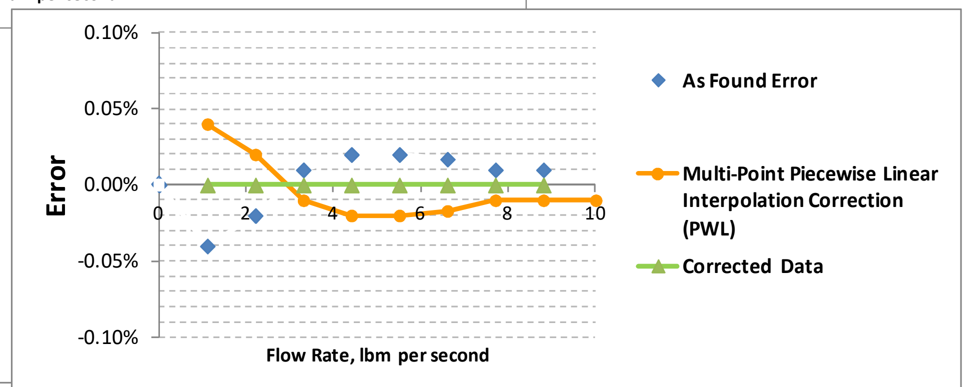
- Flow Weighted Mean Error (FWME)



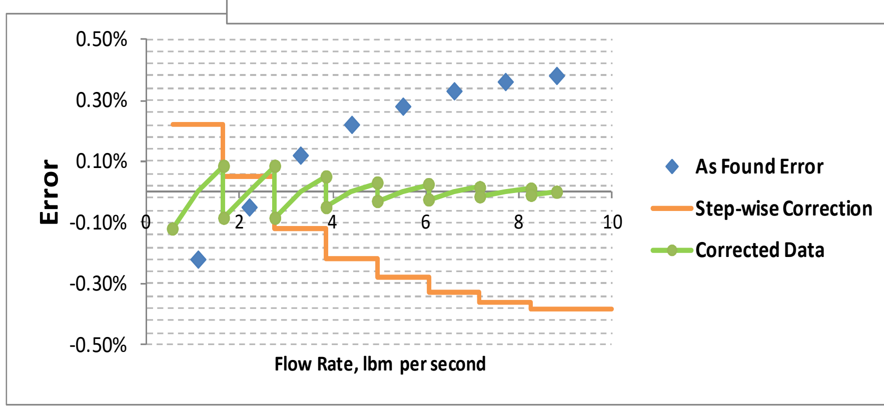
- Polynomial Algorithm



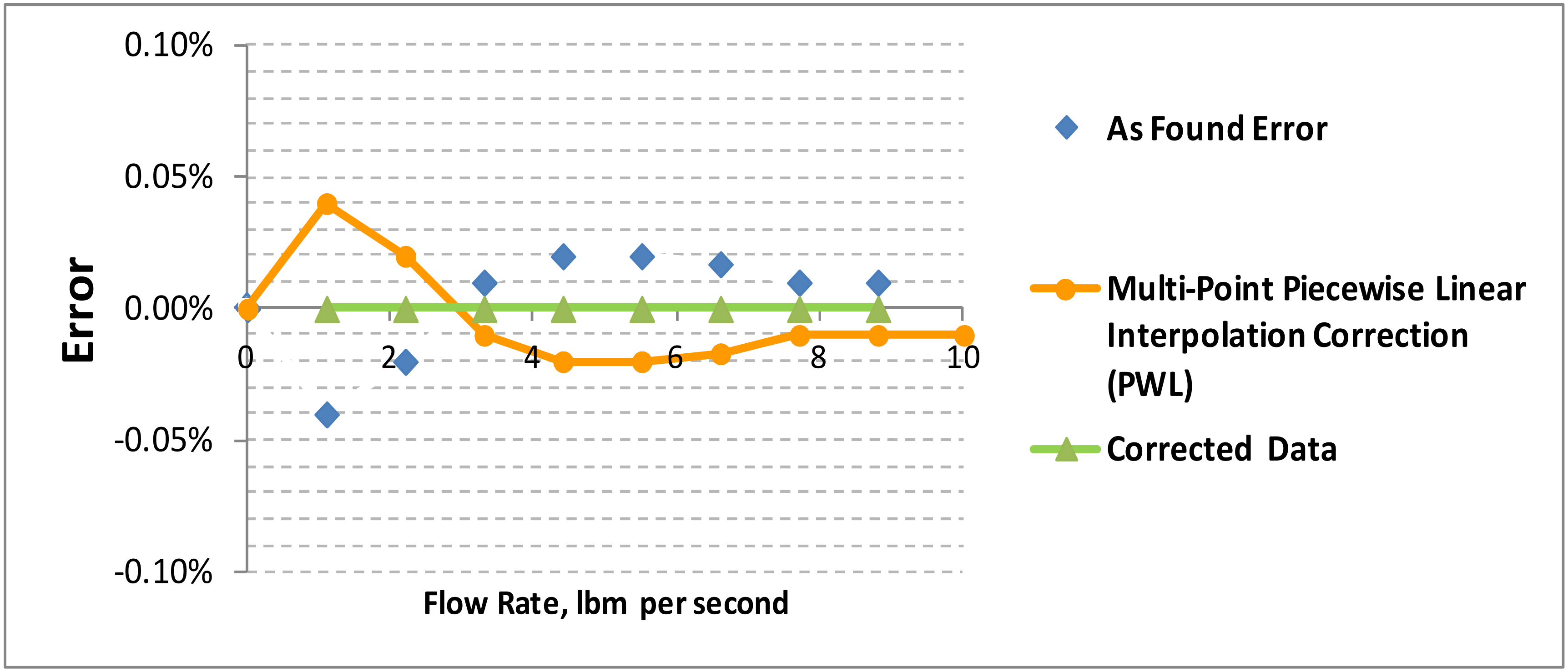
- Multi-Point Piecewise Linear Interpolation (PWL)



- Piecewise Linearization (Step-wise)

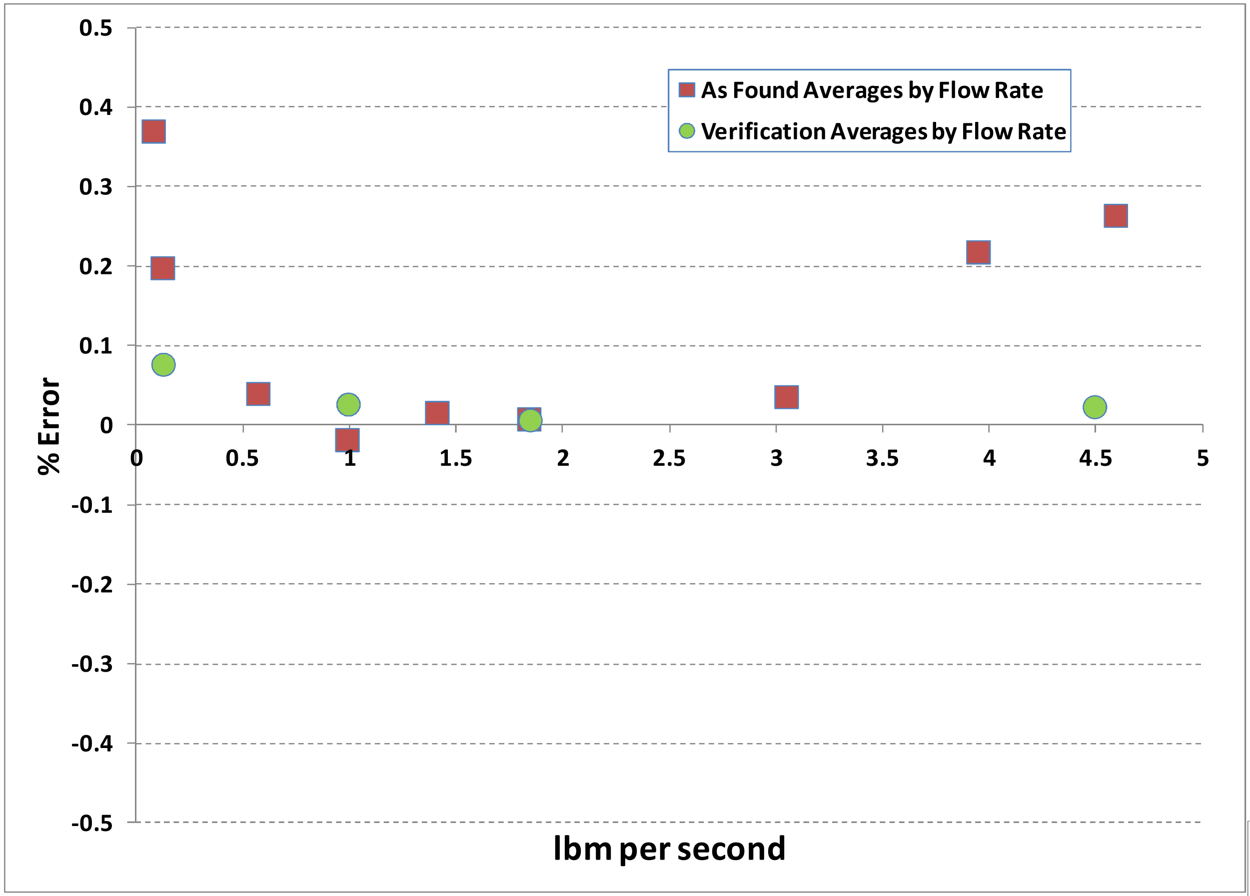


Multi-Point Piecewise Linear Interpolation (PWL)



- Correction applied at selected linearization points is equal and opposite to the average of the as-found values at the same flow rate
- Correction values applied between neighboring points are determined by linear interpolation between the two points
- Correction above the highest flow rate point are held constant
- Correction below the lowest point is based on linear interpolation to zero error at zero flow to allow meter zero adjustment to control accuracy below Q_t

Results with PWL – 1-inch Meter CMF100



Averages at Each Flow Rate

Observations

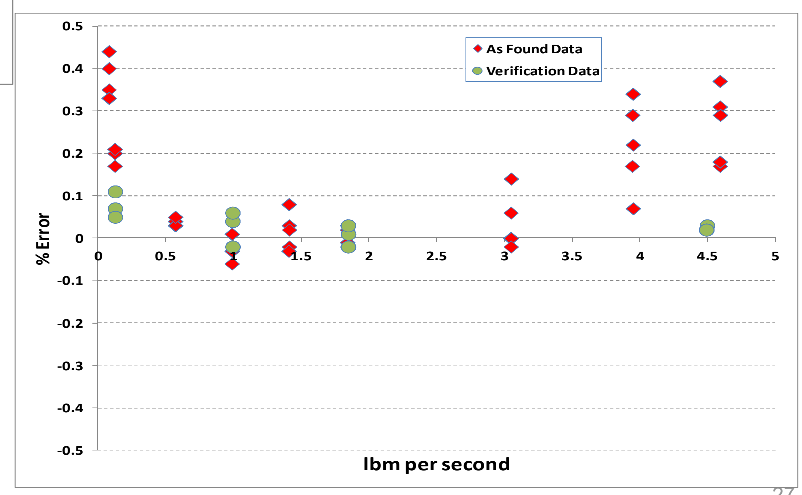
Test turndown ≈ 58 : 1

All verification averages better than ± 0.08%

Verification averages above 0.13 lbm/sec better than ± 0.027%

All verification data better than ± 0.11%

All Data



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Section 9 – Meter Verification / Flow Performance Testing

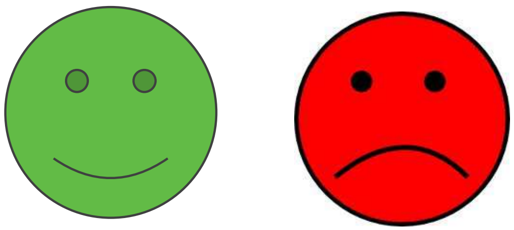
- The meter manufacturer should provide the meter operator with written field meter verification test procedures that will allow the Coriolis meter, as a component of the measuring system, to be verified as operating properly and performing within the measurement uncertainty limits required by the designer/operator
- The field verification should identify possible change in the system's performance and the cause
- The evaluation of these indicators will guide the operator in determining the need to re-zero the Coriolis meter or execute a flow performance test (in-situ or laboratory), etc.

Prior AGA 11 Coriolis Verification Practice

– **Meter Zero Verification**
  - Corrosion, erosion, mounting stress, flow tube damage, and coating
  - Catch-all diagnostic
  - Works well, but very broad indicator

– **Meter Diagnostics Check**
  - Diagnostics
    - Electronics
    - Processing and memory
    - Measurement system health
      - » Within normal limits
      - » Catastrophic failure

Pass/Fail
Not quantitative



Perform In-Situ Verifications Quickly and Easily to Increase Confidence and Reduce Downtime

SMART METER VERIFICATION

SMV is Easy to Use

- On-demand
- One button/command
- No extra equipment
- Formal report
- Less than 2 minutes
- No interruption to process or measurement
- Scales with host systems
- **Evaluate meter under “as installed” conditions**

New AGA 11 Coriolis Verification Practice

- **Meter Transmitter Verification –** The meter transmitter verification should coincide with the meter zero check. It should include the following procedures:
    - Verify the sensor calibration and correction factors in the configuration of the transmitter to be unchanged from most recent calibration.
    - Verify all transmitter diagnostic indicators to be in the normal state.
- **Coriolis Sensor Verification –** Sensor diagnostics may be available that continuously, on-command or procedurally verify the performance of the sensor and/or infer change in measurement performance. Users should consult the meter manufacturer for the availability of these types of diagnostics.
- **Temperature Verification –** The Coriolis transmitter monitors a temperature element bonded to the flow tubes of the Coriolis sensor to correct for Young's modulus of the flow tubes. Although transmitter diagnostics on this element exist, they typically identify only catastrophic failures; e.g., element open, element short, and an opening in the compensation loop.

  Use a temperature reference placed in an upstream thermowell or temporarily placed tightly against the upstream flow splitter/inlet and insulated, to verify the temperature indicated by the Coriolis meter to be within the published uncertainty of the Coriolis meter's temperature measurement plus the accuracy of the temperature reference.
- **Meter Zero Verification** – A change in the meter zero value can be used as an indicator of change in the metering conditions. This can be caused by contamination and coating of

AGA11 Section 9
– Meter Verification Cont.

- **Meter Verification @ a minimum entails…**
  - **Meter Transmitter Verification**
    - **Diagnostics**
  - **Coriolis Sensor Verification**
    - **Diagnostics**
      - **Flow Tube Structure Diagnostic (FCF)**
  - **Temperature Verification**

    Compare to upstream temperature reference.
  - **Meter Zero Verification**

    Per AGA, check within 4 weeks of installation and quarterly during first year.
      - **Zero Verification Tool**

AGA11 Section 9.2 – Periodic Flow Performance Testing

Should flow performance testing be required several options exist…

1) Remove from service and send to the manufacturer or third party lab.
2) *In-situ flow test as outlined in this section or in accordance with AGA6, Field Proving of Gas Meters Using Transfer Methods*
3) **New** - Remove from service for flow test with a portable weigh scale system or certified meter using an alternate fluid. Must have certification of transferability (3^{rd} party)

When a Meter Under Test (MUT) is tested against a field reference, the MUT should not be adjusted if the performance is found to be within the uncertainty of the field reference

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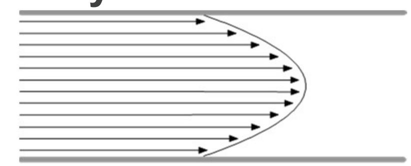
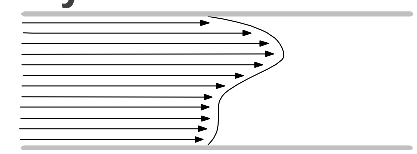
Unique Attributes of Coriolis Technology Resolves common measurement problems

- **Water calibration transfers to gas**
  - Reduced meter flow calibration and verification costs
  - Out-of-box ± 0.25 - 0.35% accuracy on gas
  - Turbine, ultrasonic, and rotary require gas calibrations
- **No flow conditioning or piping requirements**
  - Elimination of errors due to flow profile disturbances and the cost of monitoring for their occurrence
  - Major concern in use of Ultrasonic, Turbine, Orifice
- **No errors caused by pulsations and noise radiated from flow regulation**
  - Flow pulsations cause error in every flow technology except Coriolis
  - Turbine and Rotary also incur mechanical damage when subjected to pulsating flows
- **No over-registration or damage due to flow surges**
  - High rate-of-change during fuel gas start-up… "flow surge"

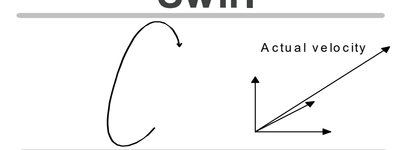
Reynolds Number



Asymmetrical Profile



Swirl

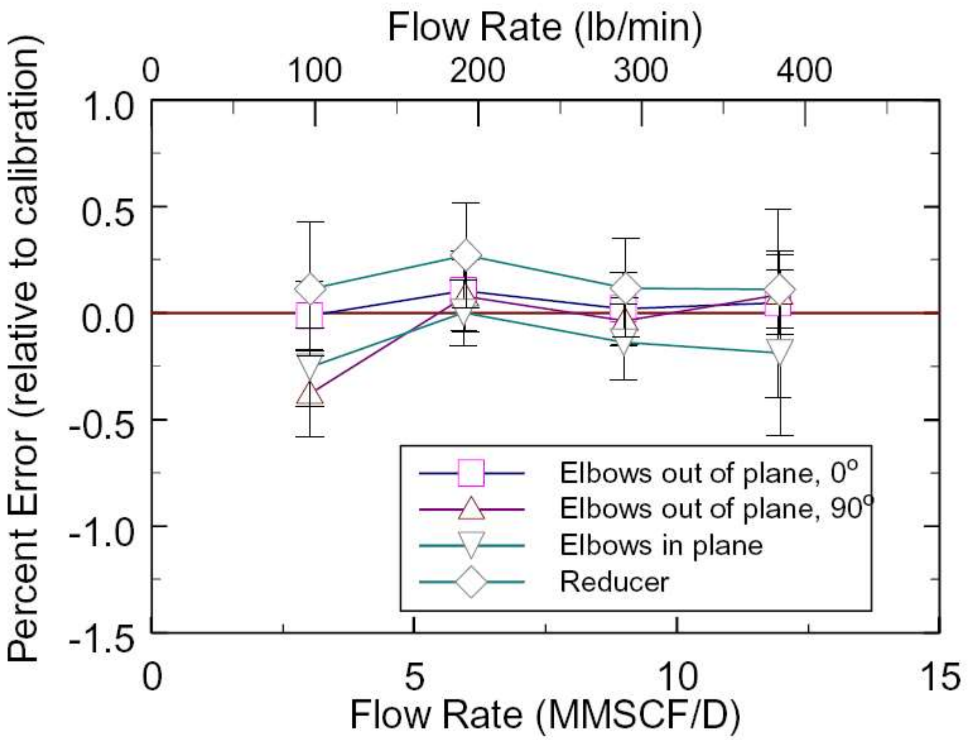


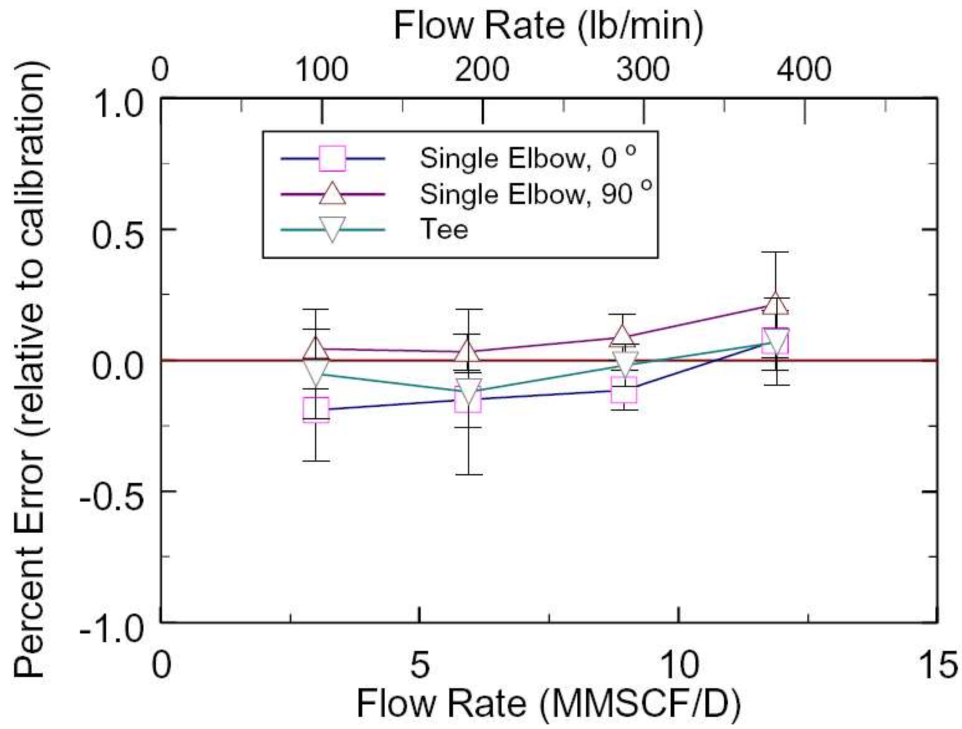
Pulsating Flow

AGA 11 – Gas Operating Conditions
"Upstream Piping and Flow Profiles"

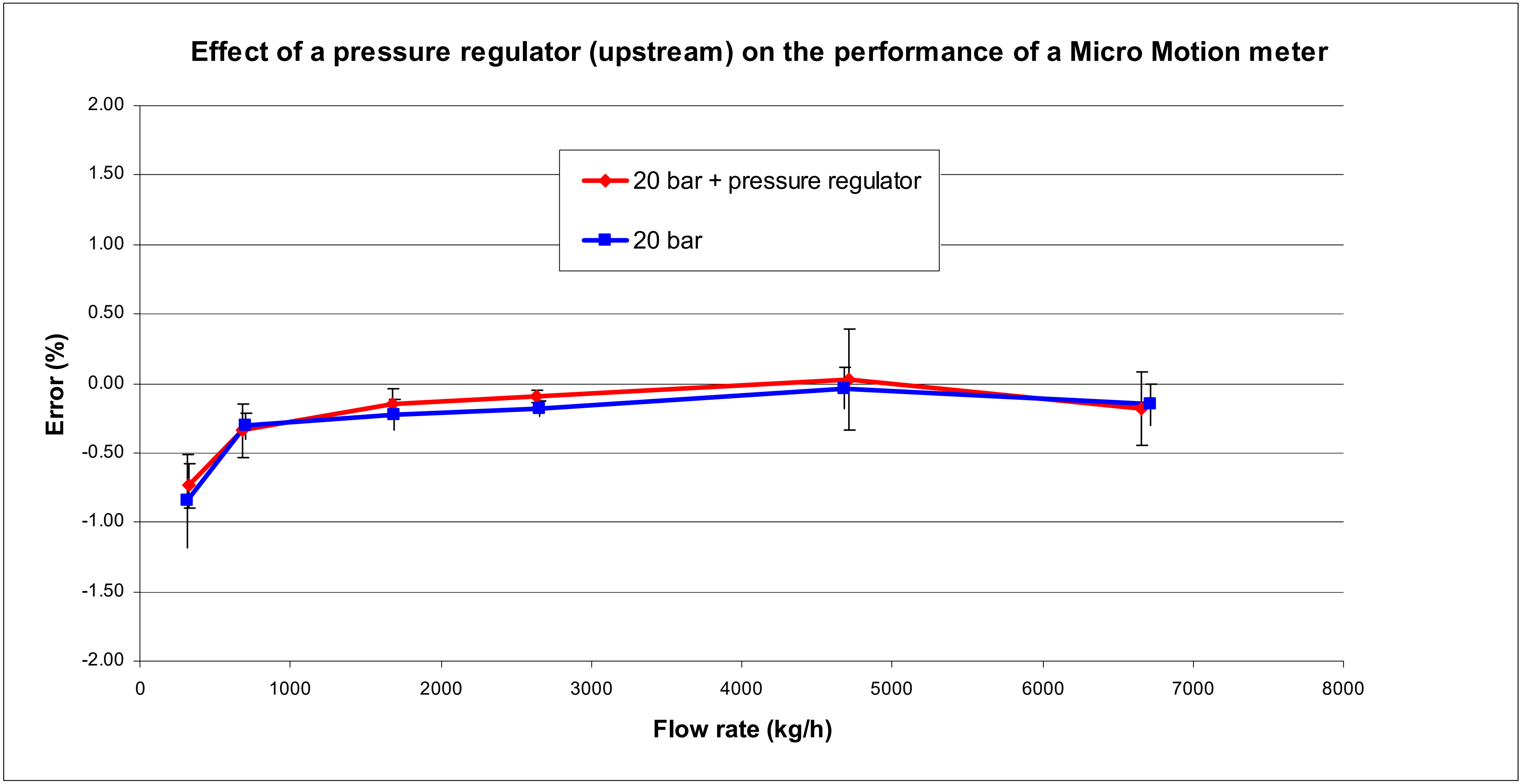
No Flow Conditioning or Special Piping Required

Performance with Lab Uncertainty

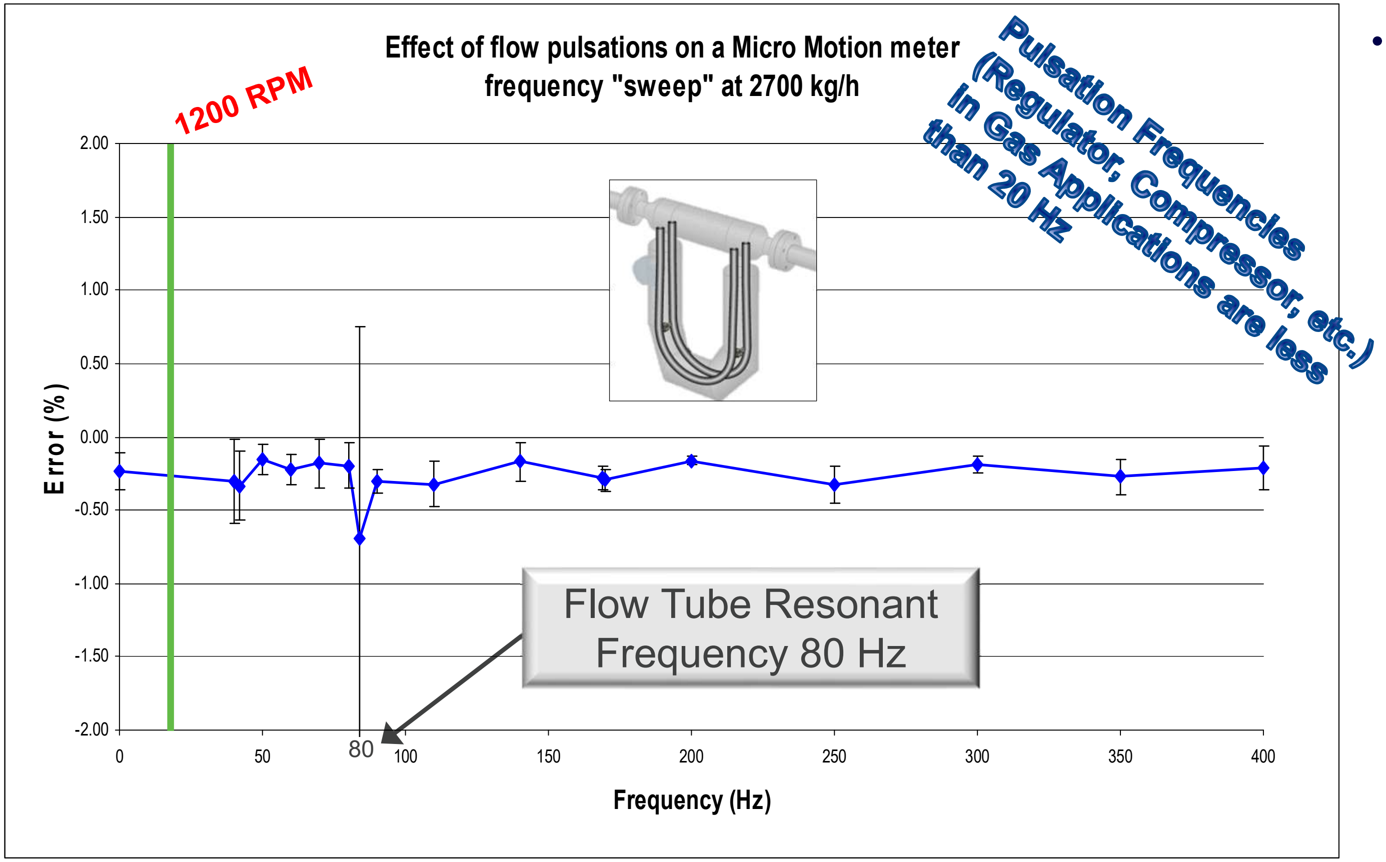




GERG Installation Requirements
“No Error Effects from Regulator Location”



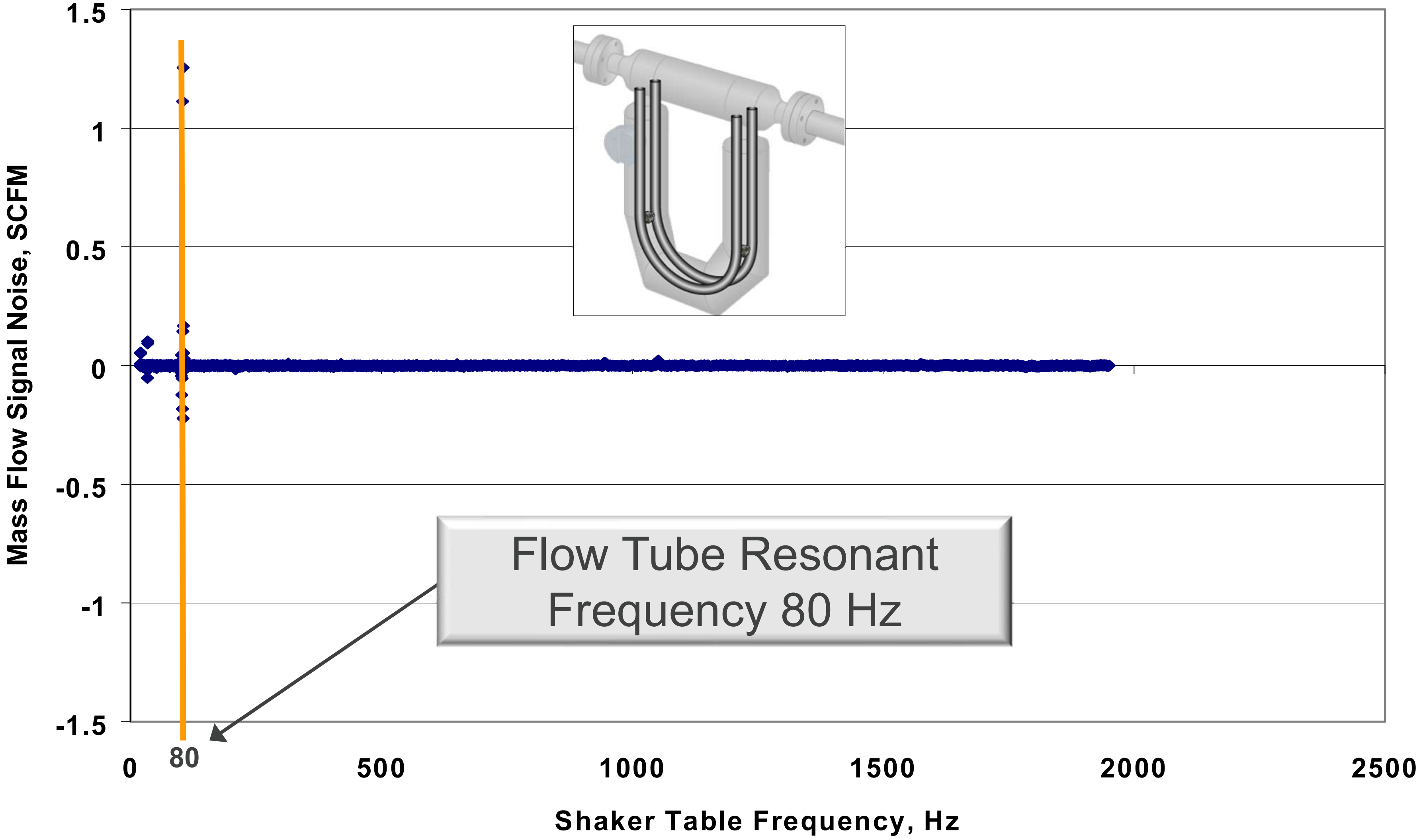
Micro Motion- Pulsation Immunity
GERG - No Gas Pulsation Error Concerns



- **Ideal Meter for…**
  - **Gas leg of separators**
  - **Fuel gas measurement to reciprocating engines**
  - **Measurement at or near inlet and outlet of reciprocating compression**
  - **Measurement near regulation; i.e. flow through regulator pulsates at low flows**

Manufacturer dependent

Micro Motion Vibration Immunity

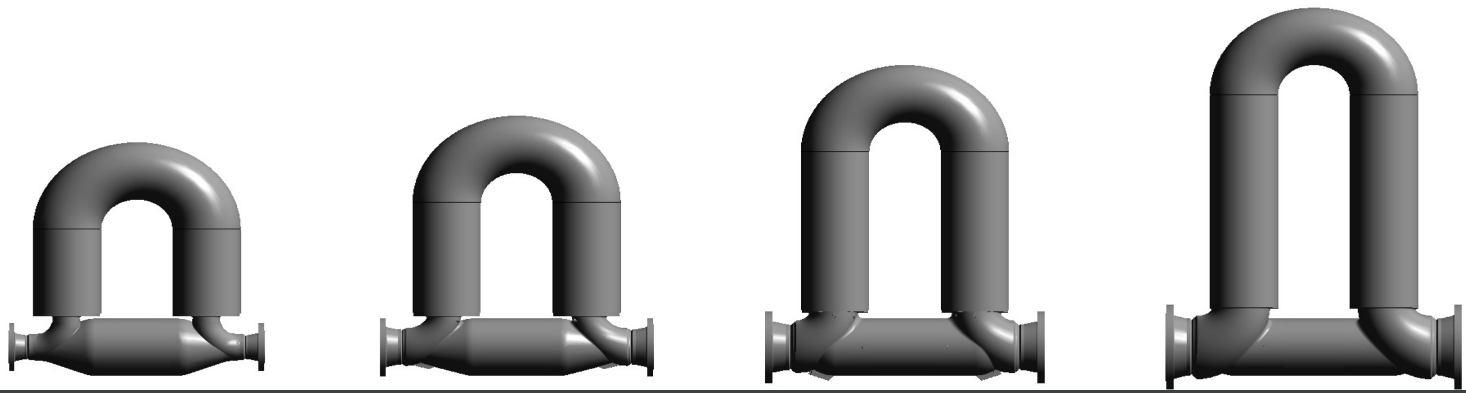


Vibration Frequency of a Reciprocating Compressor less than 2400 RPM or 40 Hz

AGA11 – Gas Velocity and Filtration

- Coriolis flow tubes typically do not erode from high gas velocities (example Orifice Plate)
- Gas velocities & pressure drop similar to other measurement technologies (Orifice, Turbine)
- Meter should be protected from abrasive particles
- Flow tube coating/debris build-up appears as zero offset (zero offset affects low-end not high-end performance)

Large Diameter Coriolis and Pressure Drop



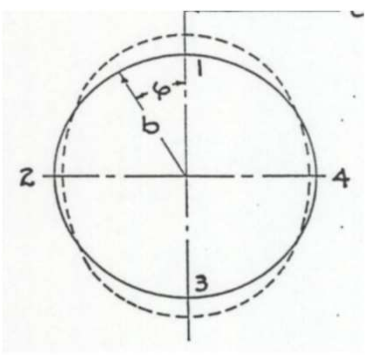
Coriolis	CMF400	CMFHC2	CMFHC3	CMFHC4
Typical Line Size	4 - 8” (100-150mm)	6 -10” (150-200mm)	8 -12” (200-250mm)	10 -16” (250-300mm)
Flow @ 6 psid	**69 MMSCFD**	**129 MMSCFD**	**223 MMSCFD**	**341 MMSCFD**
Flow @ 15 psid	187 MMSCFD	318 MMSCFD	485 MMSCFD	743 MMSCFD

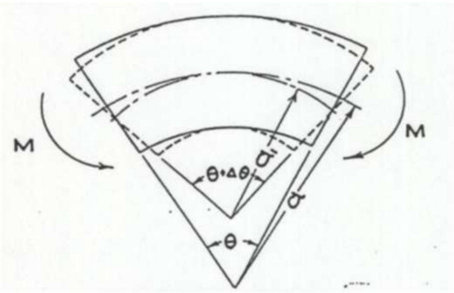
Ultrasonic Meter Comparison (Max Flow = 100 ft/sec & 6 psi pressure drop, CPA50E)				
Max Flow	**4” = 47 MMSCFD** 8” = 189 MMSCFD	**6” = 106 MMSCFD** 10” = 295 MMSCFD	**8” = 189 MMSCFD** 12” = 425 MMSCFD	**10” = 295 MMSCFD** 16” = 756 MMSCFD

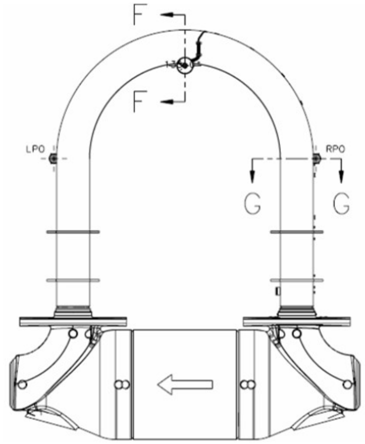
USM vs. Coriolis Maximum Flow Capacity Comparison performed w/Gulf Coast @ 800 psi and 60 Deg F Gas Flowing Density = 2.717 lb/cf

Effect of Pressure on Coriolis Meters

- Internal pressure changes the shape of the flow tube
  - Tube ovality becomes round
  - Tube bends straighten
- Changes in flow tube shape increases stiffness of flow tube
- Changes in flow tube stiffness can affect sensor calibration
- Magnitude of effect varies by meter size and design

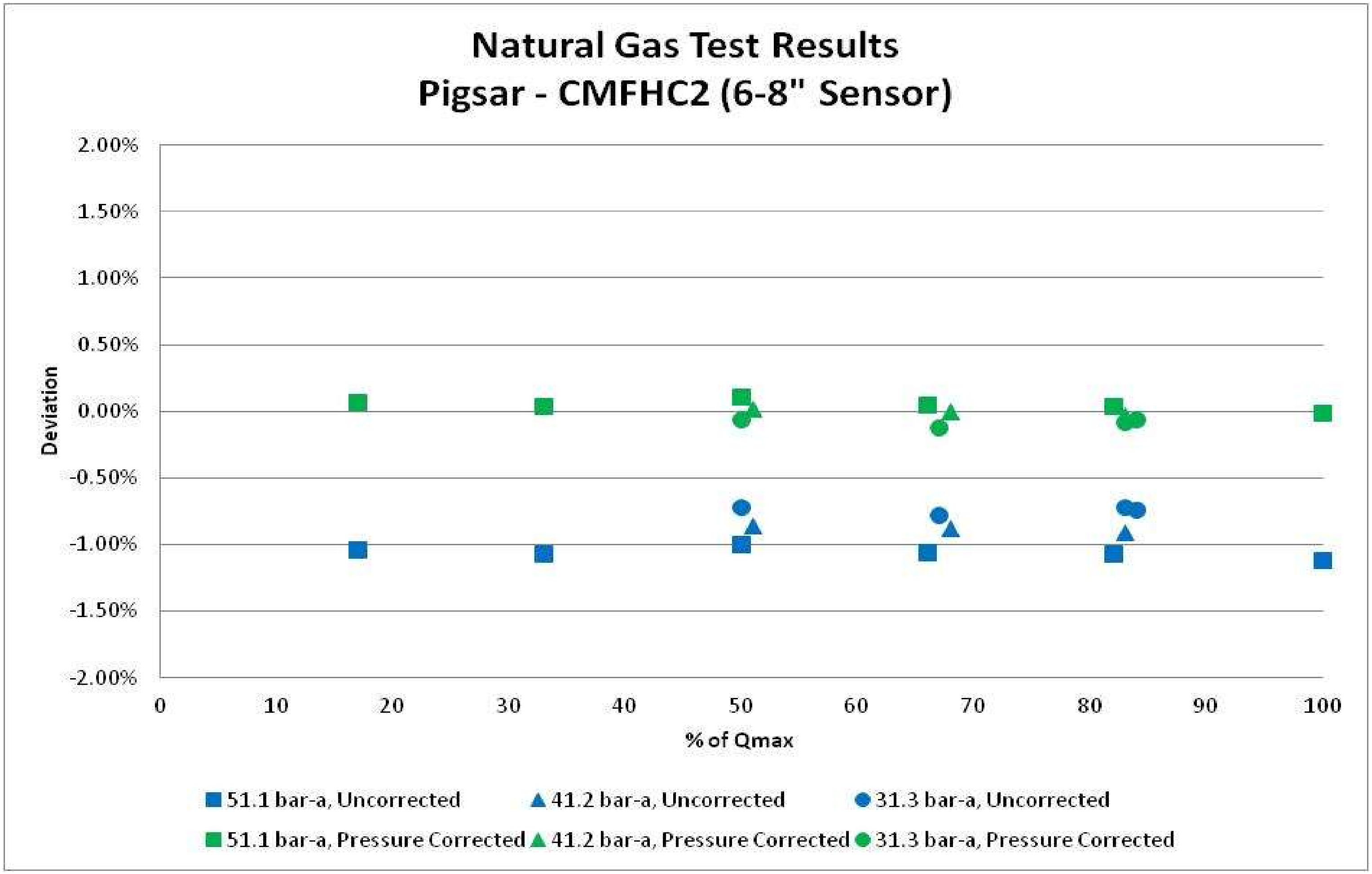






Example of Pressure Effect Compensation
Large Meter Gas Test Results

- All data collected on natural gas using meter factory calibration on water
- Data shown **with** and **without** standard **F_P pressure compensation**
- Max deviation of all compensated data < 0.25%



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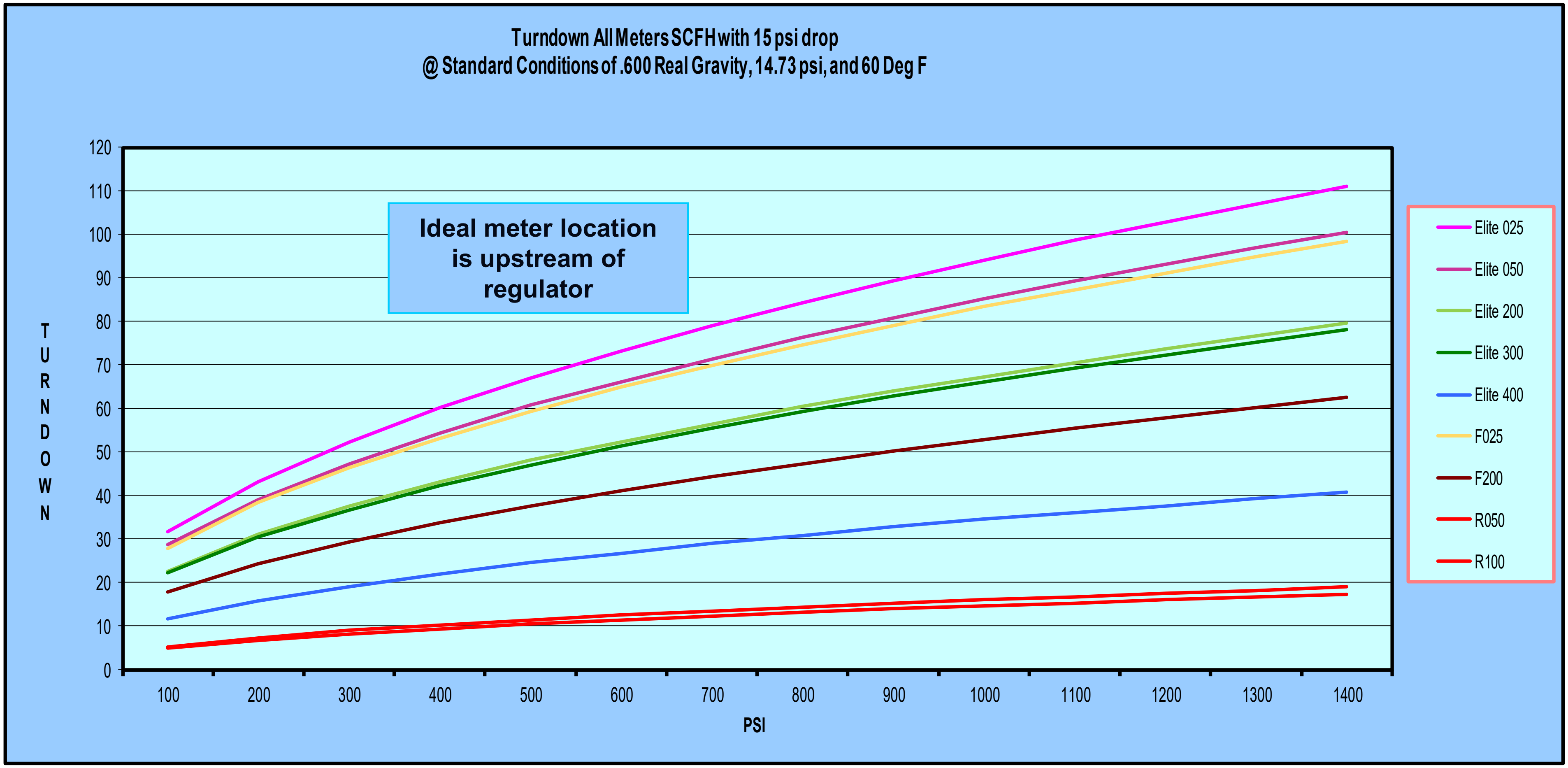
Agenda

- Introduction and Principle of Operation
- Industry Standards
- Calibration
- Maintenance Best Practices
- Application Selection and Volume Conversion
- **Meter Sizing and Installation Considerations**
- Typical Applications

Gas Sizing Best Practices - Coriolis Meter Turndown
High Pressure = High Turndown

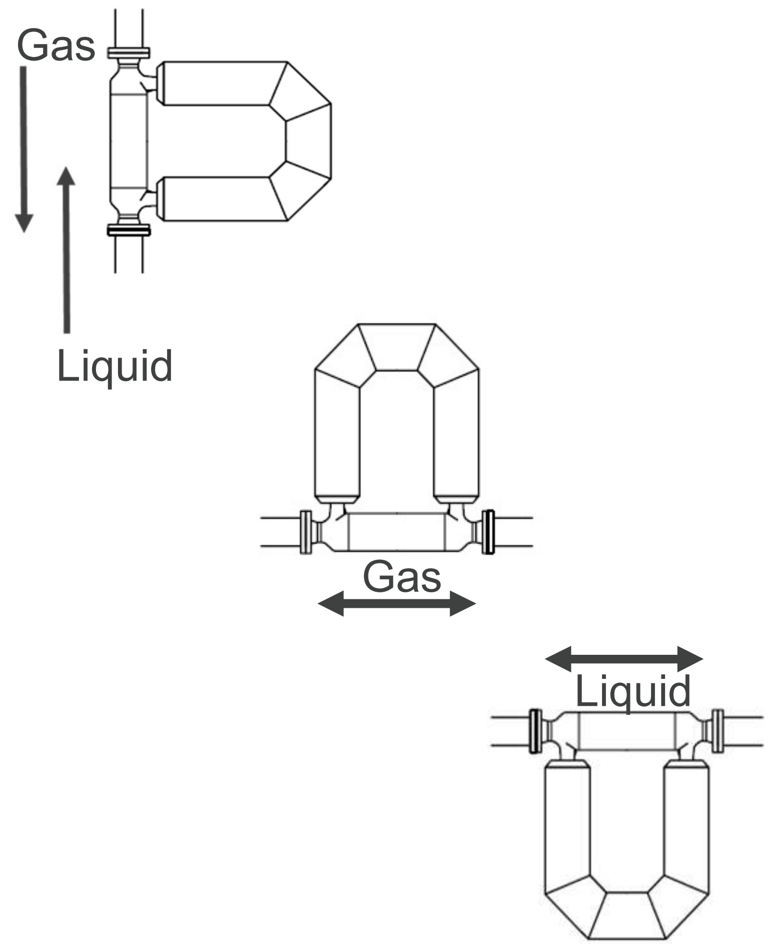


Installation Best Practices
Orientation & Piping Requirements

- **No special upstream or downstream piping requirements**

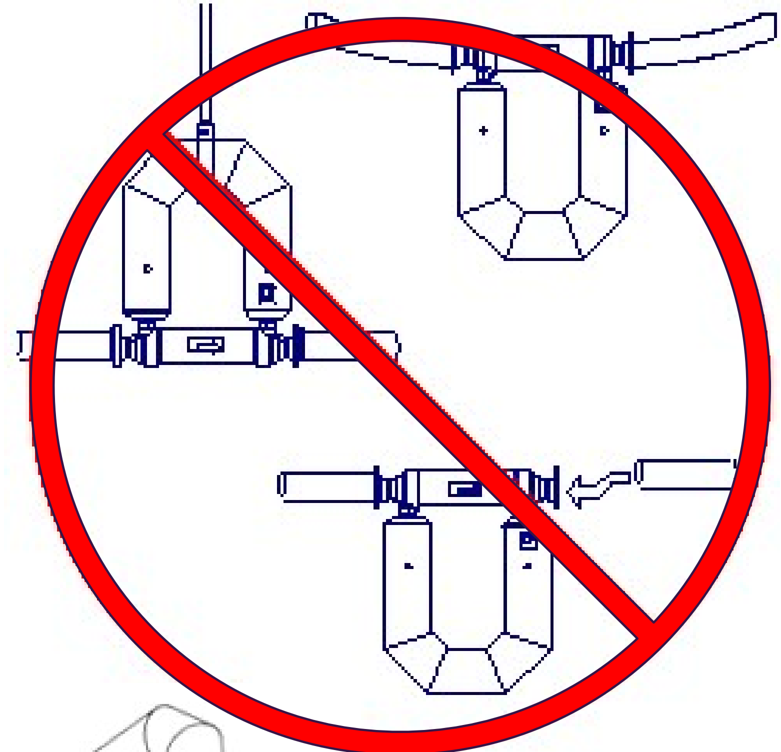
- **Vertical line installations**
  - **Flow tubes in flag position**
  - **Flow direction down preferred for gas (especially for WET GAS!!!)**
  - **Flow direction up preferred for liquid**

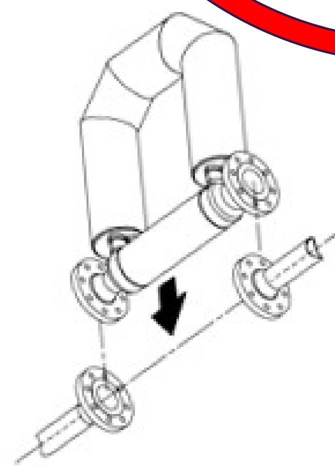
- **Horizontal line installations**
  - **Flow tubes up preferred for gas**
  - **Flow tubes down preferred for liquid**



AGA11 - Installation Best Practices
Piping Alignment and Support

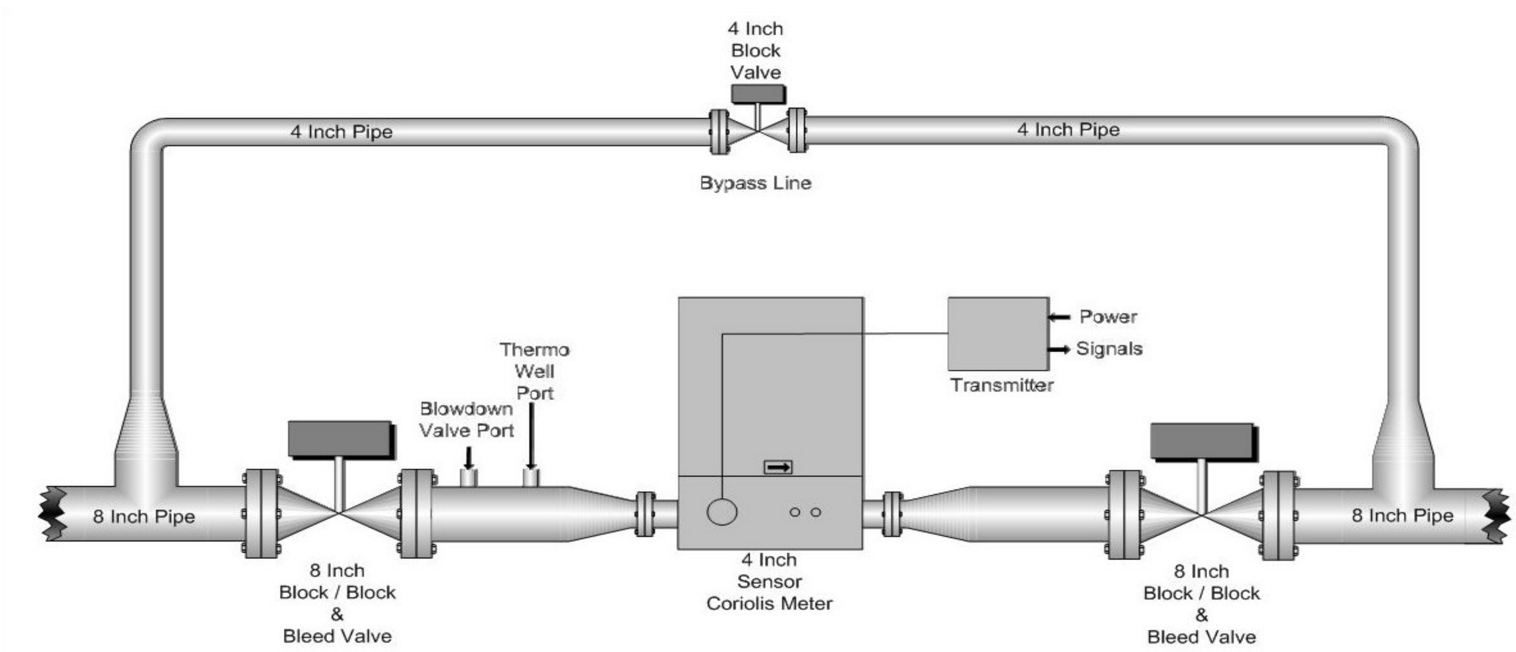
- **Proper weight support**
  - No sagging pipes
  - Piping supports installed near upstream and downstream flanges of meter
- **Meter flow tube case is sacred ground**
  - Case should not be used to support the meter or other equipment
- **Proper alignment of piping & flanges**
  - Use of fabrication spool piece when fabricating piping in the field (slip-fit desired)





AGA11 - Installation Best Practices Piping Operational Requirements

- **Upstream and Downstream Block Valves**
- **Bypass to Eliminate Interruption of Service**
- **Pressure Port Upstream of Sensor**
- **Temperature Port Upstream of Sensor**
  - **Avoid Joules Thomson Effect issues downstream**



Agenda

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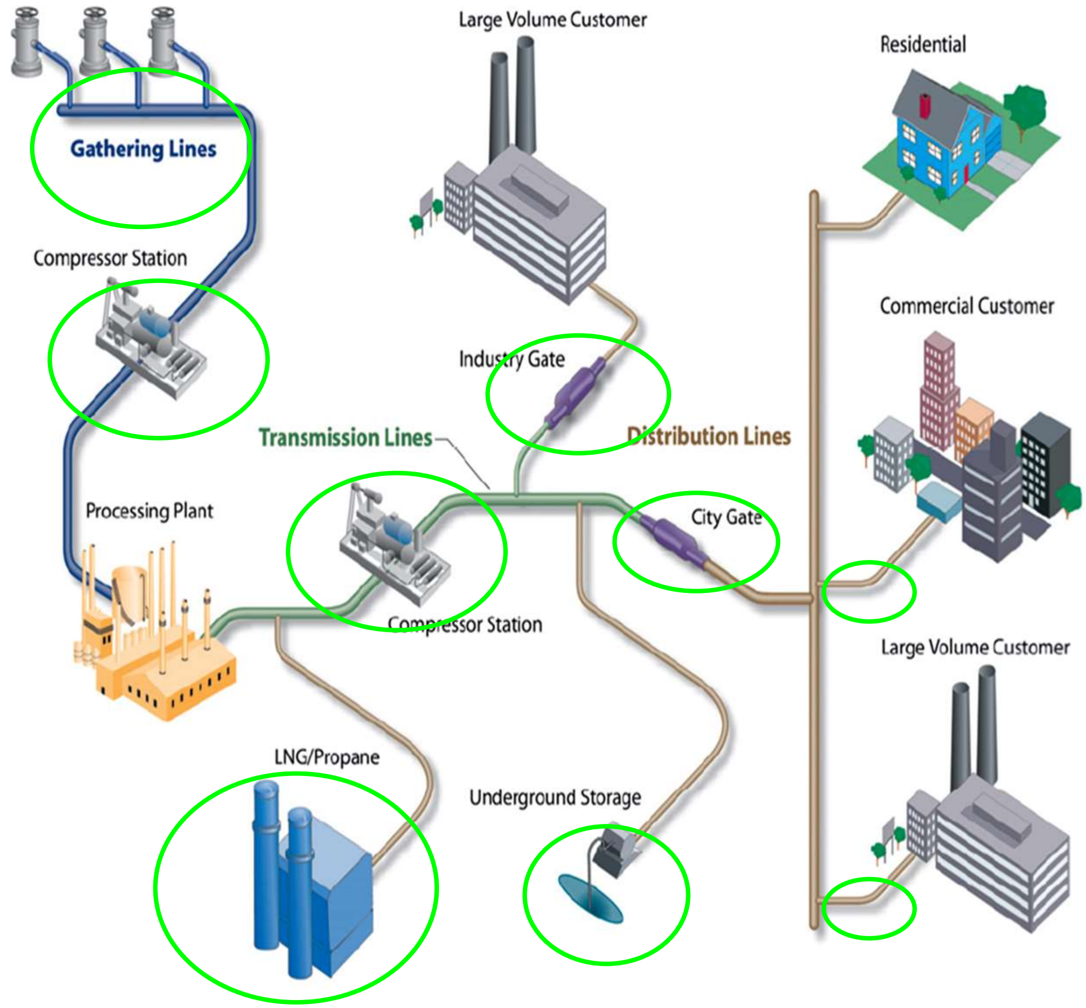
Natural Gas Industry
Coriolis Sweet Spots

- **Custody Transfer**
  - Natural gas city, commercial, and industry gates
    - Pay and check meters
  - Gathering stations
  - Specialty gas
    - Pure and unusual gas mixtures
- **Fiscal**
  - Fuel gas
  - Gas storage
- **Operations**
  - Efficiency control
  - Injection meters



The “Coriolis” Effect….

- Safety Improvement
  - Reduction in human intervention into equipment, the process, and hazardous situations
- Accurate and Efficient Asset Management
  - Reduction in measurement and control uncertainty
  - Operating cost reduction
- Sustainability of Operations
  - Improvement in system performance and reliability


Thank You!
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