The Consumer Guide to Coriolis Mass Flowmeters

Seminar Presented by
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Seminar Outline

- ***Introduction***
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

Introduction

- *Working Definition of a Process*
- *Why Measure Flow?*

Working Definition of a Process

- *A process is anything that changes*

Why Measure Flow?

- *Flow measurements provide information about the process*
- *The information that is needed depends on the process*

Why Measure Flow?

- *Custody transfer*
  - *Measurements are often required to determine the total quantity of fluid that passed through the flowmeter for billing purposes*

Why Measure Flow?

- *Monitor the process*
  - *Flow measurements can be used to ensure that the process is operating satisfactorily*

Why Measure Flow?

- *Improve the process*
  - *Flow measurements can be used for heat and material balance calculations that can be used to improve the process*

Why Measure Flow?

- *Monitor a safety parameter*
  - *Flow measurements can be used to ensure that critical portions of the process operate safely*

Seminar Outline

- *Introduction*
- ***Fluid Flow Fundamentals***
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

Fluid Flow Fundamentals

- ***Temperature***
- *Pressure*
- *Density and Fluid Expansion*
- *Types of Flow*
- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- *Hydraulic Phenomena*

Temperature

- *Measure of relative hotness/coldness*
  - *Water freezes at 0°C (32°F)*
  - *Water boils at 100°C (212°F)*

Temperature

- *Removing heat from fluid lowers temperature*
  - *If all heat is removed, absolute zero temperature is reached at approximately -273°C (-460°F)*

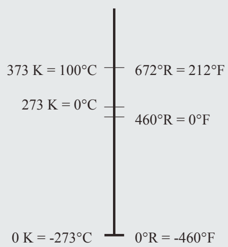
Temperature

- *Absolute temperature scales are relative to absolute zero temperature*
  - *Absolute zero temperature = 0 K (0°R)*
    - *Kelvin = °C + 273*
    - *° Rankin = °F + 460*

Temperature

- *Absolute temperature is important for flow measurement*

Temperature



Temperature

Problem

- *The temperature of a process increases from 20°C to 60°C. For the purposes of flow measurement, by what percentage has the temperature increased?*

Temperature

- *It is tempting to answer that the temperature tripled (60/20), but the ratio of the absolute temperatures is important for flow measurement*
  - *(60+273)/(20+273) = 1.137*
  - *13.7% increase*

Fluid Flow Fundamentals

- *Temperature*
- ***Pressure***
- *Density and Fluid Expansion*
- *Types of Flow*
- *Inside Pipe Diameter*
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Pressure

- *Pressure is defined as the ratio of a force divided by the area over which it is exerted (P=F/A)*

Pressure

Problem

- *What is the pressure exerted on a table by a 2 inch cube weighing 5 pounds?*
  - *(5 lb) / (4 inch^2) = 1.25 lb/in^2*
  - *If the cube were balanced on a 0.1 inch diameter rod, the pressure on the table would be 636 lb/in^2*

Pressure

- *Atmospheric pressure is caused by the force exerted by the atmosphere on the surface of the earth*
  - *2.31 feet WC / psi*
  - *10.2 meters WC / bar*

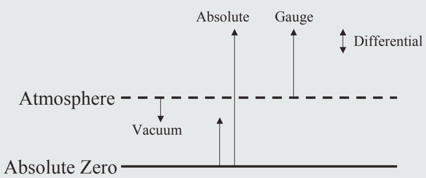
Pressure

- *Removing gas from a container lowers the pressure in the container*
  - *If all gas is removed, absolute zero pressure (full vacuum) is reached at approximately -1.01325 bar (-14.696 psig)*

Pressure

- *Absolute pressure scales are relative to absolute zero pressure*
  - *Absolute zero pressure*
    - *Full vacuum = 0 bar abs (0 psia)*
    - *bar abs = bar + 1.01325*
    - *psia = psig + 14.696*

Pressure



Pressure

- *Absolute pressure is important for flow measurement*

Pressure

Problem

- *The pressure of a process increases from 1 bar to 3 bar. For the purposes of flow measurement, by what percentage has the pressure increased?*

Pressure

- *It is tempting to answer that the pressure tripled (3/1), but the ratio of the absolute pressures is important for flow measurement*
  - *(3+1.01325)/(1+1.01325) = 1.993*
  - *99.3% increase*

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
- ***Density and Fluid Expansion***
- *Types of Flow*
- *Inside Pipe Diameter*
- *Viscosity*
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Density and Fluid Expansion

- *Density is defined as the ratio of the mass of a fluid divided its volume ($\rho=m/V$)*

Density and Fluid Expansion

- *Specific Gravity of a liquid is the ratio of its operating density to that of water at standard conditions*
  - $SG = \rho_{liquid} / \rho_{water\ at\ standard\ conditions}$

Density and Fluid Expansion

Problem

- *What is the density of air in a 3.2 ft3 filled cylinder that has a weight of 28.2 and 32.4 pounds before and after filling respectively?*

Density and Fluid Expansion

- *The weight of the air in the empty cylinder is taken into account*
  - *Mass =(32.4-28.2)+(3.2•0.075)*
    = 4.44 lb
  - *Volume = 3.2 ft*^{3}
  - *Density = 4.44/3.2 = 1.39 lb/ft*^{3}

Density and Fluid Expansion

- *The density of most liquids is nearly unaffected by pressure*
- *Expansion of liquids*
  - $V = V_0 (1 + \beta \cdot \Delta T)$
    - *V = new volume*
    - *V_0 = old volume*
    - *β = cubical coefficient of expansion*
    - *ΔT = temperature change*

Density and Fluid Expansion

Problem

- *What is the change in density of a liquid caused by a 10°C temperature rise where β is 0.0009 per °C ?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V = V_0 (1 + 0.0009 \cdot 10) = 1.009\ V_0$
  - *The volume of the liquid increased to 1.009 times the old volume, so the new density is (1/1.009) or 0.991 times the old density*

Density and Fluid Expansion

- *Expansion of solids*
  - $V = V_0 (1 + \beta \bullet \Delta T)$
    - *where* $\beta = 3 \bullet \alpha$
    - α *= linear coefficient of expansion*
- *Temperature coefficient*
  - *Stainless steel temperature coefficient is approximately 0.5% per 100°C*

Density and Fluid Expansion

Problem

- *What is the increase in size of metal caused by a 50°C temperature rise where the metal has a temperature coefficient of 0.5% per 100°C ?*

Density and Fluid Expansion

- *Calculate the change in size*
  - *(0.5 • 50) = 0.25%*
  - *Metals (such as stainless steel) can exhibit significant expansion*

Density and Fluid Expansion

- *Boyle's Law states the the volume of an ideal gas at constant temperature varies inversely with absolute pressure*
  - $V = K / P$

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Density and Fluid Expansion

- *New volume can be calculated*
  - $V = K / P$
  - $V_0 = K / P_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = P_0 / P$

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Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at constant temperature and a pressure of 28 psig affected by a 5 psig pressure increase?*

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Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = (28+14.7) / (28+5+14.7) = 0.895$
  - $V = 0.895\ V_0$
  - *Volume decreased by 10.5%*

Density and Fluid Expansion

- *Charles' Law states the the volume of an ideal gas at constant pressure varies directly with absolute temperature*
  - $V = K \cdot T$

Density and Fluid Expansion

- *New volume can be calculated*
  - $V = K \cdot T$
  - $V_0 = K \cdot T_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = T / T_0$

Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at constant pressure and a temperature of 15ºC affected by a 10ºC decrease in temperature?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = (273+15-10) / (273+15) = 0.965$
  - $V = 0.965\ V_0$
  - *Volume decreased by 3.5%*

Density and Fluid Expansion

- *Ideal Gas Law combines Boyle's and Charles' Laws*
  - $PV = n\ R\ T$

Density and Fluid Expansion

- *New volume can be calculated*
  - $P \bullet V = n \bullet R \bullet T$
  - $P_0 \bullet V_0 = n \bullet R \bullet T_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = (P_0/P) \bullet (T / T_0)$

Density and Fluid Expansion

Problem

- *How is the volume of an ideal gas at affected by a 10.5% decrease in volume due to temperature and a 3.5% decrease in volume due to pressure?*

Density and Fluid Expansion

- *Calculate the new volume*
  - $V/V_0 = 0.895 \bullet 0.965 = 0.864$
  - $V = 0.864\ V_0$
  - *Volume decreased by 13.6%*

Density and Fluid Expansion

- *Non-Ideal Gas Law takes into account non-ideal behavior*
  - *$PV = n R T Z$*

Density and Fluid Expansion

- *New volume can be calculated*
  - $P \bullet V = n \bullet R \bullet T \bullet Z$
  - $P_0 \bullet V_0 = n \bullet R \bullet T_0 \bullet Z_0$
- *Dividing one equation by the other yields*
  - $V/V_0 = (P_0/P) \bullet (T / T_0) \bullet (Z / Z_0)$

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
- *Density and Fluid Expansion*
- ***Types of Flow***
- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- *Hydraulic Phenomena*

Types of Flow

- $Q = A \cdot v$
  - Q is the volumetric flow rate
  - A is the cross-sectional area of the pipe
  - v is the average velocity of the fluid in the pipe

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Types of Flow

- Typical Volumetric Flow Units($Q = A \cdot v$)
  - $ft^2 \cdot ft/sec = ft^3/sec$
  - $m^2 \cdot m/sec = m^3/sec$
  - gallons per minute (gpm)
  - liters per minute (lpm)
  - cubic centimeters per minute (ccm)

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Types of Flow

- $W = \rho \cdot Q$
  - W is the mass flow rate
  - ρ is the fluid density
  - Q is the volumetric flow rate

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Types of Flow

- *Typical Mass Flow Units ($W = \rho \bullet Q$)*
  - *$lb/ft^3 \bullet ft^3/sec = lb/sec$*
  - *$kg/m^3 \bullet m^3/sec = kg/sec$*
  - *standard cubic feet per minute (scfm)*
  - *standard liters per minute (slpm)*
  - *standard cubic centimeters per minute(sccm)*

Types of Flow

- $Q = A \bullet v$
- $W = \rho \bullet Q$

  - Q *volumetric flow rate*
  - W *mass flow rate*
  - v *fluid velocity*
  - $\frac{1}{2}\,\rho v^2$ *inferential flow rate*

Fluid Flow Fundamentals

- *Temperature*
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Inside Pipe Diameter

- *The* *inside* *pipe diameter (ID) is important for flow measurement*
  - *Pipes of the same size have the same outside diameter (OD)*
    - *Welding considerations*
  - *Pipe wall thickness, and hence its ID, is determined by its schedule*

Inside Pipe Diameter

- *Pipe wall thickness increases with increasing pipe schedule*
  - *Schedule 40 pipes are considered "standard" wall thickness*
  - *Schedule 5 pipes have thin walls*
  - *Schedule 160 pipes have thick walls*

Inside Pipe Diameter

- *Nominal pipe size*
  - *For pipe sizes 12-inch and smaller, the nominal pipe size is the approximate ID of a Schedule 40 pipe*
  - *For pipe sizes 14-inch and larger, the nominal pipe size is the OD of the pipe*

Fluid Flow Fundamentals

- *Temperature*
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- ***Viscosity***
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Viscosity

- *Viscosity is the ability of the fluid to flow over itself*
- *Units*
  - *cP, cSt*
  - *Saybolt Universal (at 100ºF, 210 ºF)*
  - *Saybolt Furol (at 122ºF, 210 ºF)*

Viscosity

- *Viscosity can be highly temperature dependent*
  - *Water*
  - *Honey at 40°F, 80°F, and 120°F*
  - *Peanut butter*

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
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- ***Reynolds Number and Velocity Profile***
- *Hydraulic Phenomena*

Velocity Profile and Reynolds Number

- *Reynolds number is the ratio of inertial forces to viscous forces in the flowing stream*
  - $R_D = 3160 \bullet Q_{gpm} \bullet SG / (\mu_{cP} \bullet D_{in})$

Velocity Profile and Reynolds Number

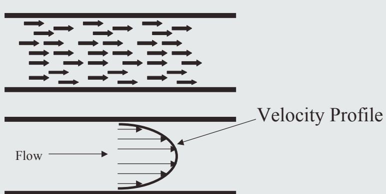
- *Reynolds number can be used as an indication of how the fluid is flowing in the pipe*
- *Flow regimes based on* R_D
  - *Laminar* < 2000
  - *Transitional* $2000 - 4000$
  - *Turbulent* > 4000

Velocity Profile and Reynolds Number

- *Not all molecules in the pipe flow at the same velocity*
- *Molecules near the pipe wall move slower; molecules in the center of the pipe move faster*

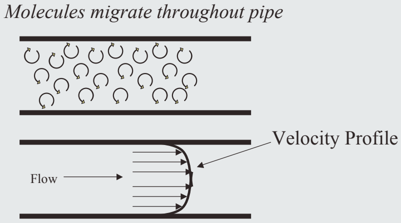
Velocity Profile and Reynolds Number

- *Laminar Flow Regime*
  - *Molecules move straight down pipe*



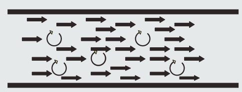
Velocity Profile and Reynolds Number

- *Turbulent Flow Regime*
  - *Molecules migrate throughout pipe*



Velocity Profile and Reynolds Number

- *Transitional Flow Regime*
  - *Molecules exhibit both laminar and turbulent behavior*

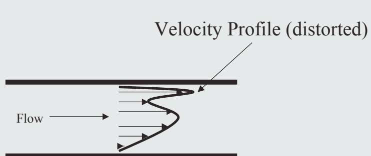


Velocity Profile and Reynolds Number

- *Many flowmeters require a good velocity profile to operate accurately*
- *Obstructions in the piping system can distort the velocity profile*
  - *Elbows, tees, fittings, valves*

Velocity Profile and Reynolds Number

- *A distorted velocity profile can introduce significant errors into the measurement of most flowmeters*



Velocity Profile and Reynolds Number

- *Good velocity profiles can be developed*
  - *Straight run upstream and downstream*
    - *No fittings or valves*
    - *Upstream is usually longer and more important*
  - *Flow conditioner*
  - *Locate control valve downstream of flowmeter*

Fluid Flow Fundamentals

- *Temperature*
- *Pressure*
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- *Inside Pipe Diameter*
- *Viscosity*
- *Reynolds Number and Velocity Profile*
- ***Hydraulic Phenomena***

Hydraulic Phenomena

- *Vapor pressure is defined as the pressure at which a liquid and its vapor can exist in equilibrium*
  - *The vapor pressure of water at 100°C is atmospheric pressure (1.01325 bar abs) because water and steam can coexist*

Hydraulic Phenomena

- *A saturated vapor is in equilibrium with its liquid at its vapor pressure*
  - *Saturated steam at atmospheric pressure is at a temperature of 100°C*

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Hydraulic Phenomena

- *A superheated vapor is a saturated vapor that is at a higher temperature than its saturation temperature*
  - *Steam at atmospheric pressure that is at 150°C is a superheated vapor with 50°C of superheat*

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Hydraulic Phenomena

- *Flashing is the formation of gas (bubbles) in a liquid after the pressure of the liquid falls below its vapor pressure*
  - *Reducing the pressure of water at 100°C below atmospheric pressure (say 0.7 bar abs) will cause the water to boil*

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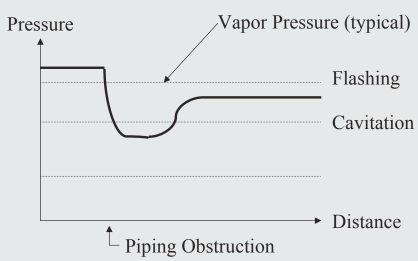
Hydraulic Phenomena

- *Cavitation is the formation and subsequent collapse of gas (bubbles) in a liquid after the pressure of the liquid falls below and then rises above its vapor pressure*
  - *Can cause severe damage in pumps and valves*

Hydraulic Phenomena

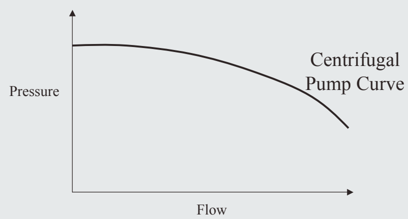


Hydraulic Phenomena

- *Energy Considerations*
  - *Claims are sometimes made that flowmeters with a lower pressure drop will save energy*

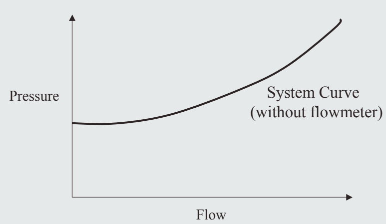
Hydraulic Phenomena

- *Energy Considerations*



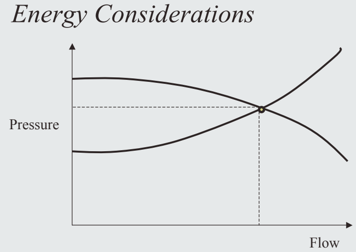
Hydraulic Phenomena

- *Energy Considerations*



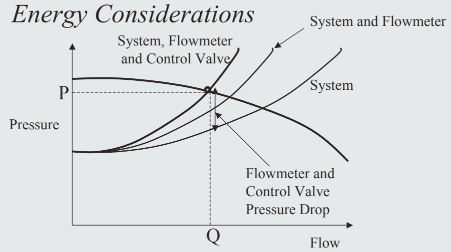
Hydraulic Phenomena

- *Energy Considerations*



Hydraulic Phenomena

- *Energy Considerations*



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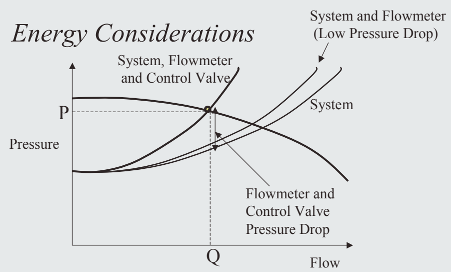
Hydraulic Phenomena

- *Energy Considerations*



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Hydraulic Phenomena

- *Energy Considerations*
  - *The pump operates at the same flow and pressure, so no energy savings are achieved by installing a flowmeter with a lower pressure drop*

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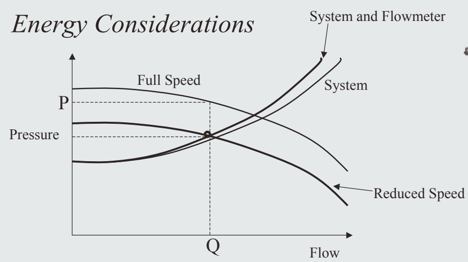
Hydraulic Phenomena

- *Energy Considerations*



Hydraulic Phenomena

- *Energy Considerations*
  - *Operating the pump at a reduced speed generates the same flow but requires a lower pump discharge pressure*
    - *Hydraulic energy generated by the pump better matches the load*
    - *Energy savings are proportional to the cube of the speed*

Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- ***Flowmeter Technology***
- *Flowmeter Performance*
- *Consumer Guide*

Coriolis Mass Flowmeter Technology

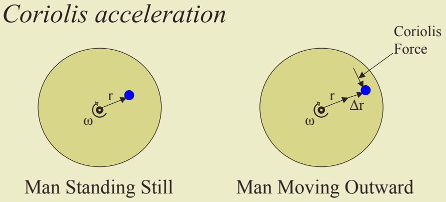
- ***Principle of Operation***
- *Tube Geometry*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Principle of Operation

- *Coriolis mass flowmeters use the properties of mass to measure mass*
  - *Thermal mass flowmeters assume constant thermal properties*

Principle of Operation

- *Coriolis acceleration*



Principle of Operation

- *Man Standing Still*
  - *Velocity in tangential plane is constant*

$$F_{tang} = m \bullet a_{tang}$$
$$= m \bullet \Delta v_{tang} / \Delta t$$
$$= m \bullet (r \bullet \omega - r \bullet \omega) / \Delta t$$
$$= m \bullet 0 / \Delta t$$
$$= 0 \text{ (no force in tangential plane)}$$

Principle of Operation

- *Man Moving Outward*
  - *Velocity in tangential plane changes*

$$F_{tang} = m \bullet a_{tang}$$
$$= m \bullet \Delta v_{tang} / \Delta t$$
$$= m \bullet ((r + \Delta r) \bullet \omega - r \bullet \omega) / \Delta t$$
$$= m \bullet \Delta r \bullet \omega / \Delta t$$
$$\neq 0 \text{ (force in tangential plane)}$$

Principle of Operation

- *Components that produce Coriolis force*
  - *Rotation*
  - *Motion towards/away from center of rotation*
  - *Resultant Coriolis acceleration*

Principle of Operation

- *U-tube Coriolis mass flowmeter*
  - *Rotation*
    - *Oscillation about a plane parallel to the centerline of the piping connections*

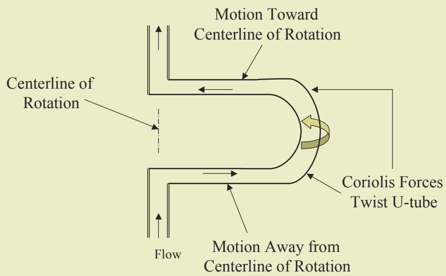
Principle of Operation

- *U-tube Coriolis mass flowmeter*
  - *Motion towards/away from center of rotation*
    - *Mass flow through U-tube towards/away from the centerline of piping connections*

Principle of Operation

- *U-tube Coriolis mass flowmeter*
  - *Coriolis force*
    - *Twist of U-tube*

Coriolis Mass Flowmeter



Principle of Operation

Experiment

- *Hold a garden hose with both hands so it sags near the floor (like a U-tube)*
  - *Turning water on/off has little affect on the position of the hose*

Principle of Operation

Experiment

- *Swing the hose toward and away from your body*
  - *Turning on the water will cause the sides of the U-tube to move towards/away from you*
  - *Stopping the swinging will stop the movement and relax the U-tube*

Principle of Operation

- *Coriolis acceleration is proportional to the mass flow*
- *Coriolis acceleration generates a force*
- *Coriolis force twists the U-tube*

Principle of Operation

- *Mass flow is proportional to the Coriolis force that twists the U-tube*
  - *Measure the twist of the U-tube*

Principle of Operation

- *Amount of twist depends on mechanical properties of the U-tube*
  - *Material*
  - *Wall thickness*
  - *Temperature*

Principle of Operation

- *Temperature Measurement*
  - *Pipe wall temperature is measured to compensate for material properties*
  - *Many Coriolis mass flowmeters offer (an optional) temperature measurement output*
    - *Not process temperature*
    - *Outside pipe wall temperature*

Principle of Operation

- *Density Measurement*
  - *The frequency of oscillation is related to fluid density*
  - *Many Coriolis mass flowmeters offer (an optional) density measurement output*

Principle of Operation

- *Viscosity Measurement*
  - *In the laminar flow regime, the mass flow measurement, temperature measurement, and external differential pressure measurement across the flowmeter is used to calculate viscosity*

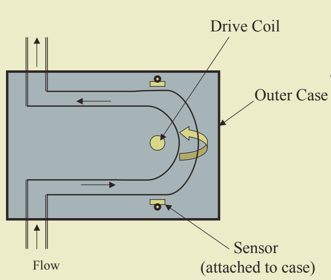
Principle of Operation

- *Viscosity Measurement*
  - *To counteract the effects of pipe vibration, one Coriolis mass flowmeter uses a weight that twists the tube*
  - *Measurement of the forces due this twist are used to determine the fluid viscosity*

Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- ***Tube Geometry***
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

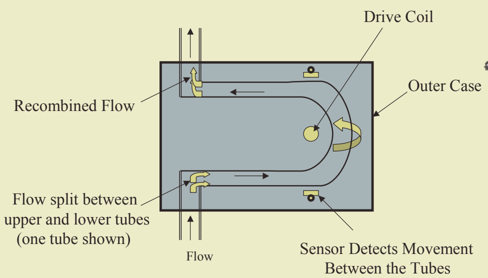
Tube Geometry – Single U-tube



Tube Geometry – Single U-tube

- *First practical design*
- *Sensors connected to case*
  - *Measure movement relative to case*
  - *Susceptible to pipe vibration*
  - *Rigid support structures*
    - *Metal plate*
    - *Concrete foundation*

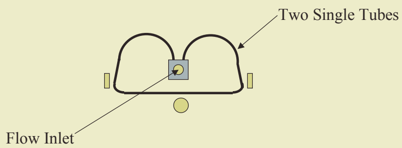
Tube Geometry – Dual U-tube



Tube Geometry – Dual U-tube

- *Flow split between two tubes*
- *Sensors connected to case*
  - *Measure relative movement of tubes*
  - *Reduced susceptibility to pipe vibration*
  - *Mount flowmeter in piping*

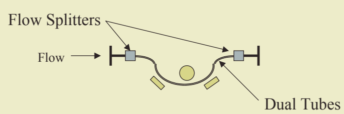
Tube Geometry – B-Tube



B-tube Design

Foxboro

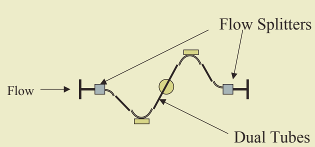
Tube Geometry – Curved Tube



Curved Tube Design

Endress+Hauser, Micromotion, Oval

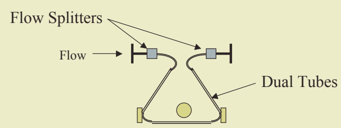
Tube Geometry – Curved Tube



Curved Tube Design

ABB

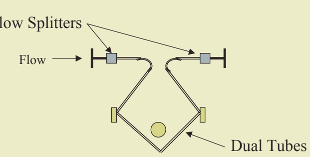
Tube Geometry – Delta



Delta Tube Design

Micromotion

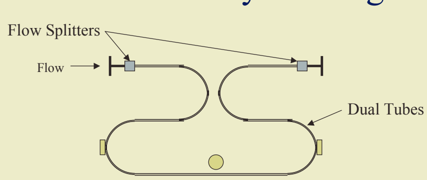
Tube Geometry – Diamond



Diamond Tube Design

Kueppers

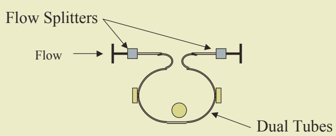
Tube Geometry – Omega



Omega Tube Design

Actaris (Schlumberger)

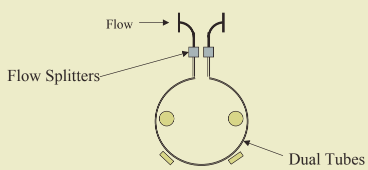
Tube Geometry – Omega



Omega Tube Design

Heinrichs

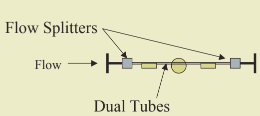
Tube Geometry – Round



Round Tube Design

Rheonik

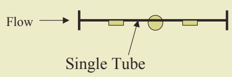
Tube Geometry – Straight



Straight Dual Tube Design

Endress+Hauser

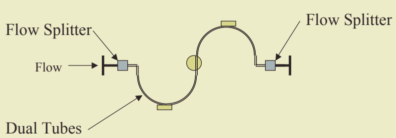
Tube Geometry – Straight



Straight Single Tube Design

Brooks, Endress+Hauser, Krohne, Micromotion, Oval

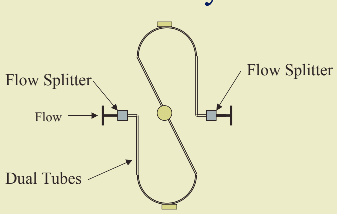
Tube Geometry – S-Tube



S-Tube Design

FMC Energy Systems

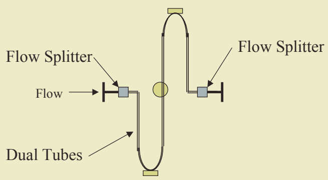
Tube Geometry – S-Tube



S-Tube Design

FMC Energy Systems

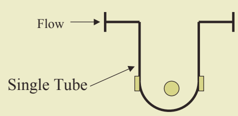
Tube Geometry – S-Tube



S-Tube Design

Krohne

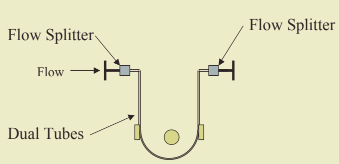
Tube Geometry– U-Tube



Single U-Tube Design

Brooks, Micromotion

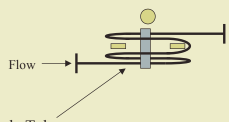
Tube Geometry– U-Tube



Dual U-Tube Design

Micromotion, Oval, Yokogawa

Tube Geometry – U-Tube



U-Tube Design
Danfoss

Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- *Tube Geometry*
- ***Flowmeter Designs***
- *Transmitter Designs*
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Coriolis Mass Flowmeter Designs

- *Liquid*
- *Gas*
- *High Pressure*
- *High Temperature*

Coriolis Mass Flowmeter Designs

- *Metal (other than stainless steel)*
- *Plastic/Polymer*
- *Sanitary*
- *Single Path*
- *Straight Path*

Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- *Tube Geometry*
- *Flowmeter Designs*
- ***Transmitter Designs***
- *Installation*
- *Accessories*
- *Other Flowmeter Technologies*

Coriolis Mass Flowmeter Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
  - *Mathematical corrections difficult*
  - *Four-wire design*

Coriolis Mass Flowmeter Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
  - *Mathematical corrections in software*
  - *Four-wire design*
  - *Remote communication (with HART)*

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Coriolis Mass Flowmeter Transmitter Designs

- *Digital*
  - *Typical design measures a parameter related to flow*
  - *Some designs digitize raw signals that are processed digitally*
  - *One design measures two-phase flow by controlling tube vibration and proprietary signal processing algorithms*

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Coriolis Mass Flowmeter Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
  - *Mathematical corrections in software*
  - *Multi-drop wiring*
  - *Remote communication*
  - *Issues with multiple protocols*

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Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- *Tube Geometry*
- *Flowmeter Designs*
- *Transmitter Designs*
- ***Installation***
- *Accessories*
- *Other Flowmeter Technologies*

Installation

- *Fluid Characteristics*
- *Piping and Hydraulics*
- *Mounting*
- *Electrical*
- *Ambient Conditions*
- *Setup Information*

Fluid Characteristics

- *Single-phase homogeneous*
  - *Liquid*
  - *Gas*
  - *Vapor*

Fluid Characteristics

- *Two-phase*
  - *Liquid/solid*
  - *Liquid/gas*
- *Avoid flashing*

Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
- *Immiscible fluids*

Piping and Hydraulics

- *For liquid applications, keep the flowmeter full of liquid*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid inverted U-tube*

Piping and Hydraulics

- *For liquid applications, orient to self-fill and self-drain*
  - *Self-filling is important to ensure a full pipe*
    - *If not, special precautions must be taken when zeroing the flowmeter*
    - *If not, gas/vapor can accumulate, especially at low flow conditions*

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Piping and Hydraulics

- *For liquid applications, keep the flowmeter full of liquid*
  - *Hydraulic design*
    - *Be careful when flowing downwards*
    - *Be careful when flowing by gravity*

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Piping and Hydraulics

- *For gas/vapor applications, keep the flowmeter full of gas/vapor*
  - *Hydraulic design*
    - *Self-draining*
    - *Vertical preferred*
    - *Avoid U-tube*

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Piping and Hydraulics

- *For gas/vapor applications, calculate pressure drop carefully*
  - *Mass flow range of a given size flowmeter is fixed*
  - *Relatively small mass occupies a relatively large volume*
  - *High velocity and high pressure drop result*
  - *Flowmeter will operate low in its range*

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Piping and Hydraulics

- *Wetted parts compatible with fluid*
- *Sanitary applications*
  - *Orient to self-fill and self-drain*
  - *Compatible with cleaning solutions*

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Piping and Hydraulics

- *Maintain good velocity profile*
  - *Locate control valve downstream of flowmeter*
  - *Provide adequate straight run*
    - *Locate most straight run upstream*
  - *Use full face gaskets*

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Piping and Hydraulics

- *Install a positive shut-off valve downstream of the flowmeter to zero the flowmeter at process temperature and process pressure*
  - *Some suppliers have specific instructions regarding gas removal when installation is not self-filling (liquid)*

Piping and Hydraulics

- *When locating two or more Coriolis mass flowmeters near each other, it is possible for their vibrations to interact*
  - *Different vibration frequencies*
  - *Isolate with supports and flexible connections*

Mounting

- *Mount the flowmeter between flanges that are parallel, axially aligned, and proper spacing*
- *Locate the flowmeter so as to reduce vibration*

Mounting

- *Some suppliers recommend:*
  - *mounting on a solid base plate*
  - *mounting heavy sensors on a rigid support*
  - *upstream bends not in certain planes that could dampen oscillations*
  - *symmetric supports up/downstream*

Electrical

- *Integral sensors reduce wiring cost*
- *Wiring*
  - *Low voltage power supply can eliminate power conduit*
  - *Fieldbus reduces wiring*

Ambient Conditions

- *Outdoor applications (-20 to 60°C)*
  - *Some designs are for indoor locations*
- *Hazardous locations*
  - *Some designs are general purpose*

Setup Information

- *GIGO (garbage in – garbage out)*
- *Entering correct information correctly is <u>critical</u>*
  - *Dimensions*
  - *Materials of construction*
  - *Fluid properties*

Setup Information

- *Failure to use correct information can cause significant error and startup problems*

Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- *Tube Geometry*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- ***Accessories***
- *Other Flowmeter Technologies*

Accessories

- *Flow Tube*
  - *NEMA 4X and IP67 (IP68)*
  - *High pressure*
  - *High temperature*
  - *Non-316SS*
  - *Sanitary*
  - *Secondary containment*

Accessories

- *Flow Tube*
  - *Purge fittings*
  - *Heating jacket*
  - *Removable insulation*
  - *Rupture disk*

Accessories

- *Transmitter*
  - *NEMA 4X and IP67*
  - *Senor wiring is often intrinsically safe*
  - *Analog output*
  - *Pulse output*
  - *Totalization and alarms*
  - *HART, Foundation Fieldbus, Profibus*

Coriolis Mass Flowmeter Technology

- *Principle of Operation*
- *Tube Geometry*
- *Flowmeter Designs*
- *Transmitter Designs*
- *Installation*
- *Accessories*
- ***Other Flowmeter Technologies***

Other Flowmeter Technologies

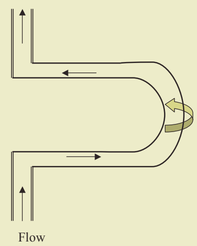
- *Coriolis Mass*
- *Differential Pressure*
- *Magnetic*
- *Positive Displacement*
- *Target*
- *Thermal*
- *Turbine*
- *Ultrasonic*
- *Vortex Shedding*

Insertion

Coriolis Mass Flowmeter

- *Coriolis mass flowmeters measure the force generated as the fluid moves towards/away from its center of rotation*

Coriolis Mass Flowmeter



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Differential Pressure Flowmeter

- *A piping restriction is used to develop a pressure drop that is measured and used to infer fluid flow*
  - *Primary Flow Element*
  - *Transmitter (differential pressure)*

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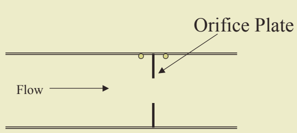
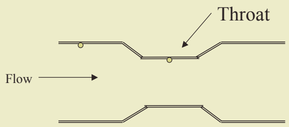
Orifice Plate Primary Flow Element



 177

Venturi
Primary Flow Element



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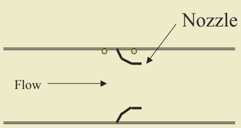
Flow Nozzle
Primary Flow Element



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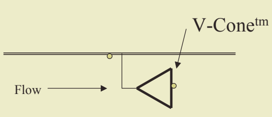
V-Cone^{tm}
Primary Flow Element



180

Differential Pressure Flowmeter

- *Pressure drop is proportional to the square of the fluid flow rate*
  - *$\Delta p \propto Q^2$ or $Q \propto sqrt(\Delta p)$*
  - *Double the flow… four times the differential*

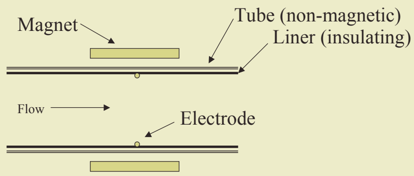
Differential Pressure Flowmeter

- *Low flow measurement can be difficult*
  - *For example, only ¼ of the differential pressure is generated at 50 percent of the full scale flow rate. At 10 percent flow, the signal is only 1 percent of the differential pressure at full scale.*

Magnetic Flowmeter

- *Fluid flow through a magnetic field generates a voltage at the electrodes that is proportional to fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

Magnetic Flowmeter



Magnetic Flowmeter

- *Traditional AC excitation was susceptible to noise and drift*
  - *A low voltage signal is generated that is susceptible to noise and cross-talk at the excitation frequency*

Magnetic Flowmeter

- *Pulsed DC excitation reduces drift by turning the magnet on and off*
  - *Noise (while the magnet is off) is subtracted from signal and noise (while the magnet is on) to reduce the effects of noise and cross-talk*
  - *Response time can be compromised*

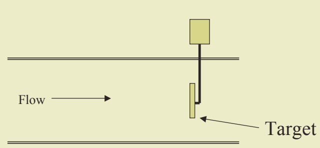
Positive Displacement Flowmeter

- *Positive displacement flowmeters measure flow by repeatedly entrapping fluid within the flowmeter*
  - *Moving parts with tight tolerances*
  - *Bearings*
  - *Many shapes*

Target Flowmeter

- *Target flowmeters determine flow by measuring the force exerted on a body (target) suspended in the flow stream*

Target Flowmeter



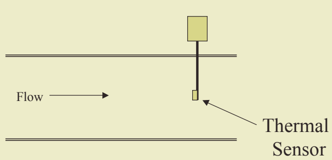
Thermal Flowmeter

- *Thermal flowmeters use the thermal properties of the fluid to measure flow*
  - *Hot Wire Anemometer*
  - *Thermal Profile*

Thermal Flowmeter
Hot Wire Anemometer

- *Hot wire anemometers determine flow by measuring the amount of energy needed to heat a probe whose heat loss changes with flow rate*

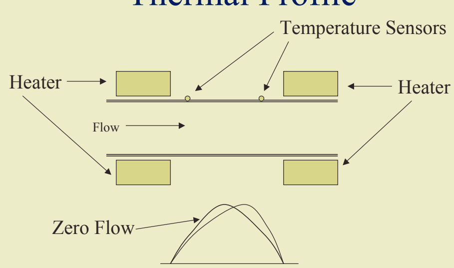
Thermal Flowmeter
Hot Wire Anemometer



Thermal Flowmeter
Thermal Profile

- *Thermal profile flowmeters determine flow by measuring the temperature difference that results in a heated tube when the fluid transfers heat from the upstream portion to the downstream portion of the flowmeter*

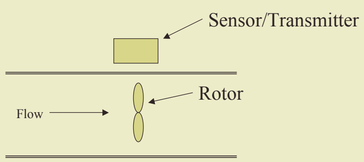
Thermal Flowmeter
Thermal Profile



Turbine Flowmeter

- *Fluid flow causes a rotor to spin whereby the rotor speed is proportional to fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

Turbine Flowmeter



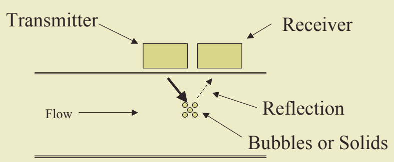
Turbine Flowmeter

- *The sensor detects the rotor blades*
- *The frequency of the rotor blades passing the sensor is proportional to fluid velocity*

Ultrasonic - Doppler

- *Doppler ultrasonic flowmeters reflect ultrasonic energy from particles, bubbles and/or eddies flowing in the fluid*

Ultrasonic - Doppler



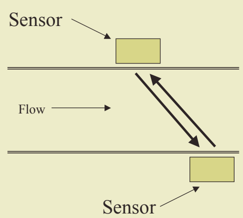
Ultrasonic - Doppler

- *Under no flow conditions, the frequencies of the ultrasonic beam and its reflection are the same*
- *With flow in the pipe, the difference between the frequency of the beam and its reflection increases proportional to fluid velocity*

Ultrasonic - Transit Time

- *Transit time (time-of-flight) ultrasonic flowmeters alternately transmit ultrasonic energy into the fluid in the direction and against the direction of flow*

Ultrasonic - Transit Time

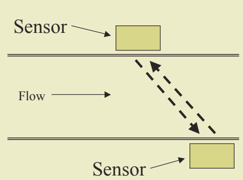


Ultrasonic - Transit Time

- *The time difference between ultrasonic energy moving upstream and downstream in the fluid is used to determine fluid velocity*

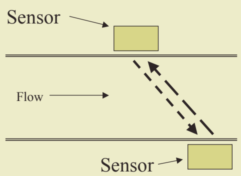
Ultrasonic - Transit Time

- *Under no flow conditions, the time for the ultrasonic energy to travel upstream and downstream are the same*



Ultrasonic - Transit Time

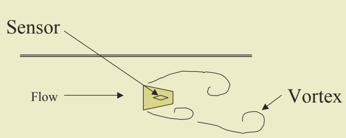
- *With flow in the pipe, the time for the ultrasonic energy to travel upstream will be greater than the downstream time*



Vortex Shedding Flowmeter

- *A bluff body in the flow stream creates vortices whereby the number of vortices is proportional to the fluid velocity*
  - *Primary Flow Element*
  - *Transmitter*

Vortex Shedding Flowmeter



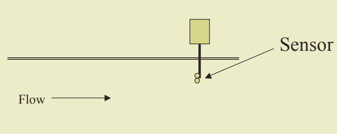
Vortex Shedding Flowmeter

- *The sensing system detects the vortices created*
- *The frequency of the vortices passing the sensing system is proportional to fluid velocity*

Insertion Flowmeter

- *Insertion flowmeter infer the flow in the entire pipe by measuring flow at one or more strategic locations in the pipe*
  - *Differential Pressure*
  - *Magnetic*
  - *Target*
  - *Thermal*
  - *Turbine*
  - *Vortex*

Insertion Flowmeter



Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- ***Flowmeter Performance***
- *Consumer Guide*

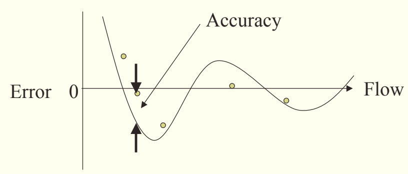
Flowmeter Performance

- ***Flowmeter Performance***
- *Performance Statements*
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

Flowmeter Performance

- *Accuracy is the ability of the flowmeter to produce a measurement that corresponds to its characteristic curve*

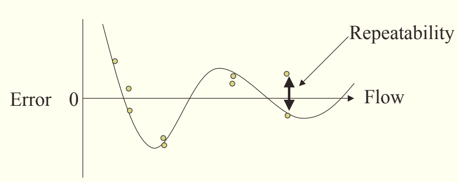
Flowmeter Performance



Flowmeter Performance

- *Repeatability is the ability of the flowmeter to reproduce a measurement each time a set of conditions is repeated*

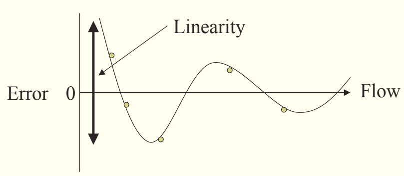
Flowmeter Performance



Flowmeter Performance

- *Linearity is the ability of the relationship between flow and flowmeter output (often called the characteristic curve or signature of the flowmeter) to approximate a linear relationship*

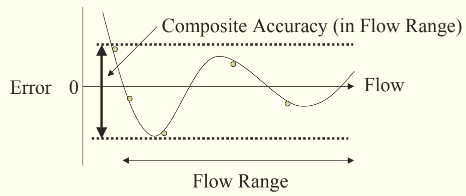
Flowmeter Performance



Flowmeter Performance

- *Flowmeter suppliers often specify the composite accuracy that represents the combined effects of repeatability, linearity and accuracy*

Flowmeter Performance



Flowmeter Performance

- *Flowmeter Performance*
- ***Performance Statements***
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

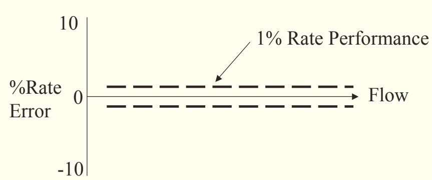
Performance Statements

- *Percent of rate*
- *Percent of full scale*
- *Percent of meter capacity (upper range limit)*
- *Percent of calibrated span*

Performance Statements

- *1% of rate performance at different flow rates with a 0-100 unit flow range*
  - *100% flow → 0.01•100 1.00 unit*
  - *50% flow → 0.01•50 0.50 unit*
  - *25% flow → 0.01•25 0.25 unit*
  - *10% flow → 0.01•10 0.10 unit*

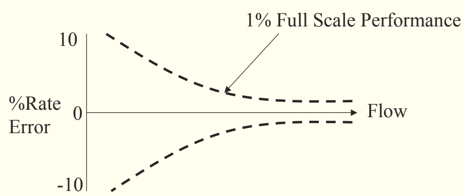
Performance Statements



Performance Statements

- *1% of full scale performance at different flow rates with a 0-100 unit flow range*
  - *100% flow → 0.01•100 1 unit = 1% rate*
  - *50% flow → 0.01•100 1 unit = 2% rate*
  - *25% flow → 0.01•100 1 unit = 4% rate*
  - *10% flow → 0.01•100 1 unit = 10% rate*

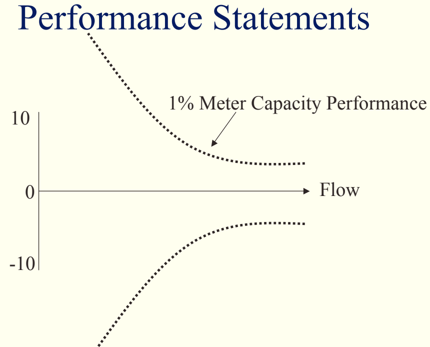
Performance Statements



Performance Statements

- *1% of meter capacity (or upper range limit) performance at different flow rates with a 0-100 unit flow range (URL=400)*
  - *100% flow → 0.01•400 4 units = 4% rate*
  - *50% flow → 0.01•400 4 units = 8% rate*
  - *25% flow → 0.01•400 4 units = 16% rate*
  - *10% flow → 0.01•400 4 units = 40% rate*

Performance Statements



Performance Statements

- *Performance expressed as a percent of calibrated span is similar to full scale and meter capacity statements where the absolute error is a percentage of the calibrated span*

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Performance Statements

- *1% of calibrated span performance at different flow rates with a 0-100 unit flow range (URL=400, calibrated span=200)*
  - *100% flow → 0.01•200 2 units = 2% rate*
  - *50% flow → 0.01•200 2 units = 4% rate*
  - *25% flow → 0.01•200 2 units = 8% rate*
  - *10% flow → 0.01•200 2 units = 20% rate*

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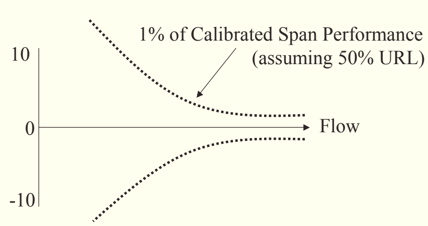
Performance Statements



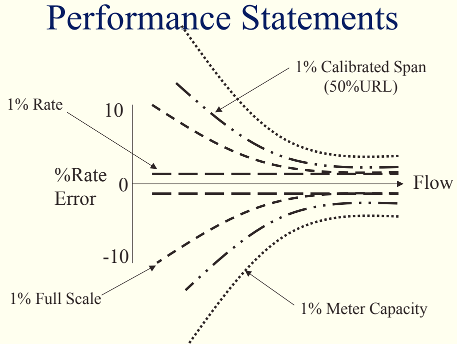
Performance Statements

- *A calibrated span statement becomes a full scale statement when the instrument is calibrated to full scale*
- *A calibrated span statement becomes a meter capacity statement when the instrument is calibrated at URL*

Performance Statements

- *Performance specified as a percent of rate, percent of full scale, percent of meter capacity, and percent of calibrated span are different*

Performance Statements



Performance Statements

- *Performance statements apply over a range of operation*
- *Turndown is the ratio of the maximum flow that the flowmeter will measure within the stated accuracy to the minimum flow that can be measured within the stated accuracy*

Performance Statements

- *Performance statements can be manipulated because their meaning may not be clearly understood*
- *Technical assistance may be needed to analyze the statements*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- ***Reference Performance***
- *Pulse Output vs. Analog Output*
- *Actual Performance*
- *Supplier Claims*

Reference Performance

- *Reference performance is the quality of measurement at a nominal set of operating conditions, such as:*
  - *Water at 20°C in ambient conditions of 20°C and 50 percent relative humidity*
  - *Long straight run*
  - *Pulse output*

Reference Performance

- *In the context of the industrial world, reference performance reflects performance under controlled laboratory conditions*

Performance Statements

- *For most Coriolis mass flowmeters, performance statements are the combination of:*
  - *Percentage of rate*
  - *Zero stability*

Performance Statements

- *Combination performance statement*
  - *Zero adjustment exists*
    - *Zero is is not well-defined*
  - *Zero adjustment is performed well*

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Reference Performance

- *Hypothetical flowmeter*
  - *0.1% rate*
  - *0.025 kg/min*
    - *Zero stability (depends on size)*

 242

Reference Performance

Example - Omission

- *Hypothetical flowmeter*
  - *0.10% rate*
- *This statement could be interpreted to apply over the entire flow range*

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Reference Performance

Example - Omission

- *Hypothetical flowmeter*
  - *0.10% rate plus 0.025 kg/min*
- *0.10% rate dominates at high flows*
- *0.025 kg/min dominates at low flows*

Reference Performance

Problem

- *What is the performance of a Coriolis mass flowmeter with the following accuracy specifications?*
  - *0.10% rate plus 0.025 kg/min*
  - *Assume a 0-100 kg/min flow range*

Reference Performance

Solution

- *Rate statement error*
  - *100% flow → 0.001•100   0.100 kg/min*
  - *50% flow → 0.001•50   0.050 “*
  - *25% flow → 0.001•25   0.025 “*
  - *10% flow → 0.001•10   0.010 “*
  - *1% flow → 0.001•1   0.001 “*

Reference Performance

Solution

- *Flow error*
  - *100%flow →0.100+0.025=0.125kg/min*
  - *50% flow → 0.050+0.025=0.075 "*
  - *25% flow → 0.025+0.025=0.050 "*
  - *10% flow → 0.010+0.025=0.035 "*
  - *1% flow → 0.001+0.025=0.026 "*

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Reference Performance

Solution

- *Performance expressed as a percent of rate*
  - *100% flow → 0.125/100 0.13 % rate*
  - *50% flow → 0.075/50 0.15 % "*
  - *25% flow → 0.050/25 0.20 % "*
  - *10% flow → 0.035/10 0.35 % "*
  - *1% flow → 0.026/1 2.60 % "*

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Reference Performance

- *Performance at low flow rates is degraded as compared to the 0.10% rate statement (while still meeting specifications)*
  - *Rate statement dominates at high flows*
  - *Zero stability dominates at low flows*

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Reference Performance

- *Rate statements are often discussed*
- *Zero stability issues are often only mentioned with prompting*
  - *Progressive disclosure*

Reference Performance

- *Flow Laboratory Performance*
  - *Flow laboratory is used to ensure that the flowmeter performs per specifications*

Reference Performance

- *Uncertainty Analysis*
  - *Formal document that quantifies flow laboratory performance*
  - *Opportunity to take a critical look at the facility*

Reference Performance

- *Uncertainty Analysis*
  - *Performance degrades as the look becomes more in-depth*
    - *Buoyancy*
    - *Analog input error*

Reference Performance

- *Uncertainty Analysis*
  - *Best when performed/reviewed independently*
  - *Results can suggest improvements*

Reference Performance

- *Flow Laboratory Performance*
  - *The "Rule of Thumb" is that the calibration standard should be at least 4 times better than instrument*

Reference Performance

- *Flow Laboratory Performance*
  - *4:1 implies uncertainty of 0.025% rate*
    - *Difficult to achieve and maintain*
    - *Shows importance of formal uncertainty analysis*

Reference Performance

- *Flow Laboratory Performance*
  - *Some suppliers have not performed an uncertainty analysis, other suppliers did not know the uncertainty*
    - *Calibrations performed in these laboratories may be suspect*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- ***Pulse Output vs. Analog Output***
- *Actual Performance*
- *Supplier Claims*

Pulse Output vs. Analog Output

- *Most suppliers specify pulse output performance*
  - *Analog output performance is typically the pulse output performance plus an absolute error*

Pulse Output vs. Analog Output

Problem

- *What is the error associated with a 4-20mA analog output that has an error of 0.010 mA?*

Pulse Output vs. Analog Output

Solution

- *The conversion error is:*
  - *0.010/(20-4) = 0.06% of full scale*
- *Some flowmeters have analog output errors of 0.10% of full scale*

Pulse Output vs. Analog Output

Solution

Flow	*0.06% Full Scale*
100 units	*0.06*100/100 = 0.06% rate*
50 “	*0.06*100/50 = 0.12 “*
25 “	*0.06*100/25 = 0.24 “*
10 “	*0.06*100/10 = 0.60 “*

Pulse Output vs. Analog Output

Solution

Flow	*0.03% Full Scale*
100 units	*0.03*100/100 = 0.03% rate*
50 “	*0.03*100/50 = 0.06 “*
25 “	*0.03*100/25 = 0.12 “*
10 “	*0.03*100/10 = 0.30 “*

Pulse Output vs. Analog Output

- *Some suppliers cannot provide an analog output accuracy specification, so the performance of the analog output may be* ***undefined***

Pulse Output vs. Analog Output

- *In some flowmeter designs, the analog output error can be **larger** than the flowmeter accuracy*
  - *Often applies to flowmeters with percent of rate accuracy*
  - *Rate error increases at low flow rates*
  - *Others often include the analog output error in their pulse accuracy statement*

Pulse Output vs. Analog Output

- *Flowmeters with percent of full scale, meter capacity, and calibrated span often include the analog output error in their pulse accuracy statement*

Pulse Output vs. Analog Output

Example

- *An analog output error of 0.10% of full scale is usually neglected for a flowmeter that exhibits 1% of full scale performance.*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- *Pulse Output vs. Analog Output*
- ***Actual Performance***
- *Supplier Claims*

Actual Performance

- *Operating Effects*
  - *Ambient conditions*
    - *Humidity*
    - *Precipitation*
    - *Temperature*
    - *Direct sunlight*

Actual Performance

- *Many flowmeters are rated to 10-90% relative humidity (non-condensing)*
  - *Outdoor locations are subject to 100% relative humidity and precipitation in various forms*

Actual Performance

- *Operating Effects*
  - *Can be significant, even though the numbers seem small*
  - *Not published by most suppliers*
    - *Information is not generally available to fairly evaluate actual performance*

Actual Performance

Example

- *The error (at 25 percent of scale and a 0°C ambient) associated with a temperature effect of 0.01% full scale per °C can be calculated as:*
  - *0.01*(20-0)/25, or 0.80% rate*

Actual Performance

- *Velocity Profile*
  - *A few Coriolis mass flowmeters can be affected by a distorted velocity profile*
    - *Provide adequate straight run*
    - *Locate upstream/downstream elbows in recommended plane*

Actual Performance

- *Fluid Properties*
  - *Reference accuracy is determined using a known fluid at known conditions*

Actual Performance

- *Fluid Properties*
  - *Variation from reference conditions may require calibration correlations that can affect flowmeter performance*
    - *Different fluid composition*
    - *Different fluid temperature*

Flowmeter Performance

- *Flowmeter Performance*
- *Performance Statements*
- *Reference Performance*
- *Analog Output vs. Pulse Output*
- *Actual Performance*
- ***Supplier Claims***

Supplier Claims

- *High Turndown*
  - *Example - Hypothetical Coriolis mass flowmeter*
    - *0.10% rate accuracy*
    - *1000:1 turndown*
  - *Sounds fantastic!*

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Supplier Claims

- *High Turndown*
  - *Further investigation reveals that the accuracy is*
    - *0.10% rate plus zero stability*
    - *1000:1 turndown*
    - *Zero stability is small*

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Supplier Claims

- *High Turndown*
  - *Even more investigation reveals that the accuracy is*
    - *0.10% rate plus zero stability*
    - *1000:1 turndown*
    - *Zero stability is 0.025 kg/min (0-100 kg/min range)*

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Reference Performance

- *High Turndown*
- *Performance expressed as a percent of rate degrades at low flows*
  - *100% flow → 0.125/100   0.13 % rate*
  - *25% flow → 0.050/25   0.20 %   "*
  - *10% flow → 0.035/10   0.35 %   "*
  - *1% flow → 0.026/1   2.60 %   "*
  - *0.1% flow → 0.025/0.1   25.0 %   "*

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Supplier Claims

- *High Turndown*
  - *Use of analog output would degrade performance even further*

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Supplier Claims

- *Low Flow Operation*
  - *Flowmeter operates at low flows, but performance expressed as a percent of rate is degraded*

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Supplier Claims

- *High Accuracy*
  - *High accuracy claims often refer to high flow rates that may not be practical*
  - *Zero stability is often hidden by omission*

Supplier Claims

- *Improved Accuracy Claims*
  - *Trend to improve rate statement for better marketability*

Supplier Claims

- *Improved Accuracy Claims*
  - *Compare zero stabilities to see whether the "improvement" is a restatement of the specifications*
    - *At least one supplier increasing zero stability to allow an "improvement" of the same flowmeter from 0.15 to 0.10% rate*

Supplier Claims

- *Inexpensive Coriolis Mass Flowmeters*
  - *Less expensive*
  - *Fewer features*
  - *Not as accurate*
  - *Performance rivals other technologies*

Seminar Outline

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- ***Consumer Guide***

Consumer Guide

User Equipment Selection Process

- *Learn about the technology*
- *Find suitable vendors*
- *Obtain specifications*
- *Organize specifications*
- *Evaluate specifications*
- *Select equipment*

Consumer Guide

User Equipment Selection Process

- *Performing this process takes time and therefore costs money*

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Consumer Guide

User Equipment Selection Process

- *Haphazard implementation with limited knowledge of alternatives does not necessarily lead to a good equipment selection*

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Consumer Guide

Guide Provides First Four Items

- ***Learn about the technology***
- ***Find suitable vendors***
- ***Obtain specifications***
- ***Organize specifications***
- *Evaluate specifications*
- *Select equipment*

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Consumer Guide

Guide Provides First Four Items

- ***Information focused on technology***
- ***Comprehensive lists of suppliers and equipment***

Consumer Guide

Guide Provides First Four Items

- ***Significant specifications***
- ***Lists of equipment organized to facilitate evaluation***

Consumer Guide

User Equipment Selection Process

- *By providing the first four items, the Consumer Guides:*
  - *make technical evaluation and equipment selection easier, more comprehensive, and more efficient*

Consumer Guide

User Equipment Selection Process

- *By providing the first four items, the Consumer Guides:*
  - *allow selection from a larger number of suppliers*
  - *simplifies the overall selection process*

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Consumer Guide

- ***Supplier Data and Analysis***
- *Attachments*
  - *Flowmeter categories*
  - *Availability of selected features*
  - *Models grouped by performance*

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Supplier Data and Analysis

- *Flow Tube Limits*
  - *Size*
    - *1-300 mm*
  - *Ambient temperature*
    - *-20 to 60°C typical*
  - *NEMA 4X, IP65, 67*

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Supplier Data and Analysis

- *Flow Tube Limits*
  - *Wetted parts*
    - *Stainless steel*
    - *Hastelloy*
    - *Titanium*

Supplier Data and Analysis

- *Flow Tube Limits*
  - *Some designs have seals*
    - *EPDM*
    - *Kalrez*
    - *PTFE*
    - *Viton*

Supplier Data and Analysis

- *Flow Tube Limits*
  - *Geometry (and Orientation)*
    - *Self-filling*
    - *Self-draining*
    - *Self-filling and self-draining*

Supplier Data and Analysis

- *Process Operating Limits*
  - *Pressure limit*
    - *1000 bar*
    - *Secondary containment*
  - *Temperature limit*
    - *200°C typical; 400°C max*

Supplier Data and Analysis

- *Pressure Drop Limits*
  - *Damage flowmeter if excessive*
  - *Pressure drop increases with increasing viscosity*
  - *Flashing*
    - *Small amount causes unstable output*
    - *Large amount can stall tubes*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Straight run*
    - *Generally not required*
    - *Some designs need straight run*
    - *Examine installation instructions <u>before</u> purchase*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Supports*
    - *None with properly supported pipe*
    - *Two upstream and two downstream*
    - *Examine installation instructions before purchase*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Orientation*
    - *Self-filling (liquid)*
    - *Self-draining (gas/vapor)*
    - *Self-filling and self-draining*
    - *Examine literature and installation instructions before purchase*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Liquid - setting zero calibration*
    - *Remove all gas/vapor and zero*
    - *If not self-filling, remove gas/vapor by operating at high flow rate for a period of time*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Gas - setting zero calibration*
    - *Remove all liquid and zero*
    - *If not self-draining, remove liquid by operating at high flow rate for a period of time*

Supplier Data and Analysis

- *Flow Tube Installation/Maintenance*
  - *Flow tube removal*
    - *Remove all liquid and remove from piping*
    - *If not self-draining, other procedures may be necessary to safely remove liquid*

Supplier Data and Analysis

- *Flow Tube Operation*
  - *Start-up*
    - *If not self-filling, gas/vapor may be present*
    - *If not self-draining, liquid may be present*
    - *Undesired phase can be removed by operating at high flow rate for a period of time*

Supplier Data and Analysis

- *Flow Tube Operation*
  - *Low flow*
    - *If not self-filling, gas/vapor may accumulate*
    - *If not self-draining, liquid may accumulate*
    - *Undesired phase can be removed by operating at high flow rate for a period of time*

Supplier Data and Analysis

- *Transmitter*
  - *4-wire device (separate power/analog wires)*
    - *Using DC power can eliminate power conduit*
  - *Typically measure forward and reverse flow*
  - *Alarms, totalization, batching*

Supplier Data and Analysis

- *Transmitter*
  - *Multivariable*
    - *Tube temperature*
    - *Fluid density*
    - *Fluid viscosity*
    - *Derived variables*
      - *Concentration*
      - *Volumetric flow*

Supplier Data and Analysis

- *Transmitter*
  - *Mounting*
    - *Integral*
    - *Remote*
    - *Spacing (distance)*

Supplier Data and Analysis

- *Transmitter*
  - *Filtering is typically used*
  - *Excessive damping can affect batching response*

Supplier Data and Analysis

- *Transmitter*
  - *Range adjustment mechanism provide insight into age of design*
    - *Analog (potentiometer)*
    - *Dip switch*
    - *Digital*

Supplier Data and Analysis

- *Performance*
  - *Flow laboratory and flow calibration stand uncertainty is important to ensure that the flowmeter meets specifications when shipped*
    - *Formal (written) uncertainty analysis*
  - *Many suppliers could not quantify their uncertainty*

Supplier Data and Analysis

- *Performance*
  - *Reference performance assumes that flowmeter is installed, calibrated, and operated properly*
    - *Pulse output accuracy is typically 0.10% rate plus zero stability*

Supplier Data and Analysis

- *Performance*
  - *Analog output accuracy*
    - *Add 0.02 to 0.06% full scale*
    - *Some suppliers could not quantify*

Supplier Data and Analysis

- *Performance*
  - *It can be difficult to compare the performance of different suppliers' equipment*

Supplier Data and Analysis

- *Operating Effects*
  - *Ambient*
    - *Temperature, humidity*
  - *Process conditions*
    - *Temperature, pressure, viscosity, composition*
    - *Two-phase*

Supplier Data and Analysis

- *Operating Effects*
  - *Other effects*
    - *Power supply voltage*

Supplier Data and Analysis

- *Operating Effects*
  - *It can be difficult to compare the operating effects of different suppliers' equipment*

Consumer Guide

- *Supplier Data and Analysis*
- ***Attachments***
  - *Flowmeter categories*
  - *Availability of selected features*
  - *Models grouped by performance*
  - *Models grouped by supplier*

Flowmeter Categories

- *Summary of offerings*
  - *Liquid*
  - *Gas*
  - *High Pressure*
  - *High Temperature*
  - *Metal (other than 316 stainless steel)*

Flowmeter Categories

- *Summary of offerings*
  - *Plastic/Polymer*
  - *Sanitary*
  - *Single Path*
  - *Straight Path*

Flowmeter Categories

- *Suppliers (21)*
- *Manufacturers (15)*
  - *7 USA*
  - *6 Germany*
  - *1 Brazil, Denmark, Japan, Mexico, Switzerland, UK*

Availability of Selected Features

- *Use of seals*
- *Secondary containment*
- *IP67 housing*
- *Hazardous location approval*
- *Rigid support or frame recommended*

Availability of Selected Features

- *Vertical piping*
  - *Self-filling and self-draining*
- *Horizontal piping*
  - *Self-filling*
  - *Self-draining*
  - *Self-filling and self-draining*

Availability of Selected Features

- *Large size*
- *Batching*
- *Communications*
  - *HART*
  - *Foundation Fieldbus*
  - *Profibus*

Availability of Selected Features

- *Less expensive design*
- *Two-phase flow*

Models Grouped by Full Scale

- *0.003 kg/min and under*
- *0.01 kg/min*
- *0.03 kg/min*
- *0.1 kg/min*
- *0.3 kg/min*
- *1 kg/min*
- *3 kg/min*

Models Grouped by Full Scale

- *10 kg/min*
- *30 kg/min*
- *100 kg/min*
- *300 kg/min*
- *1000 kg/min*
- *3000 kg/min*
- *10,000 kg/min*

Review and Questions

- *Introduction*
- *Fluid Flow Fundamentals*
- *Flowmeter Technology*
- *Flowmeter Performance*
- *Consumer Guide*

The Consumer Guide to Coriolis Mass Flowmeters

Seminar Presented by
David W. Spitzer
Spitzer and Boyes, LLC