Differential Pressure Flow/Level Measurement

Seminar Presented by
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Seminar Outline

- ***Introduction***
- *Fluid Properties*
- *Differential Pressure Flowmeters*
- *Differential Pressure Level Transmitters*
- *Consumer Guide*

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Introduction

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

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Working Definition of a Process

- *A process is anything that changes*

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Why Measure Flow and Level?

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

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Why Measure Flow and Level?

- *Custody transfer*
  - *Measurements are often required to determine the total quantity of:*
    - *Fluid that passed through the flowmeter*
    - *Material present in a tank*
  - *Billing purposes*

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Why Measure Flow and Level?

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

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Why Measure Flow and Level?

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

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Why Measure Flow and Level?

- *Monitor a safety parameter*
  - *Flow and level measurements can be used to ensure that critical portions of the process operate safely*
    - *Over/under feed*
    - *Over/under flow*

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Fluid Properties

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

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Temperature

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

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Temperature

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

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Temperature

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

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Temperature

- *<u>Absolute</u> temperature is important for flow measurement*

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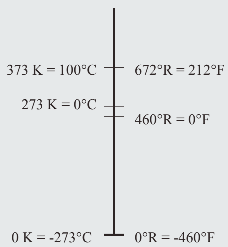
Temperature



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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?*

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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*

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Fluid Properties

- *Temperature*
- ***Pressure***
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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)*

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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*

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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*

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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)*

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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*

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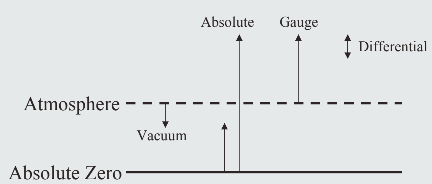
Pressure



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Pressure

- *Absolute pressure is important for flow measurement*

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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?*

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Pressure

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

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Fluid Properties

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

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Density and Fluid Expansion

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

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Density and Fluid Expansion

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

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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?*

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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*

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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*

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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 ?*

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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*

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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*

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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 ?*

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Density and Fluid Expansion

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

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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%*

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Density and Fluid Expansion

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

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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*
  - $V/V_0 = T / T_0$

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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?*

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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%*

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Density and Fluid Expansion

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

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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*
  - $V/V_0 = (P_0/P) \bullet (T / T_0)$

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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?*

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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%*

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Density and Fluid Expansion

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

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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*
  - $V/V_0 = (P_0/P) \bullet (T / T_0) \bullet (Z / Z_0)$

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Fluid Properties

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

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

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Types of Flow

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

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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*

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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*

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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*

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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)*

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Viscosity

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

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Velocity Profile and Reynolds Number

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

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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

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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*

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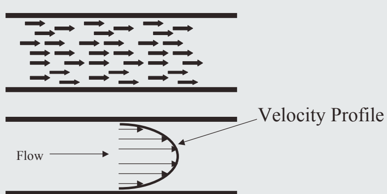
Velocity Profile and Reynolds Number

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



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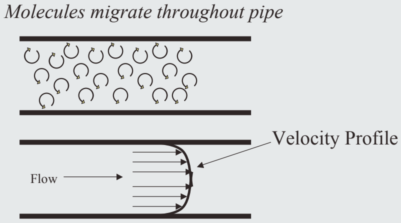
Velocity Profile and Reynolds Number

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



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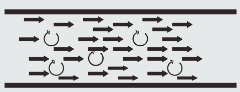
Velocity Profile and Reynolds Number

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



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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*

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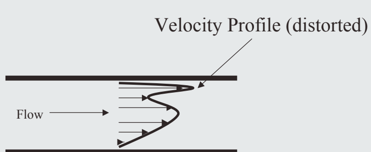
Velocity Profile and Reynolds Number

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



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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*

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Fluid Properties

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

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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*

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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*

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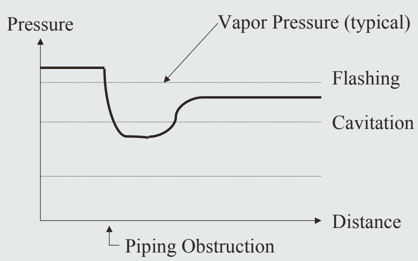
Hydraulic Phenomena



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Seminar Outline

- *Introduction*
- *Fluid Properties*
- ***Differential Pressure Flowmeters***
- *Differential Pressure Level Transmitters*
- *Consumer Guide*

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Differential Pressure Flowmeters

- ***Principle of Operation***
- *Primary Flow Elements*
- *Transmitter Designs*
- *Manifold Designs*
- *Installation*
- *Accessories*
- *Performance*

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Principle of Operation

- *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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Principle of Operation

- *Bernoulli's equation states that energy is approximately conserved across a constriction in a pipe*
  - *Static energy (pressure head)*
  - *Kinetic energy (velocity head)*
  - *Potential energy (elevation head)*

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Principle of Operation

- *Bernoulli's equation*
  - $P/(\rho \bullet g) + \frac{1}{2}v^2/g + y = \text{constant}$

P = absolute pressure
ρ = density
g = acceleration of gravity
v = fluid velocity
y = elevation

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Principle of Operation

- *Equation of Continuity*
  - $Q = A \bullet v$

Q = flow (volumetric)
A = cross-sectional area
v = fluid velocity (average)

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Principle of Operation

- *Apply the equation of continuity and Bernoulli's equation for flow in a horizontal pipe*
  - *Acceleration of gravity is constant*
  - *No elevation change*

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Principle of Operation

- *Apply Bernoulli's equation upstream and downstream of a restriction*
- $P_1 + ½\, \rho \bullet v_1^2 = P_2 + ½\, \rho \bullet v_2^2$

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Principle of Operation

- *Solve for the pressure difference and use the equation of continuity*
- $(P_1 - P_2) = ½\, \rho \bullet v_2^2 - ½\, \rho \bullet v_1^2$

$$= ½\, \rho\, [v_2^2 - v_1^2]$$
$$= ½\, \rho\, [(A_1/A_2)^2 – 1] \bullet v_1^2$$
$$= ½\, \rho\, [(A_1/A_2)^2 – 1] \bullet Q^2/A_1^2$$
$$= \text{constant} \bullet \rho \bullet Q^2$$

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Principle of Operation

- $\Delta P = \text{constant} \bullet \rho \bullet Q^2$
  - *Fluid density affects the measurement*
  - *Pressure drop is proportional to the square of the flow rate*
    - *Squared output flowmeter*
    - *Double the flow… four times the differential*

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Principle of Operation

- *Q = constant • (ΔP/ρ)^{½}*
  - *Fluid density affects the measurement*
  - *Flow rate is proportional to the square root of the differential pressure produced*
    - *Often called "square root flowmeter"*

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Principle of Operation

- *Q is proportional to 1/ρ^{½}*
- *Fluid density affects the measurement by approximately -1/2% per % density change*

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Principle of Operation

- *Liquid density changes are usually small*
- *Gas and vapor density changes can be large and may need compensation for accurate flow measurement*
  - *Flow computers*
  - *Multivariable differential pressure transmitters*

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Principle of Operation

Problem

- *What is the effect on a differential pressure flowmeter when the operating pressure of a gas is increased from 6 to 7 bar?*
  - *To simplify calculations, assume that atmospheric pressure is 1 bar abs*

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Principle of Operation

- *The ratio of the densities is (7+1)/(6+1) = 1.14*
  - *The density of the gas increased 14 percent*
- *The flow measurement is proportional to the inverse of the square root of the density which is* $(1/1.14)^{1/2} = 0.94$
  - *The flow measurement will be approximately 6 percent low*

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Principle of Operation

Problem

- *Calculate the differential pressures produced at various percentages of full scale flow*
  - *Assume 0-100% flow corresponds to 0-100 differential pressure units*

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Principle of Operation

Differential pressure as a function of flow

Flow	*ΔP*	
100 %	*100*	*dp units*
50 %	*25*	*“ “*
20 %	*4*	*“ “*
10 %	*1*	*“ “*

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Principle of Operation

- *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.*

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Principle of Operation

Problem

- *What is the differential pressure turndown for a 10:1 flow range?*
  - *$0.1^2 = 0.01$, so at 10% flow the differential pressure is 1/100 of the differential pressure at 100% flow*
  - *The differential pressure turndown is 100:1*

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Principle of Operation

- *Noise can create problems at low flow rates*
  - *0-10% flow corresponds to 0-1 dp units*
  - *90-100% flow corresponds to 81-100% dp units*

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Principle of Operation

- *Noise at low flow rates can be reduced by low flow characterization*
  - *Force to zero*
  - *Linear relationship at low flow rates*

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Principle of Operation

- *Square root relationship generally applies when operating above the Reynolds number constraint for the primary flow element*
  - *Operating below the constraint causes the flow equation to become linear with differential pressure (and viscosity)*
  - *Applying the incorrect equation will result in flow measurement error*

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Principle of Operation

Problem

- *If the Reynolds number at 100% flow is 10,000, what is the turndown for accurate measurement if the primary flow element must operate in the turbulent flow regime?*
  - *10,000/4000, or 2.5:1*

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Principle of Operation

Problem

- *Will the flowmeter operate at 10% flow?*
  - *It will create a differential pressure… however, Reynolds number will be below the constraint, so the flow measurement will not conform to the square root equation (and will not be accurate)*

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Differential Pressure Flowmeters

- *Principle of Operation*
- ***Primary Flow Elements***
- *Transmitter Designs*
- *Manifold Designs*
- *Installation*
- *Accessories*
- *Performance*

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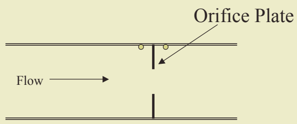
Orifice Plate
Primary Flow Element



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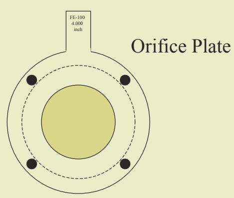
Orifice Plate
Primary Flow Element



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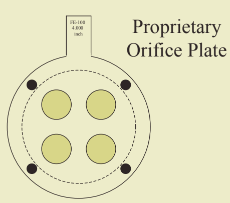
Orifice Plate
Primary Flow Element



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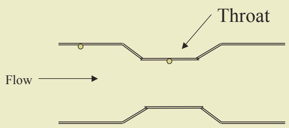
Venturi
Primary Flow Element



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Venturi
Primary Flow Element

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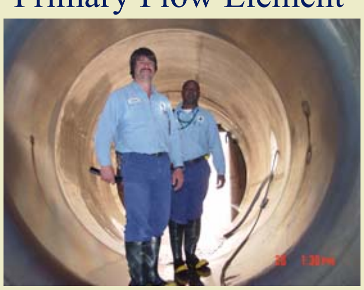
Venturi
Primary Flow Element



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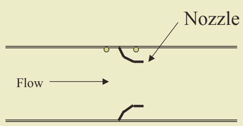
Flow Nozzle Primary Flow Element



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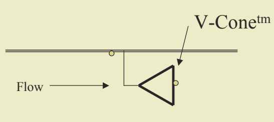
V-Cone^{tm} Primary Flow Element



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Differential Pressure Flowmeters

- *Principle of Operation*
- *Primary Flow Elements*
- ***Transmitter Designs***
- *Manifold Designs*
- *Installation*
- *Accessories*
- *Performance*

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Differential Pressure Sensor Designs

- *Capacitance*
- *Differential Transformer*
- *Force Balance*
- *Piezoelectric*
- *Potentiometer*
- *Silicon Resonance*
- *Strain Gage*

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Differential Pressure Transmitter Designs

- *Analog*
  - *Electrical components subject to drift*
    - *Ambient temperature*
    - *Process temperature*
  - *Two-wire design*

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Differential Pressure Transmitter Designs

- *Digital*
  - *Microprocessor is less susceptible to drift*
    - *Ambient temperature*
    - *Process temperature*
    - *Temperature characterization in software*
  - *Remote communication (with HART)*
  - *Two-wire design*

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Differential Pressure Transmitter Designs

- *Fieldbus*
  - *Microprocessor is less susceptible to drift*
    - *Ambient temperature*
    - *Process temperature*
    - *Temperature characterization in software*
  - *Remote communication*
  - *Issues with multiple protocols*
  - *Multi-drop wiring*

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Differential Pressure Transmitter Designs

- *Mechanical design*
  - *Spacing between connections*
    - *Orifice flange taps*
  - *Traditional*
    - *Larger diaphragm/housing*
  - *Coplanar*
    - *Smaller diaphragm/housing*

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Differential Pressure Transmitter Designs

- *High static pressure design*
  - *Typically lower performance*
- *Safety design*
  - *Automatic diagnostics*
  - *Redundancy*
  - *Reliable components*

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Differential Pressure Flowmeters

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- ***Manifold Designs***
- *Installation*
- *Accessories*
- *Performance*

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Differential Pressure Multi-Valve Manifold Designs

- *Multi-valve manifolds are used to isolate the transmitter from service for maintenance and calibration*
  - *One-piece integral assembly*
  - *Mounted on transmitter*

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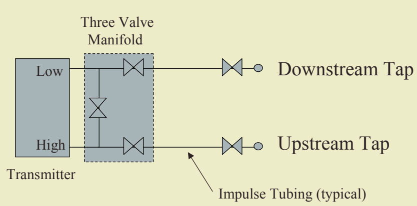
Differential Pressure Multi-Valve Manifold Designs



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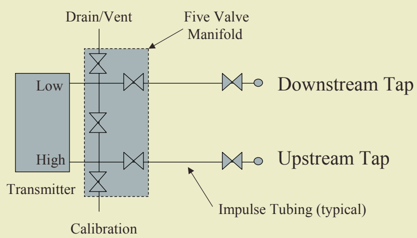
Differential Pressure Multi-Valve Manifold Designs



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Differential Pressure Multi-Valve Manifold Designs

- *Removal from service*
  - *Open bypass valve (hydraulic jumper)*
  - *Close block valves*
  - *Be sure to close bypass valve to calibrate*
  - *Use calibration and vent/drain valves (five valve manifold)*

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Differential Pressure Multi-Valve Manifold Designs

- *Return to service*
  - *Open bypass valve (hydraulic jumper)*
  - *Open block valves*
  - *Close bypass valve*

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Differential Pressure Multi-Valve Manifold Designs

- *Removal and return to service procedure may be different when flow of fluid in tubing/transmitter is dangerous*
  - *High pressure superheated steam*

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Differential Pressure Flowmeters

- *Principle of Operation*
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- *Manifold Designs*
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- *Accessories*
- *Performance*

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Principle of Operation

- *The quality of measurement is predicated on:*
  - *Proper installation of the primary flow element*
  - *Proper operation of the primary flow element (for example, Reynolds number)*
  - *Accurate measurement of the differential pressure*

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Installation

- *Fluid Characteristics*
- *Piping and Hydraulics*
- *Impulse Tubing*
- *Electrical*
- *Ambient Conditions*
- *Calibration*

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Fluid Characteristics

- *Reynolds number within constraints*
- *Fluid must not plug impulse tubing*
  - *Solids*
  - *Purge fluids*
  - *Diaphragm seals (added measurement error)*

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Fluid Characteristics

- *Within accurate flow range*
- *Corrosion and erosion*
  - *Flowmeter*
  - *Exotic (thin) diaphragm materials*
- *Coating*
- *Gas in liquid stream*
- *Immiscible fluids*

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Piping and Hydraulics

- *For liquids, keep flowmeter full*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid inverted U-tube*
  - *Be careful when flowing by gravity*

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Piping and Hydraulics

- *For gases, avoid accumulation of liquid*
  - *Hydraulic design*
    - *Vertical riser preferred*
    - *Avoid U-tube*

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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*
    - *Install flow conditioner*
  - *Use full face gaskets*

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Piping and Hydraulics

- *Wetted parts compatible with fluid*
- *Pipe quality*
  - *Use smooth round pipe with known inside diameter, wall thickness, and material*
  - *Purchasing the flowmeter and piping section controls pipe quality*

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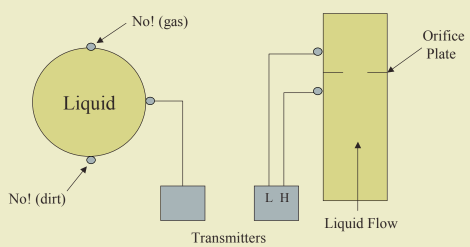
Impulse Tubing



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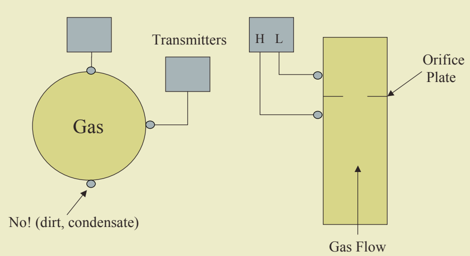
Impulse Tubing



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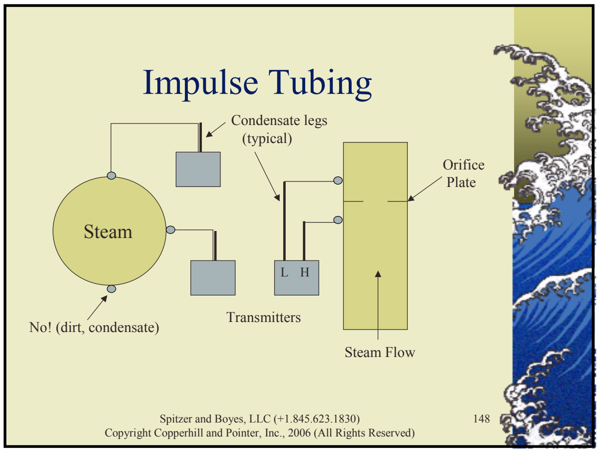
Impulse Tubing
Condensate legs
(typical)
Orifice
Plate
Steam
L H
Transmitters
No! (dirt, condensate)
Steam Flow
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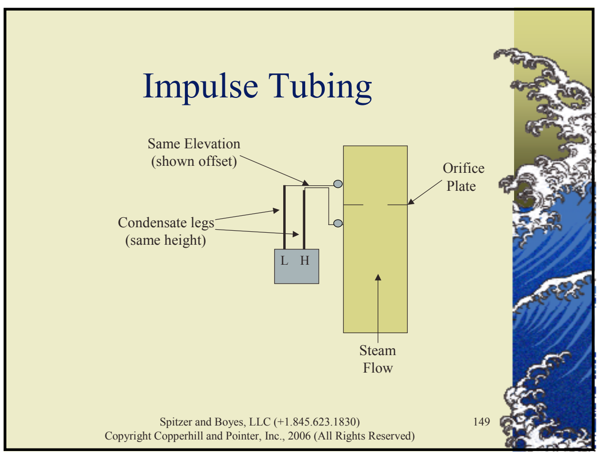
Impulse Tubing
Same Elevation
(shown offset)
Orifice
Plate
Condensate legs
(same height)
L H
Steam
Flow
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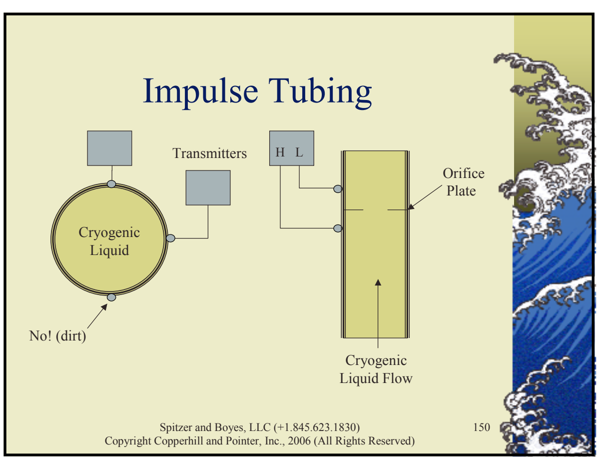
Impulse Tubing
Transmitters
H L
Orifice
Plate
Cryogenic
Liquid
No! (dirt)
Cryogenic
Liquid Flow
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Impulse Tubing

- *Liquids* *avoid collection of gas*
- *Gas* *avoid collection of liquid*
- *Vapor* *form condensate legs*
- *Hot* *locate transmitter far from taps*
- *Cold* *insulate and/or heat trace*
- *Cryogenic Liquids – avoid condensation and collection of liquid*

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Electrical

- *Wiring*
  - *Two-wire design (no power conduit)*
  - *Fieldbus reduces wiring*
- *Avoid areas of electrical noise*
  - *Radios*
  - *High voltages*
  - *Variable speed drives*

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Ambient Conditions

- *Outdoor applications (-40 to 80°C)*
  - *Avoid direct sunlight (especially low ranges)*
  - *Support transmitter well*
- *Hazardous locations*
  - *Some designs may be general purpose*

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Calibration

- *GIGO (garbage in – garbage out)*
- *Entering correct information correctly is critical*
  - *Calibration range*

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Calibration

- *Internal alignment (digital transmitters)*
  - *Pressure source*
  - *Digital indication in transmitter*
  - *Digital output indication in transmitter*
  - *Analog signal*

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Calibration

- *Zero in field*
  - *Position effects*
  - *Pressure effects*

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Differential Pressure Flowmeters

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- *Manifold Designs*
- *Installation*
- ***Accessories***
- *Performance*

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Accessories

- *Wetted parts*
  - *Diaphragm (thin)*
  - *Flanges*
  - *Drain/vent valves*
  - *Materials*
    - *Stainless steel, Monel, Hastelloy, tantalum*
  - *O-rings/gaskets (TFE, Viton^{tm})*

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Accessories

- *Non-wetted parts*
  - *Fill fluids*
    - *Silicone, halocarbon*
  - *External housing*

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Accessories

- *Transmitter*
  - *NEMA 4X and IP67 (IP68)*
  - *Hazardous locations*
  - *Intrinsically safe*
  - *HART, Foundation Fieldbus, Profibus*
  - *Mounting bracket*

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Differential Pressure Flowmeters

- *Principle of Operation*
- *Primary Flow Elements*
- *Transmitter Designs*
- *Manifold Designs*
- *Installation*
- *Accessories*
- ***Performance***

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Flowmeter Performance

- ***Definitions***
- *Performance Statements*
- *Reference Performance*
- *Actual Performance*

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Flowmeter Performance

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

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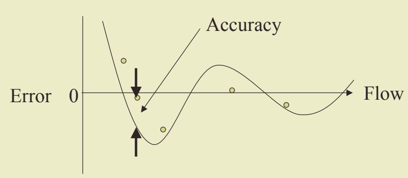
Flowmeter Performance



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Flowmeter Performance

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

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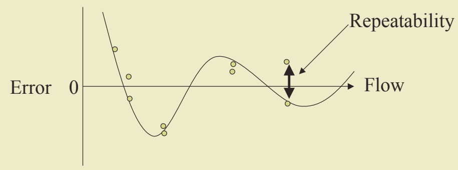
Flowmeter Performance



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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*

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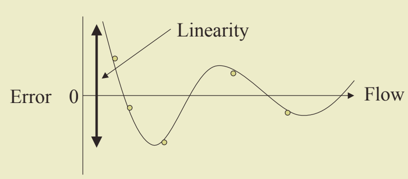
Flowmeter Performance



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Flowmeter Performance

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

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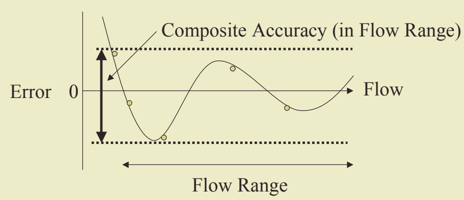
Flowmeter Performance



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Flowmeter Performance

- *Definitions*
- ***Performance Statements***
- *Reference Performance*
- *Actual Performance*

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Performance Statements

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

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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*

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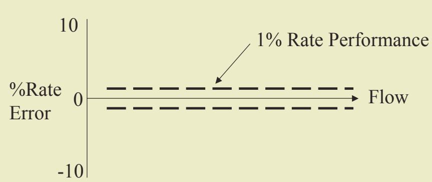
Performance Statements



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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*

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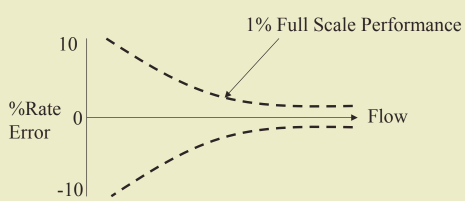
Performance Statements



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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*

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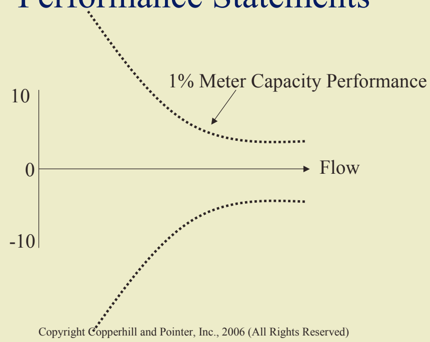
Performance Statements



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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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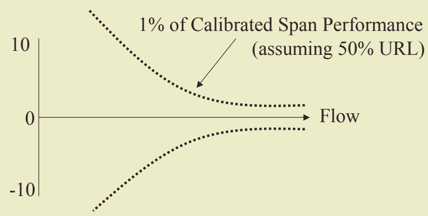
Performance Statements



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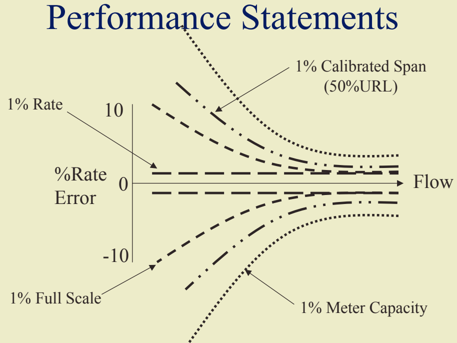
Performance Statements



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Performance Statements

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

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Flowmeter Performance

- *Definitions*
- *Performance Statements*
- ***Reference Performance***
- *Actual Performance*

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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*

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Reference Performance

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

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Reference Performance

- *Performance of the primary flow element and the transmitter must be taken into account to determine performance of flowmeter system*

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Reference Performance

- *Hypothetical primary flow element*
  - *1% rate $R_d > 4000$ and Q>10% FS*
  - *Otherwise undefined*
  - *Assumes correct design, construction, installation, calibration, and operation*

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Reference Performance

- *Hypothetical differential pressure transmitter*
  - *0.075% calibrated span*
    - *Calibrated for 0-100 units*
    - *Factory calibrated at upper range limit (URL) of 400 units*

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Reference Performance

Problem

- *What is the measurement error associated with the performance of the hypothetical differential pressure transmitter?*

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Reference Performance

- *The calibrated span is 400, so the differential pressure measurement error is 0.10% of 400, or 0.4 units at all differential pressures*

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Reference Performance

Problem

- *What is the flow measurement error associated with the performance of the hypothetical differential pressure transmitter?*

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Reference Performance

Flow	*Diff. Pressure*	*Flow Measurement Error*		
100	*100*	$1-\sqrt{(100\pm0.4)/100}$	*or*	*0.2 %rate*
50	*25*	$1-\sqrt{(25\pm0.4)/25}$	*or*	*0.8 “*
25	*6.25*	$1-\sqrt{(6.25\pm0.4)/6.25}$	*or*	*3.2 “*
10	*1.00*	$1-\sqrt{(1.00\pm0.4)/1.00}$	*or*	*18-23 “*

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Reference Performance

Problem

- *What is the flow measurement error associated with the performance of the flow measurement system (primary flow element and differential pressure transmitter)?*

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Reference Performance

- *System performance is the statistical combination of the errors associated with the components (primary flow element and transmitter)*
  - *System performance is not the mathematical sum of the individual errors*

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Flowmeter Performance

- *Definitions*
- *Performance Statements*
- *Reference Performance*
- ***Actual Performance***

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Actual Performance

- *Operating Effects*
  - *Ambient conditions*
    - *Humidity*
    - *Precipitation*
    - *Temperature*
    - *Pressure*
    - *Direct sunlight*
  - *Mounting Orientation*
  - *Stability (Drift)*

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Actual Performance

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

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Actual Performance

- *Ambient Temperature and Pressure*
  - *Information available to evaluate actual performance*
    - *Temperature effect*
    - *Pressure effect*
  - *Effects can be significant, even though the numbers seem small*

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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*

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Actual Performance

- *Reference accuracy performance statements are often discussed*
- *Operating effects, such as temperature and pressure effects are often only mentioned with prompting*
  - *Progressive disclosure*

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Actual Performance

- *Ambient Direct Sunlight*
  - *Can cause temporary calibration shift*
    - *Low range transmitters*

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Actual Performance

- *Mounting Orientation*
  - *Bench calibration vs. field calibration*
    - *Up to 5 mbar (2 inch WC) shift*

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Actual Performance

- *Stability*
  - *Drift over time*
    - *Usually faster at beginning of period*
  - *Specifications difficult to compare*
    - *Different ways over different periods of time*

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Actual Performance

- *Combining Operating Effects*

$$\text{Estimated Error} = \sqrt{error_1^2 + error_2^2 + error_3^2 + \ldots}$$

where the errors in like units

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Seminar Outline

- *Introduction*
- *Fluid Properties*
- *Differential Pressure Flowmeters*
- ***Differential Pressure Level Transmitters***
- *Consumer Guide*

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Differential Pressure Level Transmitters

- ***Liquid Pressure***
- *Static Liquid Interface*
- *Types of Level Measurement*
- *Vessel Geometry*
- *Dynamic Phenomena*
- *Installation*
- *Differential Pressure Level Calculations*

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Liquid Pressure

- *Bernoulli's Theorem states that the pressure exerted by a liquid in an open tank is independent of the cross-sectional area of the liquid*

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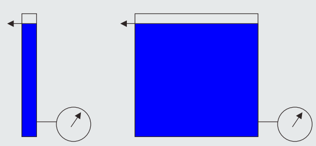
Liquid Pressure



Open tanks overflowing with the same liquid

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Liquid Pressure

- *The pressure exerted by a liquid in an open tank is dependent on the height of the liquid*

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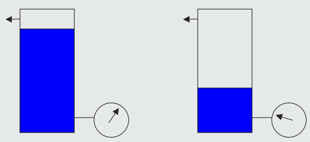
Liquid Pressure



Open tanks with the same liquid

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Liquid Pressure

- *The pressure exerted by a liquid in an open tank is dependent on the density of the liquid*

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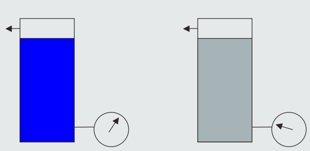
Liquid Pressure



Open Tank
High Density Liquid

Open Tank
Low Density Liquid

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Liquid Pressure

- *The pressure exerted by a liquid in a pressurized tank is dependent on the height of the liquid, its density, and the pressure in the vapor space*

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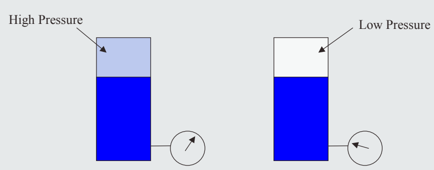
Liquid Pressure



Liquids have the same density and same level

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Liquid Pressure

- *The liquid pressure exerted can be calculated (in like units):*
  - *(Height x Density) + Static Pressure*

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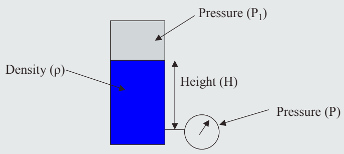
Liquid Pressure



$P = P_1 + \rho \cdot H$

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Differential Pressure Level Transmitters

- *Liquid Pressure*
- ***Static Liquid Interface***
- *Types of Level Measurement*
- *Vessel Geometry*
- *Dynamic Phenomena*
- *Installation*
- *Differential Pressure Level Calculations*

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Static Liquid Interface

- *Static liquid interface tends to be perpendicular to direction of gravity*
  - *Level identical across vessel*
  - *One level measurement can be representative of level in entire vessel*

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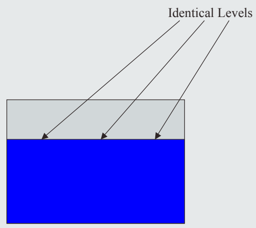
Static Liquid Interface



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Differential Pressure Level Transmitters

- *Liquid Pressure*
- *Static Liquid Interface*
- ***Types of Level Measurement***
- *Vessel Geometry*
- *Dynamic Phenomena*
- *Installation*
- *Differential Pressure Level Calculations*

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Types of Level Measurement

- *Related Quantities*
  - *Level*
  - *Volume*
  - *Mass*

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Types of Level Measurement

- $m = \rho \bullet V$
  - *m* mass
  - *ρ* density or bulk density
  - *V* volume

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Types of Level Measurement

- *Typical Units* ($m = \rho \bullet V$)
  - $lb/ft^3 \bullet ft^3 = lb$
  - $kg/m^3 \bullet m^3 = kg$

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Types of Level Measurement

- *Level measurement*
  - *Height of material in vessel*
    - *feet*
    - *meters*

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Types of Level Measurement

- *Inferred volume of material in vessel*
  - *Measure level*
  - *Use tank geometry to calculate volume*

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Types of Level Measurement

- *Volume of material in vessel*
  - *Round vertical flat bottom tank*

    $V = \frac{1}{4} \cdot \pi \cdot D^2 \cdot H$
  - *Dish / cone*
  - *Horizontal tank*

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Types of Level Measurement

Problem

- *What is the inferred volume of liquid in a round vertical flat bottom tank that is 2 meters in diameter when the liquid level is measured to be 4 meters above the bottom?*

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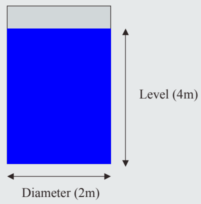
Types of Level Measurement



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Types of Level Measurement

- *Calculate the inferred liquid volume*

$$V = \frac{1}{4} \cdot \pi \cdot D^2 \cdot H$$
$$= \frac{1}{4} \cdot \pi \cdot 2^2 \cdot 4$$
$$= 12.57\ m^3$$

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Types of Level Measurement

- *Inferred level measurement*
  - *Measure*
  - *Use material properties (density / bulk density) to calculate level*
    - $H = \Delta P / \rho$

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Types of Level Measurement

Problem

- *What is the level of liquid with a density of 0.9 g/cm³ in a round vertical flat bottom tank that is 2 meters in diameter when the pressure at the bottom of the tank is 4 meters of water column?*

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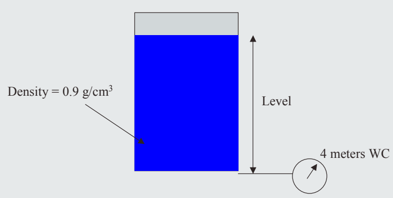
Types of Level Measurement



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Types of Level Measurement

- *Calculate the inferred level*
  - *Noting that 1 meter of liquid is generates the same pressure as 0.9 meters of water (WC)*

    H = *4 m WC • (1 m liquid / 0.9 m WC)*

    = *4.44 meters*

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Types of Level Measurement

- *Mass measurement*
  - *Quantity (mass) of material in vessel*
    - *pounds*
    - *kilograms*

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Types of Level Measurement

- *Inferred volume measurement*
  - *Measure mass of material*
  - *Use material properties (density / bulk density) to calculate volume*

$$V = m / \rho$$

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Types of Level Measurement

Problem

- *What is the volume of liquid with a density of 0.9 g/cm^3 in a round vertical flat bottom tank that is 2 meters in diameter when the weight of the liquid is 12 MT?*

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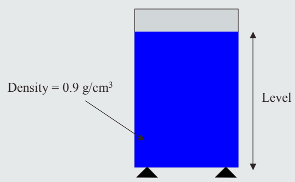
Types of Level Measurement



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Types of Level Measurement

- *Calculate the volume*

  $V = m / \rho$

  $= 12000\ kg / 900\ kg/m^3$

  $= 13.33\ m^3$

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Types of Level Measurement

- *Inferred mass measurement*
  - *Measure level*
  - *Use tank geometry to calculate volume*
  - *Use volume and material properties (density / bulk density) to calculate mass*

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Types of Level Measurement

- *Inferred mass measurement*
  - *Calculate volume using tank geometry*
    - *Vertical round flat bottom tank*

      $V = \frac{1}{4} \cdot \pi \cdot D^2 \cdot H$
  - *Calculate mass using density*
    - $m = \rho \cdot V$

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Types of Level Measurement

Problem

- *What is the inferred mass of a liquid with a density of 0.9 g/cm³ in a round vertical flat bottom tank that is 2 meters in diameter when the liquid level is measured to be 4 meters above the bottom?*

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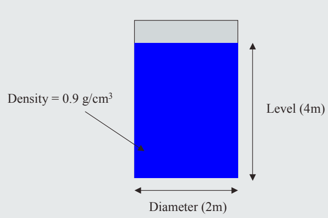
Types of Level Measurement



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Types of Level Measurement

- *The inferred liquid volume was previously calculated*

$V = \frac{1}{4} \bullet \pi \bullet D^2 \bullet H$

$= \frac{1}{4} \bullet \pi \bullet 2^2 \bullet 4$

$= 12.57\ m^3$

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Types of Level Measurement

- *Calculate the mass of the liquid*

$m = \rho \bullet V$

$= 900\ kg/m^3 \bullet 12.57\ m^3$

$= 11313\ kg$

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Types of Level Measurement

- *Level and mass measurements are subject to uncertainty*
- *Inferred measurements are subject to additional uncertainty*
  - *Density*
  - *Geometry*

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Differential Pressure Level Transmitters

- *Liquid Pressure*
- *Static Liquid Interface*
- *Types of Level Measurement*
- ***Vessel Geometry***
- *Dynamic Phenomena*
- *Installation*
- *Differential Pressure Level Calculations*

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Vessel Geometry

- *The* <u>*inside*</u> *vessel dimensions are important for inferring volume/mass*
  - *Drawings often show outside dimensions*
    - *Wall thickness*

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Vessel Geometry

- *Drawings often state nominal tank volume*
  - *Calculations based upon actual dimensions will likely be different*

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Vessel Geometry

- *Inferred (level and mass) measurements should take into account:*
  - *Unmeasured volume*
  - *Dish / cone volume*
  - *Vessel orientation*

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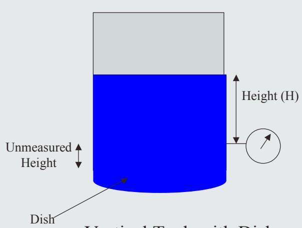
Vessel Geometry



Vertical Tank with Dish

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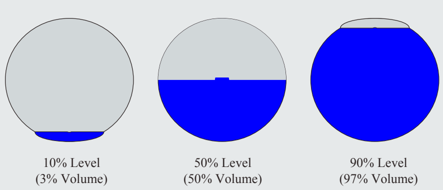
Vessel Geometry



Horizontal Tank (Non-linear Level Measurement)

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Vessel Geometry

- *A reference location (datum) should be determined based upon*
  - *Sensing technology*
  - *Sensor location*
  - *Vessel geometry*

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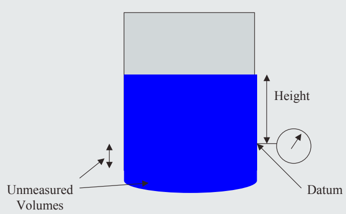
Vessel Geometry



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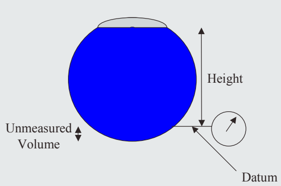
Vessel Geometry



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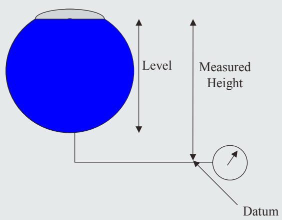
Vessel Geometry



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Vessel Geometry

- *Units of Measurement*
  - *Percent level*
  - *Volume (m^3)*
  - *Mass (kg)*
  - *Height (m)*

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Vessel Geometry

- *Units of Measurement*
  - *Can be zero-based or offset to account for vessel geometry*
  - *Two (or more) units may be used to meet the requirements of multiple users*

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Vessel Geometry

- *Units of Measurement*
  - *Percent level (e.g. 0-100 percent)*
    - *Advantage - common value for all tanks*
      - *Can help avoid over/underflows*
    - *Disadvantage - amount of material in vessel not indicated*

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Vessel Geometry

- *Units of Measurement*
  - *Volume (e.g. 0.55-8.5 m^3)*
    - *Advantage - indicates volume of material in vessel*
    - *Disadvantage - amount of material in vessel not indicated*

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Vessel Geometry

- *Units of Measurement*
  - *Volume (e.g. 0.55-8.5 m^3)*
    - *Disadvantage - most tanks are different sizes, so operator should be trained to avoid overflowing the vessel*
      - *More confusing for operator due to different numbers for each tank*

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Vessel Geometry

- *Units of Measurement*
  - *Mass (e.g. 550-8500 kg)*
    - *Advantage - indicates amount of material in vessel*

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Vessel Geometry

- *Units of Measurement*
  - *Mass (e.g. 550-8500 kg)*
    - *Disadvantage - most tanks are different sizes, so operator should be trained to avoid overflowing the vessel*
      - *More confusing for operator due to different numbers for each tank*

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Vessel Geometry

- *Units of Measurement*
  - *Height (e.g. 0-10 meters)*
    - *Advantage - indicates actual level*
    - *Disadvantage - amount of material in vessel not indicated*

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Vessel Geometry

- *Units of Measurement*
  - *Mass (e.g. 0-10 meters)*
    - *Disadvantage - most tanks are different heights, so operator should be trained to avoid overflowing the vessel*
      - *More confusing for operator due to different heights for each tank*

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Vessel Geometry

Signal	Signal	Fill	Kg	Kg (with dish)
20 mA	100 %	100 %	1000	1040
16 mA	75 %	88 %	880	920
4 mA	0 %	12 %	120	160
0 mA				

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Differential Pressure Level Transmitters

- *Liquid Pressure*
- *Static Liquid Interface*
- *Types of Level Measurement*
- *Vessel Geometry*
- *Dynamic Phenomena*
- *Installation*
- *Differential Pressure Level Calculations*

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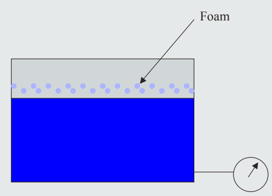
Dynamic Phenomena - Foam



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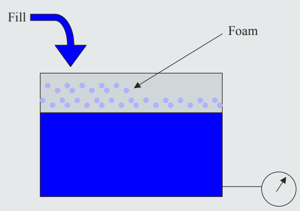
Dynamic Phenomena - Foam



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Dynamic Phenomena - Foam

- *Reducing foam*
  - *De-foaming additives*
  - *Submerged fill can sometimes reduce formation of foam*

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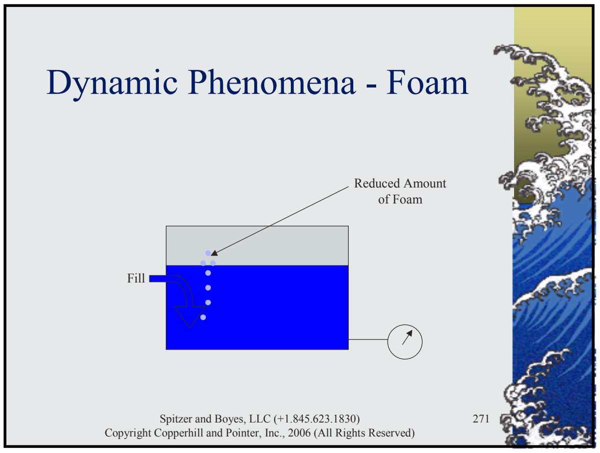
Dynamic Phenomena - Foam
Reduced Amount of Foam
Fill
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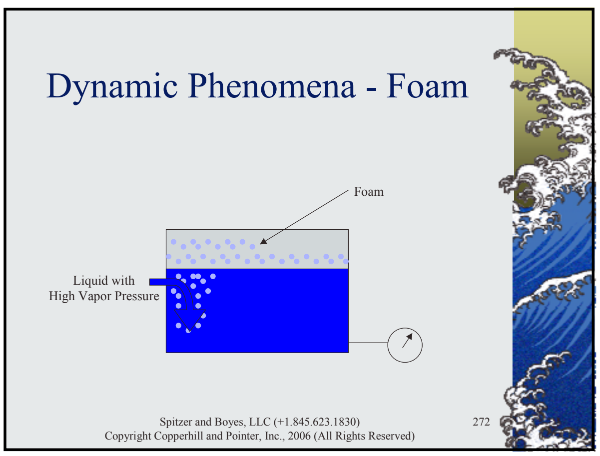
Dynamic Phenomena - Foam
Foam
Liquid with High Vapor Pressure
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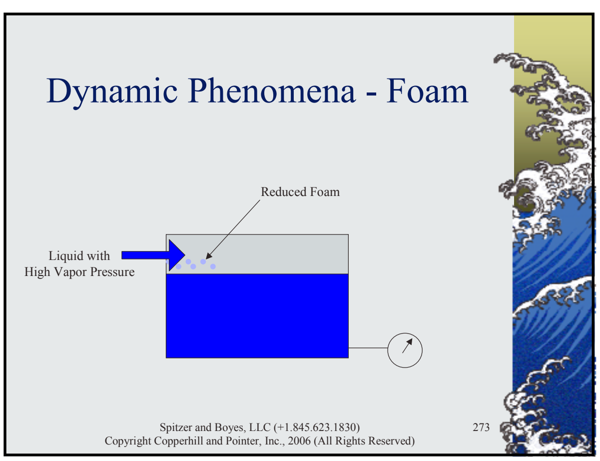
Dynamic Phenomena - Foam
Reduced Foam
Liquid with High Vapor Pressure
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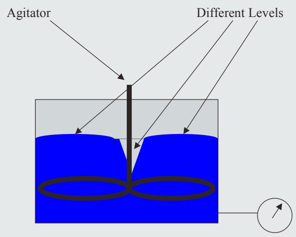
Dynamic Phenomena - Mixing



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Dynamic Phenomena - Boiling

- *Affects interface*
  - *Non-static interface*
    - *Measurement can usually be averaged*
  - *Alters interface geometry*
  - *Can raise level (from static)*

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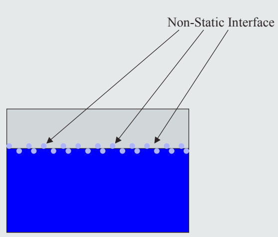
Dynamic Phenomena - Boiling



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Differential Pressure Level Transmitters

- *Liquid Pressure*
- *Static Liquid Interface*
- *Types of Level Measurement*
- *Vessel Geometry*
- *Dynamic Phenomena*
- ***Installation***
- *Differential Pressure Level Calculations*

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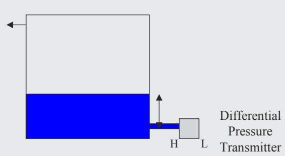
Installation – Open Vessel



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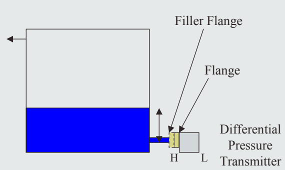
Installation – Open Vessel



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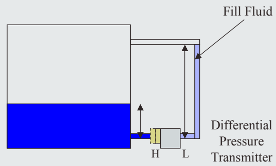
Installation – Closed Vessel



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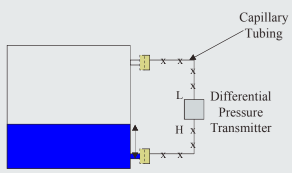
Installation – Closed Vessel



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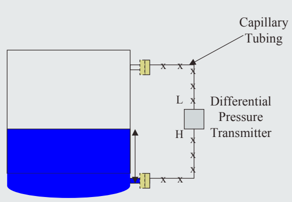
Installation – Closed Vessel



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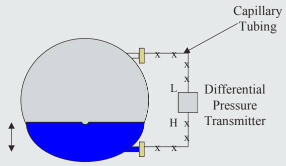
Installation – Horizontal Vessel



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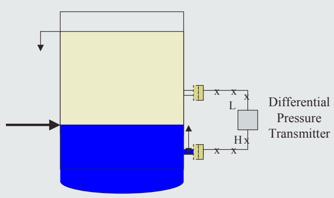
Installation – Interface Level



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Installation

- *Impulse Tubing*
  - *Liquid - avoid collection of gas*
    - *Hot* *locate transmitter far from taps*
    - *Freezing* *insulate and/or heat trace*
  - *Gas - avoid collection of liquid*

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Differential Pressure Level Transmitters

- *Liquid Pressure*
- *Static Liquid Interface*
- *Types of Level Measurement*
- *Vessel Geometry*
- *Dynamic Phenomena*
- *Installation*
- ***Differential Pressure Level Calculations***

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Differential Pressure Level Classroom Exercise 1

A vertical cylindrical tank is 10 meters high with a diameter of 3 meters. The tank contains water that overflows 9 meters above its flat bottom. A differential pressure level transmitter is mounted on a tap located 1 meter above the bottom of the tank. Calculate the calibration of the differential pressure level transmitter.

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Differential Pressure Level Classroom Exercise 2

A vertical cylindrical tank rated for 4 bar of pressure and full vacuum is 6 m high. The tank has a diameter of 2 meters and contains a liquid with a specific gravity of 0.95. A differential pressure level transmitter is mounted on a tap located 0.50 meters above the lower tangent line of the tank. The low-pressure nozzle is located 0.50 meters below the upper tangent line of the tank and has a fill fluid with a specific gravity of 1.05. Calculate the calibration of the differential pressure level transmitter.

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Differential Pressure Level Classroom Exercise 3

A vertical cylindrical tank rated for 4 bar of pressure and full vacuum is 6 m high. The tank has a diameter of 2 meters and contains a liquid with a specific gravity of 0.95. A differential pressure level transmitter is mounted on a tap located 0.50 meters above the lower tangent line of the tank. The low-pressure nozzle is located 0.50 meters below the upper tangent line of the tank and has a fill fluid with a specific gravity of 1.05. Calculate the calibration of the differential pressure level transmitter.

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Differential Pressure Level Classroom Exercise 4

A vertical cylindrical separation tank is 6 m high with a diameter of 2 meters. The tank is used to separate water with a specific gravity of 1.00 from a liquid with a specific gravity of 0.88 that overflows 0.50 meter below the top of the tank. The nozzles for the differential pressure level transmitter with diaphragm seals are located 0.50 meter above and below the middle of the tank. The capillary fill fluid has a specific gravity of 1.05. Assume that the transmitter is located at the same elevation as the lower nozzle. Calculate the calibration of the differential pressure level transmitter.

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Seminar Outline

- *Introduction*
- *Fluid Properties*
- *Differential Pressure Flowmeters*
- *Differential Pressure Level Transmitters*
- ***Consumer Guide***

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Consumer Guide

User Equipment Selection Process

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

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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***

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Consumer Guide

Guide Provides First Four Items

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

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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*

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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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Review and Questions

- *Introduction*
- *Fluid Properties*
- *Differential Pressure Flowmeters*
- *Differential Pressure Level Transmitters*
- *Consumer Guide*

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Differential Pressure Level Classroom Exercise 1

Empty Tank $H = 0\ m$
$L = 0\ m$
$\Delta P = H\text{-}L = 0\text{-}0 = 0\ m$

Full Tank $H = (9\text{-}1) \bullet 1.0 = 8\ m$
$L = 0\ m$
$\Delta P = H\text{-}L = 8\text{-}0 = 8\ m$

Calibration: 0 to 8 meters WC

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Differential Pressure Level Classroom Exercise 2

Empty Tank $H = 0\ m$
$L = (5.50\text{-}0.50) \bullet 1.05 = 5.25\ m$
$\Delta P = H\text{-}L = 0\text{-}5.25 = -5.25\ m$

Full Tank $H = (5.50\text{-}0.50) \bullet 0.95 = 4.75\ m$
$L = (5.50\text{-}0.50) \bullet 1.05 = 5.25\ m$
$\Delta P = H\text{-}L = 4.75\text{-}5.25 = -0.50\ m$

Calibration: -5.25 to -0.50 meters WC

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Differential Pressure Level Classroom Exercise 3

Empty Tank H = 0 m

L = (5.50-0.50) ● 1.05 = 5.25 m

ΔP = H-L = 0-5.25 = -5.25 m

Full Tank H = (5.50-0.50) ● 0.95 = 4.75 m

L = (5.50-0.50) ● 1.05 = 5.25 m

ΔP = H-L = 4.75-5.25 = -0.50 m

Calibration: -5.25 to -0.50 meters WC

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Differential Pressure Level Classroom Exercise 4

Zero Interface

H = (4.00-2.00)●0.88 + (5.50-4.00)●0.88 = 3.08 m

L = (4.00-2.00)●1.05 + (5.50-4.00)●0.88= 3.42 m

ΔP = H-L = 3.08-3.42 = -0.34 m

Full Interface

H = (4.00-2.00)●1.00 + (5.50-4.00)●0.88 = 3.32 m

L = (4.00-2.00)●1.05 + (5.50-4.00)●0.88= 3.42 m

ΔP = H-L = 3.32-3.42 = -0.10 m

Calibration: -0.34 to -0.10 meters WC

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Differential Pressure Flow/Level Measurement

Seminar Presented by

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