

# **Instrument Consultant Training**

## **Module 1 Pressure Measurement**





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# Introduction

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Accurate measurement of liquid, gas, and steam pressure is a basic requirement for many industrial processes to operate safely, efficiently, and with optimum quality control. Many plants use more pressure-measurement and control devices than all other types of measurement and control instruments combined.

Some pressure-measurement devices use complex technology, while others are quite simple. The accuracy and precision of the different pressure-measurement instruments also varies widely. This module introduces you to the basic principles of pressure measurement and explains the benefits of accurate pressure measurement and control in process industries. In addition, descriptions of the different pressure-measurement and control devices available will be presented.

This module contains the following sections:

- ❑ What is Pressure?
- ❑ Why Measure Pressure?
- ❑ Pressure Terminology
- ❑ Pressure Based Measurements
- ❑ Pressure Measurement and Control

## **PERFORMANCE OBJECTIVE**

After you have completed this module, you will understand and be able to explain the basis upon which pressure-measurement products are differentiated in the process control industry.





# What Is Pressure?

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Before learning about pressure measurement, it is necessary to understand pressure measurement. This section describes the basic principles of pressure.

## **LEARNING OBJECTIVES**

After you have completed this section, you will be able to:

- ☐ Define *pressure*
- ☐ Explain how changes in force and force over an area affect pressure
- ☐ Explain how level, density, and pressure on the surface of the liquid affect the pressure of a liquid
- ☐ Explain how vessel volume and temperature can affect the pressure of a gas



# The Pressure Equation

*Pressure* is the amount of force applied over a defined area. The relationship between pressure, force, and area is represented in the following formula:

$$P = \frac{F}{A}$$

Where:

- P = Pressure
- F = Force
- A = Area

If a force (due to physical contact) is applied over an area, pressure is being applied. Pressure increases if the force increases or the size of the area over which the force is being applied decreases.

Weight X and Weight Y in Figure 1.1 are applying different amounts of pressure to the surface, even though the two weights are each 100 lb (4536 kg). Weight X has a base of 100 in<sup>2</sup> (645 cm<sup>2</sup>). Therefore, the pressure being applied by Weight X is 100 lb of force being applied over an area of 100 in<sup>2</sup>, or 1 lb/in<sup>2</sup> (703 kg/m<sup>2</sup>).

$$\text{Pressure}_x = \frac{100 \text{ lb (4536 kg)}}{100 \text{ in}^2 (645 \text{ cm}^2)} = 1 \text{ lb/in}^2 (703 \text{ kg/m}^2)$$

Weight Y is resting on a 1 in<sup>2</sup> base. Therefore, the pressure being applied by Weight Y is 100 lb of force being applied over an area of 1 in<sup>2</sup> (6.45 cm<sup>2</sup>) or 100 lb/in<sup>2</sup> (70307 kg/m<sup>2</sup>).

$$\text{Pressure}_y = \frac{100 \text{ lb (4536 kg)}}{1 \text{ in}^2 (6.45 \text{ cm}^2)} = 100 \text{ lb/in}^2 (70.307 \text{ kg/m}^2)$$

## Activities

1. Define *pressure*.
2. An increase in the area over which a force is applied results in a(n) **increase / decrease** in pressure.

1. Force applied over a defined area  
2. Decrease





# The Pressure Equation

## Activities

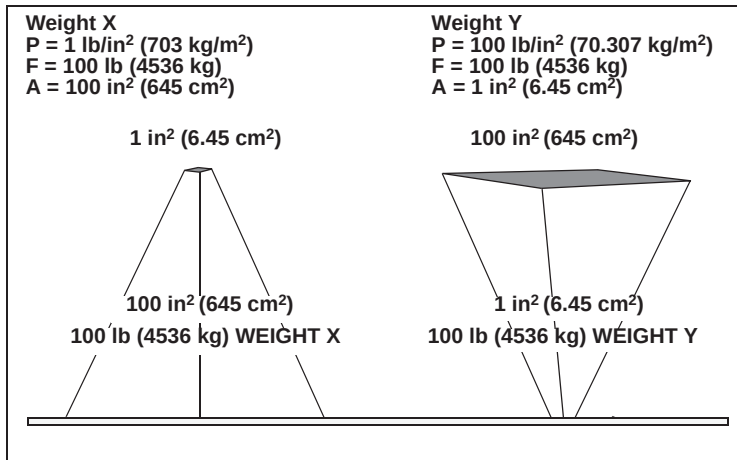


Figure 1.1: Force Over Area

To better understand the relationship between force and area, think about the impact of your weight sitting on a bed. The force is produced by your weight, which, in this example, will remain constant. If you lie down on the bed, your weight is applied over a large area and the bed is compressed to a certain degree. If you stand on the bed on one foot, your weight is applied to a much smaller area and the bed compresses much more. The force (your weight) is now being applied over a smaller area—therefore the pressure is increased.



# Pressure Variables

The factors that influence the pressure of a liquid are different from the factors that influence the pressure of a gas. Therefore, when measuring pressure, it is important to understand the pressure properties of liquids and gases.

## HYDROSTATIC PRESSURE (HEAD PRESSURE)

The pressure exerted by a liquid is influenced by three factors:

- Height of liquid in a column
- Density of the liquid
- Ullage pressure (pressure in the vapor space)

### Liquid Level

The pressure at the bottom of a column of liquid increases as the height of the liquid in the column increases. Pressure is affected by the height rather than the volume of a liquid. If other factors (e.g., density of the liquid and pressure on the surface of the liquid) are constant, the pressure at the bottom of a larger diameter tank will be equal to the pressure at the bottom of a smaller diameter tank when the height of liquid is the same. Refer to Figure 1.2, where PT is a pressure transmitter mounted at the bottom of the tank.

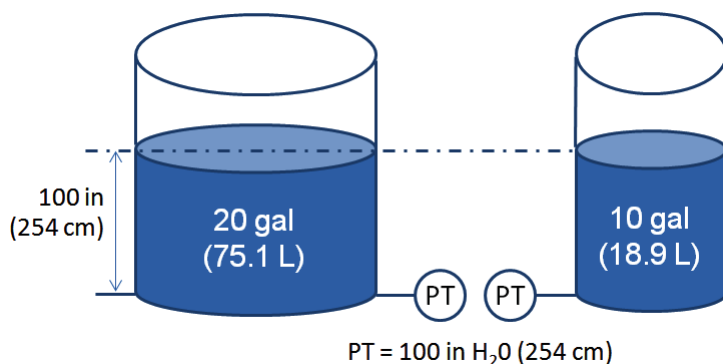


Figure 1.2: Hydrostatic Pressure

Because hydrostatic pressure is directly proportional to the height (i.e., level) of the liquid, pressure measurement is used for level measurement.

## Activities

3. The pressure at the bottom of a glass of water **increases/decreases** as the glass is filled.



# Pressure Variables

An example from everyday life might be your experience of swimming five feet beneath the surface of a swimming pool and swimming five feet beneath the surface of a large lake. Even though the lake contains a far greater amount of water, the pressure on your body at a five foot depth is the same in the lake and in the pool.

## Density of a Liquid

*Density* is the mass of a particular substance per unit of volume.

$$\text{Density} = \text{Mass} / \text{Volume}$$

A liquid with a greater density has a greater mass per unit of volume. Liquids with greater densities will produce greater hydrostatic pressure (head) than liquids with lower density.

For density to be meaningful, it must be stated at a known temperature. This is called the reference temperature. This is because density of a liquid changes with temperature. Density of a liquid decreases as temperature increases.

Density is often represented in terms of specific gravity. *Specific gravity* is the ratio of the density of a particular liquid to the density of water at a reference temperature.

Water has a density of 1,000 kg/m<sup>3</sup> (62 lb/ft<sup>3</sup>) at 50 °F (10 °C). The density of gasoline is 660 kg/m<sup>3</sup> (41 lb/ft<sup>3</sup>) at 50 °F (10 °C). To calculate the specific gravity of gasoline, divide the density of gasoline by the density of water:

$$\frac{660 \text{ kg/ m}^3}{1,000 \text{ kg/ m}^3} = 0.66$$

Because specific gravity is a unitless ratio of densities, it does not change as units of measure change. Therefore, the specific gravity of gasoline at 60° F (15.6° C) is always 0.66, even if the density of gasoline and the density of water are expressed in a different unit of measure (e.g., lb/ft<sup>3</sup>):

$$\frac{41.2038 \text{ lb/ ft}^3}{62.43 \text{ lb/ ft}^3} = 0.66$$

## Activities

4. Define *density*.

5. Explain why expressing density in different units does not affect the specific gravity calculation.

4. Density is the mass of a particular substance per unit of volume
5. Because specific gravity is a ratio of densities, it does not change as units of measure change.



# Pressure Variables

## Head Pressure (Ullage Pressure)

*Head Pressure or Ullage Pressure* is pressure that is exerted on the surface of a liquid. In an open tank, *atmospheric pressure* (the pressure exerted by the Earth's atmosphere) is the pressure on the surface. A Gage Pressure measurement is sufficient for level measurement. In a closed tank, it is common practice to fill the vapor space with buffer gas. This is done in order to protect the products inside the tank or to prevent them from evaporating into the atmosphere. This buffer gas will exert a pressure on the column of liquid that must be subtracted from the measurement of the height of liquid or error will result. Differential Pressure measurement, where the low side reference leg is connected to the vapor space will allow the head pressure to be subtracted out. PUT IN BOX: Gage Pressure is used for Open Tank measurement, Differential Pressure must be used for Closed Tank measurement.

## GAS PROPERTIES

Unlike a liquid, a gas will exert equal pressure on all parts of the container in which it is held. Two factors affect the pressure exerted by a gas:

- Volume of the container in which the gas is held
- Temperature of the gas

Common practice in process industries is to refer to both liquids and gases as *fluids*.

The relationship between pressure, temperature, and volume of a gas can be determined by applying the ideal gas law.

Ideal Gas Law:

$$PV = nRT$$

## Gas Pressure vs. Volume Relationship

At a constant temperature, the relationship between the pressure (P) exerted by a gas and the volume of the container (V) in which it is held is known as *Boyle's law*. Because a gas can be compressed, the pressure of a gas increases proportionately as the volume of the container in which the gas

## Activities

6. Pressure applied to the surface of a liquid has **an effect / no effect** on the pressure beneath the surface.
7. What are the three factors that influence the measurement of pressure exerted by a liquid.
8. What happens to the gas pressure in a vessel holding 20 m<sup>3</sup> (706 ft<sup>3</sup>) of gas if the contents are transferred to a tank with double the capacity? (Assume all other factors do not change.)



## Pressure Variables

is held decreases. Conversely, if a set amount of gas is transferred to a larger container, the pressure will decrease in proportion to the increase in container volume.

Boyle's Law:

$$V_1 P_1 = V_2 P_2$$

### Gas Pressure vs. Volume and Temperature

Gas pressure is affected by changes in temperature. As the temperature of a gas increases, the energy of the individual gas molecules increases as well. As a result, the gas molecules collide with the vessel wall more frequently and with greater force, and the pressure exerted against the inside wall of the vessel increases.

If the volume of the vessel holding a gas and the amount of gas are unchanged, the pressure exerted by the gas on the vessel walls will change in proportion to changes in the temperature of the gas.

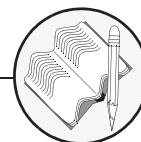
The relationship is supported by the ideal gas law in the form of this equation:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

### Activities

9. What happens to the gas pressure in a vessel containing 20 m<sup>3</sup> (706 ft<sup>3</sup>) of gas if the gas is heated? (Assume all other factors remain unchanged.)

9. Pressure will increase as temperature increases



**COMPLETE WORKBOOK EXERCISE 1.1 ON PAGE 47**





# Why Measure Pressure?

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Process industries measure pressure for several reasons, and the most common are discussed in this section.

## **LEARNING OBJECTIVE**

After you have completed this section, you will be able to:

- List and briefly explain the four most common reasons for measuring pressure:
  - Safety
  - Process efficiency
  - Cost savings
  - Measurement of other process variables



# Why Measure Pressure?

*Process industries* are organizations that transform one substance into another (e.g., crude oil into gasoline, pulp into paper, steam into electricity). Four of the most common reasons that process industries measure pressure follow:

- ❑ Safety
- ❑ Process efficiency
- ❑ Cost savings
- ❑ Measurement of other process variables

## SAFETY

Pipes, tanks, valves, flanges, and other equipment used with pressurized fluids in process industries are designed to withstand the stress of a specific range of pressures. Accurate pressure measurement and precise control help prevent pipes and vessels from bursting. In addition, pressure measurement and control help minimize equipment damage, reduce the risk of personal injury, and prevent leaks of potentially harmful process materials into the environment. Pressure measurement used to control the level and flow of process materials helps to prevent backups, spills, and overflows. By monitoring the pressure in the process, actions can be taken to prevent (or minimize) an environmental release or personal injury/exposure.

## PROCESS EFFICIENCY

In most cases, process efficiency is highest when pressures (and other process variables) are maintained at particular values or within a narrow range of values. Accurate pressure measurement can help sustain the conditions required for maximum efficiency. For example, the piece of paper on which these words are written was created from a pulp solution put through a paper machine at a specific pressure. If the pressure had gone above or below the setpoint (required range), the result would have been scrap instead of a usable sheet of paper. The efficiency of a process is directly related to the quality of the product being produced.

## Activities

1. List four reasons why process industries measure pressure.

1. Safety; process efficiency; Inferred measurement of other variables; cost savings





# Why Measure Pressure?

## COST SAVINGS

The equipment used to create pressure or vacuum in process industries (e.g., pumps and compressors) uses considerable energy. Because energy costs money, a precise pressure measurement can save money by preventing the unnecessary expense of creating more pressure or vacuum than is required to produce the desired results for a particular process. Scrap also adds unnecessary costs. Scrap may require reworking (more energy is required) and the overall output is reduced (lost production).

Therefore, quality is a sub-component of both process efficiency and cost savings.

## MEASUREMENT OF OTHER PROCESS VARIABLES

Pressure is directly proportional to numerous process variables. Consequently, pressure transmitters are frequently used in other applications, including:

- Flow rate through a pipe
- Level of fluid in a tank
- Density of a substance
- Liquid interface measurement

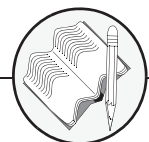
For example, the differential pressure across a restriction in a pipe is proportional to flow. This makes pressure a very important measurement in the process industries.

## Activities

2. How does accurate pressure measurement help process industries save money?
3. List two process properties that can be inferred from a pressure measurement.

2. By keeping pumps, compressors, and other devices used to create pressure or a vacuum running efficiently
3. Level; flow; density; interface

COMPLETE WORKBOOK EXERCISE 1.2 ON PAGE 48







# Pressure Terminology

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Pressure measurements can be expressed in many different units. Some units are more popular in one part of the world than another. Some pressure-measurement units are more useful for one type of application than another.

For a measurement to be useful, the reference point from which the measurement is being taken must be known. For example, a measurement of three miles is meaningless unless we know where the three miles begin. Basic reference points of pressure measurement are introduced in this section, along with descriptions of measurable pressures you will encounter in the field.

## **LEARNING OBJECTIVES**

After you have completed this section, you will be able to:

- ❑ Recognize and explain the basis of the units used for pressure measurement
- ❑ Differentiate between the following three reference points of pressure measurement:
  - Absolute
  - Gage
  - Differential
- ❑ Differentiate between the following three measurable pressures:
  - Head (hydrostatic) pressure
  - Static (line) pressure
  - Vapor pressure



# Pressure Units

Pressure units can be divided into two categories: units of force over area and units referenced to a column of fluid.

## UNITS OF FORCE OVER AREA

The following are units of force over a defined area:

- ❑ Pounds per square inch (psi)
- ❑ Kilograms per square centimeter ( $\text{kg}/\text{cm}^2$ )
- ❑ Grams per square centimeter ( $\text{g}/\text{cm}^2$ )— $1 \text{ g}/\text{cm}^2 = 1/1,000 \text{ kg}/\text{cm}^2$
- ❑ Pascals (Pa or  $\text{N}/\text{m}^2$ )—N stands for *newton*
- ❑ Kilopascals (kPa)— $1 \text{ kPa} = 1,000 \text{ Pa}$
- ❑ Bar— $1 \text{ bar} = 100,000 \text{ Pa}$
- ❑ Millibar (mbar)— $1 \text{ mbar} = 1/1,000 \text{ bar}$

## UNITS REFERENCED TO COLUMNS OF FLUID

The following are units of pressure referenced to a column of fluid:

- ❑ Inches of water ( $\text{inH}_2\text{O}$  at  $68^\circ\text{F}$  [ $20^\circ\text{C}$ ] or at  $39.2^\circ\text{F}$  [ $4^\circ\text{C}$ ])
- ❑ Feet of water ( $\text{ftH}_2\text{O}$ )
- ❑ Meters of water ( $\text{mH}_2\text{O}$ )
- ❑ Millimeters of water ( $\text{mmH}_2\text{O}$ )
- ❑ Inches of mercury ( $\text{inHg}$ )
- ❑ Millimeters of mercury ( $\text{mmHg}$ )
- ❑ Atmosphere (atm)—The pressure exerted by the earth's atmosphere at sea level
- ❑ Torr— $1 \text{ torr} = 1 \text{ mmHg}$

Pressure expressed in units of distance are a useful, even though they do not represent a force over a defined area. Expressing the pressure unit of measure in a format common to a ruler or tape measure makes the measurement easier to understand. Beware, however, unless the fluid is actually water, the actual level in the tank will be different due to the difference in density of the fluid. This is because the level is equal to the height x density.

## Activities

1. What is the abbreviation for kilopascals?

1. kPa



## Pressure Units

Consider a pressure of 1 inH<sub>2</sub>O (2.5 mbar) pressure is applied by a one-inch column of water at reference conditions. Because the temperature is specified, the density will remain constant and the measurement unit fixed.

Another commonly used fluid for pressure measurement is the element mercury (Hg), often expressed as a pressure measurement in *inches of mercury* (inHg). Consider a pressure of 1 inHg. It is equal to the amount of pressure applied by a one-inch-high column of mercury with a density of 13.5951 g/cm<sup>3</sup>. Again, because density is specified, the measurement unit remains fixed.

Millimeters of mercury (mmHg) is also used to express pressure. 1 mmHg is the amount of pressure applied by a 1 mm high column of mercury with a density of 13.5951 g/cm<sup>3</sup>.

Units of pressure can also be expressed in *atmospheres* (atm). 1 atm is equal to the pressure exerted by the earth's atmosphere at sea level. 1 atm is equal to 101.325 kPa, or approximately 14.6959 psi.

*Torr* is a unit of pressure based on atmosphere (1 torr equals 1/760 atm). One torr is approximately equal to 1 mmHg.

### Activities

2. Why is temperature specified in inches of water pressure measurement units?
3. List three pressure-measurement units referenced to a column of fluid.

2. Water is the reference condition of the unit of measurement  
3. inH<sub>2</sub>O; torr; inHg; and atm



# Pressure Units

## CONVERTING UNITS OF PRESSURE

Product literature (e.g., manuals, product data sheets, product price lists) for each pressure device lists the pressure range the device can safely operate. However, the pressure units used in the product literature may not be the same as the units specified by a customer. Therefore, unit conversions are often required.

For example, a customer identifies 40 bar as the maximum amount of pressure for a particular process. The customer wants to know what range transmitter to select. The product literature lists pressure ranges in psi, so a conversion from bar to psi is necessary before a recommendation can be made.

Units of pressure can be converted using a conversion table, such as the table below, that shows the relationships between different units of pressure (e.g., how many bar equal 1 psi). To convert 40 bar to psi, look in the conversion table to find that one bar equals 14.5038 psi. Because you need the psi value of 40 bar, multiply 14.5038 by 40 to obtain a value of 580.151 psi. Now you can refer to the product literature to determine the proper transmitter range suitable for the application.

## Activities

- Use the table below to convert 115 inH<sub>2</sub>O into mbar. What is the value?

|              |                    | Convert To |         |                    |                    |         |         |        |         |                                       |
|--------------|--------------------|------------|---------|--------------------|--------------------|---------|---------|--------|---------|---------------------------------------|
| Convert From |                    | psi        | kPa     | inH <sub>2</sub> O | mmH <sub>2</sub> O | inHg    | mmHg    | bar    | mbar    | kg/cm <sup>2</sup> gm/cm <sup>2</sup> |
|              | psi                | 1          | 6.8948  | 27.7296            | 704.332            | 2.0360  | 51.7149 | 0.0689 | 68.9476 | 0.0703 70.3070                        |
|              | kPa                | 0.1450     | 1       | 4.0218             | 102.155            | 0.2953  | 7.5006  | 0.0100 | 10.000  | 0.0102 10.197                         |
|              | inH <sub>2</sub> O | 0.0361     | 0.2486  | 1                  | 25.4000            | 0.0734  | 1.8650  | 0.0025 | 2.4864  | 0.0025 2.5355                         |
|              | mmH <sub>2</sub> O | 0.0014     | 0.0098  | 0.0394             | 1                  | 0.0029  | 0.0734  | 0.0001 | 0.0979  | 0.00001 0.0998                        |
|              | inHg               | 0.0412     | 3.3864  | 13.6195            | 345.936            | 1       | 25.4000 | 0.0339 | 33.8639 | 0.0345 34.532                         |
|              | mmHg               | 0.0193     | 0.1333  | 0.5362             | 13.6195            | 0.0394  | 1       | 0.0013 | 1.3332  | 0.0014 1.3595                         |
|              | bar                | 14.5038    | 100.000 | 402.184            | 10215.5            | 29.5300 | 740.062 | 1      | 1000    | 1.0197 1019.72                        |
|              | mbar               | 0.0145     | 0.1000  | 0.4022             | 10.2155            | 0.0295  | 0.7501  | 0.001  | 1       | 0.0010 1.0197                         |
|              | kg/cm <sup>2</sup> | 14.2233    | 98.0665 | 394.408            | 10018.0            | 28.9590 | 735.559 | 0.9807 | 980.665 | 1 1000                                |
|              | gm/cm <sup>2</sup> | 0.0142     | 0.0981  | 0.3944             | 10.0180            | 0.0290  | 0.7356  | 0.0010 | 0.9807  | 0.001 1                               |

4. 285.936 mbar



## Reference Pressures

Pressure-measurement devices can be categorized according to the measured reference pressure. *Reference pressure* is the pressure measurement that is compared to the actual measured pressure of the process. The three reference pressures are:

- Absolute
- Gauge
- Differential

Absolute and gauge devices measure the difference between the pressure of the process fluid and a reference pressure. Differential devices take two pressure measurements of the process fluid at different points and compute the difference.

### ABSOLUTE PRESSURE

Absolute pressure measurements reference measured pressure to a perfect vacuum (0 psia). Because no pressure reading can be less than a perfect vacuum, an absolute pressure-measurement device will never have a negative reading.

One example of an absolute pressure application is to provide a reference to barometric pressure.

### Activities

5. What does an absolute pressure device use as a reference pressure?

5. A perfect vacuum



# Reference Pressures

## GAGE PRESSURE

A gage pressure transmitter has its low side referenced to the surrounding atmosphere (approximately 14.7 psi or **101.6 kPa**). The high side, then, measures the process. Changes in atmospheric pressure will impact the process and the low side the the transmitter the same, so that there is no impact on high side measurement.

Gage pressure transmitters are often used to measure pressure in a pipe or liquid level in an open tank.

## DIFFERENTIAL PRESSURE

A differential pressure transmitter has both its high and low side connected to the process.

Changes in atmospheric pressure do not affect the output of differential pressure-measurement instrument instrumentation because both measured pressure and reference pressure are equally influenced by exposure to the atmosphere.

Differential pressure transmitter are often used to measure flow or liquid level in a closed tank

## Activities

6. What does a gauge pressure device use as a reference pressure?
7. How many process connections do differential pressure-measurement instruments have?





## Reference Pressures

In a “closed” tank, differential pressure transmitters are used. The high side sensor located at the bottom tap will measure both the liquid level and the vapor pressure. The low side sensor, located at the top tap and above the liquid level, will only measure the vapor pressure. Since the DP transmitter measurement is  $DP = P_{\text{High}} - P_{\text{Low}}$ , and both the high and low sides include the vapor space pressure, it is subtracted out. The resulting output is the true level measurement.

### Activities

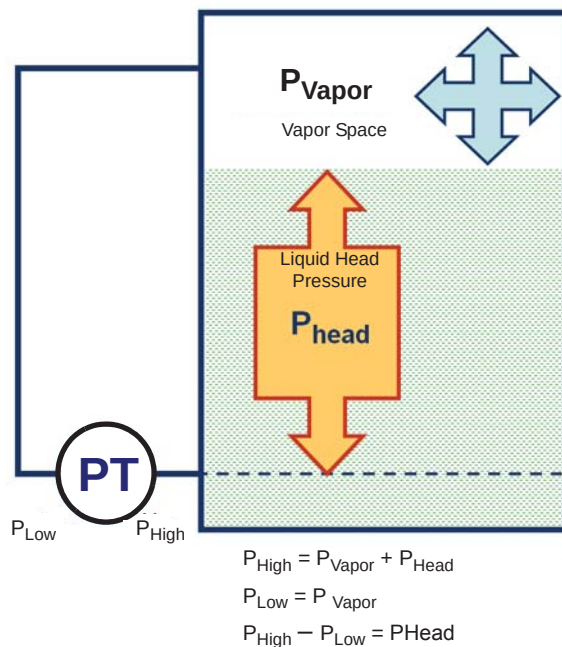


Figure 1.3: DP Transmitter



# Reference Pressures

## DESIGNATING REFERENCE PRESSURES

The designator “a” for *absolute* and “g” for *gage* is often used to define the pressure units and to indicate the reference pressure or type of instrumentation. Thus, the pressure unit “psi” is sometimes represented as **psig** or **psia** and the unit “bar” as **barg** or **bara**.

## Converting Absolute Pressure Measurements

An absolute pressure measurement registers the pressure of the surrounding atmosphere as part of the pressure reading, whereas a gauge pressure measurement references atmospheric pressure. Therefore, absolute values can be converted to gauge values by subtracting the atmospheric pressure from the absolute pressure reading (Figure 1.4).

$$P_a = P_g + P_{atm}$$

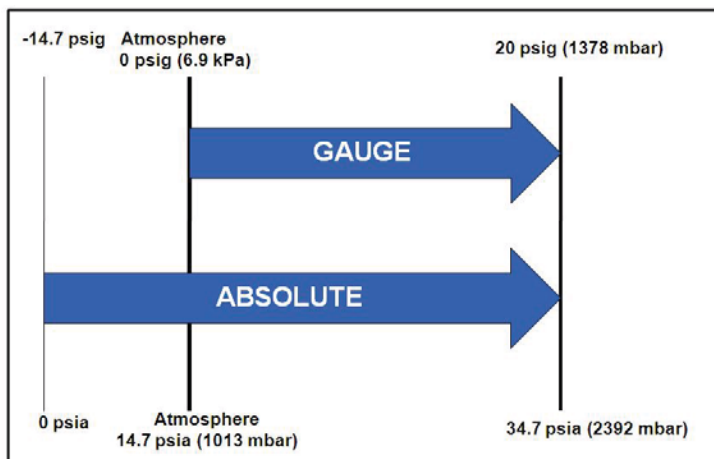


Figure 1.4: Comparison of Absolute and Gauge Values

For example, to find the gauge value for an absolute pressure-measurement device that reads 34.7 psia (2392 mbar) and is surrounded by an atmosphere of 14.7 psia (1013 mbar), use the following equation:

$$34.7 \text{ psia} - 14.7 \text{ psia} = 20 \text{ psig}$$

## Activities

8. What does the designation *psig* represent?

9. In psi, what would a gauge pressure-measurement device read at atmospheric pressure?

10. In psi, what would an absolute pressure-measurement device read at atmospheric pressure?

8. Pounds per square inch gauge  
9. 0 psig  
10. Approximately 14.7 psia



## Reference Pressures

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To convert a gauge value to an absolute value, simply reverse the process described above. Add atmospheric pressure to the gauge value.

$$20 \text{ psig} + 14.7 \text{ psia} = 34.7 \text{ psia}$$

14.7 psia (1013 mbar) is slightly higher than the standard pressure value of 1 atm, which is 14.6959 psi (1013 mbar). The value changes depending on the weather and the location of the instrumentation, but normally does not vary more than a few tenths. For most applications, using a value of 14.7 psia (1013 mbar) for atmospheric pressure is sufficient.

### ***Activities***



## Activities

- ☐ Head pressure
- ☐ Static pressure
- ☐ Vapor pressure

## HEAD PRESSURE

*Head pressure*, also known as *hydrostatic pressure*, is the pressure exerted by a column of fluid (Figure 1.5). Head pressure is directly proportional to the specific gravity (S.G.) of the fluid and the height of the fluid column.

$$\text{Head Pressure} = \text{Height (H)} \times \text{S.G.}$$

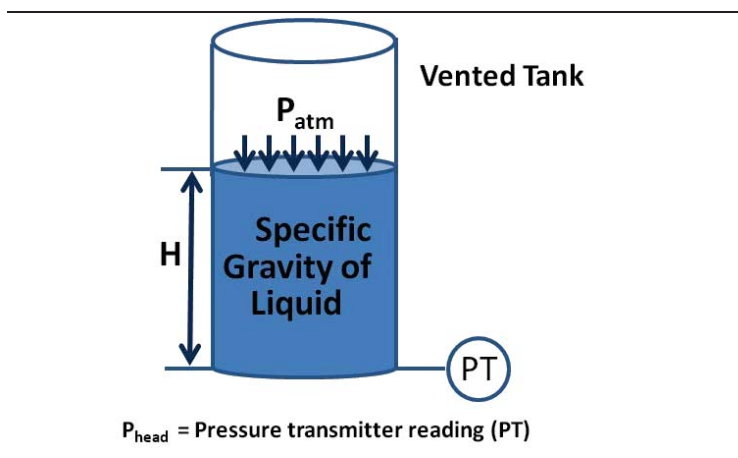


Figure 1.5: Head Pressure

Pressure transmitter mounting position must be considered

$\rho$  = fluid density  
 $h$  = vertical distance from the tap to the fluid  
 $P_{PT}$  = pressure at the tap  
 $P_{meas}$  = pressure measured at the transmitter

Pressure transmitter mounting position must be considered to quantify the effect based on the vertical distance from the tap and the density of the fluid in the wet leg or capillary seal. Once quantified, the impact can be factored out of the measurement.

11. Define *head pressure*.
12. Head pressure is proportional to the **temperature / specific gravity** of a fluid.



# Measured Pressures

## STATIC PRESSURE

*Static pressure* or *line pressure* is the pressure exerted in a closed system. It is most commonly measured in flow applications and refers to the pressure exerted by the fluid in the pipe. Another example of static pressure can be found in a common boiler system. As the water in the boiler is heated, pressure increases.

## VAPOR PRESSURE

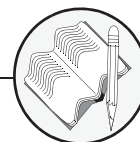
Vapor pressure is the result of a fluid's vaporization and is a measured pressure in closed systems. *Vaporization* is the transformation of a substance from a liquid state to a gas state (e.g., water to steam). The transformation occurs at a specific temperature for each liquid. For example, water turns to steam (boils) at 212 °F (100 °C). Vapor pressure is most commonly measured in closed tank DP level applications, whereby the vapor pressure is the low side transmitter measurement.

## Activities

13. What is static pressure?
14. Define *vaporization*.
15. As pressure increases, the boiling point of a liquid **increases / decreases**.

13. Pressure exerted by the fluid in the pipe  
14. The transformation of a liquid into a gas  
15. Increases

**COMPLETE WORKBOOK EXERCISE 1.3 ON PAGE 49**







# Pressure Based Measurement

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Pressure-measurement readings can be used in many applications. Examples include calculating flow rate, liquid level, and fluid density. This is because a known relationship exists between pressure and density, pressure and level, and pressure and fluid flow through a pipe.

## **LEARNING OBJECTIVES**

After completing this section, you will be able to describe how pressure measurement can be used to determine:

- ☐ The rate of flow of a fluid through a pipe
- ☐ The level of a liquid in a tank
- ☐ The density of a fluid in a tank
- ☐ The interface level of different fluids in a vessel



# Pressure Based Measurement

## FLOW

A common use of a pressure measurement is to determine a fluid's flow rate through a pipe. As a fluid flows through a pipe restriction, the fluid pressure drops. The differential pressure measured is proportional to flow rate.

The flow equation used to determine flow rate for DP flowmeters is based on Bernoulli's equation, which shows that flow rate (Q) is proportional ( $\alpha$ ) to the square root of differential pressure ( $\Delta P$ ):

$$Q \propto \sqrt{\Delta P}$$

Approximately half of all flow measurements are made by differential

**Note:** For more information on DP Flow, see the Flow Measurement module.

## Activities

1. Pressure will be greater on the **upstream / downstream** side of a restriction in a pipe than on the **upstream / downstream** side.
2. The flow rate is proportional to the \_\_\_\_\_ of DP.

1. Upstream; downstream
2. Square root





# Pressure Based Measurements

## LEVEL

The level of a liquid in a tank or vessel can be determined from the pressure measurement by this equation:

$$\text{Height of Liquid} = \frac{\text{Pressure}}{\text{Specific Gravity}}$$

Closed tanks or vessels use a DP transmitter to account for the vapor space pressure. Open tanks or vessels can use a GP transmitter or a DP transmitter with the low side vented to the atmosphere.

Over half of all level measurements in the process industry apply a pressure transmitter.

**Note:** For more information on DP Level measurement, see the Level Measurement module.

## DENSITY MEASUREMENT

Pressure is equal to the height of the column of liquid being measured multiplied by the specific gravity of the liquid. Therefore, if the height of the column is a known constant (as in the case of the distance between two pressure measurement points on a vessel), the density can be inferred from the pressure readings using the following equation:

$$\Delta P = \frac{\Delta \rho \cdot g \cdot h}{g_c}$$

## Activities

3. To get density from a pressure measurement, divide pressure by the **density / height / specific gravity** of the column of liquid.

3. Height



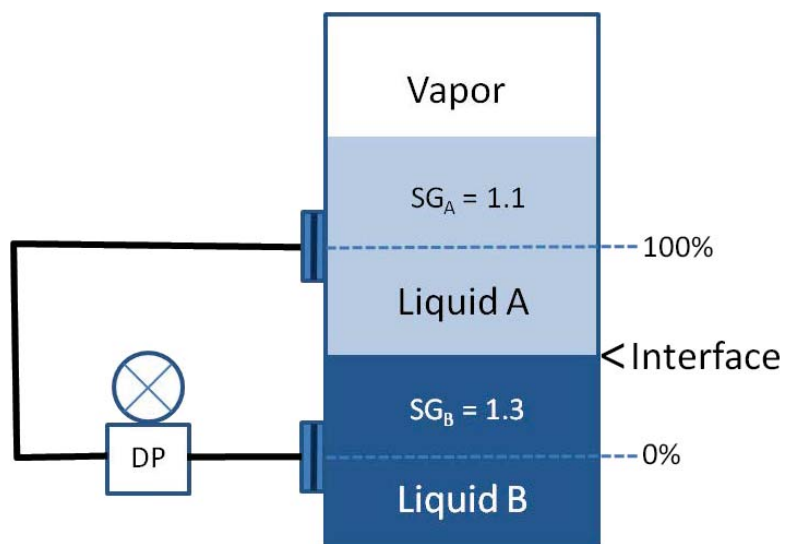
# Pressure Based Measurement

Density measurements are often used in the brewing industry to determine stages of fermentation.

## Activities

### INTERFACE MEASUREMENT

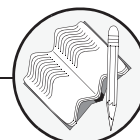
An *interface* is the boundary between two *immiscible* (incapable of being mixed) fluids with different densities (e.g., oil and water). An interface measurement finds the boundary between two liquids stored in the same tank. For example, when oil and water occupy the same vessel, the oil floats on top of the water. The interface between the two fluids is the upper level of the water and the lower level of the oil. If the density of both fluids is known, interface location can be determined using pressure measurement. See Figure 1.6 for an example.



$$\text{Interface} = \text{DP} \times (\text{SG}_B - \text{SG}_A)$$

Figure 1.6: Interface Measurement Example

COMPLETE WORKBOOK EXERCISE 1.4 ON PAGE 53



# Pressure Measurement and Control

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Pressure-measurement instruments vary widely in accuracy, complexity, the amount of maintenance they require, and their suitability to different applications.

## **LEARNING OBJECTIVES**

After you have completed this section, you will be able to:

- ❑ Identify two types of pressure gauges
- ❑ Explain the operations of the two types of liquid column gauges:
  - Barometers
  - Manometers
- ❑ Name the parts of a mechanical pressure gauge
- ❑ Describe the operation and use of pneumatic pressure cells
- ❑ Describe the operation of the following electronic pressure transmitters:
  - Variable capacitance
  - Piezoresistive
  - Piezoelectric
  - Variable inductance
  - Variable reluctance
  - Vibrating wire
  - Strain gauge



# Pressure Gauges

There are two types of pressure-measurement gauges: liquid column gauges and mechanical gauges. In a liquid column gauge, the height of a column of liquid varies in response to applied pressure. Mechanical gauges have mechanical parts that move in response to applied pressure.

## LIQUID COLUMN GAUGES

Below are two types of liquid column pressure gauges:

□ *Barometer*

□ *Manometer*

### Barometer

A *barometer* is a device that measures atmospheric pressure. A barometer consists of a clear, hollow tube with one end plugged. The open end of the tube is placed in a reservoir of liquid, typically mercury (Figure 1.7).

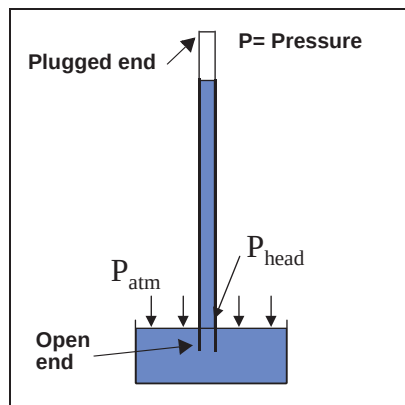


Figure 1.7: Barometer

Mercury barometer measurement is recorded in atmospheric pressure in inches or millimeters (torr); the pressure is related to the level of the mercury's height in the vertical column. One atmosphere is equivalent to about 29.9 inches (75.95 cm) of mercury. High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column. Low pressure allows the mercury to drop to a lower level in the column by lowering the force on the reservoir.

## Activities

1. What are the two types of liquid column gauges?

1. Barometer, manometer



# Pressure Gauges

The distance from the top of the liquid in the reservoir to the top of the liquid in the barometer is the *barometric* (atmospheric) *pressure*. If atmospheric pressure changes, the level of the fluid in the tube changes as well.

Barometers are highly accurate and are often used as references for calibrating other pressure measurement devices. Barometers are also commonly used for weather forecasting.

## Manometer

A derivation of the barometer is the u-tube manometer. A *manometer* is a clear, U-shaped tube partially filled with fluid. One leg of the manometer is the reference side; the other leg is the measured side. A pressure measurement is made by comparing the fluid levels of the column in each leg of the U-tube manometer (Figure 1.8).

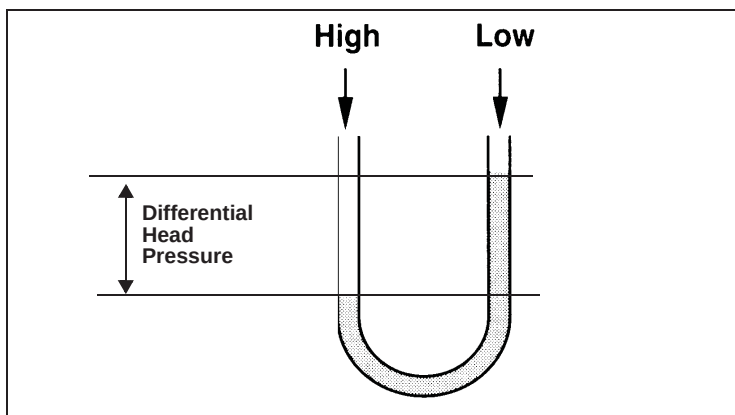


Figure 1.8: U-Tube Manometer

If the reference side of the U-tube manometer is open to atmospheric pressure, the manometer will function as a gauge instrument. If the reference side of the U-tube manometer is sealed, a vacuum exists above the fluid column on the reference side of the manometer. A manometer with a sealed reference side will function as an absolute instrument.

## Activities

2. How is a pressure measurement made with a manometer?

2. It measures pressure by comparing the fluid level in one leg to the fluid level in the other leg of the U-tube



# Pressure Gauges

## MECHANICAL PRESSURE GAUGES

Mechanical pressure gauges have two basic parts:

- Sensing device
- Mechanical dial or indicator (connected to the sensing device; gives a pressure reading)

The most common types of pressure-sensing devices are:

- Bourdon tubes
- Bellows and capsules

Mechanical pressure gauges are still widely used in the process control industry.

### Bourdon Tubes

*Bourdon tubes* are curled, flexible tubes with one closed end. As fluid flows into a bourdon tube, the tube straightens. As pressure increases, the tube straightens further. When pressure decreases, the tube springs back to its original shape. The motion is mechanically transferred to indicate the resulting pressure on a meter. Several different metals and other materials are used to make bourdon tubes.

Bourdon tubes come in four designs (Figure 1.9, Figure 1.10, and Figure 1.10):

- C-shaped
- Helical
- Spiral
- Twisted

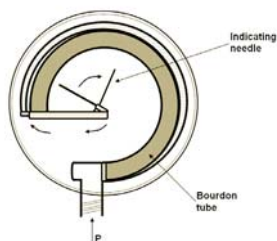


Figure 1.9: C-Shaped Bourdon Tube

## Activities

3. What are the four designs of bourdon tubes?

3. C shaped; twisted; helical; spiral



# Pressure Gauges

## Activities

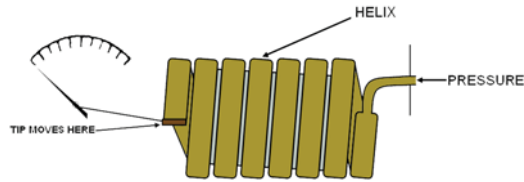


Figure 1.10: Helical Bourdon Tube

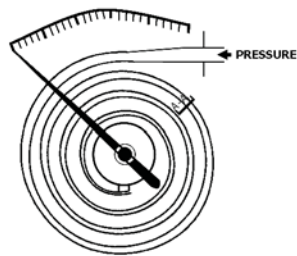


Figure 1.11: Spiral Bourdon Tube



# Pressure Gauges

## Capsules and Bellows

*Capsules* and *bellows* are pleated, flexible chambers that expand when filled with material under pressure. The individual chambers of a capsule are sealed. Only the first chamber is actually in contact with process pressure. Bellows open inside (Figure 1.12).

Capsules tend to spring back to their original shape when the pressure is released. Bellows often require an external spring to push them back into shape. A reference pressure may also be applied to the outside of the capsule or bellows (Figure 1.13).

## Activities

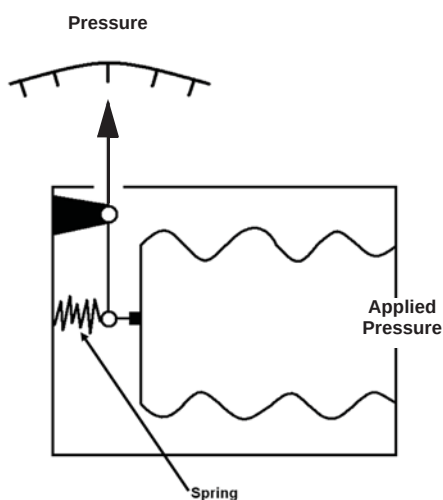


Figure 1.12: Bellows

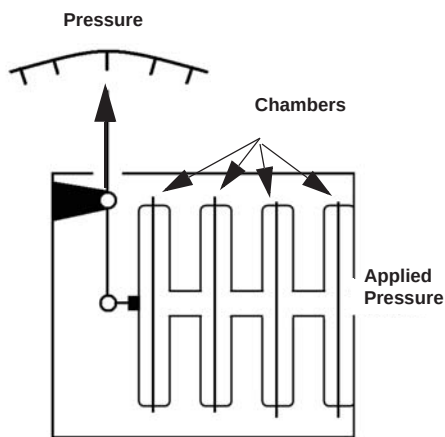


Figure 1.13: Capsular Element





# Pneumatic Pressure Cells

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Pneumatic devices consist of these components:

- ❑ *Sensing device*—Usually a diaphragm, bourdon tube, or capsular element
- ❑ *Supply pressure nozzle*—A steady stream of air flows through the supply nozzle
- ❑ *Flapper*—Connected to the sensing device; directs more or less of the air flow from the supply nozzle to the output pressure nozzle
- ❑ *Output pressure nozzle*—Receives a stream of air (regulated by the flapper) from the supply nozzle and directs the air stream out of the instrument to the actuator (or relay).

Because of the need to run pneumatic piping, reconfiguration of a pneumatic system is costly. In addition, pneumatic devices are less accurate than electronic devices.

## Activities

4. What are the parts of a pneumatic transducer?

4. Sensing device; supply nozzle; output nozzle; flapper



# Pneumatic Pressure Cells

## PNEUMATIC CONTROLLERS

A *pneumatic controller* is a device that, in response to an input pressure, sends a pneumatic output to a relay. A *relay* is a device that sends a pneumatic impulse strong enough to physically accomplish some action (e.g., open or close a valve) to regulate the process.

For example, as process pressure increases, a sensing device moves. Because the sensing device is connected to the flapper, the flapper also moves. The flapper is set to move back and forth over the opening of the supply nozzle in a way that directs more air flow through the output nozzle. Therefore, as process pressure increases, the air pressure output of the pneumatic device increases proportionately. In response to the output signal from the pneumatic controller, a valve in a relay opens allowing more pneumatic pressure to be sent to a valve. The pneumatic pressure sent by the relay adjusts the setting of the control valve in order to keep the process pressure within defined limits.

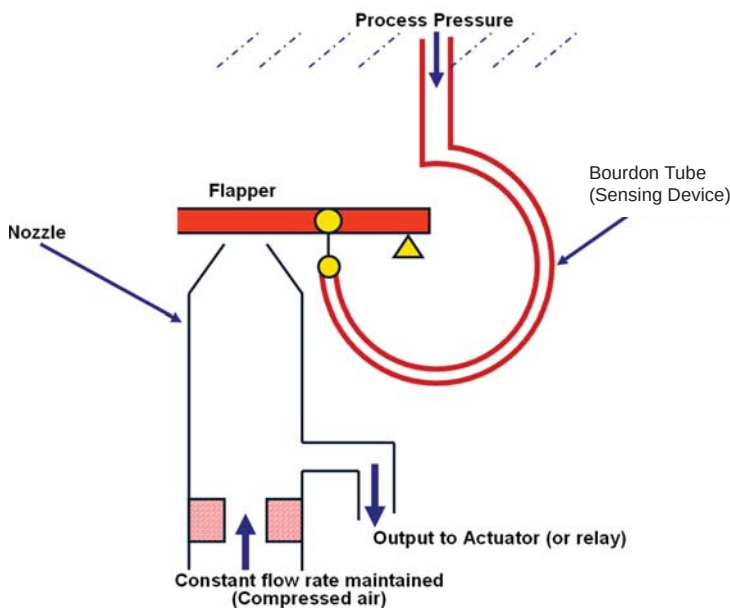


Figure 1.14: Pneumatic Controller

## Activities

5. What is a *pneumatic controller*?

5. A device that sends a pneumatic output in response to an input pressure



# Pneumatic Pressure Cells

## PNEUMATIC TRANSMITTERS

A *pneumatic transmitter* responds to an input pressure, puts out a proportionate, standardized pneumatic signal.

The most common industry standard for the output of pneumatic transmitters is 3–15 psig (206–1034 mbar). The pneumatic transmitter is calibrated so that when the process pressure is at its lowest acceptable point, the output of the transmitter is 3 psig (206 mbar). When the process pressure is at its maximum acceptable limit, the transmitter output is 15 psig. Pneumatic transmitter signals between 3 psig and 15 psig correspond to process pressures within the operating range (see Figure 1.15).

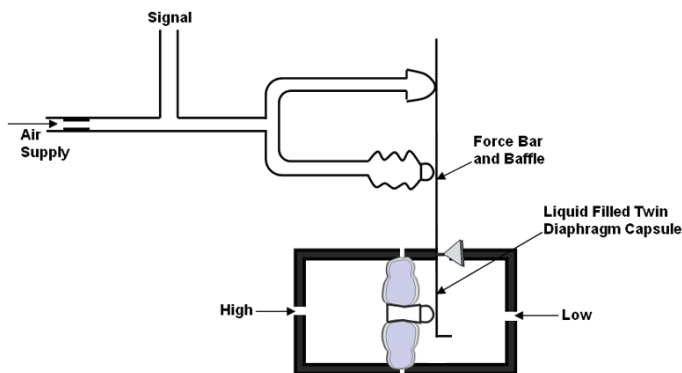


Figure 1.15: Pneumatic Transmitter

## Activities



# Electronic Pressure Transmitters

Electronic transmitters convert input process pressure into a digital or electrical signal. Electronic transmitters have two basic parts:

- Sensor
- Electronics

Like a mechanical pressure gauge's sensing device, the sensor of an electronic pressure transmitter physically responds to changes in input pressure. The sensor converts the physical movement into an electrical property, such as capacitance, voltage, inductance, or reluctance. The electronics part of the transmitter changes the output of the sensor into a standard electronic signal.

The most widely used electronic signal in the process control industry is the 4–20 mA signal. The 4–20 mA signal of an electronic transmitter is calibrated to relate the lowest process pressure point to an output of 4 mA from the transmitter. The maximum process pressure is calibrated to the 20 mA output of the transmitter. Therefore, the transmitter outputs between 4 mA and 20 mA correspond to process pressures within the operating range.

Several types of sensors used with electronic pressure transmitters are listed below:

- Variable capacitance
- Piezoresistive
- Piezoelectric
- Variable inductance
- Variable reluctance
- Vibrating wire
- Strain gauge

## VARIABLE CAPACITANCE

*Capacitance* is the ability of a substance to hold an electrical charge. A *capacitor* consists of two conductive plates aligned with one another but not making contact. The space between the plates is filled by an insulating medium known as a *dielectric*. The variable capacitance sensor for most pressure transmitters uses oil as the dielectric medium. Three factors affect the capacitance of a variable capacitance sensor:

- Surface area of the plates
- Insulating properties of the dielectric
- Distance between the plates

## Activities

6. List the two basic parts of an electronic pressure transmitter.

7. What is the most widely used electronic signal in the process control industry?

8. Define *capacitance*.

6. Sensor and electronics  
7. 4–20 mA signal  
8. The ability of a substance to hold an electric charge



# Electronic Pressure Transmitters

---

Considering the three factors that affect capacitance, only the distance between the capacitor plates is allowed to vary. The surface area and dielectric oil do not change.

The variable capacitor consists of a sensing diaphragm located between two capacitor plates with dielectric oil between the plates and diaphragm. Because the sensing diaphragm needs to be surrounded by the dielectric, it cannot be directly exposed to process pressure or fluid. Exposed directly to the process is the isolating diaphragm (Figure 1.16). Process pressure is applied to the isolating diaphragm, causing the sensing diaphragm to move. The movement of the sensing diaphragm results in a change in distance between the capacitor plates. A change in distance is a change in capacitance and directly proportional to the applied pressure.

## Operation

During operation, the isolating diaphragms and dielectric fluid on the process and reference sides of the sensor transmit the process and reference pressure to the dielectric fluid. The fluid in turn transmits the process and reference pressure to the sensing diaphragm in the center of the variable capacitance sensor. The sensing diaphragm deflects in response to the applied differential pressure. In gauge pressure transmitters, atmospheric pressure is transmitted to the low side of the sensing diaphragm. In absolute pressure transmitters, a reference pressure is maintained on the low side. The displacement of the sensing diaphragm is proportional to the pressure. Capacitor plates on both sides detect the position of the sensing diaphragm. The differential capacitance between the sensing diaphragm and the other capacitor plates is converted electronically to an appropriate current, voltage, or digital output signal.

## Activities

9. **True or False?** In a variable capacitance pressure transmitter, the isolating diaphragms will not be in contact with the process or reference pressure.

9. False



# Electronic Pressure Transmitters

## Activities

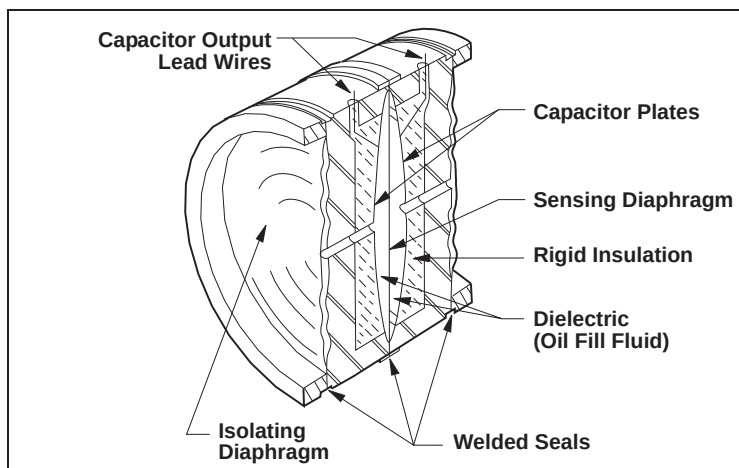


Figure 1.16: Variable Capacitance Sensor

### Benefits and Limitations of Variable Capacitance Devices

Variable capacitance devices are very durable, accurate and vibration resistant. They can be calibrated to measure both large and small amounts of pressure. The design reduces the potential damage due to overpressure conditions. Variable capacitance devices can be sensitive to changes in temperature.

Pressure transmitters that use variable capacitance are the most popular in the process control industry.

### PIEZORESISTANCE

*Resistance* is the amount of opposition to the flow of electricity exhibited by a particular conductor. A *piezoresistor* is a piece of metal or a semiconductor that exhibits a change in resistance when bent or stretched. In a piezoresistive transmitter, pressure is transmitted through a fill fluid from an isolating diaphragm to a piezoresistor (Figure 1.17). As the piezoresistor is flexed by pressure, its resistance changes. Typically, the piezoresistor is part of a configuration of electrical conductors and resistors measuring changes in resistance called a *wheatstone bridge*. The change in resistance is then converted by the electronic components of the transmitter into a standard control signal, commonly a milliamper, voltage, or digital control signal.

10. What is a *piezoresistor*?

11. What is a *wheatstone bridge* used for?

10. A piece of metal or a semiconductor that exhibits a change in electrical resistance when bent or stretched

11. To measure changes in resistance



# Electronic Pressure Transmitters

## Activities

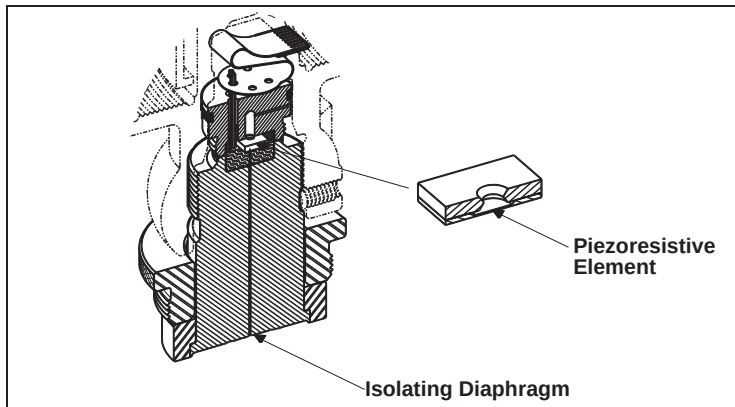


Figure 1.17: Piezoresistive Sensor

### Benefits and Limitations of Piezoresistive Devices

Piezoresistive devices are very responsive to pressure changes and highly accurate. Like variable capacitance devices, piezoresistive devices are sensitive to changes in temperature.

### PIEZOELECTRIC

The sensor of a piezoelectric transmitter consists of a pressure-sensing device, such as a diaphragm, connected to a piezoelectric crystal. A *piezoelectric crystal* is a natural or synthetic crystal that produces a voltage in response to applying a pressure. The piezoelectric crystal produces a very small voltage. The voltage is amplified and converted by the transmitter electronics into a standard control signal—commonly a milliampere, voltage, or digital control signal.

### Benefits and Limitations of Piezoelectric Devices

Piezoelectric measurement devices are sensitive to changes in pressure, but are not particularly good at measuring static pressure. Piezoelectric devices are temperature and vibration sensitive. Because of these limitations, piezoelectric technology is not widely used in the process control industry.

12. What happens when pressure is applied to a piezoelectric crystal?

12. The crystal produces a standard control signal



# Electronic Pressure Transmitters

---

## STRAIN GAUGE

The electrical property of resistance of a conductive substance changes as that substance is stretched. In a strain gauge, one end of a wire is attached to an elastic sensing device, and the other end of the wire is secured in place. As the sensing device moves in response to changes in pressure, the wire is stretched or relaxed. The variations in strain on the wire cause measurable changes in the resistance property of the wire. Changes in resistance are electronically converted into standard control signals, such as milliampere, voltage, or digital control signals.

Some strain gauges use foil cemented to the back of a sensing device instead of wires. As the amount of strain on the foil changes, resistance changes as well.

Piezoresistive transmitters are a form of strain gauge.

### Benefits and Limitations of Strain Gauge Devices

Strain gauges can be very sensitive to small changes in pressure, but the output of the strain gauge (i.e., a change in resistance) is very small and requires amplification. Strain gauges that are cemented to a sensing device can become partially detached and therefore inaccurate. Strain gauges are also extremely sensitive to temperature changes.

## VARIABLE INDUCTANCE

*Inductance* occurs when a body with magnetic or electrical properties passes those properties to another body without making contact. In a variable inductance transmitter, a movable iron core is surrounded by a coil of wire. An alternating current (ac) input is run through the coil. The iron core is attached to a sensing device (e.g., diaphragm or capsule). As the sensing device moves in response to pressure, the iron core moves in relation to the surrounding coil. The change in position of the iron core causes a proportionate change in the inductance of the coil. The change in inductance can be measured and converted electronically to a standard control signal, commonly a milliampere, voltage, or digital control signal.

## Activities





# Electronic Pressure Transmitters

## Benefits and Limitations of Variable Inductance Devices

Variable inductance devices are durable and not greatly influenced by vibration. They are, however, sensitive to fluctuations in temperature and to changes in the ambient electromagnetic field.

## VARIABLE RELUCTANCE

Variable reluctance transmitters convert changes in inductance into a standard milliampere, voltage, or digital control signal, but are configured differently than variable inductance transmitters. Two coils are placed on either side of a magnetic diaphragm. An ac voltage is run through the coils, which turns the coils into electromagnets. As the magnetic diaphragm moves closer to one coil and farther from the other in response to pressure, the inductance of the coils changes because of changes in the magnetic field around the coils. The property of a body to create change in a magnetic field is called *reluctance*.

## Benefits and Limitations of Variable Reluctance Devices

Because the basic operating principle is similar to variable inductance devices, variable reluctance devices exhibit similar characteristics. Variable reluctance devices are sensitive to fluctuations in temperature and in the ambient electromagnetic field.

## VIBRATING WIRE

Passing a current through a wire in a magnetic field causes the wire to vibrate. Changes in the wire tension will change the frequency of the wire vibration. If one end of the wire is attached to an elastic sensing device, such as a diaphragm, changes in pressure on the diaphragm will cause proportionate changes in the vibrational frequency of the wire. The frequency is measured and converted into a standard control signal, commonly a milliampere, voltage, or digital control signal.

## Activities

13. Define the electrical property of *reluctance*.

14. **True or false?** The electronic components of a pressure transmitter convert the frequency of the vibrating wire into a standard control signal.

13. The property of a body to create change in a magnetic field
14. True



# Electronic Pressure Transmitters

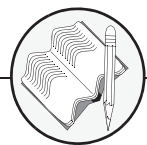
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## Benefits and Limitations of Vibrating Wire Devices

Because vibrating wire technology is dependent on measuring vibration, mechanical vibration of the device can cause inaccurate outputs.

## Activities

**COMPLETE WORKBOOK EXERCISE 1.5 ON PAGE 55**





# Workbook Exercises

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*Note: All exercise answers are located at the end of this module.*

## EXERCISE 1.1—WHAT IS PRESSURE?

1. In the equation:  $P = F/A$ ,  
P is \_\_\_\_\_ (Pressure / Power / Pound)  
F is \_\_\_\_\_ (Frequency / Farad / Force)  
A is \_\_\_\_\_ (Altitude / Area / Amplitude)
  
2. A closed tank with a volume of 18,000 ft<sup>3</sup> holds gas at a temperature of 500 °F and at a pressure of 2,000 psia. Would it be a good idea to transfer the gas to another closed tank with a volume of 6,000 ft<sup>3</sup> and a pressure limit of 4,000 psia?
  - a) Yes, transferring the gas is a good idea because pressure will increase to approximately 2,660 psia only, which is well within the specified pressure limit of the smaller tank.
  - b) Yes, transferring the gas is a good idea because the pressure of 2,000 psia will be well within the 4,000 psia pressure limit of the smaller tank.
  - c) No, transferring the gas is not a good idea because the pressure will increase to 6,000 psia, which is much more than the 4,000 psia pressure limit of the smaller tank.
  - d) No, transferring the gas is not a good idea because it is not possible to transfer a gas at a temperature of 500 °F.
  
3. A closed tank with a volume of 18,000 ft<sup>3</sup> holds gas at a temperature of 500 °F and at a pressure of 2,000 psia. If the gas is cooled to 100 °F, will it be a good idea to transfer the gas to another closed tank with a volume of 6,000 ft<sup>3</sup> and a pressure limit of 4,000 psia?
  - a) Yes, transferring the gas is a good idea because the decrease in pressure will be proportionate to the decrease in temperature.
  - b) No, transferring the gas is not a good idea because the pressure will not decrease below the 4,000 psia pressure limit of the smaller tank.
  - c) No, transferring the gas is not a good idea because it is not possible to transfer a gas at a temperature of 100 °F.



# Workbook Exercises

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## EXERCISE 1.2—WHY MEASURE PRESSURE?

1. Match each pressure-measurement application to the correct scenario.

\_\_\_ Process efficiency

\_\_\_ Safety/environmental

\_\_\_ Inferred measurement

\_\_\_ Cost savings

a) A flanged connection on a pipe has burst pressure limit of 750 psig. If the pressure exceeds 750 psig, the connection will release toxic fluid.

b) A dairy uses a compressor to pump air into the top of a closed tank to force milk out of the tank and into a pipeline. To save money, the compressor should be turned off as soon as the tank is empty.

c) A commercial brewer needs to know at what point in the process to begin cold filtering.

d) A natural gas distributor uses a differential pressure measurement to determine the amount of gas being distributed through a pipe to a customer.



# Workbook Exercises

## EXERCISE 1.3—PRESSURE TERMINOLOGY

1. An oil refinery uses a process that produces a maximum pressure of 35 bar. The refinery manager asks if the process connection of a particular Rosemount transmitter is rated to withstand such a pressure. The Rosemount product literature lists the pressure ratings in psig.

Use the table below to determine the pressure reading in psig, then circle an answer below.

- a)  $35 \times 14.5038 = 507.633$  psig
- b)  $35 \times 0.0193 = 0.6755$  psig
- c)  $35 \times 29.5300 = 1033.55$  psig
- d)  $35 \times 0.0689 = 2.4115$  psig

To use the table:

- Locate the units you are converting from in the column on the left.
- Locate the units you are converting to in the top row.
- Locate the factor at the intersection of the Convert From row and the Convert To column.
- Multiply the units you are converting from by the factor to convert the units.

Convert To

| Convert From |                    | psi     | kPa     | inH <sub>2</sub> O | mmH <sub>2</sub> O | inHg    | mmHg    | bar    | mbar    | kg/cm <sup>2</sup> | gm/cm <sup>2</sup> |
|--------------|--------------------|---------|---------|--------------------|--------------------|---------|---------|--------|---------|--------------------|--------------------|
|              | psi                | 1       | 6.8948  | 27.7296            | 704.332            | 2.0360  | 51.7149 | 0.0689 | 68.9476 | 0.0703             | 70.3070            |
|              | kPa                | 0.1450  | 1       | 4.0218             | 102.155            | 0.2953  | 7.5006  | 0.0100 | 10.000  | 0.0102             | 10.197             |
|              | inH <sub>2</sub> O | 0.0361  | 0.2486  | 1                  | 25.4000            | 0.0734  | 1.8650  | 0.0025 | 2.4864  | 0.0025             | 2.5355             |
|              | mmH <sub>2</sub> O | 0.0014  | 0.0098  | 0.0394             | 1                  | 0.0029  | 0.0734  | 0.0001 | 0.0979  | 0.00001            | 0.0998             |
|              | inHg               | 0.0412  | 3.3864  | 13.6195            | 345.936            | 1       | 25.4000 | 0.0339 | 33.8639 | 0.0345             | 34.532             |
|              | mmHg               | 0.0193  | 0.1333  | 0.5362             | 13.6195            | 0.0394  | 1       | 0.0013 | 1.3332  | 0.0014             | 1.3595             |
|              | bar                | 14.5038 | 100.000 | 402.184            | 10215.5            | 29.5300 | 740.062 | 1      | 1000    | 1.0197             | 1019.72            |
|              | mbar               | 0.0145  | 0.1000  | 0.4022             | 10.2155            | 0.0295  | 0.7501  | 0.001  | 1       | 0.0010             | 1.0197             |
|              | kg/cm <sup>2</sup> | 14.2233 | 98.0665 | 394.408            | 10018.0            | 28.9590 | 735.559 | 0.9807 | 980.665 | 1                  | 1000               |
|              | gm/cm <sup>2</sup> | 0.0142  | 0.0981  | 0.3944             | 10.0180            | 0.9290  | 0.7356  | 0.0010 | 0.9807  | 0.001              | 1                  |



## Workbook Exercises

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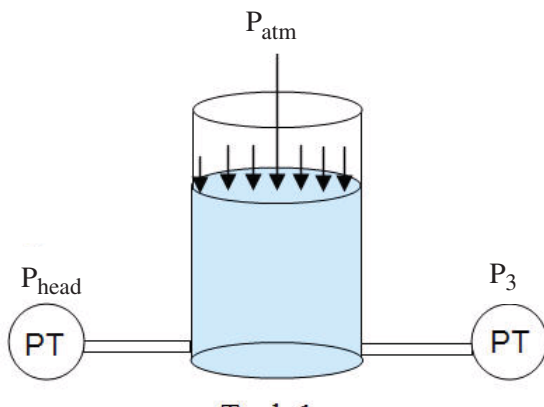
2. The pressure reading of an absolute transmitter on an open tank is 500 psia. If atmospheric pressure is 14.7 psi, what is the gauge pressure of the tank?
- a)  $500 \text{ psia} / 14.7 \text{ psia} = 34.01 \text{ psig}$
  - b)  $500 \text{ psia} + 14.7 \text{ psia} = 514.7 \text{ psig}$
  - c)  $500 \text{ psia} \times 14.7 \text{ psia} = 7350 \text{ psig}$
  - d)  $500 \text{ psia} - 14.7 \text{ psia} = 485.3 \text{ psig}$
3. A constant operating pressure is known as \_\_\_\_\_ pressure, while the pressure exerted by a column of fluid is known as \_\_\_\_\_ pressure.
- a) Head
  - b) Static
  - c) Vapor



## Workbook Exercises

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4. If the pressure on the surface ( $P_{\text{atm}}$ ) of Tank 1 is 14.7 psia and the pressure exerted by the column of fluid ( $P_{\text{head}}$ ) is 4.3 psig, what is the pressure reading ( $P_3$ ) when using an absolute instrument measurement device?
- a) 3.41 psia
  - b) 19.0 psia
  - c) 63.21 psia
  - d) 10.4 psia



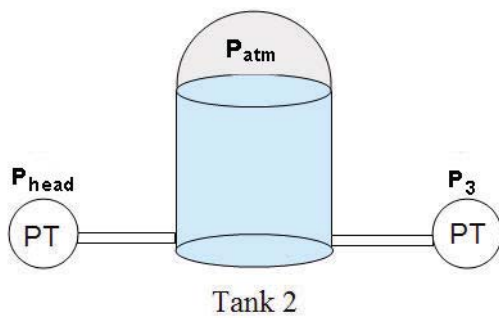
5. If Tank 1 above has a  $P_{\text{atm}}$  of 14.7 psia and a  $P_{\text{head}}$  of 20.7 psia, what is the value of  $P_3$  when measured by a gauge instrument?
- a) 14.7 psig, because the gauge instrument subtracts the liquid column pressure and takes only the atmospheric pressure.
  - b) 19.0 psig, because the gauge instrument gives the summation of liquid column pressure and atmospheric pressure.
  - c) 6.0 psig, because the gauge instrument subtracts the atmospheric pressure and gives only the liquid column pressure.
  - d) 10.4 psig, because the gauge instrument subtracts the liquid column pressure from the atmospheric pressure.



## Workbook Exercises

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6. Tank 2 has a  $P_{\text{atm}}$  value of  $-2$  psig, a  $P_{\text{head}}$  value of  $6.2$  psig, and is located in an environment where the atmospheric pressure is  $14.7$  psia. What is the value of  $P_3$  when using an absolute instrument measurement device?
- a)  $18.9$  psia
  - b)  $22.9$  psia
  - c)  $2.04$  psia
  - d)  $78.74$  psia







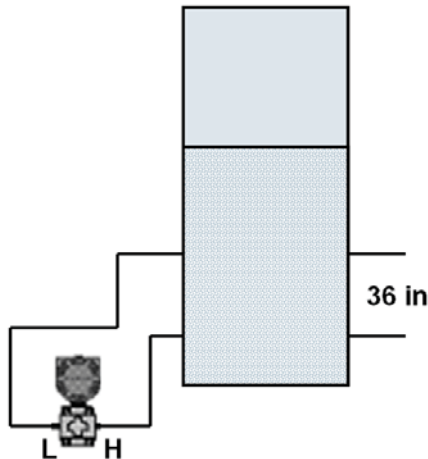
# Workbook Exercises

## EXERCISE 1.4—INFERRING NON-PRESSURE VARIABLES

- If the specific gravity of a process fluid in an open tank is 1.3 and the measured gauge pressure is 150 inH<sub>2</sub>O, what is the fluid level in the tank?
  - Pressure / Specific Gravity, or:  $150 / 1.3 = 115.4$  in
  - Pressure x Specific Gravity, or:  $150 \times 1.3 = 195$  in
  - Pressure + Specific Gravity, or:  $150 + 1.3 = 151.3$  in
  - Pressure – Specific Gravity, or:  $150 - 1.3 = 148.7$  in
- In the figure below, the pressure at the bottom is 12 psig and the pressure at the top is 10 psig. The difference between the two provides a differential pressure value of 2 psig, which converts to 55.4592 inH<sub>2</sub>O. Using the conversion table on the next page, complete the following formula to determine the specific gravity of the fluid:

55.4592 \_\_\_\_ 36 = \_\_\_\_\_

- |      |            |
|------|------------|
| a) + | a) 91.4592 |
| b) – | b) 1.540   |
| c) / | c) 19.4592 |





# Workbook Exercises

|              |                    | Convert To |         |                    |                    |         |         |        |         |                    |                    |
|--------------|--------------------|------------|---------|--------------------|--------------------|---------|---------|--------|---------|--------------------|--------------------|
| Convert From |                    | psi        | kPa     | inH <sub>2</sub> O | mmH <sub>2</sub> O | inHg    | mmHg    | bar    | mbar    | kg/cm <sup>2</sup> | gm/cm <sup>2</sup> |
|              | psi                | 1          | 6.8948  | 27.7296            | 704.332            | 2.0360  | 51.7149 | 0.0689 | 68.9476 | 0.0703             | 70.3070            |
|              | kPa                | 0.1450     | 1       | 4.0218             | 102.155            | 0.2953  | 7.5006  | 0.0100 | 10.000  | 0.0102             | 10.197             |
|              | inH <sub>2</sub> O | 0.0361     | 0.2486  | 1                  | 25.4000            | 0.0734  | 1.8650  | 0.0025 | 2.4864  | 0.0025             | 2.5355             |
|              | mmH <sub>2</sub> O | 0.0014     | 0.0098  | 0.0394             | 1                  | 0.0029  | 0.0734  | 0.0001 | 0.0979  | 0.00001            | 0.0998             |
|              | inHg               | 0.0412     | 3.3864  | 13.6195            | 345.936            | 1       | 25.4000 | 0.0339 | 33.8639 | 0.0345             | 34.532             |
|              | mmHg               | 0.0193     | 0.1333  | 0.5362             | 13.6195            | 0.0394  | 1       | 0.0013 | 1.3332  | 0.0014             | 1.3595             |
|              | bar                | 14.5038    | 100.000 | 402.184            | 10215.5            | 29.5300 | 740.062 | 1      | 1000    | 1.0197             | 1019.72            |
|              | mbar               | 0.0145     | 0.1000  | 0.4022             | 10.2155            | 0.0295  | 0.7501  | 0.001  | 1       | 0.0010             | 1.0197             |
|              | kg/cm <sup>2</sup> | 14.2233    | 98.0665 | 394.408            | 10018.0            | 28.9590 | 735.559 | 0.9807 | 980.665 | 1                  | 1000               |
|              | gm/cm <sup>2</sup> | 0.0142     | 0.0981  | 0.3944             | 10.0180            | 0.9290  | 0.7356  | 0.0010 | 0.9807  | 0.001              | 1                  |

3. According to Bernoulli's equation, flow rate is proportional to the \_\_\_\_\_ of differential pressure.
- a) Inverse
  - b) Square root
  - c) Cube root

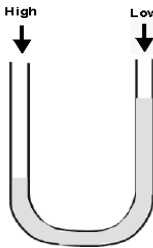


# Workbook Exercises

## EXERCISE 1.5—PRESSURE MEASUREMENT AND CONTROL

1. Match each technology or device to the correct description.

- |                          |                                                                                                                             |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| ___ Manometer            | a) Exposes a crystal to changes in pressure and measures the corresponding changes in voltage being put out by the crystal. |
| ___ Piezo-resistive      | b) Is the most popular electronic sensing technology in the process control industry.                                       |
| ___ Variable capacitance | c) Uses a semiconductor that exhibits a change in resistance when bent or flexed.                                           |
| ___ Piezo-electric       | d)                                                                                                                          |



2. Match each technology or device to the correct description.

- |                                                    |                                                                                                    |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------|
| ___ Variable capacitance                           | a) Is the most common pneumatic output signal in the process control industry.                     |
| ___ 3–15 psig                                      | b) Is particularly sensitive to changes in the ambient electromagnetic field.                      |
| ___ Variable inductance and/or variable reluctance | c) Consists of a twisted tube with one closed end that straightens when filled with process fluid. |
| ___ Bourdon tube                                   | d) Is the most common electronic output signal in the process control industry.                    |
| ___ 4–20 mA scale                                  | e) Has di-electric fluid as part of the sensing device.                                            |



# Workbook Answers

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## Exercise 1.1—What Is Pressure?

1. Pressure, Force, Area
2. c
3. a

## Exercise 1.2—Why Measure Pressure?

1. c, a, d, b

## Exercise 1.3—Pressure Terminology

1. a
2. d
3. b, a
4. b
5. c
6. a

## Exercise 1.4—Inferring Non-Pressure Variables

1. a
2. c, b
3. b



# Workbook Answers

## Exercise 1.5—Pressure Measurement and Control

1. Match each technology or device to the correct description.

d Manometer

a) Exposes a crystal to changes in pressure and measures the corresponding changes in voltage being put out by the crystal.

c Piezo-resistive

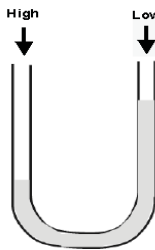
b) Is the most popular electronic sensing technology in the process control industry.

b Variable capacitance

c) Uses a semiconductor that exhibits a change in resistance when bent or flexed.

a Piezo-electric

d)



2. Match each technology or device to the correct description.

e Variable capacitance

a) Is the most common pneumatic output signal in the process control industry.

a 3–15 psig

b) Is particularly sensitive to changes in the ambient electromagnetic field.

b Variable inductance  
and/or variable reluctance

c) Consists of a twisted tube with one closed end that straightens when filled with process fluid.

c Bourdon tube

d) Is the most common electronic output signal in the process control industry.

d 4–20 mA scale

e) Has di-electric fluid as part of the sensing device.

