Introduction to Pressure Measurement

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Objectives

After you have read this unit, you should able to

- **Define** "What is Pressure"?
- **List and briefly explain** the need for measuring pressure.
- **Name** different methods for pressure measurement
- **Explain** the working principle of manometers, elastic elements (diaphragms, bellows and Bourdon tubes) to measure pressure and also **explain** the different method of vacuum pressure measurement.
- **Describe** the general construction, installation and **identify** the materials of pressure sensors.
- **Compare** all the pressure measuring instruments in terms of their overall performance and cost and **select** the proper pressure measuring instrument for a particular range of pressure.

Introduction

- Measurement of pressure inside a pipeline or a container in an industrial environment is a challenging task, keeping in mind that pressure may be very high, or very low (vacuum); the medium may be liquid, or gaseous.
- 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.
- Most relevant to industrial measurement of pressure in three modes namely **absolute-mode, gauge-mode** and **differential-mode** measurements.

The Pressure Equation

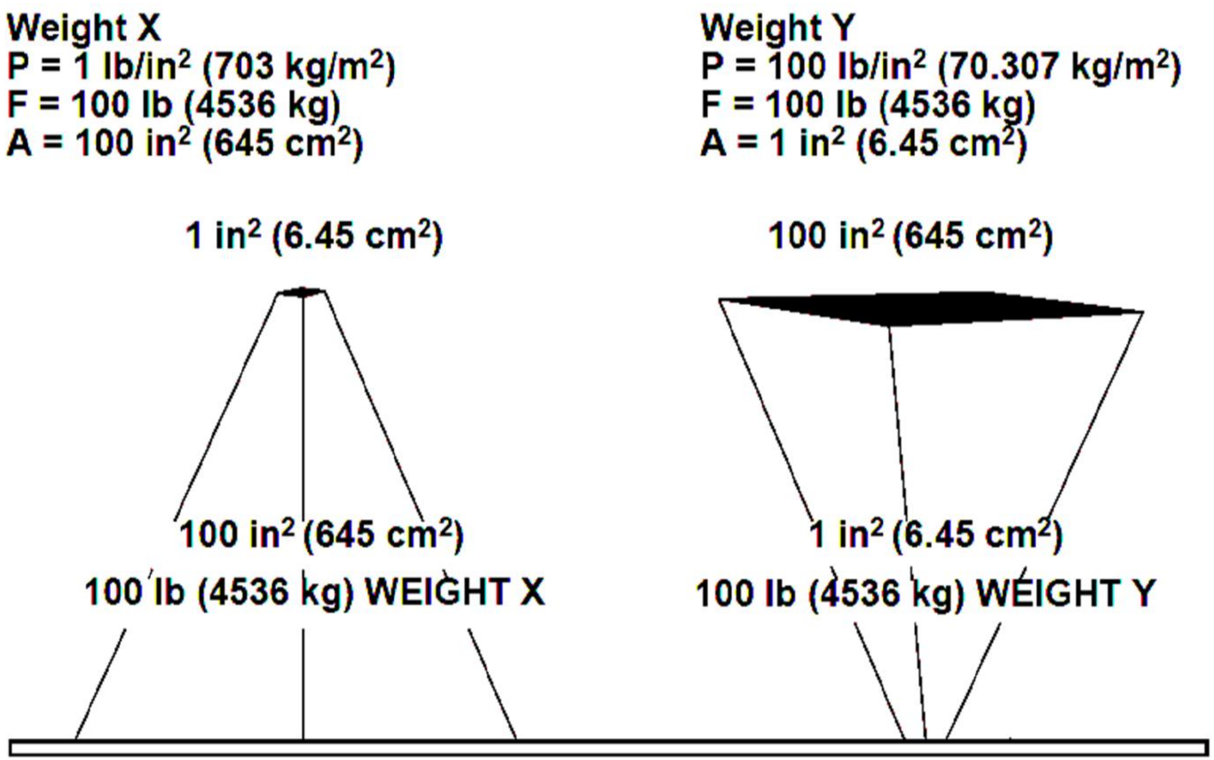
- Pressure is the amount of force applied over a defined area.
- The relationship between pressure, force, and area is represented in the following formula:

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

- 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.

EXPLANATION

- Weight X and Weight Y in Figure are applying different amounts of pressure to the surface, even though the two weights are each 100 lb (4536 kg).



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 (kg/cm2)
  - Grams per square centimeter (g/cm2)—1 g/cm2 = 1,000 kg/cm2
  - Pascals (Pa or N/m2)—N stands for *newton*
  - Kilopascals (kPa)—1 kPa = 1,000 Pa
  - Bar—1 bar = 100,000 Pa
  - Millibar (mbar)—1 mbar = 1/1,000 bar

Pressure Units

- **UNITS REFERENCED TO COLUMNS OF FLUID**
- The following are units of pressure referenced to a column of fluid:
  - Inches of water (inH2O at 68 °F [20 °C] or at 39.2 °F [4 °C])
  - Feet of water (ftH2O)
  - Meters of water (mH2O)
  - Millimeters of water (mmH2O)
  - Inches of mercury (inHg)
  - Millimeters of mercury (mmHg)
  - Atmosphere (atm)—The pressure exerted by the earth's atmosphere at sea level
  - Torr—1 torr = 1 mmHg

USEFUL PRESSURE UNITS

Useful units and conversion factors:

- 1 Pascal or 1 Pa = 1 N/m2,
- 1 atmosphere = 760 mm mercury column

  = 1.013×105Pa
- 1 mm mercury column = 1 Torr
- 1 Torr = 1.316×10-3 atmosphere = 133.3 Pa
- 1 bar = 105 Pa

Reference Pressures

- The three types 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 is 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.

Gauge Pressure

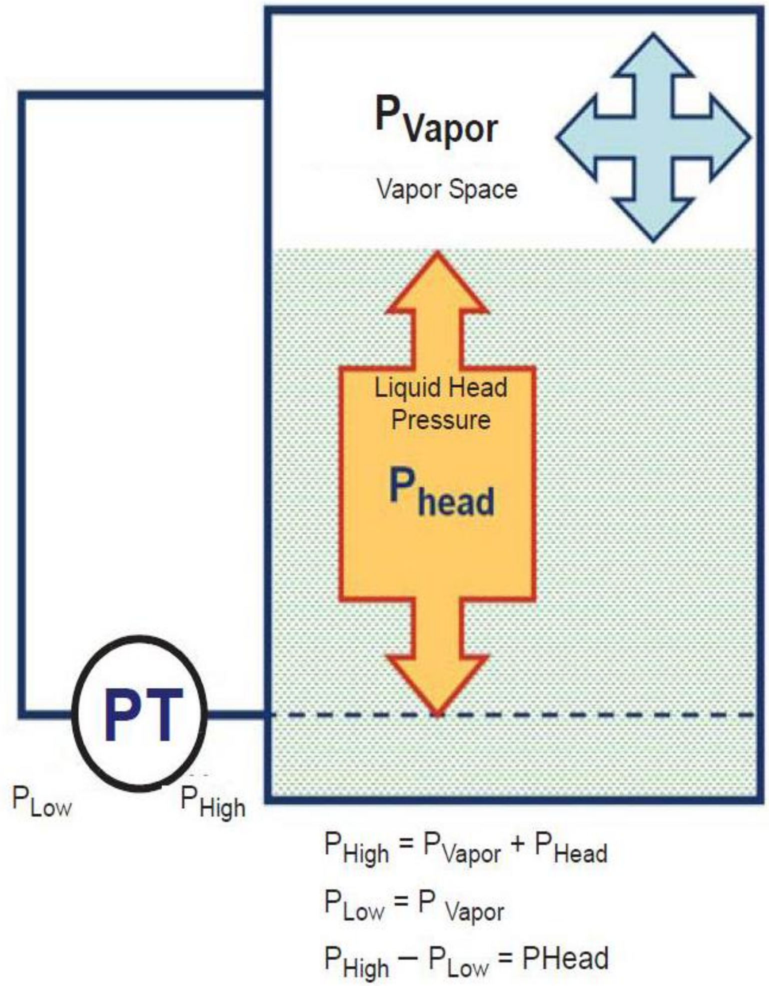
- A gauge pressure transmitter has its low side referenced to the surrounding atmosphere (approximately 14.7 psi or 101.6kPa).
- The high side, then measures the process.
- Changes in atmospheric pressure will impact the process and the low side of the transmitter the same, so that there is no impact on high side measurement.
- **Gauge pressure transmitters are often used to measure pressure in a pipe or liquid level in an open tank.**

Differential Pressure

- Differential pressure transmitter has its high and low side which are connected to the process.
- **Differential pressure transmitters are often used to measure flow or liquid level in a closed tank.**

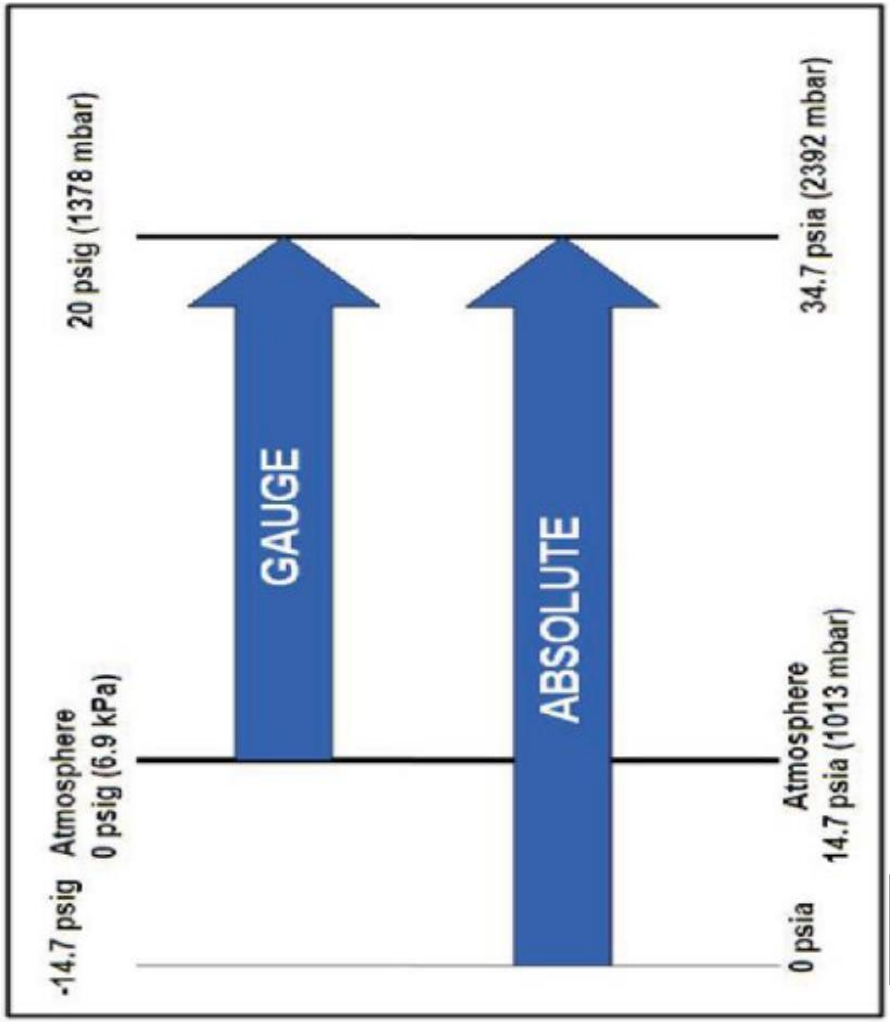
Illustration

- 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 and above the liquid level, will only measure the vapor pressure.
- Since the DP transmitter measurement is DP=PHIGH-PLOW and both the high and low side include the vapor space pressure, it is subtracted out. The resulting output is the true level measurement.



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.**



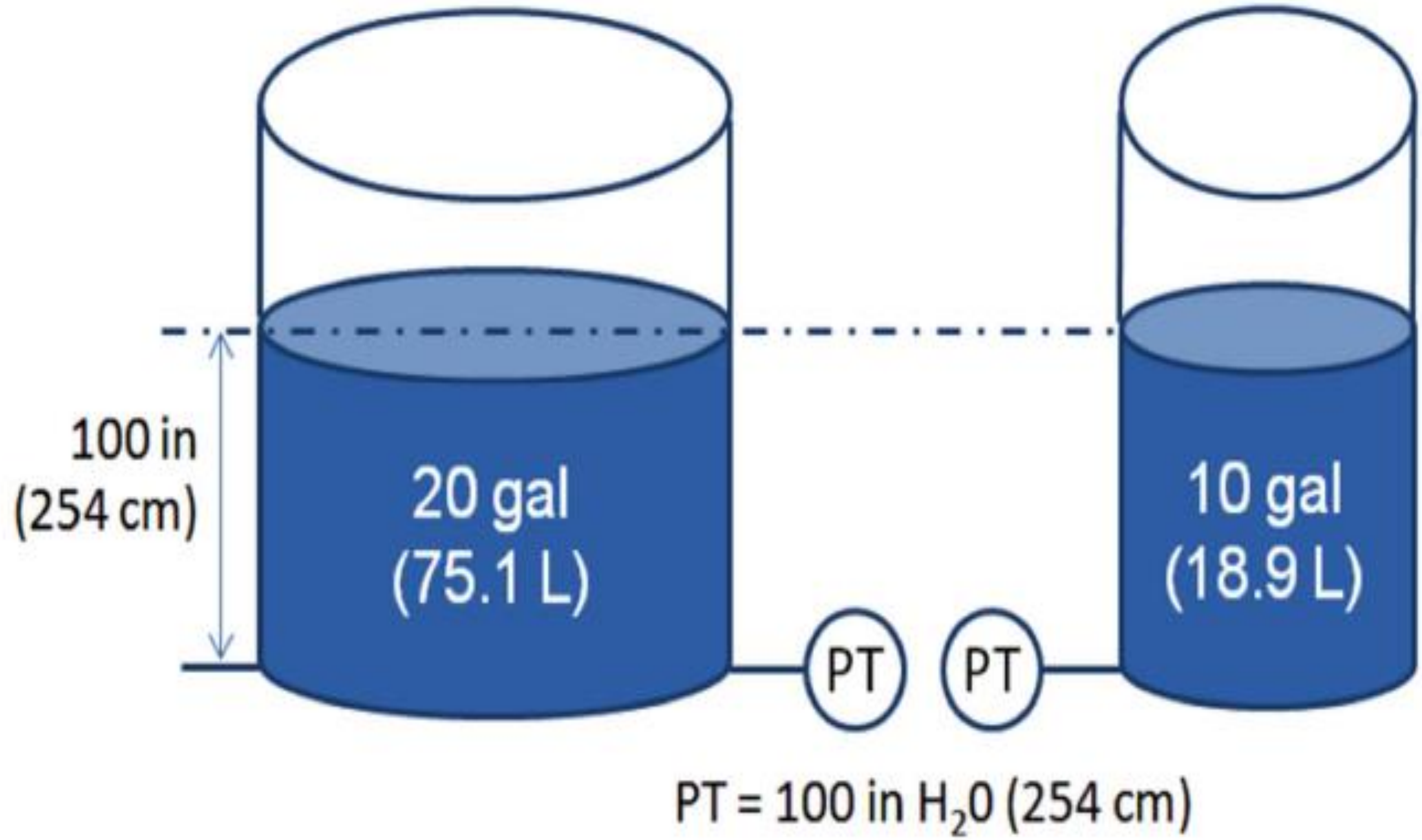
PRESSURE VARIABLES

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

Height of liquid in a column

- 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 will be equal to the pressure at the bottom of a smaller tank when the height of liquid is the same.

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


100 in
(254 cm)
20 gal
(75.1 L)
10 gal
(18.9 L)
PT
PT
PT = 100 in H2O (254 cm)

Density of a Liquid

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

$$Density = \frac{Mass}{Volume}$$

- 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.

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 gauge pressure measurement is sufficient for level measurement.

Head Pressure (Ullage Pressure)

- 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 atmosphere.
- This buffer gas will exert a pressure on the column of liquid that must be subtracted from the measurement of the height of the liquid column otherwise error will occur.
- Differential pressure measurement, where the low side reference leg is connected to the vapor space will allow the head pressure to be subtracted out.

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 as 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:

$$P_1V_1 = P_2V_2$$

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.

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

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.

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 set point (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.

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