Engineering Thermodynamics MEA1110

Unit I

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Unit-I

Introduction: Basic Concepts and Definitions (Thermodynamic Systems, Properties, States, Processes, Cycles, Thermodynamic Equilibrium, Quasi-Static Process), Pressure and its Measurement, Zeroth Law of Thermodynamics, Temperature and its Measurement.

Pressure

$$\Delta P = P_2 - P_1 = \rho g \, \Delta z = \gamma_s \, \Delta z$$

If we take point 1 to be at the free surface of a liquid open to the atmosphere, where the pressure is the atmospheric pressure P_{atm}, *then* the pressure at a depth *h from the free surface becomes* $P = P_{\text{atm}} + \rho g h$ or $P_{\text{gage}} = \rho g h$

For fluids whose density changes significantly with elevation,

$$\frac{dP}{dz} = -\rho g$$

The pressure difference between points 1 and 2 can be determined by

$$\Delta P = P_2 - P_1 = -\int_1^2 \rho g \, dz$$

Pressure in a fluid at rest is independent of the shape or cross section of the container. It changes with the vertical distance, but remains constant in other directions.

Pascal's Law

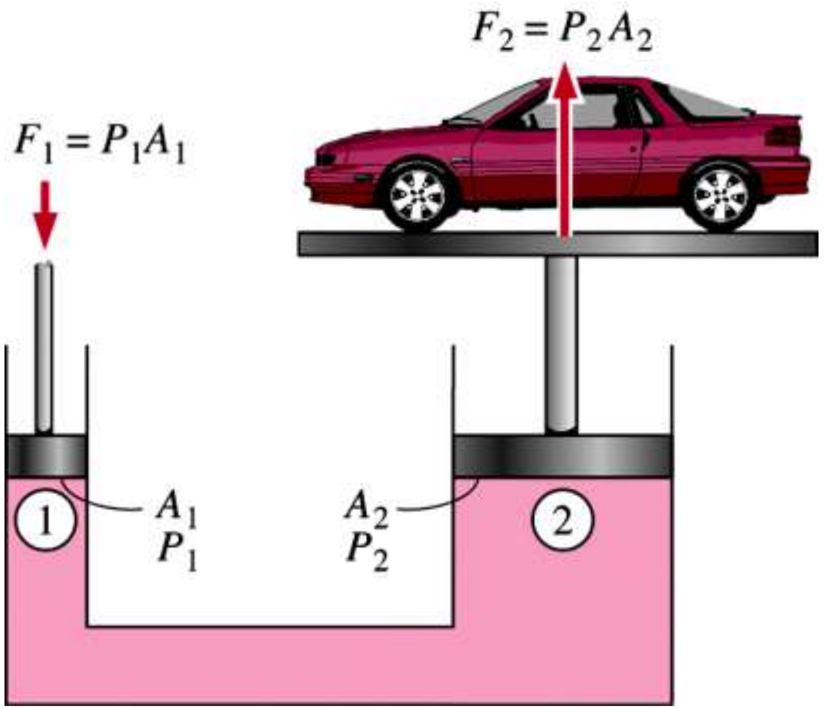
A consequence of the pressure in a fluid remaining constant in the horizontal direction is that *the pressure applied to a confined fluid increases the pressure throughout by the same amount. This is called* ***Pascal's law, after*** Blaise Pascal (1623–1662).

Ideal Mechanical Advantage

- A small input force generates a large output force
- Pressure applied to a confined fluid increases the pressure throughout by the same amount.
- In picture, pistons are at same height:

$$P_1 = P_2 \rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2} \rightarrow \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

- Ratio A_2/A_1 is called ideal mechanical advantage

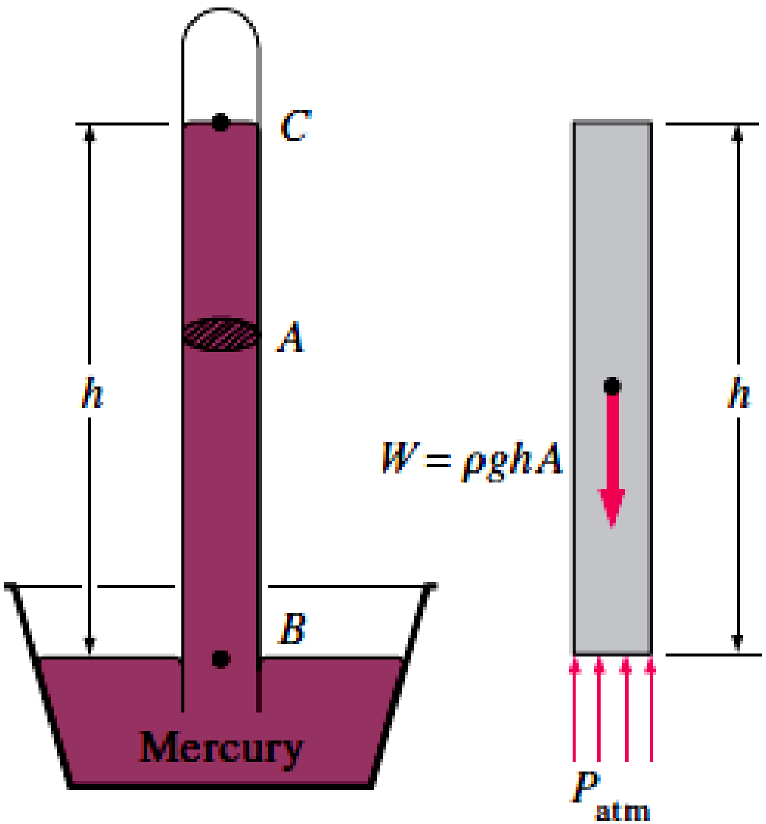


The mercury barometer

- Atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as the barometric pressure.

- A frequently used pressure unit is the standard atmosphere, which is defined as the pressure produced by a column of mercury 760 mm in height at 0°C (ρ_{Hg}=13,595kg/m^3) under standard gravitational acceleration (g =9.807 m/s^2).

- The Italian Evangelista Torricelli (1608–1647) was the first to prove that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere.



Mercury has an extremely small vapor pressure at room temperature (almost vacuum), thus p_C = 0. Writing a force balance in the vertical direction gives

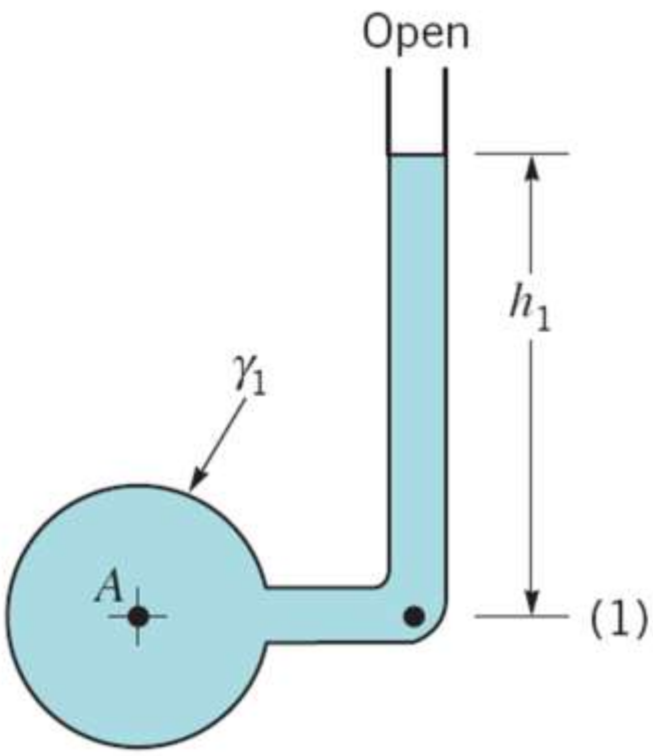
$$P_{atm} = \rho g h$$

The Manometers and Manometry

- Science of pressure measurement is called **Manometry.**
- The device similar to barometer and used to measure pressure is called *Manometer*.
- Manometers measure a pressure difference by balancing the weight of a fluid column between the two pressures of interest.
- Three common types of manometers are ***Piezometer tube, U-tube Manometer and Inclined tube manometer***.

Piezometer tube

- An elevation change of h_1 in a fluid at rest corresponds to $\Delta p/\rho g$.
- A device based on this is called a Piezometer tube.
- $p_A = p_1 - p_{atm} = \rho g h_1$
- $p_{Agage} = p_{1gage} = \rho g h_1$
- $p_A \propto h_1$
- Disadvantages:
  - Can't measure Gas pressures
  - Can't measure pressure in vacuum
  - Difficult to measure large pressure.

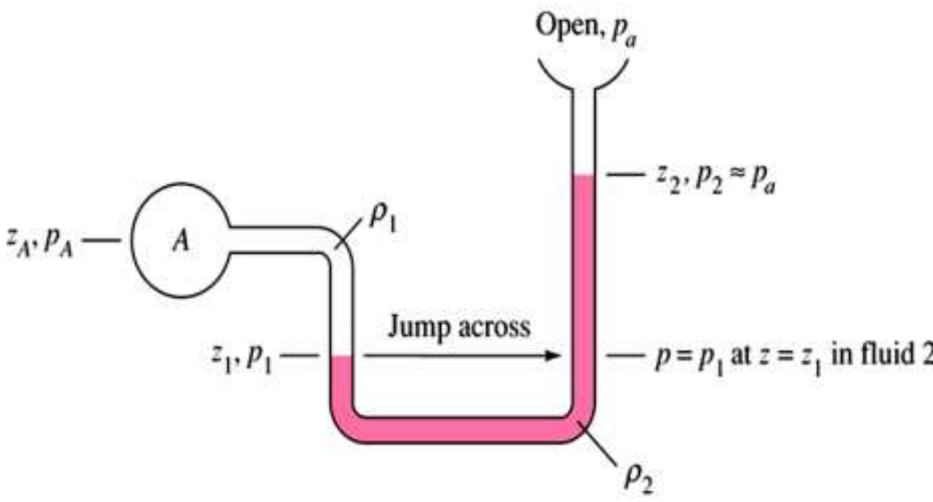


U-tube Manometer

- A manometer consists of a U-tube containing one or more fluids such as mercury, water, alcohol, or oil.
- Heavy fluids such as mercury are used if large pressure differences are anticipated.
- Overcomes the advantage of Piezometer tube.
- It is commonly used to measure small and moderate pressure differences.

Manometric calculation

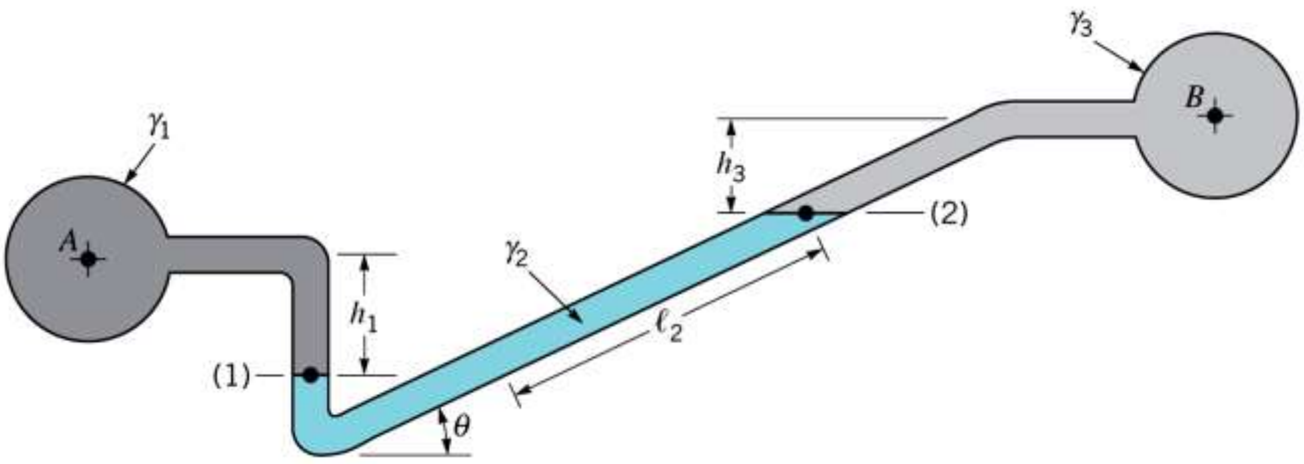
1. Begin writing pressures from any end of manometer.
2. Keep on adding pressure increments on going **down** through the fluid in *same* column. Use equation: $\mathbf{p_{down} = p^{up} + \gamma|\Delta h|}$
3. Jump across to other column when two points in same fluid are at equal elevations (Pascal's Law).
4. Keep on repeating steps 2 and 3 until you reach other end.
5. Solve the system of equations of obtain unknown pressures.



$$p_A + \gamma_1|z_A - z_1| - \gamma_2|z_1 - z_2| = p_2 = p_{atm}$$

Inclined tube manometer

- Its difficult to detect small pressure changes in U-tube manometer.
- To detect small pressure changes, inclined tube manometer is used.
- One leg is inclined at angle θ (variable) with horizontal.
- Difference in level as seen in inclined tube is l_2.
- Pressure difference is *not due* to l_2 but due to its *vertical projection* i.e. $\boldsymbol{l_2 sin\theta}$.
- $p_A - p_B = \gamma_2 l_2 \boldsymbol{sin\theta} + \gamma_3 h_3 - \gamma_1 h_1$
- If A and B contain gas (gas pressures are usually neglected), so
- $p_A - p_B = \gamma_2 l_2 \boldsymbol{sin\theta}$
- ***or*** $l_2 = \frac{p_A - p_B}{\boldsymbol{sin\theta}}$



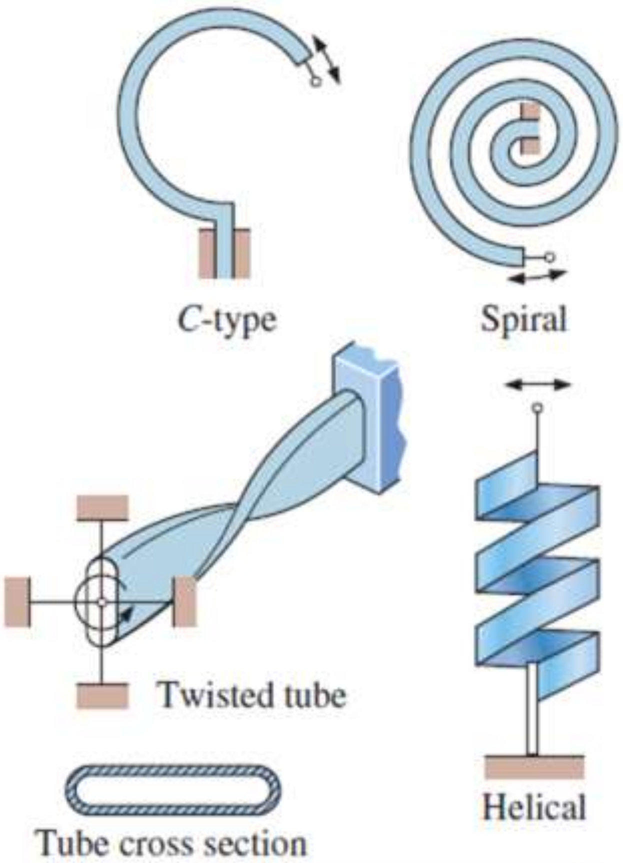
Other Pressure Measurement Devices

Bourdon tube: Consists of a hollow metal tube bent like a hook whose end is closed and connected to a dial indicator needle.

Pressure transducers: Use various techniques to convert the pressure effect to an electrical effect such as a change in voltage, resistance, or capacitance. Pressure transducers are smaller and faster, and they can be more sensitive, reliable, and precise than their mechanical counterparts.

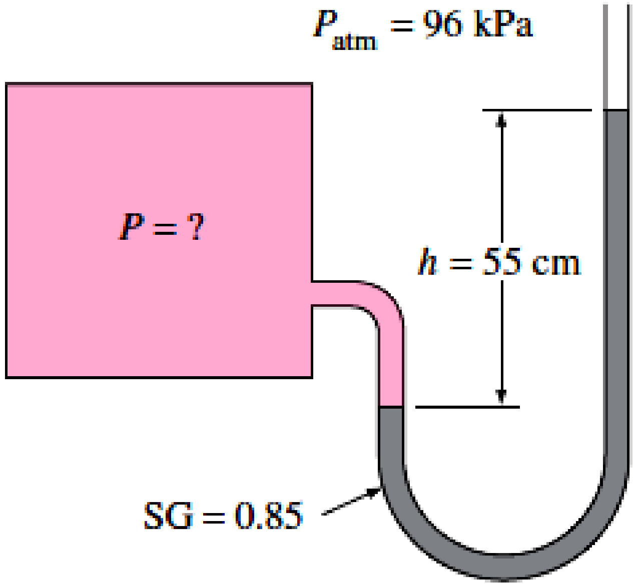
Strain-gage pressure transducers: Work by having a diaphragm deflect between two chambers open to the pressure inputs.

Piezoelectric transducers: Also called *solid-state pressure transducers*, work on the principle that an electric potential is generated in a crystalline substance when it is subjected to mechanical pressure.



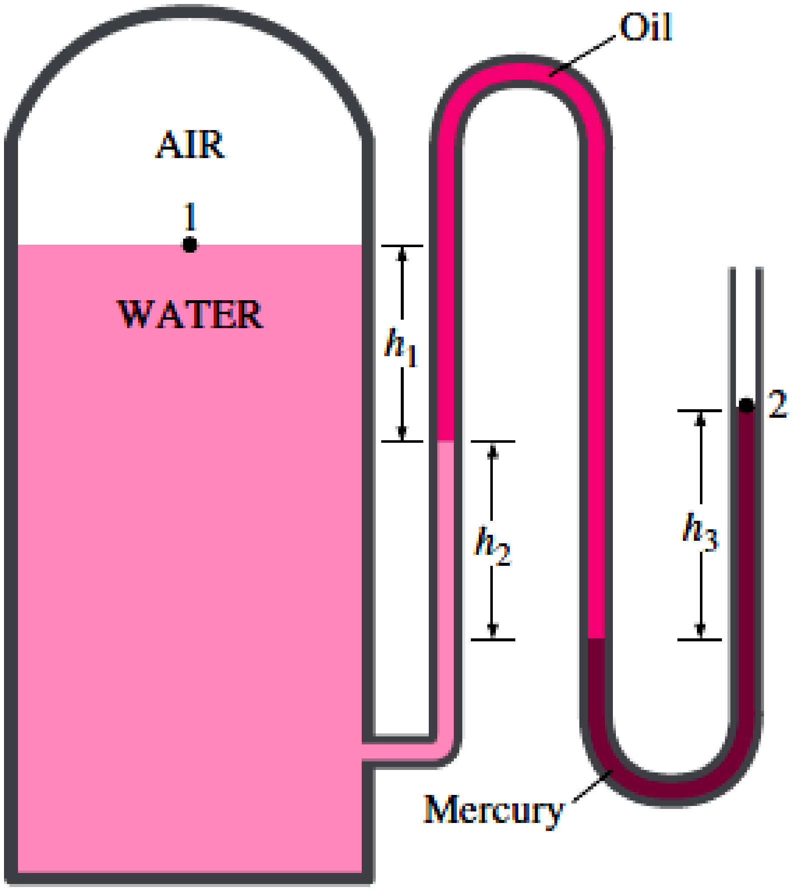
Numerical Problem

1. A manometer is used to measure the pressure in a tank. The fluid used has a specific gravity of 0.85, and the manometer column height is 55 cm, as shown in Fig. 1. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.



Numerical Problem

2. The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in Fig. 2. The tank is located on a mountain at an altitude of 1400 m where the atmospheric pressure is 85.6 kPa. Determine the air pressure in the tank if *h1= 0.1 m, h2 =0.2 m, and h3 = 0.35 m. Take the densities of water, oil, and mercury to be 1000* kg/m3, 850 kg/m3, and 13,600 kg/m3, respectively.



Numerical Problem

3. The piston of a vertical piston–cylinder device containing a gas has a mass of 60 kg and a cross-sectional area of 0.04 m2, as shown in Fig. 3. The local atmospheric pressure is 0.97 bar, and the gravitational acceleration is 9.81 m/s2. (*a) Determine the pressure inside the cylinder. (b) If some heat is* transferred to the gas and its volume is doubled, do you expect the pressure inside the cylinder to change?