Al-Mustaqbal University

Department of Biomedical Engineering

Third Stage / 1st Course

"Transport Phenomena for BME"

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Lecture 4

Hydrostatic Application: Transmission of Fluid Pressure

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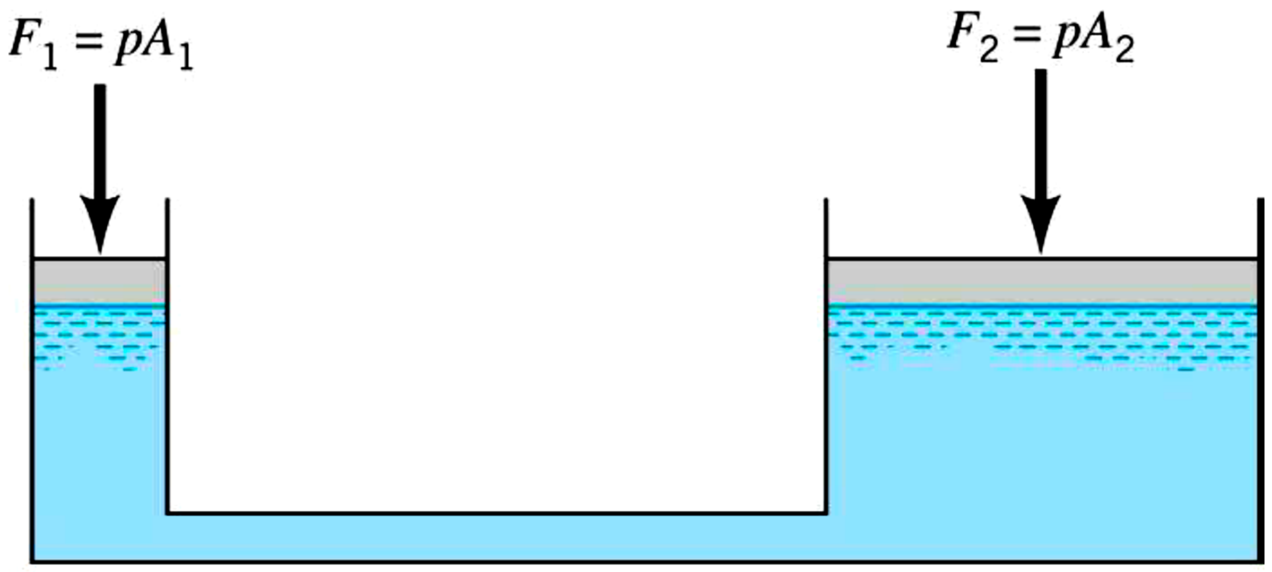


- Mechanical advantage can be gained with equality of pressures
- A small force applied at the small piston is used to develop a large force at the large piston.
- This is the principle between hydraulic jacks, lifts, presses, and hydraulic controls
- Mechanical force is applied through jacks action or compressed air for example

$$F_2 = \frac{A_2}{A_1} F_1$$

Measurement of Pressure

The **difference** in the levels of the **liquid** raised in the two tubes **will** denote the **pressure difference** between the **two points**

- **Mercury Barometer**

$$\sum F_y = p_{atm}A - W - p_{vapor}A = 0$$

$$\sum F_y = p_{atm}A - \rho g.Ah - p_{vapor}A = 0$$

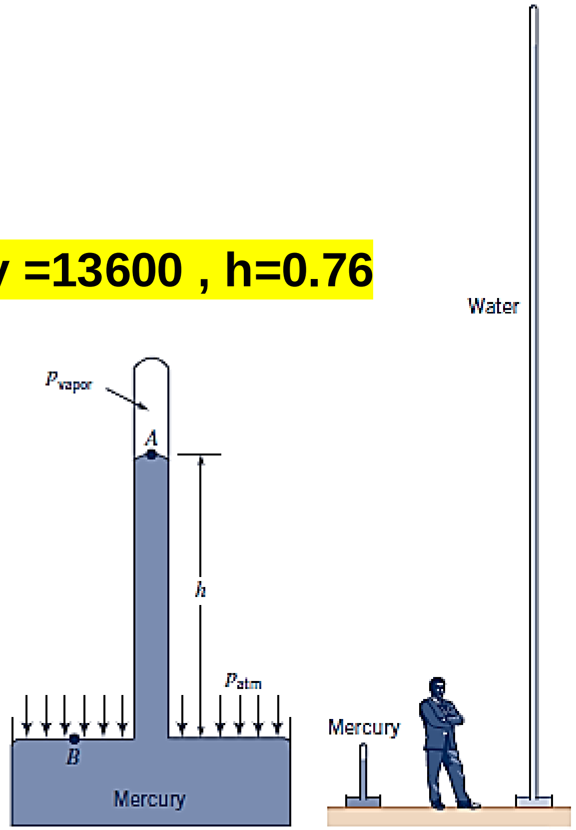
$$\therefore \; p_{atm} = \rho gh + p_{vapor} = \gamma h + p_{vapor}$$

$$P_{atmospher} = \rho_{mercery}.g.h_{mercery}$$

$$P_{atmospher} = 1.013 \times 10^5 \frac{N}{m^2} = 1.013 \times 10^5 \; pa = 101{,}325 \; pa$$

$$1 \, atmosphere = 760 \, mmHg = 29.92 \, in \, of \, Hg = 101{,}325 \, pa = 14.7 \, psi$$

Density of mercury =13600 , h=0.76



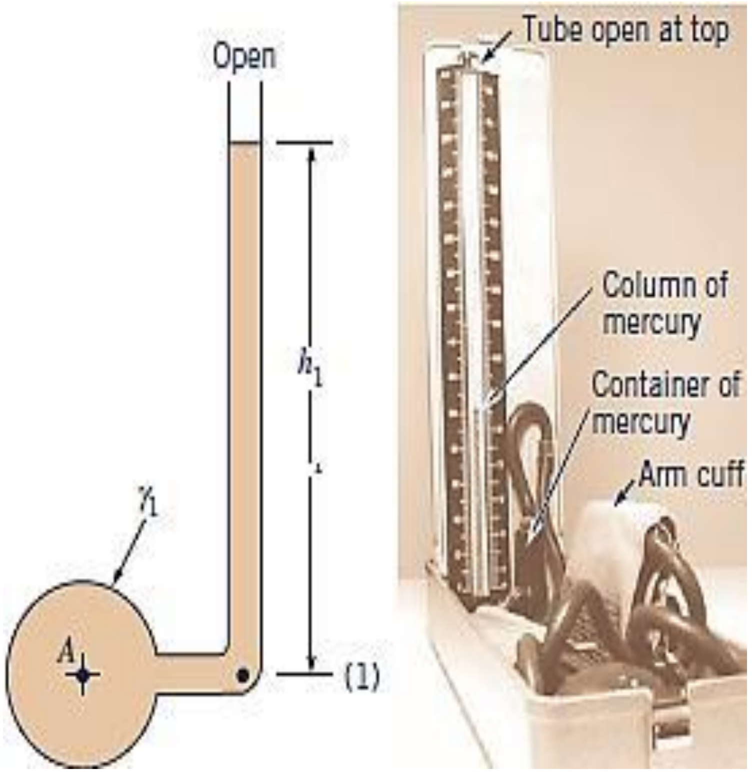
Measurement of Pressure

- **A. The Piezometer Tube Manometer**

$$p_A = \gamma h + p_o$$

Note that since the tube is open at the top, the pressure po can be set equal to zero (we are now using gage pressure)

$$p_A = \gamma_1 h_1$$



Measurement of Pressure

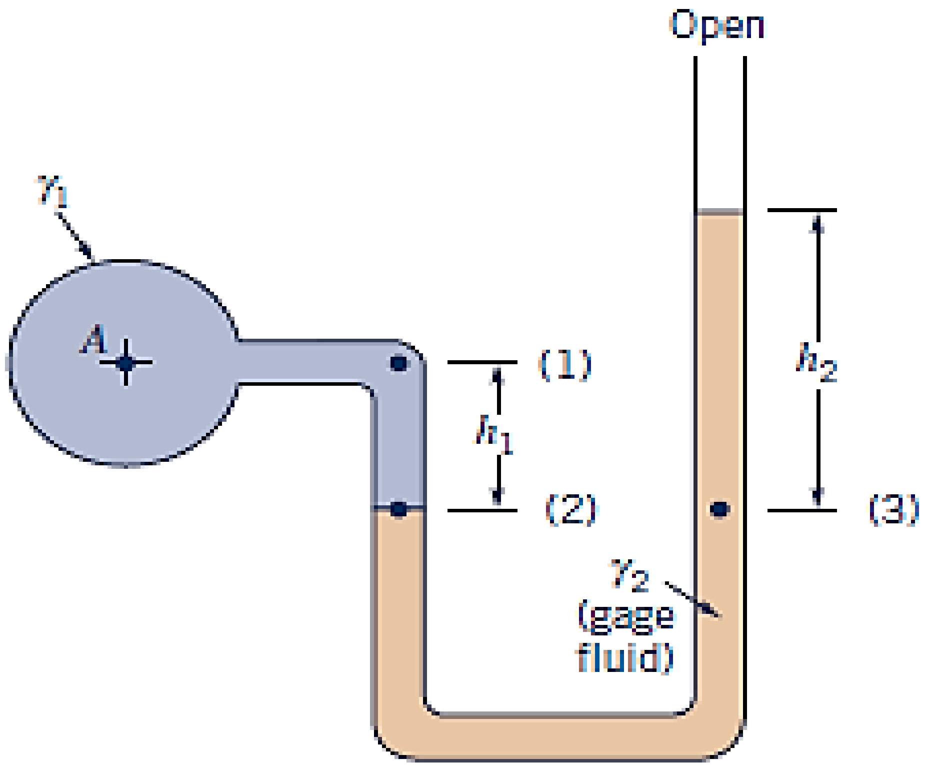
- **B. U.-Tube Manometer**

$$p_A + \gamma_1 h_1 - \gamma_2 h_2 = 0$$

$$p_A = \gamma_2 h_2 - \gamma_1 h_1$$

If A does contain a gas, the contribution of the gas column, $\gamma 1 h 1$ is almost always negligible so that $pA \approx p2$ and in this instance Eq above becomes

$$p_A = \gamma_2 h_2$$

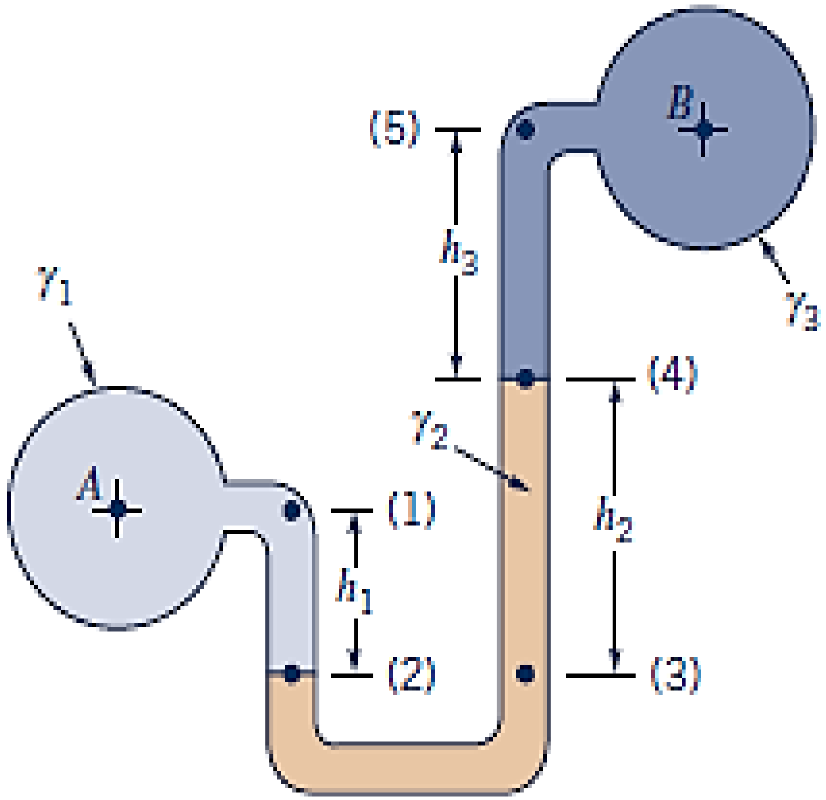


Measurement of Pressure

- **B. U.-Tube Manometer**

$$p_A + \gamma_1 h_1 - \gamma_2 h_2 - \gamma_3 h_3 = p_B$$

$$p_A - p_B = \gamma_2 h_2 + \gamma_3 h_3 - \gamma_1 h_1$$



Measurement of Pressure

- **C.Inclined-TubeManometer**

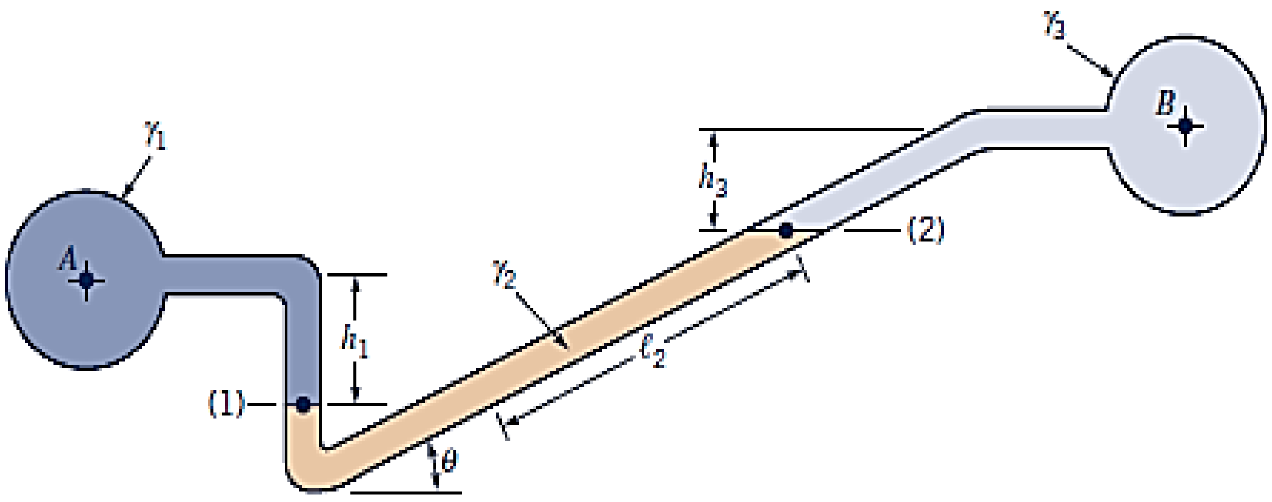
$$p_A + \gamma_1 h_1 - \gamma_2 \ell_2 \sin\theta - \gamma_3 h_3 = p_B$$

$$p_A - p_B = \gamma_2 \ell_2 \sin\theta + \gamma_3 h_3 - \gamma_1 h_1$$

If pipes **A** and **B** contain a gas, then

$$p_A - p_B = \gamma_2 \ell_2 \sin\theta$$

$$\ell_2 = \frac{p_A - p_B}{\gamma_2 \sin\theta}$$



Examples

- Freshwater and seawater flowing in parallel horizontal pipelines are connected to each other by a double U tube manometer, as shown in Figure Determine the pressure difference between the two pipelines ρw=1000 kg/m ^{3} ρHg=13600 kg/m ^{3} and ρsea=1035 kg/m ^{3} Can the air column be ignored in the analysis? hw=50cm,hHg=10cm,$hsea$=30cm

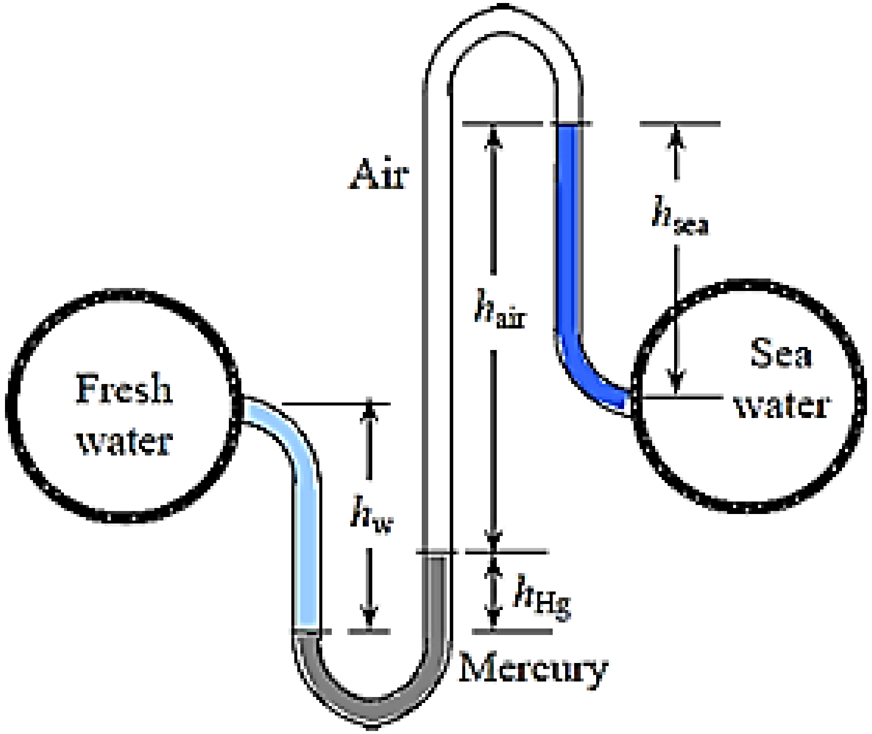
$$P_1 + \rho_w g h_w - \rho_{Hg} g h_{Hg} - \rho_{air} g h_{air} + \rho_{sea} g h_{sea} = P_2$$

Rearranging and neglecting the effect of air column on pressure,

$$P_1 - P_2 = -\rho_w g h_w + \rho_{Hg} g h_{Hg} - \rho_{sea} g h_{sea}$$
$$= g(\rho_{Hg} h_{Hg} - \rho_w h_w - \rho_{sea} h_{sea})$$

Substituting,

$$P_1 - P_2 = (9.81\,\text{m/s}^2)[(13{,}600\,\text{kg/m}^3)(0.1\,\text{m}) - (1000\,\text{kg/m}^3)(0.5\,\text{m}) - (1035\,\text{kg/m}^3)(0.3\,\text{m})]\left(\frac{1\,\text{kN}}{1000\,\text{kg}\cdot\text{m/s}^2}\right)$$
$$= 5.39\,\text{kN/m}^2 = \mathbf{5.39\,kPa}$$



Examples

- The water in a tank is pressurized by air, and the pressure is measured by a multifluid manometer as shown in Fig. 1-49. 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.

$$P_1 + \rho_{water} g h_1 + \rho_{oil} g h_2 - \rho_{mercury} g h_3 = P_{atm}$$

Solving for P_1 and substituting,

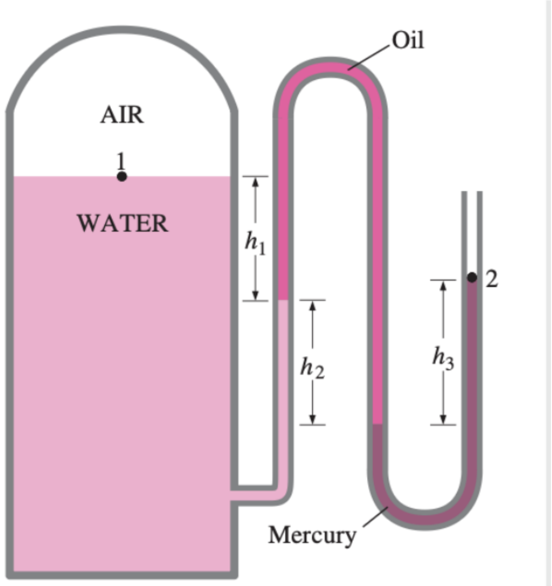
$$P_1 = P_{atm} - \rho_{water} g h_1 - \rho_{oil} g h_2 + \rho_{mercury} g h_3$$

$$= P_{atm} + g(\rho_{mercury} h_3 - \rho_{water} h_1 - \rho_{oil} h_2)$$

$$= 85.6\ \text{kPa} + (9.81\ \text{m/s}^2)[(13{,}600\ \text{kg/m}^3)(0.35\text{m}) - 1000\ \text{kg/m}^3)(0.1\ \text{m})$$

$$-(850\ \text{kg/m}^3)(0.2\ \text{m})]\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right)$$

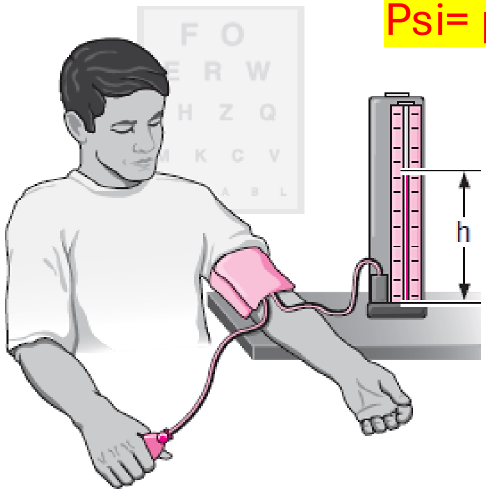
$$= 130\ \text{kPa}$$



Examples

Blood pressure is usually measured by wrapping a closed air filled jacket equipped with a pressure gage around the upper arm of a person at the level of the heart Using a mercury manometer and a stethoscope, the systolic pressure (the maximum pressure when the heart is pumping) and the diastolic pressure (the minimum pressure when the heart is resting) are measured in mmHg The systolic and diastolic pressures of a healthy person are about 120 mmHg and 80 mmHg, respectively, and are indicated as 120 /80 Express both of these gage pressures in kPa ,psi and meter water column $\rho water$=1000kgm^3,$\rho mercury$=13600kg/m^3)

Psi= pound per square



Solution

$$P_{high} = \rho g h_{high} = (13{,}600\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.12\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) = \mathbf{16.0\ kPa}$$

$$P_{low} = \rho g h_{low} = (13{,}600\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(0.08\ \text{m})\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right)\left(\frac{1\ \text{kPa}}{1000\ \text{N/m}^2}\right) = \mathbf{10.7\ kPa}$$

Noting that 1 psi = 6.895 kPa,

$$P_{high} = (16.0\ \text{kPa})\left(\frac{1\ \text{psi}}{6.895\text{kPa}}\right) = \mathbf{2.32\ psi} \quad \text{and} \quad P_{low} = (10.7\ \text{kPa})\left(\frac{1\ \text{psi}}{6.895\text{kPa}}\right) = \mathbf{1.55\ psi}$$

$$P = \rho_{water} g h_{water} = \rho_{mercury} g h_{mercury} \quad \rightarrow \quad h_{water} = \frac{\rho_{mercury}}{\rho_{water}} h_{mercury}$$

Therefore,

$$h_{water,\,high} = \frac{\rho_{mercury}}{\rho_{water}} h_{mercury,\,high} = \frac{13{,}600\ \text{kg/m}^3}{1000\ \text{kg/m}^3}(0.12\ \text{m}) = \mathbf{1.63\ m}$$

$$h_{water,\,low} = \frac{\rho_{mercury}}{\rho_{water}} h_{mercury,\,low} = \frac{13{,}600\ \text{kg/m}^3}{1000\ \text{kg/m}^3}(0.08\ \text{m}) = \mathbf{1.09\ m}$$