CHAPTER 11

Fluid Mechanics

CONTENTS

1. GASES, LIQUIDS AND DENSITY

- **A fluid** is any substance that can flow; we use the term for both liquids and gases

- **Density:** the density of a fluid is defined as its mass per unit volume.

$$\rho = \frac{m}{V}$$ (The SI unit for density is kg/m^3)

Example 11 - 1

1. If $72\ \mathrm{Kg}$ of a fluid measures $60\ m^3$. What is its density?

$$\rho = \frac{m}{V} = \frac{72}{60} = 1.2\ \mathrm{kg}/m^3$$

2. An oil has a density of $852\ \mathrm{Kg}/m^3$ and a volume of $5\ m^3$. What is its mass?

$$m = \rho V = 852 \times 5 = 4260\ \mathrm{kg}$$

3. The density of human blood is $1025\ \mathrm{Kg}/m^3$. What is the volume of $0.02\ \mathrm{Kg}$ of blood?

$$\rho = \frac{m}{V} \Longrightarrow V = \frac{m}{\rho} = \frac{0.02}{1025} = 1.9 \times 10^{-5} m^3$$

2. PRESSURE IN A FLUID

. The pressure (P) at that point as the normal force per unit area

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

. The SI unit of pressure is the Pascal, where

$$1\ \mathrm{Pascal} = 1\ \mathrm{Pa} = 1\ \mathrm{N}/m^2$$

. Atmospheric pressure (atm) is the pressure of the earth's atmosphere

$$1\ atmosphere\ (\mathrm{atm}) = 1.013 \times 10^5\ \mathrm{Pa}$$

Example 11 - 2

1. A hose causes a force of $8000\ N$ from the water over an area of $0.25\ m^2$. Calculate the pressure

$$p = \frac{F}{A} = \frac{8000}{0.25} = 32000 \text{ Pa} = 32 \text{ kPa}$$

2. On a liquid enclosed in a container, a force of $30\ N$ is applied by a piston that has an area of $10\ m^2$. What is the value of the pressure exerted?

$$p = \frac{F}{A} = \frac{30}{10} = 3 \text{ Pa}$$

- **Pressure and Depth**

➢ The pressure at a depth in a fluid of constant density is equal to the pressure of the atmosphere plus the pressure due to the weight of the fluid

$$\boldsymbol{p = p_o + \rho g h}$$

where p is the pressure at a particular depth (called the absolute pressure), p_o is the atmospheric pressure, ρ is the density of the fluid, g is the acceleration do the gravity, and h is the depth.

- The excess pressure above atmospheric pressure ($\rho\mathrm{gh}$) is usually called gauge pressure:

$$\boldsymbol{p_g = p - p_o = \rho \mathrm{gh}}$$

Example 11 – 3

1. What is gauge pressure in a fluid with density $\rho = 800\,\mathrm{kg/m^3}$ at a depth $h = 2.5\,m$. Given the acceleration due to gravity $\mathrm{g} = 9.8\,\mathrm{m/s^2}$

$$p_g = \rho\mathrm{gh} = 800 \times 9.8 \times 2.5 = 19600\ \mathrm{Pa} = 19.6\ \mathrm{kPa}$$

2. The pressure at the surface ocean is atmospheric pressure $p_o = 1.01\times10^5$ Pa. What is the absolute pressure at a depth $h = 15\ m$. Given the density of water $\rho = 1000\,\mathrm{kg/m^3}$ and $\mathrm{g} = 9.8\,\mathrm{m/s^2}$

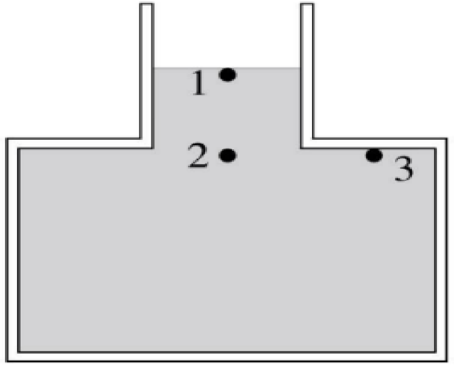
$$p = p_o + \rho gh$$

$$p = (1.01 \times 10^5\ \mathrm{Pa}) + (1000\,\mathrm{kg/m^3})(9.8\,m/s^2)(15m) = 2.48 \times 10^5\ \mathrm{Pa}$$

3. When the atmospheric pressure $p_o = 1.01\times10^5$Pa, the absolute pressure in water at a depth of is read to be 1.85×10^5Pa. Find the gauge pressure at this depth

$$p_g = p - p_o = (1.85\times10^5\mathrm{Pa}) - (1.01\times10^5\mathrm{Pa}) = 84\ \mathrm{kPa}$$

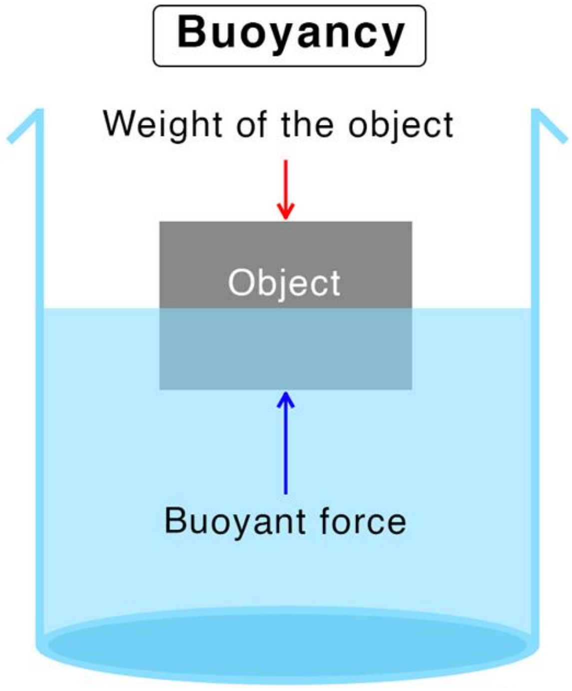
4. For the tank filled with water shown in figure compare the pressure at the points 1, 2 and 3



$$p_2 = p_3 > p_1$$

3. BUOYANCY

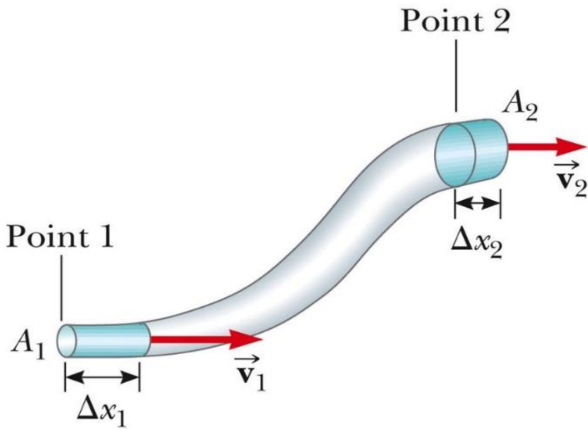
- When an object is immersed in a fluid, wholly or partially, the fluid exerts an upward force opposite its weight. This phenomenon is known as buoyancy, and the upward thrust is known as the buoyant force



- The buoyant force on an object fully submerged in a liquid depends on the object's volume and the density of the liquid

4. FLUID FLOW

- **The Continuity Equation:** the mass of a moving fluid doesn't change as it flows. This leads to an important quantitative relationship called **the continuity equation**



$A_1 v_1 = A_2 v_2$ (continuity equation, incompressible fluid)

A_1 and A_2 are the cross-sectional area at points 1 and 2

Example 11 – 4

Water with a speed $v_1 = 1.5\, m/s$ enters through a first pipe of cross-sectional area $A_1 = 3.14\, cm^2$. The water then flows through a second, connected pipe of cross-sectional area $A_2 = 0.78\, cm^2$. Find the flow speed in the Second pipe

$$v_2 = \frac{A1}{A2} v_1 = \frac{3.14\, cm^2}{0.78\, cm^2} (1.5\ \mathrm{m/s}) = 6.0\ \mathrm{m/s}$$

- **The flow rate** : Flow rate Q is defined as the quantity of fluid that is passing through a cross-section of a pipe in a specific period of time. Flow rate and velocity are related by:

$$Q = Av$$ (The SI unit of the flow rate is m^3/s)

where A is the cross-sectional area of the flow and v is its average velocity

Example 11 – 5

1- The flow rate of water through a pipe is $10\,m^3/s$ and the velocity of the flow is $5\,m/s$. Find the cross-sectional area of the pipe

$$Q = Av \Longrightarrow A = \frac{Q}{v} = \frac{10}{5} = 2\,m^2$$

2- A pipe with a cross-sectional area of $3\,m^2$ contains water that flows at an average velocity of $2\,m/s$. Calculate the flow rate of water in the pipe.

$$Q = Av = 3 \times 2 = 6\ m^3/s$$

5. BERNOULLI'S EQUATION

- Bernoulli's equation: **Bernoulli's equation states that for a moving fluid, the pressure plus the total mechanical energy is constant everywhere in the fluid.**

$$\underbrace{p}_{pressure\ head} + \underbrace{\tfrac{1}{2}\rho v^2}_{Kinetic\ head} + \underbrace{\rho g h}_{potential\ head} = constant$$

p **is the pressure,** ρ **the fluid density,** v **the fluid velocity, and** h **the elevation**

- Limitation on the use of the Bernoulli equation:

Bernoulli's equation can be used for the following conditions:

1- The fluid is incompressible, then its density remains constant.

2- The fluid is non-viscous (no mechanical energy is lost)

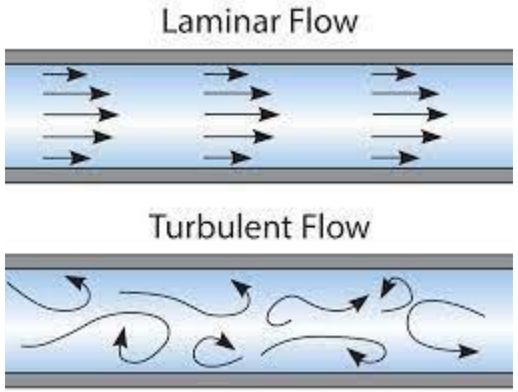
3- The flow is streamline (laminar), not turbulent.

4- the velocity of the fluid at any point does not change during the period observation (steady flow)

6. VISCOSITY AND TURBULENCE

Viscosity is internal friction in a fluid. Viscous forces oppose the motion of one portion of a fluid relative to another.

Turbulence: When the speed of a flowing fluid exceeds a certain critical value, the flow is no longer laminar. Instead, the flow pattern becomes extremely irregular and complex, and it changes continuously with time; This irregular, chaotic flow is called turbulence.



Example 11 –6 Answer check

1. Bernoulli's equation is only valid for

A- incompressible fluid	**B-** non-viscous fluid	**C-** steady flow	**D-** laminar flow	**E- all of the above**

2. The term "ρgh" in the Bernoulli's equation is known as

A- kinetic head	**B-** pressure head	**C-** velocity head	**D- potential head**	**E-** density head

3. $A_1 v_1 = A_2 v_2$ expresses the

A- continuity equation	**B-** momentum equation	**C-** energy equation	**D-** pressure equation	**E-** Bernoulli's equation

4. Fluid offer resistance to motion due to internal friction, this property is called:

A- buoyancy	**B- viscosity**	**C-** continuity	**D-** density	**E-** specific gravity

5. when is a fluid flow called turbulent:

A- high viscosity of fluid
B- the speed of a flowing fluid exceeds a certain critical value
C- the density of the fluid is low
D- the fluid is at rest
E- all the above