UNIT THREE
FLUID MECHANICS

INTRODUCTION

Matter most commonly exists as solids, liquids or gases. Liquid and gas are both fluids: in contrast to solids they lack the ability to resist deformation. As a result fluid moves, or flows under the action of the force. Fluid mechanics refers to the study of fluid behavior at rest and in motion. Fluid mechanics has a wide range of applications in mechanical and aerodynamic engineering, in biological systems, and in many more fields.

➢ **At the end of this unit, you will be able to:**
   ❖ Develop knowledge and understanding of the concepts related to fluids and pressure.
   ❖ Gain knowledge and understanding of Pascal's principle and Archimedes' principle.
   ❖ Understand the behaviors of fluid flow.
   ❖ Develop skills of solving problems related to fluid mechanics.

3.1. Fluid Statics

At the end of this section, you will be able to:
   ❖ Explain the properties of solids, liquids and gases.
   ❖ Define pressure.
   ❖ Convert values of pressure from one pressure unit to another.
   ❖ Explain causes of pressure in gas and liquids.
   ❖ Define absolute, atmospheric and gauge pressure.
   ❖ Define density and relative density.
   ❖ Solve problems related to pressure, density and specific gravity.

➢ Fluid statics deals with nature of fluids at rest.
➢ The fluid can be either gaseous or liquid.
➢ In fluid statics, there is no relative motion between adjacent fluid layers, and no shear (tangential) stresses.
➢ The only stress in fluid statics is the normal stress, which is the pressure.
➢ Fluid statics is used to determine the forces acting on floating or submerged bodies and the forces developed by devices like hydraulic presses and car jacks.
➢ The design of many engineering systems such as water dams and liquid storage tanks requires the determination of the forces acting on their surfaces using fluid statics.

Properties of solids, liquids and gases: atoms in solids are very close to each other.
➢ The force between them acts as a spring that allows the atoms to vibrate without changing positions relative to their neighboring atoms.
➢ Thus, a solid resist all types of stress because the atoms are not able to move about freely.
➢ Solids also resist compression, because their atoms are relatively fixed distance apart.
➢ Under compression, the atoms would be forced into one another.
➢ The molecular spacing in the liquid phase is not much different from that of the solid phase except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely.
➢ In a liquid, the intermolecular forces are weaker relative to solids, but still strong compared with gases.

- Liquids deform easily when stressed and do not spring back to their original shape once the force is removed because the atoms are free to slide about and change neighbors.
- That is, they flow (so they are a type of fluid), with the molecules held together by their mutual attraction.
- Atoms in gases are separated by distances that are large compared with the size of the atoms.
- The forces between gas atoms are therefore very weak, except when the atoms collide with one another.
- Gases thus not only flow but they are relatively easy to compress because there is much space and little force between atoms.
- A gas also expands until it encounters the walls of the container and fills the entire available space.
- In contrast, if we move the liquid filling a small container to a much larger container, the liquid volume remains the same independent of the container's shape.
- Solids maintain not only their volume but also their shape.

3.1.1. Pressure in Fluid

- The normal component of force acting on a surface per unit area is called the normal stress, and the tangential component of force acting on a surface per unit area is called shear stress.
- For fluid at rest, the shear stress is zero and the only existing stress is the normal stress and is called pressure.
- Pressure is defined as a normal force exerted by a fluid (or a solid) per unit area.
- If F is the magnitude of the force exerted on the fluid (or solid) at a particular point and *A* is the surface area at which this force is applied, the pressure P at this particular point is defined as the ratio of the force to the contact area A over which that force is exerted:

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

- Pressure is a scalar quantity because it is proportional to the magnitude of the force. If a large force acts on a small area, the pressure is large.
- The unit of pressure is Newton's per square meter (N/m^2) in the SI system.
- Another name for the SI unit of pressure is the Pascal (Pa):
- In addition to Pascal there are other units of pressure such as millimeter mercury (mmHg), torr, atmosphere (atm) and pounds per square meter (psi) with their relation shown as follow:

$$1atm = 760mmHg = 760torr = 101.3kPa = 14.7psi$$

SELF TEST-1
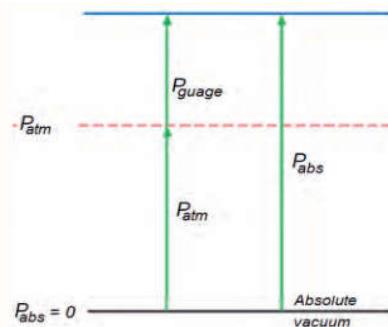
CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. Which one of the following statement is TRUE?
   A. Solid substances are easily deformed than liquid and gases substances, because of weak intermolecular forces between solid atoms.

B. Liquid substances are compress than gases substances, because of weak intermolecular forces between liquid atoms than gases substances.

C. Gases substances are more compress than solid and liquid, because of atoms of gases are more close to each other than liquid and solids.

D. Gases substances are more compress than solid and liquid, because of atoms of gases are more spaced than liquid and solids.

2. As a woman walks, her entire weight is momentarily placed on one of her shoes. What is the pressure exerted on the floor by the shoe if it has an average width 10 cm and average length of 30 cm and the woman's mass is 55.0 kg?

A. 18kPa   B. 12kPa   C. 20kPa   D. 8kPa

3. Why are gases easy to compress, while liquid and solids are almost incomprehensible?

  A. The force between gas atoms is very strong

  B. There is much space and little molecular force between atoms

  C. There is no inter-molecular force between atoms

  D. The gases are stay longer at a fixed position

4. Pressure of 18kpa is equal to:

A. 135.04mmHg   C. 1.8atm

B. 26.1psi   D. 2.61torr

3.1.1.1. Pressure in Gases

➢ As air particles move randomly in space, they eventually collide with the solid surfaces of any objects in that space.

➢ In each of these collisions, the particle exerts an impulsive force on the object.

➢ However, when a huge number of particles bombard a solid surface at a constant rate, these collisions collectively exert an approximately constant force on the object.

➢ This impulsive force must be what we feel when we are trying to squeeze the balloon.

➢ As we blow a balloon, we add air particles to the interior of the balloon; thus there are more particles inside colliding with the walls.

➢ This greater collision rate results in a larger outward average force on each part of the balloon's surface, causing it to expand outward.

➢ The force exerted by the gas on the walls of the container per unit contact area gives the pressure of the gas.


Figure 3.1 Absolute, gauge, and vacuum pressures

➢ The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure).

➤ Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the gauge pressure.

➤ Absolute and gauge pressures are related to each other by:

$$P_{gauge} = P_{abs} - P_{atm}$$

Where, P_{gauge} = gauge pressure

P_{abs} = Absolute pressure

P_{atm} = atmospheric pressure

➤ Like other pressure gauges, the gauge used to measure the air pressure in an automobile tire reads the gauge pressure.

➤ Therefore, the common reading of 32.0 psi indicates a pressure of 32.0 psi above the atmospheric pressure

SELF TEST-2

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. What is the absolute pressure at a location where the atmospheric pressure is 14.3 psi and the gauge pressure of an automobile tire is 32.0 psi?

   A. 45.6psi   B. 46.3psi   C. 54.6psi   D. 23.5psi

2. The actual pressure at a given position is:

   A. Atmospheric pressure   C. Absolute pressure

   B. Local pressure   D. Pressure difference

3. The absolute pressure in water at a depth of 8 m is read to be 175 kPa. What is the local atmospheric pressure if the gauge pressure at this depth is 78.4 KPa?

   A. 100kPa   C. 86.8kPa

   B. 96.6kPa   D. 67.8kPa

3.1.2. Density

➤ Density is an important characteristic of substances.

➤ It is crucial, for example, in determining whether an object sinks or floats in a fluid.

➤ It directly affects pressure of fluids (gases and liquids). Density is a much more useful physical quantity for gases.

➤ Density is the mass per unit volume of any object.

➤ It is calculated by dividing the mass of an object by its volume.

$$\rho = \frac{m}{V}$$

➤ The unit of density is kg/m^3.

➤ Density measures the mass of one cubic meter of a substance.

➤ For example, at sea level and 0°C the mass of 1.0 m^3 of air is 1.3 kg. We say that the density of air is 1.3 kg/m^3.

➤ If we had 2.0 m^3 of air at sea level, its mass would be 2.6 kg. Its density is still 1.3 kg/m^3.

➤ The density of most gases is proportional to pressure and inversely proportional to temperature.

➤ Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible.

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. Identify the incorrect statement about the **density** of substance:
   A. Density is the quantity that determine wether an object is sink or float.
   B. Density is a measure of the amount of masses of substance in a given volume.
   C. Density of most gases is directly proportional to pressure and inversely proportional to temperature.
   D. Denser objects are float on less dense fluids.

2. Assume the following about a person: mass is 80 kg; dimensions are 1.8m tall, 0.3m wide, and 0.1m thick; and volume is, $V = 1.8m \times 0.3m \times 0.1m = 0.054m^3$. What is the density of this person?
   A. $1500kg/m^3$ C. $1200kg/m^3$
   B. $1000kg/m^3$ D. $1800kg/m^3$

3. An iron ball with radius 2.5cm has a mass of 1.0kg. What is density of this iron?
   A. $1.5 \times 10^6 m^3$ C. $1.5 \times 10^4 m^3$
   B. $1.5 \times 10^5 m^3$ D. $1.5 \times 10^3 m^3$

3.1.2.1. Relative density

➢ Sometimes the density of a substance is given relative to the density of another substance.

➢ Specific gravity, or relative density is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which density of water is 1000kg/m³).

$$\text{Specific gravity} = S_G = \frac{\rho}{\rho_{water}}$$

➢ From ideal gas equation, we can determine the relation between density, pressure, and temperature as follows:

$$P = \frac{m}{V} R_{specific} T = \rho R_{specific} T$$
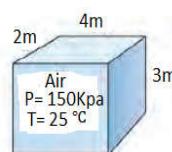
Where, P is the absolute pressure, V is the gas volume, n is number of mole, T is the thermodynamic (absolute) temperature, $\rho = \frac{m}{V}$ is the density, and $R_{specific} = \frac{R}{M}$ is the specific gas constant.

➢ The specific gas constant is different for different gases and R is the universal gas constant whose value is $R = 8.314 \text{ J/mol. K}$ and M is the molar mass of the gases.

SELF TEST-4

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTION.

1. The air in a room whose dimensions are $2m \times 3m \times 4m$ at 150 kPa and 25°C as shown Figure below, then what are the specific gravity and mass of the air in the room respectively? (given: the specific gas constant of air is $R/M = 0.287 \text{ kpa.m}^3/kg.k$)
   A. 0.00175 and 4.2kg
   B. 0.00175 and 42kg
   C. 0.0175 and 42kg
   D. 1.75 and 42kg

3.2. Pressure in fluids at rest

At the end of this section, you will be able to:
- ❖ State Pascal's principle.
- ❖ Explain how Pascal's principle is used in hydraulic press machine.
- ❖ Discuss how pressure depends on the depth of fluid.
- ❖ Discuss the working principles of pressure measuring devices like barometers and manometers.
- ❖ Perform simple experiments related to pressure.
- ❖ Solve problems related to Pascal's principle, fluid depth and atmospheric pressure.

➤ As gas particles collide with the walls of the container in which they reside, they exert pressure.
➤ In fact, if you place any object inside a gas, the gas particles exert the same pressure on the object as the gas exerts on the walls of the container.
➤ Do liquids behave in a similar way? The particles in a liquid are in continual random motion, somewhat similar to particles in gases
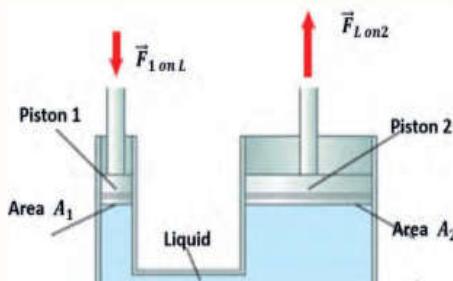
3.2.1. Pascal's principle

➤ Pushing the piston in to a confined fluid in one direction causes a greater pressure in the fluid close to the piston.
➤ Almost immediately the pressure throughout the fluid increases uniformly, fluid is pushed out of all of the holes in the container.
➤ This phenomenon was first discovered by French scientist Blaise Pascal in 1653 and is called Pascal's principle.

Pascal's principle: States that a change in the pressure applied to a static fluid is transmitted undiminished to every point of the fluid and to the walls of the container.

Hydraulic press: One of the technical applications of Pascal's Principle is a hydraulic press which is a form of simple machine that converts small forces into larger forces, or vice versa.

➤ Automobile mechanics use hydraulic presses to lift cars, and dentists and barbers use them to raise and lower their clients' chairs.
➤ The hydraulic brakes of an automobile are also a form of hydraulic press.
➤ Most of these devices work on the simple principle illustrated in Figure 3.2, although the actual devices are usually more complicated in construction.


Figure 3.2 Schematic of hydraulic press

➤ The pressure in the fluid just under piston 1 is,

$$P_1 = \frac{F_1}{A_1}$$

➢ The pressure in the fluid just under piston 2 is,

$$P_2 = \frac{F_2}{A_2}$$

➢ Therefore, by using the concept of Pascal's principle, the down ward force on piston one (F_1) is given by:

$$F_1 = \left(\frac{A_1}{A_2}\right) F_2$$

➢ The upward force on piston two (F_2) is given by:

$$F_2 = \left(\frac{A_2}{A_1}\right) F_1$$

➢ A hydraulic press is a force multiplying machine. It reduces the amount of force needed to lift a load.

➢ A small force is applied at small piston to raise a heavy load at the larger piston. However, the work done by the two pistons is the same. That is,

$$W_{by\ piston\ 1} = W_{by\ piston\ 2}$$

SELF TEST-5
CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. A hydraulic lift has a small piston with surface area $0.002 m^2$ and a larger piston with surface area $0.4 m^2$. Piston 2 and the car placed on piston 2 have a combined mass of 2000 kg. What is the minimal force that piston 1 needs to exert on the fluid to slowly lift the car? $(g=10 m/s^2)$
   A. 100N   B. 180N   C. 120N   D. 200N

2. Based on question number **2**, if you needed to lift the car about 0.2 m above the ground, what distance would you have to push down on the small piston?
   A. 10m   B. 40m   C. 30m   D. 15m

3. Hydraulic lift and hydraulic jacks work on:
   A. Bernoulli's principle   C. Archimedes' principle
   B. Pascal's principle   D. Newton's principle

Variation of pressure with depth:
➢ At the Earth's surface, the air pressure exerted on you is a result of the weight of air above you.

➢ This pressure is reduced as you climb up in altitude and the weight of air above you decreases.

➢ There are two reasons why air pressure decreases as altitude increases: density and depth of the atmosphere.

➢ Most gas molecules in the atmosphere are pulled close to Earth's surface by gravity, so gas particles are denser near the surface.

➢ With more gas particles in a given volume, there are more collisions of particles and therefore greater pressure.

➢ The depth (distance from top to bottom) of the atmosphere is greatest at sea level and decreases at higher altitudes.

➢ With greater depth of the atmosphere, more air is pressing down from above.

➢ Therefore, air pressure is greatest at sea level and falls with increasing altitude.

➢ On top of Mount Everest, which is the tallest mountain on Earth, air pressure is only about one-third of the pressure at sea level.

3.2.2. Measuring pressure

➢ Under the water, the pressure exerted on you increases with increasing depth.

➢ In this case, the pressure being exerted upon you is a result of both the weight of water above you and that of the atmosphere above you.

➢ You may notice an air pressure change on an elevator ride that transports you many floors, but you need only dive one meter or below the surface of a pool to feel a pressure increase.

➢ The difference is that water is much denser than air, about 775 times as dense.
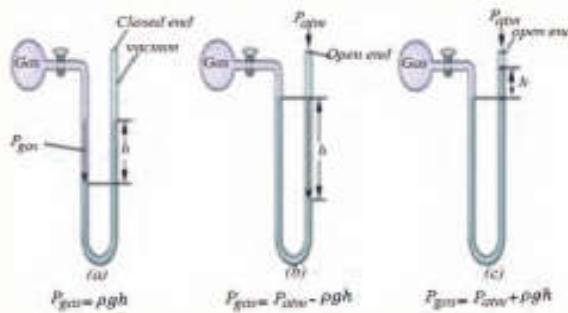
Barometer: Atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as the barometric pressure.

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

➢ Note that the length and the cross-sectional area of the tube have no effect on the height of the fluid column of a barometer.

➢ The pressure from barometer reading is given by:

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

Manometer: A manometer is a device similar to a barometer that can be used to measure the pressure of a gas trapped in a container.

➢ The distance between the liquid levels in the two arms of the tube (h in Figure 3.3) is proportional to the pressure of the gas in the container.

Figure 3.3 Measurement of gas pressure with manometer (a) closed end manometer (b) open end manometer with atmospheric pressure greater than gas pressure (c) open end manometer with atmospheric pressure less than gas pressure

Closed-end manometer: is a **U**-shaped tube with one closed arm and the other arm connected to the gas whose pressure is to be measured, and a nonvolatile liquid (usually mercury) in between.

Open-end manometer: is the same as a closed-end manometer, but one of its arms is open to the atmosphere.

> In this case, the distance between the liquid levels corresponds to the difference in pressure between the gas in the container and the atmosphere.
> This device is mainly used to measure low pressure differences accurately.
> In the Figure 3.3, let us use the principle of hydrostatic equilibrium. The pressure in the gas supply for the situations shown in Figure 3.3 are given as follow:
  1. For closed end manometer:

$$\boxed{P_{gas} = \rho gh}$$

  2. For open end manometer with atmospheric pressure greater than gas pressure:

$$\boxed{P_{gas} = P_{atm} - \rho gh}$$

  3. Open end manometer with atmospheric pressure less than gas pressure:

$$\boxed{P_{gas} = P_{atm} + \rho gh}$$

> Where ρ denotes density of the liquid, g denotes gravitational constant, h is the height of the liquid column.
> **Note that** the cross-sectional area of the tube has no effect on the differential height h, and thus the pressure exerted by the fluid. However, the diameter of the tube should be large enough (more than several millimeters) to ensure that the surface tension effect and thus the capillary rise is negligible.

SELF TEST-6

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. What is the atmospheric pressure at a location where the barometric reading is 740$mmHg$ and the gravitational acceleration is (g = 9.81m/s^2). Assume the temperature of mercury to be 10°C, at which its density is 13,595 kg/m^3)
   A. 98.5kPa   C. 65kPa
   B. 89kPa   D. 45kPa

2. Which one of the following devices used to measure the atmospheric pressure?
   A. Barometer   C. Thermometer
   B. Manometer   D. Anemometer

3. An open manometer is used to measure the pressure of a gas in a tank. The fluid used has a specific gravity of 0.55, and the fluid column in the open arm is 35 cm above the gas connected arm, if the local atmospheric pressure is 1.00 kPa, what is the pressure of the gas? (use: g = 9.81m/s^2)
   A. 0.9kpa   C. 1.9kpa
   B. 2.9kpa   D. 1kpa

4. Based on question number **3**, if closed-end manometer is used to measure the pressure of a gas in a tank, what is the pressure of the gas?
   A. 0.9kpa   C. 1.9kpa
   B. 2.9kpa   D. 1kpa

3.3. Archimedes' principle

At the end of this section, you will be able to:
   ❖ Define the buoyant force.
   ❖ Classify floating and submerging objects comparing the objects and the fluid density.
   ❖ Solve problems related to buoyant force

Buoyant Force: It is extremely difficult to push a ball down under water because of the large upward force exerted by the water on the ball.

➢ The upward force exerted by a fluid on any immersed object is called a **buoyant force**. Where does this buoyant force come from?

➢ Buoyant force is based on the fact that pressure increases with depth in a fluid. This means that the upward force on the bottom of an object in a fluid is greater than the downward force on the top of the object.

➢ There is a net upward or buoyant force on any object in any fluid.

➢ Buoyant force is also called up thrust force.

➢ How a buoyance force is exerted by gas particle can be observed from the link: https://phet.colorado.edu/en/simulations/balloons-and-buoyancy.

➢ How large is this buoyant force? To answer this question, think about what happens when a submerged object is removed from a fluid. The space it occupied is filled by fluid having a weight W.

➢ Since this weight is supported by surrounding fluid, the magnitude of buoyant force on an object must equal the weight of the fluid displaced by the object.

➢ It is a tribute to the Greek mathematician and inventor Archimedes (287–212 B.C.) that he stated this principle long before concepts of force were well established.

➢ Archimedes' principle is stated as follows: The buoyant force on an object equals the weight of the fluid it displaces. In equation form, Archimedes' principle is given as:

$$F_B = W_{\text{fluid displaced}}$$

Totally submerged object: When an object is totally submerged in a fluid of density ρ_{fluid}, the volume V_{disp} of the displaced fluid is equal to the volume of the object V_{obj}; so, the magnitude of the upward buoyant force is, $F_B = \rho_{\text{fluid}} g V_{\text{object}}$.

➢ If the object has a mass M and density ρ_{object}, its weight is equal to $F_g = Mg = \rho_{\text{object}} g V_{\text{object}}$, and the net force on the object is $F_B - F_g = (\rho_{\text{fluid}} - \rho_{\text{object}}) g V_{\text{object}}$.

➢ Hence, if the density of the object is less than the density of the fluid, the downward gravitational force is less than the buoyant force and the unsupported object accelerates upward.

➢ If the density of the object is greater than the density of the fluid, the upward buoyant force is less than the downward gravitational force and the unsupported object sinks.

➢ If the density of the submerged object equals the density of the fluid, the net force on the object is zero and the object remains in equilibrium. It can be anywhere inside the fluid. Therefore, the direction of motion of an object submerged in a fluid is determined only by the densities of the object and the fluid.

Floating object: Now consider an object of volume V_{object} and density $\rho_{\text{object}} < \rho_{\text{fluid}}$ in static equilibrium floating on the surface of a fluid, that is, an object that is only partially submerged.

➢ In this case, the upward buoyant force is balanced by the downward gravitational force acting on the object.

➢ If V_{fluid} is the volume of the fluid displaced by the object (this volume is the same as the volume of that part of the object beneath the surface of the fluid), the buoyant force has a

magnitude $F_B = \rho_{fluid}gV_{disp}$,Because the weight of the object is $F_g = Mg = \rho_{object}gV_{object}$ and $F_B = F_g$.

➤ Therefore, the law of floatation is expressed as:

$$\frac{V_{disp}}{V_{object}} = \frac{\rho_{object}}{\rho_{fluid}}$$

➤ This equation shows that the fraction of the volume of a floating object that is below the fluid surface is equal to the ratio of the density of the object to that of the fluid.

SELF TEST-7

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. One of the following statement is correctly describe *Archimede's principle:*
   A. The magnitude of buoyant force acting on an object which is submerged into fluid is equal to the weight of an object.
   B. The magnitude of buoyant force acting on an object which is submerged into fluid is equal to the weight of the fluid in which the object is immersed.
   C. The magnitude of buoyant force acting on an object which is submerged into fluid is equal to the weight of the displaced fluid.
   D. The magnitude of buoyant force acting on an object which is submerged into fluid is equal to the sum of the weight of an object and fluid.

2. According to Archimede's principle, if $5m^3$ volume of object totally submerged into water, how many liters of water displaced due to this object?
   A. 5L   C. 500L
   B. 5000L   D. 50L

3. If three objects that has mass of 20kg, 12kg and 30kg are submerged into different volume of liquid, the buoyant force exerted on masses of 20kg, 12kg and 30kg are 250N, 100N and 400N respectively, then which one of the following is correct about the positions of the objects in the liquid? (use: $g = 10$ m/s^2)
   A. The object that has a mass of 20kg is at the bottom of liquid.
   B. The object that has a mass of 12kg is at the bottom of the liquid.
   C. The object that has a mass of 30kg is at the bottom of the liquid.
   D. The object that has a mass of 12kg is at the top of the liquid.

4. A rectangular wooden block floats with 40 % of its volume over water. What is the density of this block?
   A. 400kg/m^3 C. 600kg/m^3
   B. 750kg/m^3 D. 450kg/m^3

5. An iceberg floats in seawater. What percent of the iceberg lies above the water level? (given: density of sea water and iceberg are 1030 kg/m^3 and 917 kg/m^3 respectively)
   A. 89%   C. 11%
   B. 75%   D. 25%

6. What is the buoyant force on 10,000 metric tons (1.00×10^7 kg) of solid carbon steel completely submerged in water and the position of the carbon steel? (use: $g = 9.81$m/s^2)
   A. 1.3×10^7N, sink   C. 9.81×10^7N, float
   B. 1.3×10^7N, float   D. 9.81×10^7N, sink

7. A 75.0kg man floats in fresh water with 3.00% of his volume above water when his lungs are empty, and 5.00% of his volume above water when his lungs are full. What is the volume of air he inhales?

   A. $0.2m^3$ C. $0.02m^3$
   B. $0.002m^3$ D. $0.0002m^3$

8. Two objects have the same volume, but one is heavier than the other. When they are completely submerged in oil, on which one does the oil exert a greater buoyant force?

   A. The heavier objects   C. Equal buoyant forces acting on both objects
   B. The lighter objects   D. Undetermined

3.4. Fluid flow

At the end of this section, you will be able to:

   ❖ Differentiate steady and turbulent fluid flow.
   ❖ Define flow rate.
   ❖ Derive equation of continuity from flow rate.
   ❖ Explain the cause and working principle of some common activities or experiences.
   ❖ Solve problems on equation of continuity.

➢ Fluid flow is caused by differences in pressure.
➢ When the pressure in one region of the fluid is lower than in another region, the fluid tends to flow from the higher pressure region toward the lower pressure region.
➢ For example, large masses of air in Earth's atmosphere move from regions of high pressure into regions of low pressure creating what we call wind.

Steady and turbulent fluid flow: When fluid is in motion, its flow can be characterized as being steady fluid flow if each particle of the fluid follows a smooth path such that the paths of different particles never cross each other.

➢ In steady flow, every fluid particle arriving at a given point in space has the same velocity.
➢ The laminar flow always occurs when the fluid flow with low velocity and in small diameter
   pipes.
➢ Above a certain critical speed, turbulent fluid flow occurs.
➢ Turbulent flow is irregular flow characterized by small whirlpool-like regions.
➢ The adjacent layers of the fluid cross each other and move randomly in a zigzag manner.
➢ The turbulent flow occurs when the velocity of the fluid is high and it flows through larger diameter pipes.
➢ As a solid surface is acted by a frictional force when it slides over another solid, there is also an internal frictional force in liquid, called viscosity, when two adjacent layers of fluid try to move relative to each other.
➢ Viscosity causes part of the fluid's kinetic energy to be transformed to internal energy.
➢ This mechanism is similar to the one by which the kinetic energy of an object sliding over a rough, horizontal surface decreases.
➢ The path taken by a fluid particle under steady flow is called a streamline.
➢ The velocity of the particle is always tangent to the streamline.
➢ A set of streamlines form a tube of flow.

➢ In laminar flow, fluid particles cannot flow into or out of the sides of this tube; if they could, the streamlines would cross one another and results in turbulent flow.

Flow rate: Flow rate Q is defined to be the volume of fluid passing by some location through

an area during a period of time.

➢ In symbols, this can be written as:

$$V = \frac{Q}{t}$$

Where V is the volume and t is the elapsed time.

➢ The SI unit for flow rate is $\mathbf{m^3/s}$, but a number of other units for Q are in common use.

Equation of continuity: Because the fluid is incompressible, the same amount of fluid must flow past any point in the tube in a given time to ensure continuity of flow.

➢ In this case, because the cross-sectional area of the pipe decreases, the velocity must necessarily increase.

➢ This logic can be extended to say that the flow rate must be the same at all points along the pipe.

➢ In particular, for points 1 and 2

$$Q_1 = Q_2$$
$$A_1 v_1 = A_2 v_2$$

➢ This is called the equation of continuity and is valid for any incompressible fluid where v_1 is the average speed of the fluid passing cross section A_1 and v_2 is the average speed of the fluid passing cross section A_2.

➢ The equation of continuity is used to relate the cross-sectional area and average speed of fluid flow in different parts of a rigid vessel carrying an incompressible fluid.

➢ You can visualize effect of cross-sectional area on velocity of fluid flow from the link: https://phet.colorado.edu/en/simulations/fluid-pressure-and-flow.

➢ Since liquids are essentially incompressible, the equation of continuity is valid for all liquids.

➢ However, gases are compressible, and so the equation must be applied with caution to gases if they are subjected to compression or expansion.

➢ Fluid flow has important implications in biological systems for example, in the flow of blood through blood vessels.

➢ The blood pressure against the wall of a vessel depends on how fast the blood is moving.

➢ Pressure is lower when the blood is moving faster.

➢ Similarly, a snoring sound occurs when air moving through the narrow opening above the soft palate at the back of the roof of the mouth has lower pressure than nonmoving air below the palate.

➢ The normal air pressure below the soft palate, where the air is not moving, pushes the palate
closed.

➢ When airflow stops, the pressures equalize and the passage reopens.

➢ The rhythmic opening and closing of the soft palate against the throat leads to the snoring sound.

➢ Pressure is also very important in wind musical instruments.

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. How many a cubic meter of blood does the heart pump in a 25-year life time, assuming the average flow rate is 5.00 L/min?

   A. 65700m³   C. 657000m³

   B. 657000m³   D. 657m³

2. **Equation of continuity** is applied to:

   A. high viscous fluid   C. non-viscous fluid

   B. highly compressible fluid   D. turbulent flow of fluid

3. A nozzle with a radius of 0.250 cm is attached to a garden hose with a radius of 0.900 cm. The flow rate through hose and nozzle is 0.500 L/s. What is the ratio of the speed of the water when pass through the hose to when it pass through the nozzle?

   A. 13   C. 0.77

   B. 0.077   D. 0.707

4. Identify the **CORRECT** statement

   A. Laminar flow of fluid is flow in which fluid particles move in a *zigzag* way.

   B. Laminar flow of fluid is flow in which fluid particles continuously changing velocity both in magnitude and direction.

   C. Turbulent flow of fluid is flow in which fluid particles move in a *stream line* way.

   D. Laminar flow of fluid is flow in which fluid particles continuously moving at a constant velocity.

5. One of the following is the factors that affects **fluid flow**:

   A. Pressure of the fluid   C. The diameter of the pipe through which the fluid flow.

   B. Density of the fluid   D. Viscosity of the fluid   E. All

6. Blood flows at an average speed of 0.40 m/s in a horizontal artery of radius 1.0cm. The average pressure is $1.4 \times 104 \, N/m^2$ above atmospheric pressure (the gauge pressure).What is the average speed of the blood past a constriction where the radius of the opening is 0.30cm?

   A. 11m/s   C. 4.4m/s

   B. 5.5m/s   D. 2.5m/s

3.5. Safety and high pressure systems

At the end of this section, you will be able to:

❖ List high- pressure systems.

❖ List application of high-pressure system.

❖ Identify the common causes of risk in the high-pressure systems.

❖ Familiarized the safety measures related to high pressure systems.

➢ Pressure far greater than 1 atmosphere (most of the time greater than 50 atm) is considered as high pressure.

➢ High pressure is used for many applications.

➢ High pressure cookers are used in a kitchen to cook food.

➢ Gas cylinders containing liquid petroleum gas at high pressure are used as fuel.

➢ Gas cylinders are also used to seal different types of gases at high pressure for laboratory or medical use.

➢ The bicycle and car tires are inflated by high pressure tire inflator.

➢ High pressure is also used in high pressure washers.

➢ In physical science (physics and chemistry) high pressure is important to study physical properties of various materials (mainly solids) and to transform their nature.

➢ Many materials undergo fascinating changes in their physical and chemical characteristics when subjected to high pressure.

➢ The application of high pressure to biological samples is also of technological relevance because it is known that the microorganism activity is diminished or canceled by application of high pressures, a process called pascalization.

➢ Pascalization can be used to increase the shelf lives of perishable foodstuffs: juice, fish, meat, dairy products, etc.

➢ High pressure affects many scientific and technological fields, like biology, chemistry, environmental engineering, food technology, material science, pharmacy, and physics.

➢ High pressure equipment may consist of high-pressure compressors (or pumps), high pressure piping (fittings, seals, tubing and valves), high pressure vessels, Steam Generator, Safety Accessories and high-pressure instrumentation

High pressure compressors (pumps): A compressor is a mechanical device that increases the pressure of a gas by reducing its volume.

➢ Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe.

➢ Heated pressure equipment are intended for generation of steam or super-heated water at temperatures higher than 110°C and having a volume greater than two liters.

➢ This includes all pressure cookers.

➢ Because of severe stresses, it is essential to design and fabricate high-pressure machines very carefully

High pressure vessels: Pressure vessel means a housing designed and built to contain fluids under pressure including its direct attachments up to the coupling point connecting it to other equipment.

➢ A vessel may be composed of more than one chamber.

Safety Accessories: These accessories include safety valves and bursting discs, as well as limiting devices.

➢ Limiting devices can either activate the means for correction or shutdown and lock-out, such as pressure switches and temperature switches.

High-pressure instrumentation: To operate high-pressure plants, adequate control- and measuring devices are required.

➢ High-pressure instrumentation is available for purposes like pressure, temperature, flow and level measurements.

Safety for high pressure equipment

➢ If pressure systems or equipment fails and bursts violently apart, it can seriously injure or kill people and cause serious damage to property.

➢ The main hazards from pressure are: impact from the blast of an explosion, impact from parts of equipment that fail or any flying debris, impact with the released liquid or gas (such as steam), fire resulting from the escape of flammable liquids or gases.

❖ **Common causes of pressure system and equipment risks include:**
  ➢ Damaged equipment or system design
  ➢ Poor or no maintenance
  ➢ An unsafe system of work
  ➢ Operator error due to lack of training/supervision
  ➢ Incorrect installation
  ➢ Inadequate repairs or modifications

SELF TEST-9

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTION.

1. A high pressure equipment that used to increase pressure by decreasing the volume of gases:
   A. High pressure compressor   C. High pressure instrumentation
   B. High pressure vessels   D. Steam generators