Mechanical Properties of Fluids

Case Study Based Questions

Read the following passages and answer the questions that follow:

1. Streamlines are the pathways or trajectories of fluid particles in a constant flow. The path of fluid particles is determined by the idea of fluid mechanics in physics. The liquid in a continuous stream is flowing, but the streamlines are stationary. The liquid speed is often high where streamlines swarm together; the liquid is somewhat calm where they open out. A streamline is a route that is perpendicular to the instantaneous velocity direction. Streamlines primarily operate in laminar flow rather than turbulent flow because laminar flow produces steady motion.

(A) What is streamlined and what are its properties?

(B) Do the two streamlines intersect each other in a streamline flow?

(C) How does water pressure one meter below the surface of a small pond compared to water pressure one meter below the surface of a huge lake?

Ans. (A) The path taken by a fluid particle under a steady flow is streamline. The properties of streamlined flow are:

(1) The tangent at any point in the streamline gives the direction of the fluid velocity at that point.

(2) Two streamlines never intersect each other.

(B) A tangent drawn from any point on the streamline indicates the direction of flow of the liquid. As two tangents (different) at a point will indicate two directions of fluid flow which is impossible. Hence, the two streamlines do not cross each other in streamline flow.

(C) Liquid pressure is given by the formula, Liquid pressure = weight density of the liquid x height Liquid pressure is independent of the area of the liquid at a particular depth. So, water pressure 1 m below the surface of a small pond will be the same as that due to water pressure 1 m below the surface of a huge lake.

2. A hydraulic lift is a device for moving objects using force created by pressure on a liquid inside a cylinder that moves a piston upward. Incompressible oil is pumped into the cylinder, which forces the piston upward. When a valve opens to release the oil, the piston lowers by gravitational force. The principle for hydraulic lifts is based on Pascal's law for generating force or motion, which states that pressure change on an incompressible liquid in a confined space is passed equally throughout the liquid in all directions. The concept of Pascal's law and its application to hydraulics can be seen in the example below, where a small amount of force is applied to an incompressible liquid on the left to create a large amount of force on the right.

(A) The rectangular vessel's base measures 10 cm x 18 cm. Mixture is pumped into the hole to a depth of 4 cm. What is the base's pressure? What is the base's thrust? [g= 10 m/s^2.]

(a) 7.2 N

(b) 8.3 N

(c) 5.7 N

(d) 7.5 N

(B) A girl weighs 50 kg and balances on a single heel while wearing high heel shoes. The heel is circular, with a 1 cm diameter. How much pressure does the heel put on the horizontal floor?

(a) 8.24 x 106 Nm-2

(b) 6.24 x 106 Nm-2

(c) 10.24 x 106 Nm-2

(d) 2.24 x 106 Nm-2

(C) A hydraulic automobile lift is designed to lift vehicles weighing up to 3000 kg. The piston carrying the load has a cross- sectional area of 425 cm^2. What is the maximum pressure that the smaller piston must withstand?

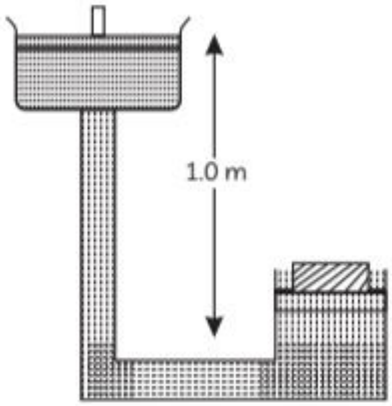
(a) 6.92 x 105 Nm-2

(b) 6.02 x 104 Nm-2

(c) 6.92 x 103 Nm-2

(d) 6.92 x 102 Nm-2

(D) A hydraulic press with a larger piston of diameter 30 cm at a height of 1.0 m above the smaller piston of diameter 5 cm is shown in the figure. The smaller piston has a mass of 10 kg. What is the force that the larger piston exerts on the load? Oil in the press has a density of 750 kg/m^3.



(a) 3000.0 N
(b) 3009.6 N
(c) 3009.3 N
(d) 3009.2 N

(E) To lift an automobile of 5000 kg, a hydraulic lift with a large piston 800 cm^2 in area is employed. Calculate the force that must be applied to a small piston of area 5 cm^2 to achieve it.
(a) 612. 5 N
(b) 306. 25 N
(c) 153.12 N
(d) 408.56 N

Ans. (A) (a) 7.2 N
Explanation: Area of base
= 10 cm x 18 cm
= 180 cm^2
= 180 × 10^{-4} m^2
Depth of water, h=4 cm = 4 x 10^{-2} m
Density of water, p = 10^3 kg/m^3
Pressure on the base, P = phg
= 10^3 x 4 x 10^{-2} x 10 = 400 Pa

Thrust on the base, F = P x A
=400 x 180 x 10^{-4} = 7.2 N

(B) (b) 6.24 x 10^6 Nm^{-2}
Explanation: Force F = 50 x 9.8 N

$$\text{Area, } A = \frac{\pi D^2}{4} = \frac{\pi(1\times10^{-2})^2}{4}$$

$$= \frac{3.14\times10^{\ 4}m^2}{4}$$

$$\text{Pressure, } P = \frac{F}{A} = \frac{50\times9.8\times4}{3.14\times10^{-4}}$$

$$= 6.24 \times 10^6 Nm^{-2}$$

(C) (a) 6.92 x $10^5 Nm^{-2}$
Explanation: Area of the cross-section of a bigger piston,
A = 425 cm^2 = 425 × 10^{-4} m^2
Maximum load on the bigger piston,
F = 3000 × 9.8 N
:- Pressure on the bigger piston,

$$P = \frac{F}{A} = \frac{3000\times9.8}{425\times10^{-4}}$$

According to Pascal's law, the smaller piston would bear the same pressure as the bigger piston equal to 6.92 x 105 N/m^2
(D) (b) 3009.6 N
Explanation: Force on the smaller piston
F = mg = 10 x 9.8 = 98 N

Pressure by larger piston,

$$P = \frac{4\times F}{\pi D_1^2} = \frac{4F}{3.14\times0.09} = 14.15 \text{ F.Pa}$$

Now pressure difference =

$$P = 750 \times 1 \times 9.8 = 7350 \text{ Pa}$$

$$\text{Now } 7350 = 49936.3\text{ F} - 14.15\text{ F or}$$

$$F = 3009.6 \text{ N}$$

(E) (b) 306.25 N
Explanation: Force on large piston

$F_1 = mg$

$F_1 = 5000 \times 9.8$ N

= 4.9 x 104 N

Given area of large piston,

$A_1 = 800\ cm^2$

Pressure on the large piston

$$(P) = \frac{F_1}{A_1}$$

$$= \frac{4.9 \times 10^4}{800 \times 10^{-4}}$$

$$= 6.125 \times 10^5 \text{ Pa}$$

Since the liquid transmits pressure equally, therefore the pressure on the small piston will be equal to the pressure on the large piston.

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

Given area of small piston

$A_2 = 5\ cm^2$

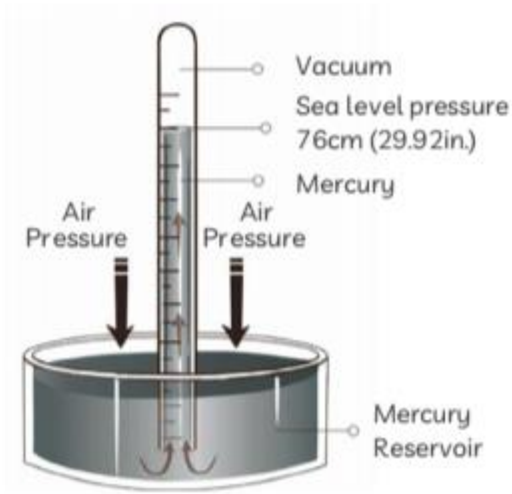
∴ Force applied on small piston

$$F_2 = P \times A_2$$

$$= 6.125 \times 10^5 \times (5 \times 10^{-4})$$

$$= 306.25 \text{ N}$$

3. Pioneering scientists discovered atmospheric pressure (also known as barometric or air pressure) in the 17th century, and determined a startling new fact-that air has weight. Evangelista Torricelli, one of the first to discover atmospheric pressure, once said, "We live submerged at the bottom of an ocean of the element air." The Earth's gravitational field is pulling on air, and this pull, or "pressure" of air, is called atmospheric pressure. Torricelli also went on to develop the mercury barometer, an instrument used to measure atmospheric pressure.

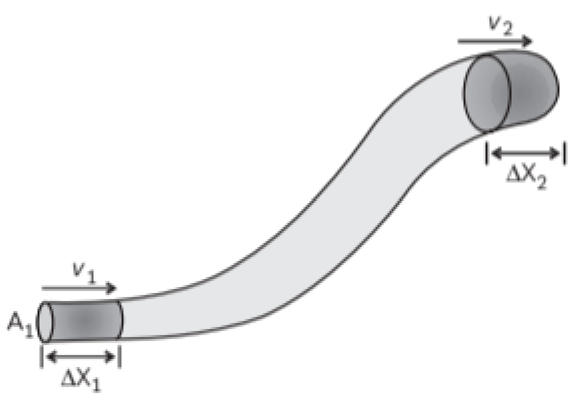


(A) The speed of blood flow in the human heart is greater in the arteries (broad) than in the capillaries (narrow). However, the equation of continuity (av = constant) appears to predict that the speed should be greater in the capillaries. How are you going to deal with this apparent inconsistency?
(B) Why is blood pressure more in the human body at the feet than at the brain?
(C) What happens when a capillary tube of insufficient length is dipped in a liquid?

Ans. (A) In the human heart, the capillaries are many more than arteries. Therefore, the total area of the cross-section of the capillaries is greater than that of the arteries. In accordance with the equation of continuity i.e., av = constant, as the total effective area (a) of the capillaries is large, the speed (v) of blood flow is small.
(B) The height of the blood column in the human body is more at the feet than at the brain as pressure is directly dependent on the height of the column, so the pressure is more at the feet than at the brain.
(C) When a capillary tube of insufficient length is dipped in a liquid, the radius of

curvature increases so that hr = constant. That is pressure on the concave side becomes equal to the pressure exerted by the liquid column so the liquid does not overflow.

4. The transport of some quantities, such as fluid or gas, is described by the continuity equation. The equation describes how a fluid conserves mass while moving. The continuity equations conserve many physical phenomena such as energy, mass, momentum, natural quantities, and electric charge. The continuity equation is useful for determining the flow of fluids and their behaviour as they move through a pipe or hose. The Continuity Equation is used on tubes, pipes, rivers, ducts with flowing fluids or gases, and many other structures. The continuity equation can be expressed in an integral form and applied in a finite region, or it can be expressed in a differential form and applied at a point.



Bernoulli's theorem, in fluid dynamics, relation among the pressure, velocity and elevation in a moving fluid (liquid or gas), the compressibility and viscosity of which are negligible and the flow of which is steady, or laminar. Bernoulli's principle is applicable to those non-viscous liquids which have laminar or streamlined flow. It means that a liquid in which its particles exert no force on each other i.e. the speed of all particles of the liquid is the same.

(A) Bernoulli's principle is based on the conservation of

(a) momentum

(b) energy and momentum both

(c) mass

(d) energy

(B) Water is flowing through a horizontal pipe in a streamline flow, at the narrowest part of the pipe:

(a) both pressure and velocity remain constant.

(b) velocity is maximum and pressure is minimum.
(c) both the pressure and velocity are maximum.
(d) both the pressure and velocity are minimum.

(C) In houses, away from municipal water tanks often find it difficult to get water on the top floor. This happens because:

(a) water wets the pipe.
(b) the pipes are not of uniform diameter.
(c) the viscosity of water is high.
(d) of loss of pressure during the flow of water.

(D) In which of the following types of flows is Bernoulli's theorem strictly applicable?

(a) streamline and rotational
(b) turbulent and rotational
(c) turbulent and irrotational
(d) streamline and irrotational

(E) Viscosity of gases:

(a) decreases with increases in tem- perature
(b) independent of temperature
(c) increases with an increase in tem- perature
(d) may increase or decrease depending on nature of gas [Delhi Gov. QB 2022]

Ans. (A) (d) energy

Explanation: The law of energy conservation serves as the foundation for Bernoulli's principle. We compare the total energy of a flowing liquid at various sites flowing under constant pressure difference (including pressure energy, potential energy, and kinetic energy).

(B) (b) velocity is maximum and pressure is minimum.

Explanation: The product of cross section area and velocity is constant in streamline flow (equation of continuity). Thus, the pipe's smallest section has the highest velocity. Also, we know that the total amount of potential energy, kinetic energy, and pressure energy remains constant according to Bernoulli's theorem. Potential energy is equal at all sites since the pipe is horizontal. Due to the fact that velocity (kinetic energy) is at its highest at the narrowest region of the pipe, pressure (pressure energy) will be at its lowest there.

(C) (d) of loss of pressure during the flow of water

Explanation: People frequently have trouble getting water on the top level in homes distant from the municipal water tanks. This occurs as a result of significant water pressure loss due to friction between the water and the pipeline.

(D) (d) streamline and irrotational

Explanation: The Bernoulli's principle may be used with non-viscous liquids that flow laminarly or smoothly. It denotes a liquid whose particles do not interact with one another, i.e., the liquid's particles move at the same speed. Moreover, the liquid must move in streamlines; that is, the liquid running through one pipeline (imaginary pipeline) must not mix with the liquid flowing through another pipeline. This type of flow is streamlined. Moreover, streamlined flow is the opposite of turbulent flow. Hence, a turbulent liquid

will defy Bernoulli's law. However this streamlined flow won't happen if the liquid is turned. As a result, this kind of liquid will not be subject to Bernoulli's principle.

(E) (c) increases with an increase in temperature

Explanation: Gas viscosity is directly correlated with temperature. Hence, the viscosity will increase as the temperature rises.