

FLUID DYNAMICS

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

Understand that viscous forces in a fluid cause a retarding force on an object moving through it.

Use Stokes' law to derive an expression for terminal velocity of a spherical body falling through a viscous fluid under laminar conditions.

Understand the terms steady (laminar, streamline) flow, incompressible flow, non-viscous flow as applied to the motion of an ideal fluid.

Appreciate the equation of continuity Av = Constant for the flow of an ideal and incompressible fluid.

Appreciate that the equation of continuity is a form of the principle of conservation of mass.

Derive Bernoulli's equation in form $P + \frac{1}{2}\rho v^2 + \rho gh$ = constant.

Explain how Bernoulli effect is applied in the filter pump, atomizers, in the flow of air over an aerofoil, venturimeter and in blood physics.

Give qualitative explanations for the swing of a spinning ball.

INTRODUCTION

The study of fluids in motion is relatively complicated, but analysis can be simplified by making a few assumptions. The analysis is further simplified by the use of two important conservation principles; the conservation of mass and the conservation of energy. The law of conservation of mass gives us the equation of continuity while the law of conservation of energy is the basis of Bernoulli's equation. The equation of continuity and the Bernoulli's equation along with their applications in aeroplane and blood circulation are discussed in this chapter.

Q.1 Define fluid dynamics.

Fluid

"Those substances which can flow from one point to the other are called fluid."

For examples; liquids and gases.

Q.2 Explain what do you understand by viscosity.

Ans. **VISCOSITY**

"The frictional effect between different layers of the flowing fluid is described in terms of viscosity of fluid." **(OR)** "The property of fluid due to which they resist their flow is also known as viscosity." **(OR)** Fraction in fluids is known as viscosity.

Viscosity measures how much force is required to slide one layer of liquid over another layer. Substances that do not flow easily, such as thick tar and honey etc; have large co–efficient of viscosities, (η). Substances which flow easily like water have small coefficient of viscosities. Since, liquids and gases have non zero viscosity, a force is required if an object is to be moved through them.

Unit

As, $F = 6 \pi \eta r v$

$$\eta = \frac{F}{6\pi r v}$$

As $$= \frac{N}{m\ m/s}$$

$$= \frac{Ns}{m^2}$$

$$= Nm^{-2} s$$

or $\eta = kg\ m / s^2\ m^{-2} s$

$$= kg\ m^{-1} s^{-1}$$

Dimensions

$$[\eta] = [ML^{-1} T^{-1}]$$

Q.3 Define drag force and Stoke's law.

Ans. **DRAG FORCE (VISCOUS DRAG)**

"An object moving through a fluid experiences a retarding force is called a drag force." The drag force

For Your Information	
Viscosities of Liquids and Gases at 30°C	
Material	**Viscosity 10^{-3} (Nsm^{-2})**

increases as the speed of the object increases.

Stoke's Law

The drag force 'F' on a sphere of radius 'r' moving slowly with speed 'v' through a fluid of viscosity 'η' is given by Stoke's law as under

$$F_d = 6 \pi \eta r v_t$$

At high speeds the force is no longer proportional to the speed.

Note: *With rise in temperature, viscosity of liquid decreases and viscosity of gases increases.*

Air	0.019
Acetone	0.295
Methanol	0.510
Benzene	0.564
Water	0.801
Ethanol	1.000
Plasma	1.6
Glycerin	6.29

Q.4 Define terminal velocity. Also derive the expression for terminal velocity. (OR) Define terminal velocity. Prove that terminal velocity is directly proportional to the square of the radius.

Ans. **TERMINAL VELOCITY**

Maximum constant velocity of an object falling vertically downward when the weight of the object is equal to drag force is called terminal velocity.

Explanation

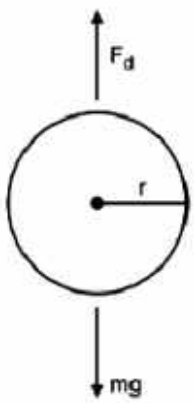
Consider a water droplet such as that of fog falling vertically, the air drag on the water droplet increases with speed. The droplet accelerates rapidly under the force of gravity which pulls the droplet downward. However, the upward drag force on it increases as the speed of the droplet increases.

Since, the droplet is moving downward.

$$\therefore \quad mg > F_d$$

The net force on droplet is

$$F_{net} = mg - F_d$$



As the speed of droplet continues to increase, the drag force eventually approaches the weight in the magnitude. Finally when the magnitude of drag force becomes equal to the weight, the net force acting on the droplet is zero. Then the droplet will fall with Constant speed (Maximum speed) is called Terminal velocity.

$$\therefore \quad F_{net} = 0$$

$$\therefore \quad 0 = mg - F_d$$

$$mg = F_d$$

$$mg = 6\pi \eta r V_t$$

$$V_t = \frac{mg}{6\pi \eta r} \quad \ldots\ldots\ldots (1)$$

or $V_t \propto m$

Where r, g, η are constant then

The more massive an object, faster it falls through a fluid.

As, ρ (density) $= m / V$

$$m = \rho V$$

As droplet is of spherical shape; so

Volume of sphere is

$$V = \frac{4}{3}\pi r^3$$

Then $$m = \rho \times \frac{4}{3}\pi r^3$$

Putting this value in equation (1);

$$\therefore \quad V_t = \frac{\rho\, 4/3\, \pi\, r^3\, g}{6\pi \eta r}$$

$$= \frac{4r^2 \rho g}{18 \eta}$$

$$V_t = \frac{2 \rho g r^2}{9 \eta}$$ which is the expression for the terminal velocity

or $V_t \propto r^2$ where $\frac{2\rho g}{9\eta}$ is constant

Hence, terminal velocity is directly proportional to the square of radius of droplet.

Can You Do That?



A table tennis ball can be made suspended in the stream of air coming from the nozzle of chair dryer.

Q.5 What is fluid flow? What is the difference between stream line and turbulent flow?

Ans. **FLUID FLOW**

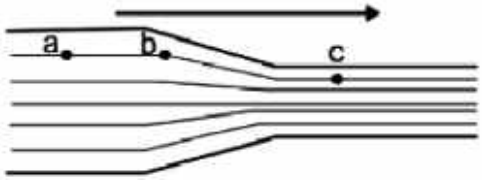
When a fluid is in motion, its flow can be:

(i) Streamline flow

(ii) Turbulent flow

(i) Streamline Flow

"The flow is said to be streamline or laminar if every particle that passes a particular point, moves along exactly the same path as followed by particles which passed that points earlier." **(OR)** "If velocity of the particles at different points does not change with time, the flow is called streamline flow."



Stream Line

In this case each particle of fluid moves along a smooth path called a streamline as shown in figure. The different streamline cannot cross each other. This condition is called steady flow condition. If the streamlines cross each other the particle will go in one direction or other and flow will not be steady flow, it will be a turbulent flow.

(ii) Turbulent Flow

"The irregular or unsteady flow of the fluid is called turbulent flow."

Ideal Fluid

Such a fluid which satisfy the following conditions is called an ideal fluid.

(i) The fluid is non–viscous i.e. there is no internal frictional force between adjacent layers of fluid.

(ii) The fluid is incompressible i.e. its density is constant.

(iii) The fluid motion is steady.

Do You Know?


Formula one racing cars have a streamlined design.


Dolphins have streamlined bodies to assist their movement in water.

Q.6 State and explain equation of continuity.

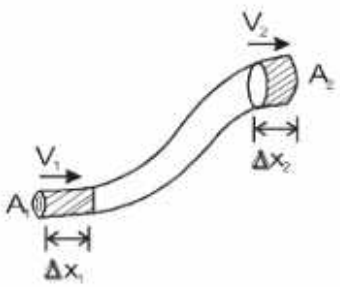
Ans. EQUATION OF CONTINUITY

Statement

The product of cross-sectional area of the pipe and the fluid speed at any point along the pipe is a constant. This constant equals the volume flow per second of the fluid or simply flow rate. **(OR)** If the fluid is incompressible and the flow is steady, the mass of the fluid is conserved i.e., the mass that flows into the bottom of the pipe through A_1 in a time Δt must be equal to mass of the liquid that flows out A_2 in the same time.

Explanation

Consider a fluid flowing through a pipe of non–uniform size. The particles in the fluid move along the streamlines in a steady state flow as shown in Fig.



In a small time Δt, the fluid at the lower end of tube moves a distance Δx_1, with a velocity V_1. If A_1 is area of cross-section of this end, then the mass of the fluid contained in the shaded region is

As, $\rho = m / V$

$= \Delta x_1 \times A_1$

$\therefore \quad \Delta m_1 = \rho_1 A_1 \Delta x_1 \quad \ldots\ldots\ldots (1)$

As, $S = V t$

$\therefore \quad \Delta x_1 = V_1 \Delta t$

Putting in equation (1)

$\therefore \quad \Delta m_1 = \rho_1 A_1 V_1 \Delta t \quad \ldots\ldots\ldots (2)$

Tidbits



As the water falls, its speed increases and so its cross sectional area decreases as mandated by the continuity equation.

Where ρ_1 is the density of fluid. Similarly the fluid that moves with velocity V_2 through the upper end of pipe of area A_2 in the same time Δt has a mass

$$\Delta m_2 = \rho_2 A_2 V_2 \Delta t \quad \ldots\ldots\ldots (3)$$

If the fluid is incompressible and the flow is steady, the mass of the fluid is conserved.

$$\therefore \quad \Delta m_1 = \Delta m_2$$

Putting values from equation (2) and equation (3)

$$\rho_1 A_1 V_1 \Delta t = \rho_2 A_2 V_2 \Delta t$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

This equation is known as the equation of continuity. Since density is constant for the steady flow of incompressible fluid.

$\therefore \quad \rho_1 = \rho_2 = \rho$

$\therefore \quad \rho A_1 V_1 = \rho A_2 V_2$

$A_1 V_1 = A_2 V_2$

or $AV = \text{Constant}$

or $V = \frac{1}{A} \text{Constant}$

$V \propto \frac{1}{A}$

Note: *Equation of continuity obeys law of conservation of mass.*

Q.7 State and explain Bernoulli's equation.

Ans. BERNOULLI'S EQUATION (OR THEOREM)

Introduction

A fundamental equation in fluid dynamics which deals with the steady flow of an incompressible and non-viscous fluid is called Bernoulli's equation.

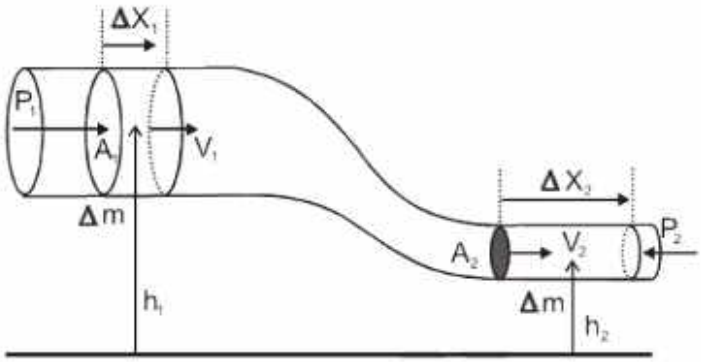
Statement

Bernoulli's theorem states that the sum of pressure, K.E. per unit volume and P.E. per unit volume, in a steady flow of an incompressible and non–viscous liquid has the same value."

Mathematically,

$$P + \frac{1}{2}\rho V^2 + \rho g h = \text{Constant}$$

Consider the flow of fluid which is incompressible, non-viscous and flows in a steady state manner through the pipe in time 't' as shown in figure.



The force on the upper end of the fluid is P_1A_1 (since $P = F/A \therefore F = PA$) where P_1 is the pressure and A_1 is the area of cross section of pipe at the upper end. The work done on the fluid, in moving it through a distance Δx_1 will be

$$W_1 = \vec{F} \cdot \vec{\Delta x_1}$$
$$= F \Delta x_1 \cos 0^\circ$$
$$= P_1 A_1 \Delta x_1 \times 1$$
$$W_1 = P_1 A_1 \Delta x_1 \quad \ldots\ldots\ldots (1)$$

If V_1 is velocity of fluid at this end then,

As $S = V t$

$\Delta x_1 = V_1 t$

$\therefore$ equation (1) becomes

$$W_1 = P_1 A_1 V_1 t$$

Similarly work done on the fluid at lower end is,

$$W_2 = \vec{F}_2 \cdot \vec{\Delta x_2}$$
$$= F_2 \Delta x_2 \cos 180^\circ$$
$$= P_2 A_2 \Delta x_2 (-1) \qquad (\because F_2 = P_2 A_2)$$
$$= - P_2 A_2 \Delta x_2$$
$$W_2 = - P_2 A_2 V_2 t \qquad (\because \Delta x_2 = V_2 t)$$

Where V_2 is the velocity of the fluid at lower end. P_2 is the pressure, A_2 is the area of cross section of lower end and Δx_2 is the distance moved by the fluid in the same time interval 't'. The work W_2 is taken to be negative because this work is done against the fluid force.

Total work done

$$W = W_1 + W_2$$
$$\therefore \quad W = p_1 A_1 V_1 t + (- p_2 V_2 A_2 t)$$
$$W = p_1 A_1 V_1 t - p_2 A_2 V_2 t \quad \ldots\ldots\ldots (2)$$

From equation of continuity

$$A_1 V_1 = A_2 V_2$$

$\left[\Delta m = \rho A V t\right]$

$\left[\frac{\Delta m}{} = AV t\right]$

$\therefore$ equation (2) becomes

$$\therefore \quad W = P_1 V - P_2 V$$

$$W = (P_1 - P_2) V$$

$$\text{Since} \quad \rho = \frac{m}{V}$$

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

$$\therefore \quad W = \frac{m}{\rho}(P_1 - P_2) \qquad \ldots\ldots\ldots (3)$$

Part of this work is utilized by the fluid in changing its K.E. and a part of it is used in changing its gravitational P.E.

$$\text{Change in K.E.} = \Delta \text{K.E} = \frac{1}{2} m V_2^2 - \frac{1}{2} m V_1^2$$

$$\text{Change in P.E.} = \Delta \text{P.E.} = mg h_2 - mg h_1$$

Where h_1 and h_2 are the heights of upper and lower ends of pipe respectively.

Applying law of conservation of energy to this volume of the fluid.

$$W = \Delta K.E. + \Delta P.E.$$

$$\frac{m}{\rho}(P_1 - P_2) = m\left(\frac{1}{2} V_2^2 - \frac{1}{2} V_1^2 + g h_2 - g h_1\right)$$

$$P_1 - P_2 = \frac{1}{2}\rho V_2^2 - \frac{1}{2}\rho V_1^2 + \rho g h_2 - \rho g h_1$$

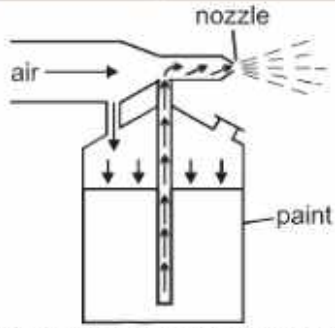
$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

This is Bernoulli's equation and is often expressed

$$\text{As} \quad P + \frac{1}{2}\rho V^2 + \rho g h = \text{Constant}$$

Note: Law of conservation of energy is the basis of Bernoulli's theorem.

Interesting Information



A stream of air passing over a tube dipped in a liquid will cause the liquid to rise in the tube as shown. This effect is used in perfume bottles and paint sprayers.

Do You Know?



A chimney works best when it is tall and exposed to air currents, which reduces the pressure at the top and force the upward flow of smoke.

APPLICATIONS OF BERNOULLI'S EQUATION

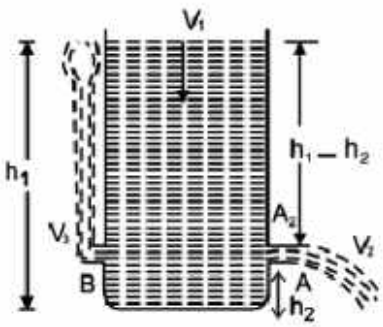
There are two applications of Bernoulli's theorem:

Q.8 State and explain Torricelli's theorem.

Ans. **TORRICELLI'S THEOREM**

Statement

"The speed of efflux (outward flow of gas or liquid) is equal to the velocity gained by the fluid in falling through the distance $(h_1 - h_2)$ under the action of gravity."



Explanation

Suppose a large tank of fluid has two small orifices A and B on it as shown in figure. Now we find speed with which the water flows from the orifice A.

Since the orifices are so small, the efflux speeds V_2 and V_3 will be much larger than the speed V_1 of the top of surface of water. Therefore, $V_1 \approx 0$.

As Bernoulli's equation is

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

Putting $V_1 = 0$

$$\therefore \quad P_1 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

Since $P_1 = P_2 = P$ (Atmospheric pressure)

$$\therefore \quad P + \rho g h_1 = P + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$\rho g h_1 = \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$\frac{1}{2}\rho V_2^2 = \rho g h_1 - \rho g h_2$$

$$\frac{1}{2}\rho V_2^2 = \rho g (h_1 - h_2)$$

$$\frac{1}{2} V_2^2 = g (h_1 - h_2)$$

$$V_2^2 = 2g (h_1 - h_2)$$

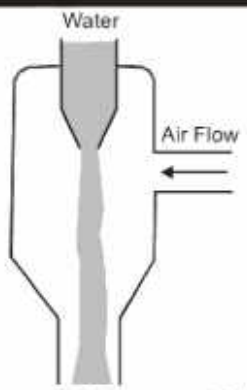
Taking square root on both sides.

$$V_2 = \sqrt{2g (h_1 - h_2)}$$

Which is the Torricelli's theorem.

Note: Notice that the speed of the efflux of liquid is the same as the speed of a ball that falls through a height $(h_1 - h_2)$. The top level of the tank has moved down a little and the P.E. has been

For Your Information

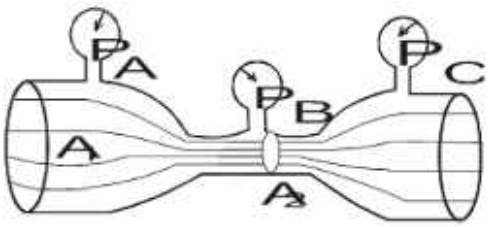


A filter pump has a constriction in the centre, so that a jet of water from the tap flows faster here. This cause a drop in pressure near it and air, therefore, flows in from the side tube. The air and water together are expelled through the lower part of the pump.

Q.9 What is the relation between fluid speed and pressure? (OR) Prove that where the pressure is low, the speed will be high.

Ans. **RELATION BETWEEN SPEED AND PRESSURE OF THE FLUID**

Suppose that water flows through a pipe system as shown in figure.



Clearly, the water will flow faster at B than it does at A or C. $\left(\because V \propto \frac{1}{A}\right)$.

Now we compare the pressure at B with that at A. As the Bernoulli's equation is

$$P_A + \frac{1}{2}\rho V_A^2 + \rho g h_A = P_B + \frac{1}{2}\rho V_B^2 + \rho g h_B$$

Since the average height at both places is same.

$\therefore$ P.E. is same at both places.

$$\therefore \quad P_A + \frac{1}{2}\rho V_A^2 + \rho g h = P_B + \frac{1}{2}\rho V_B^2 + \rho g h$$

$$\therefore \quad P_A + \frac{1}{2}\rho V_A^2 = P_B + \frac{1}{2}\rho V_B^2$$

Let $V_A = 0.20$ m/s, $V_B = 2$m/s

For water;

$$\rho = 1000 \text{ kg/m}^3$$

$$\therefore \quad P_A + \frac{1}{2}(1000)(2)^2 = P_B + \frac{1}{2}(1000)(2)^2$$

$$P_A + 500\,(0.04) = P_B + 500 \times 4$$

$$P_A + 20 = P_B + 2000$$

$$P_A - P_B = 2000 - 20$$

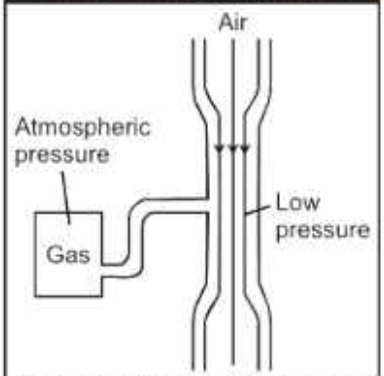
$$P_A - P_B = 1980 \text{ Nm}^{-2} \text{ (Pa)}$$

$$\therefore \quad P_A > P_B$$

This shows that the pressure in the narrow pipe where the streamlines are closer together is much smaller than in the wider pipe. Thus, where the speed is high, the pressure will be low.

Example

Interesting Information



The carburetor of a car engine uses a Venturi duct to feed the correct mix of air and petrol to the cylinders. Air is drawn through the duct and along a pipe to the cylinders. A tiny inlet at the side of duct is fed with petrol. The air through the duct moves very fast, creating low pressure in the duct, which draws petrol vapour into the air stream.



The lift on an aeroplane is due to this effect. The flow of air around an aeroplane wing is illustrated in figure. The wing is designed to deflect the air so that streamlines are closer together above the wing than below it. We have seen in figure that where the streamlines are forced closer together, the speed is faster. Thus, air is travelling faster on the upper side of the wing than on the lower. The pressure will be lower at the top of the wing, and the wing will be forced upward.

Similarly, when a tennis ball is hit by a racket in such a way that spins as well as moves forward, the velocity of the air on one side of the ball increases (figure) due to spin and air speed in the same direction as at B and hence, the pressure decreases. This gives an extra curvature to the ball known as swing which deceives an opponent player.

Q.10 Explain venturi relation.

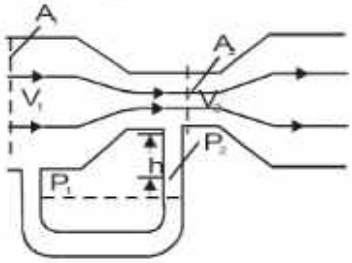
Ans. **VENTURI RELATION**

If one of the pipe has a much smaller diameter than the other, as shown in Fig. It is assumed that the pipes are horizontal so that $\rho g\, h$ terms become equal and can, therefore, be dropped then

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

$$P_1 - P_2 = \frac{1}{2}\rho\left(V_2^2 - \frac{1}{2}\rho V_1^2\right)$$

$$= \frac{1}{2}\rho\left(V_2^2 - V_1^2\right)$$



As the cross sectional area A_2 is small as compared to the area A_1, then from equation of continuity $V_1 = (A_2/A_1)\, V_2$, will be small as compared to V_2. Thus for flow from a large pipe to a small pipe we can neglect V_1 on the right hand side of equation, hence,

$$P_1 - P_2 = \frac{1}{2}\rho V_2^2$$

This is known as Venturi relation, which is used in Venturi–meter, a device used to measure speed of liquid flow.

Q.11 Explain the flow of blood inside the human body. How the blood pressure is measured?

Ans. **BLOOD FLOW**

Blood is incompressible fluid with density nearly equal to that of water. High concentration of red blood cells (about 50%) increases its viscosity from three to five times that of water. Blood vessels are not rigid. They stretch like a rubber hose. Under normal circumstances the volume of blood is sufficient to keep the vessels inflated at all times, even in the relaxed state between heart beats. This means that there is tension in the walls of blood vessels and so

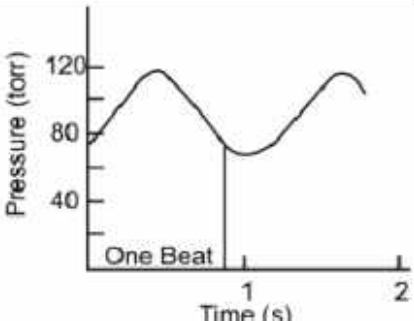
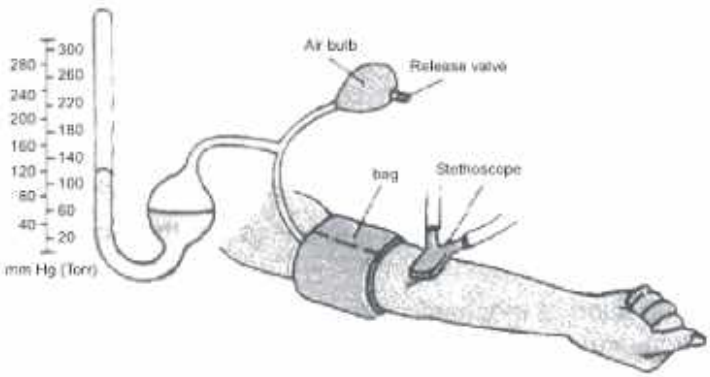


Figure shows the variation in blood pressure as the heart beats. The pressure varies from high (systolic) pressure of 120 torr to a low (diastolic) pressure of about 70 – 80 torr between beats in normal healthy person.

The instrument which is used to measure the blood pressure dynamically is called sphygmomanometer. It is shown in figure.



An inflatable bag is wound around the arm of a patient and external pressure on the arm is increased by inflating the bag. The effect is to squeeze the arm and compress the blood vessels inside. When the external pressure applied becomes larger than systolic pressure, the vessels collapse cutting off the flow of blood. Opening the release valve on the bag gradually decreases the external pressure.

A stethoscope detects the instant at which the external pressure becomes equal to the systolic pressure. At this point the first surges of blood flow through the narrow stricture which produces a high flow speed. As a result, the flow is initially turbulent.

As the pressure drops, the external pressure eventually equals the diastolic pressure. From this point, the vessel no longer collapse during any portion of the flow cycle. The flow changes from turbulent to laminar and the gurgle in stethoscope disappear. This is the signal to record diastolic pressure.

Note: (i) 1 Torr = 133.3 Nm^{-2}.

(ii) For blood pressure Torr or mm of Hg is used instead of SI unit of pressure i.e. Nm^{-2}.

SOLVED EXAMPLES

EXAMPLE 6.1

A tiny water droplet of radius 0.010 cm descends through air from a high building. Calculate its terminal velocity. Given that η for air = 19×10^{-6} kg $m^{-1}s^{-1}$ and density of water ρ = 1000 kgm^{-3}.

Data

Radius of water droplet = r = 0.010 cm

$= 0.010 \times 10^{-2}$ m

$= 1 \times 10^{-4}$ m

For air = η = 19×10^{-6} kg m^{-1} s^{-1}

Density of water = ρ = 1000 kg m^{-3}

To Find

Terminal velocity = V_t = ?

SOLUTION

Using: $V_t = \frac{2 g r^2 \rho}{9 \eta}$

$= \frac{2 (9.8) (1 \times 10^{-4})^2 1000}{9 \times 19 \times 10^{-6}}$

$= \frac{2000 \times 9.8 \times 10^{-8}}{9 \times 19 \times 10^{-6}}$

$= \frac{9.8 \times 2 \times 10^{-5} \times 10^{6}}{9 \times 019}$

$= \frac{2 \times 9.8 \times 10}{9 \times 019}$

$= \frac{196}{171}$

= 1.1 m/s

Terminal velocity = V_t = 1.1 m/s

EXAMPLE 16.2

A water hose with an internal diameter of 20mm at the outlet discharges 30 kg of water in 60s. Calculate the water speed at the outlet. Assume the density of water is 1000 kgm^{-3} and its flow is steady.

Data

Diameter of hose = d = 20mm
= 20×10^{-3} m
= 2×10^{-2} m

Mass of water = m = 30 kg

Time = t = 60 sec

Density of water = ρ = 1000 kg m^{-3}

To Find

Speed of water = V = ?

SOLUTION

From equation of continuity

$$m = \rho A V \Delta t$$

Also $$V = \frac{m}{\rho A \Delta t}$$

Since area of cross section $A = \pi r^2$

$$\therefore \quad V = \frac{m}{\rho \pi r^2 \Delta t}$$

$$= \frac{30}{1000 \times 3.14 \left(\frac{d}{2}\right)^2 60} \qquad \left(\therefore\ r = \frac{d}{2}\right)$$

$$= \frac{30}{1000 \times 3.14 \frac{d^2}{4} \times 60}$$

$$= \frac{30 \times 4}{1000 \times 3.14 \times 60 \times (2 \times 10^{-2})^2}$$

$$= \frac{120}{1000 \times 3.14 \times 60 \times 4 \times 10^{-4}}$$

$$= \frac{2}{3.14 \times 4 \times 10^{-1}}$$

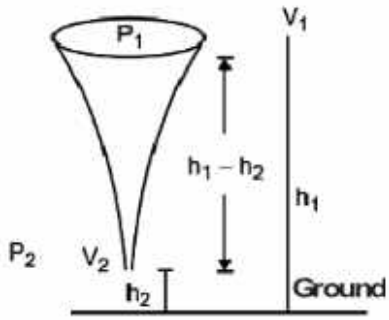
$$= \frac{10}{}$$

Speed of water = V = 1.6 m/s

EXAMPLE 6.3

Water flows down hill through a closed vertical funnel. The flow speed at the top is 12.0 cms^{-1}. The flow speed at the bottom is twice the speed at the top. If the funnel is 40 cm long and the pressure at the top is 1.103 x 10^5 Nm^{-2}, what is the pressure at the bottom?

Data



Flow speed at top = V_1 = 12 cm/s
= 0.12 m/s

Flow speed at bottom = V_2 = 24 cm/s
= 0.24 m/s

Length of funnel = h = $h_1 - h_2$
= 40 cm
= 0.4 m

Pressure at top = P_1 = 1.013×10^5 Nm^{-2}

To Find

Pressure at bottom = P_2 = ?

SOLUTION

Using Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

$$P_2 = P_1 + \frac{1}{2}\rho V_1^2 - \frac{1}{2}\rho V_2^2 + \rho g h_1 - \rho g h_2$$

$$= P_1 + \tfrac{1}{2}\rho (V_1^2 - V_2^2) + \rho g (h_1 - h_2)$$

$$= 1.013 \times 10^5 + \frac{1}{2}(1000)[(.12)^2 - (.24)^2] + 1000 \times 9.8 \times 0.4$$

$$= 1.013 \times 10^5 + 500\,(.0144 - 0.0576) + 980 \times 4$$

$$= 1.013 \times 10^5 + 500\,(-0.0432) + 3920$$

$$= 1.013 \times 10^5 - 21.6 + 3920$$

$$= 1.013 \times 10^5 + 3898.4$$

$$= 1.013 \times 10^5 + 0.039984 \times 10^5$$

$$= 10^5\,(1.013 + 0.03898)$$

$$= 1.05 \times 10^5 \text{ Nm}^{-2}$$



FLUID DYNAMICS

Each question has four possible answers, encircled the correct answer:

1. The fractional effect between different layers of a flowing fluid is called:

(a) Viscosity of the fluid **(b)** Velocity of the fluid

(c) Displacement of the fluid **(d)** Acceleration of the fluid

2. The force required to slide one layer of the liquid over another layer is measured by:

(a) Acceleration **(b)** Viscosity

(c) Momentum **(d)** Velocity

3. An object moving through a fluid experience a retarding force is called:

(a) Centripetal force **(b)** Horizontal force

(c) Drag force **(d)** Gravitational force

4. The study of the properties of fluid at rest is called:

(a) Viscosity **(b)** Fluid dynamic

(c) Fluid static **(d)** Friction

5. The study of properties of fluids in motion is called:

(a) Viscosity **(b)** Fluid dynamics

(c) Fluid static **(d)** Friction

6. Drag force between two layers under consideration depends upon:

(a) Distance between the layers **(b)** Relative velocity

(c) Surface area of layer **(d)** All of these

7. The drag force between different layers of the liquid is given by:

(a) $F_d = 6\pi\eta rv$ **(b)** $F_d = \dfrac{6\pi\eta}{rv}$

(c) $F_d = \dfrac{6\pi\eta r}{v}$ **(d)** None of these

8. Stoke's law holds for:

(a) Cylindrical bodies **(b)** Cubical bodies

(c) Spherical bodies **(d)** None of these

9. According to Stoke's law, drag force depends on:

(a) Coefficient of viscosity **(b)** Terminal velocity

(c) Radius of the spherical body **(d)** All of these

10. The drag force increases as the speed of particle:

(a) Increases **(b)** Decreases

(c) Remains constant **(d)** None of these

11. The drag force F_d on a sphere of radius r moving slowly with speed v through the fluid of viscosity η is given by:

(a) $4\pi\eta rv$ **(b)** $6\pi\eta rv$

(c) $2\pi\eta rv$ **(d)** $3\pi\eta rv$

12. The word fluid means:

(a) To fall **(b)** To rise

(c) To flow **(d)** None of these

13. Stokes law obey only:

(a) Ideal fluid **(b)** Viscous fluid

(c) Perfect fluid **(d)** Non-ideal fluid

14. The formula $F_d = 6\pi\eta rv$ is derived by:

(a) Einstein **(b)** Newton

(c) Sadi Carnot **(d)** Stoke

15. Due to increase in temperature, the viscosity of the fluid:

(a) Increases **(b)** Decreases

(c) Remains constant **(d)** Becomes double

16. The dimensions of coefficient of viscosity are:

(a) $[ML^{-1}T^{-2}]$ **(b)** $[ML^{2}T^{-1}]$

(c) $[ML^{-1}T^{-1}]$ **(d)** None of these

17. Viscosity of the gases with rise in temp:

(a) Increases **(b)** Decreases

(c) Remains constant **(d)** None of these

18. Which one of the following is most viscous:

(a) Glycerine **(b)** Coal Tar

(c) Honey **(d)** None of these

19. The SI unit of coefficient of viscosity is:

(a) $kg\ m^{-1}s^{-1}$ **(b)** $Nm^{2}s^{2}$

(c) $kg\ m^{2}s^{-2}$ **(d)** $kg\ ms^{-2}$

20. Internal friction of a fluid is called:

(a) Surface tension **(b)** Resistance

(c) Viscosity **(d)** None of these

21. When the magnitude of the drag force becomes equal to the weight, the net force acting on the droplet is:

(a) Zero **(b)** Maximum

(c) Remains the same **(d)** None of these

22. The drag force increases as the speed of the object:

(a) Decreases **(b)** Increases

(c) Remains constant **(d)** None of these

23. The force of friction that comes into action after the motion has started is called:

(a) Limiting friction **(b)** Static friction

(c) Friction **(d)** None of these

24. A body of mass m is falling downward in a viscous medium with terminal velocity v, net force on the body is:

(a) mg **(b)** $mg - 6\pi\eta rv$

(c) $6\pi\eta rv - mg$ **(d)** Zero

25. Viscosity of air is:

(a) $0.019 \times 10^{3}\ Nsm^{-2}$ **(b)** $0.019 \times 10^{-3}\ N\text{-}sm^{-2}$

(c) $0.0019 \times 10^{-3}\ N\text{-}sm^{-2}$ **(d)** $0.0019 \times 10^{3}\ N\text{-}sm^{-2}$

26. The viscosity of water is:

(a) $0.019 \times 10^{-3}\ N\text{-}sm^{-2}$ **(b)** $0.801 \times 10^{-3}\ N\text{-}sm^{-2}$

(c) $6.29 \times 10^{-3}\ N\text{-}sm^{-2}$ **(d)** $0.081 \times 10^{3}\ N\text{-}sm^{-2}$

27. The viscosity of glycrine is:

(a) $0.019 \times 10^{-3}\ Nsm^{-2}$ **(b)** $0.801 \times 10^{-3}\ Nsm^{-2}$

(c) $6.29 \times 10^{-3}\ N\text{-}sm^{-2}$ **(d)** $6.29 \times 10^{3}\ Nsm^{-2}$

28. The maximum velocity attained by a spherical droplet when drag force F and the weight of the droplet becomes equal is called:

(a) Instantaneous velocity **(b)** Terminal velocity

(c) Uniform velocity **(d)** None of these

29. The terminal velocity in case of spherical droplet is directly proportional to the:

(a) Square of the radius **(b)** Radius of the droplet

(c) Half of the radius **(d)** None of these

30. The terminal velocity of the spherical object is given by:

(a) $v_t = \frac{2gr^2\rho}{9\eta}$ **(b)** $v_t = \frac{mg}{4\pi\eta r}$

(c) $v_t = \frac{mg}{6\pi\eta r}$ **(d)** None of these

31. The terminal velocity of water droplet of radius 1×10^{-4} m and density 1000 kg/m^3 falling through air of viscosity 19×10^{-6} kg/ms is:

(a) 1.5 m/s **(b)** 2.3 m/s

(c) 3.4 m/s **(d)** 1.1 m/s

32. The terminal velocity v_t of a sphere of radius r in fluid of viscosity η depends upon:

(a) Radius **(b)** Viscosity

(c) Density **(d)** All of above

33. If each particle of fluid passing through a point follows the same path, then flow is called:

(a) Regular flow **(b)** Streamline flow

(c) Normal flow **(d)** Turbulent flow

34. The irregular flow of the fluids is called:

(a) Regular flow **(b)** Normal flow

(c) Turbulent flow **(d)** Streamline flow

35. For the steady flow of incompressible fluid, the equation of continuity is given by:

(a) $A_1v_1 = A_2v_2$ **(b)** $\frac{A_1}{v_1} = \frac{A_2}{v_2}$

(c) $\frac{v_1}{A_1} = \frac{v_2}{A_2}$ **(d)** $A_1v_1t_1 = A_2v_2t_2$

36. The product of cross-sectional area of the pipe and the fluid speed at any point along the pipe is:

(a) Zero **(b)** Constant

(c) Variable **(d)** None of these

37. A fog droplet falls vertically through air with an acceleration:

(a) Greater than g **(b)** Less than g

(c) Equal to g **(d)** Equal to zero

38. The formula for continuity is given by the relation:

(a) $\rho_1v_2v_1 = \rho_2v_1v_2$ **(b)** $\rho_1A_1v_1 = \rho_2v_2A_2$

(c) $\rho_2A_2v_1 = \rho_1A_1v_2$ **(d)** None of these

39. The SI units of flow rate is:

(a) m^2/s^2 **(b)** m^3/s

(c) m^3/s^2 **(d)** m^2/s

40. Bernoullis equation is based upon law of conservation of:

(a) Momentum **(b)** Energy

(c) Mass **(d)** All of these

41. The fluid which is in compressible and non-viscous is called:

(a) Viscous fluid **(b)** Non-ideal fluid

(c) Ideal fluid **(d)** Perfect fluid

42. When the velocity of a liquid flowing steadily in a tube increases, its pressure:

(a) Becomes zero **(b)** Remains the same

(c) Increases **(d)** Decreases

43. The application of Bernoulli's theorem is:

(a) Torricelli's theorem **(b)** Venturi relation

(c) Both (a) and (b) **(d)** None of these

44. According to Bernoulli's theorem, velocity and pressure:

(a) Are inversely proportional **(b)** Are directly proportional

(c) Have no relation **(d)** None of these

45. Bernoulli's equation includes as a special case of:

(a) Torricelli's theorem **(b)** Stoke's law

(c) Newton's laws **(d)** None of these

46. When there is no change in pressure at the beginning and end of a flow process, Bernoulli's equation reduces to:

(a) $v = \sqrt{2gh}$ **(b)** $P = \rho gh$

(c) $P + \frac{1}{2}\rho v^2 = \text{Constant}$ **(d)** None of these

47. If the cross-sectional area of the pipe decreases, the speed of the fluid must increases according to:

(a) Venturi relation **(b)** Equation of continuity

(c) Torricelli's thereom **(d)** None of these

48. Bernoulli's equation is applicable to points flow:

(a) In a streamline flow **(b)** In any non-viscous liquid

(c) In a steady of flowing liquid **(d)** None of these

49. The Torricellis expression is expressed as:

(a) $v_2 = \sqrt{2g(h_1 + h_2)}$ **(b)** $v_2 = \sqrt{2g(h_1 + h_2)}$

(c) $v_2 = \sqrt{2g(h_1 - h_2)}$ **(d)** None of these

50. The velocity of efflux of a liquid from an orifice is:

(a) $\sqrt{gh}$ **(b)** $\sqrt{2gh}$

(c) $\frac{gh}{2}$ **(d)** $2\sqrt{gh}$

51. The Venutri relation is given by:

(a) $P_1 + P_2 = \rho v_2^2$ **(b)** $P_1 - P_2 = \rho v_2^2$

(c) $P_1 - P_2 = \frac{1}{2}\rho v_2^2$ **(d)** $P_1 + P_2 = \frac{1}{2}\rho v_2^2$

52. The speed of efflux is equal to the velocity gained by the falling fluid under the action of gravity through a certain height is called:

(a) Torricell's theorem **(b)** Venture's theorem

(c) Cornot engine **(d)** None of these

53. Venturi meter is a device used to measure:

(a) Viscosity of fluid **(b)** Density of fluid

(c) Pressure of fluid **(d)** Speed of fluid

54. The fundamental equation in fluid dynamics which relates the pressure with speed fluid and height is:

(a) Bernoulli's equation **(b)** Equation of continuity

(c) Torricelli's equation **(d)** Venturi equation

55. The Bernoulli's equation is written as:

(a) $P - \frac{1}{2}\rho v^2 = \text{Constant}$ **(b)** $P + \frac{1}{2}\rho v^2 + \rho gh = \text{Constant}$

(c) $P + \frac{1}{2}\rho v^2 - \rho gh = \text{Constant}$ **(d)** None of these

56. The pressure will be low, where the speed of fluid is:

(a) High **(b)** Low

(c) Zero **(d)** Constant

57. At any two points along streamline flow, the sum of the pressure, P.E per unit volume and K.E per unit volume remains constant, this is the statement:

(a) Equation of continuity **(b)** Venturi relation

(c) Terricelli's theorem **(d)** Bernoulli's theorem

58. The speed of efflux of liquid is the same as the speed of ball falls through a height of:

(a) $h_1 + h_2$ **(b)** $h_2 - h_1$

(c) $h_1 - h_2$ **(d)** None of these

59. Blood is an incompressible fluid having a density nearly equal to that of:

(a) Water **(b)** Oil

(c) Milk **(d)** All of these

60. Human blood pressure is measured in:

(a) N/m^2 **(b)** Torr

(c) Pascal **(d)** cm

61. Blood has a density:

(a) Greater than water **(b)** Equal to water

(c) Less than water **(d)** None of these

62. Blood pressure is measured by:

(a) Barometer **(b)** Stetho scope

(c) Sphygmomanometer **(d)** Hydrometer

63. Blood is an:

(a) Incompressible fluid **(b)** Compressible fluid

(c) Ideal fluid **(d)** Perfect fluid

64. The instrument which detects the instant at which the external pressure becomes equal to the systolic pressure is called:

(a) Manometer **(b)** Sphygmomanometer

(c) Barometer **(d)** Hydrometer

65. Tubes of narrow bore and liquids of high viscosity and low density promote:

(a) Streamline flow **(b)** Turbulent flow

(c) Both (a) and (b) **(d)** None of these

66. Streamlines passing through a given cross-section normally form:

(a) Liquid does not cross the boundaries of tubes of flow

(b) Tubes of flow

(c) Steady flow do not overlap each other

(d) All of these

67. Dimensions of $\left[\frac{1}{2}\rho v^2\right]$ are:

(a) $[ML^{-1}T^{-1}]$ **(b)** $[ML^{3}T^{-2}]$

(c) $[ML^{-1}T^{-2}]$ **(d)** $[ML^{-1}T^{-1}]$

68. Dimensions of $[\rho gh]$ are:

(a) $[ML^{-1}T^{-2}]$ **(b)** $]ML^{-3}T^{-2}]$

(c) $[ML^{-1}T^{-1}]$ **(d)** $[ML^{-2}T^{-2}]$

69. In the formula for velocity of efflux $v = \sqrt{2gh}$ where h is:

(a) The height of orifice from the bottom of the vessel

(b) Height of liquid column above the orifice

(c) Height of liquid column

(d) None of these

70. Sphygmo is a:

(a) Greek word **(b)** Spanish word

(c) Latin word **(d)** None of these

71. Sphygmo means:

(a) Liver **(b)** Pulse

(c) Liver **(d)** Heart

72. Bunsen burner works on the principle of:

(a) Venturi effect **(b)** Torricilli's effect

(c) Bernoulli's effect **(d)** None of these

73. In Laminar flow, adjacent layers:

(a) Mix with each other **(b)** Smoothly slide one over the other

(c) Oppose each other **(d)** None of these

74. A man is standing near a fast moving train:

(a) To fall towards the track **(b)** To fall away from the track

(c) No effect **(d)** None of these

75. Two boats moving parallel in a river:

(a) Remain always parallel **(b)** Pulled towards each other due to less pressure

(c) Get a part due to increase in pressure **(d)** None of these

76. Streamlines are:

(a) Largely spaced on the upper side than on the inner side of the wing

(b) Equally spaced both on the upper and lower side of the wing

(c) Closer together on the upper side of the wing

(d) None of these

77. A fluid is said to be ideal if it is:

(a) Non-viscous, incompressible and streamline

(b) Non-viscous and streamline

(c) Non-viscous and incompressible

(d) None of these

78. The blood pressure varies from high systolic pressure to low diastolic pressure of about:

(a) 80 – 90 torr **(b)** 75 – 85 torr

(c) 75 – 80 torr **(d)** None of these

79. 1 torr in N/m^2 is:

(a) 129 N/m^2 **(b)** 133.3 N/m^2

(c) 135.6 N/m^2 **(d)** 125 N/m^2

80. The systolic pressure is about:

(a) 120 torr **(b)** 125 torr

(c) 115 torr **(d)** 130 torr

81. Blood pressure of a person:

(a) Increases with age **(b)** Decreases with age

(c) Remain same **(d)** None of these

82. The smoot or steady streamline flow is known as:

(a) Turbulent flow **(b)** Laminar flow

(c) Simple flow **(d)** None of these

83. The velocity of liquid below which its flow is laminar is called:

(a) Critical velocity **(b)** Escape velocity

(c) Relative velocity **(d)** None of these

84. For which position, will the maximum blood pressure in the body have the smallest value:

(a) Standing one's leg **(b)** Lying horizontally

(c) Standing up right **(d)** None of these

85. The smooth r steady streamline flow is called:

(a) Turbulent flow **(b)** Laminar flow

(c) Simple flow **(d)** Regular flow

86. Friction in fluids is known as:

(a) Drag force **(b)** Viscosity

(c) Surface tension **(d)** None

87. Unit of coefficient of viscosity:

(a) $Nm^{-2}s$ **(b)** $kg\ m^{-1}s^{-1}$

(c) Both (a), (b) **(d)** None

88. When the magnitude of the drag force becomes equal to the weight, the net force acting on the droplet:

(a) Minimum **(b)** Zero

(c) Maximum **(d)** None

89. If velocity of particle at different points does not change with time, flow is:

(a) Streamline **(b)** Laminar

(c) Steady **(d)** All

90. Equation of continuity is the basis of law of conservation of:

(a) Mass **(b)** Momentum

(c) Energy **(d)** None

91. The product of cross-sectional area of the pipe and the fluid speed at any point along the pipe:

(a) Constant **(b)** Flow rate

(c) Volume flow per second **(d)** All

92. As Bernoulli's equation $P + \frac{1}{2}\rho v^2 + \rho gh = \text{Constant}$. Here $\frac{1}{2}\rho v^2$ is:

(a) K.E. **(b)** K.E. per unit volume

(c) K.E. per unit time **(d)** None

93. Torricelli's theorem is:

(a) $\sqrt{2g}$ **(b)** $\sqrt{2g(h_1 - h_2)}$

(c) $\sqrt{2g(x_1 - x_2)}$ **(d)** None

94. A device used to measure speed of liquid flow:

(a) Venturi-meter **(b)** Speed-meter

(c) Sphyginomeno-meter **(d)** None

95. A liquid flows through a pipe of varying diameter. The velocity of the liquid is 2 m/s at a point where the diameter is 6 cm. The velocity of the liquid at a point where diameter is 3 cm will be:

(a) 1 m/s **(b)** 4 m/s

(c) 8 m/s **(d)** 16 m/s

96. The dimensional formula of surface tension is:

(a) $[MLT^{-1}]$ **(b)** $[MLT^{-2}]$

(c) $[ML^0T^{-2}]$ **(d)** $[ML^{-1}T^{-1}]$

ANSWERS

1.	(a)	**2.**	(b)	**3.**	(c)	**4.**	(c)
5.	(b)	**6.**	(d)	**7.**	(a)	**8.**	(c)
9.	(d)	**10.**	(a)	**11.**	(b)	**12.**	(c)
13.	(b)	**14.**	(d)	**15.**	(b)	**16.**	(c)
17.	(a)	**18.**	(b)	**19.**	(a)	**20.**	(c)
21.	(a)	**22.**	(b)	**23.**	(a)	**24.**	(b)
25.	(b)	**26.**	(b)	**27.**	(c)	**28.**	(b)
29.	(a)	**30.**	(a)	**31.**	(d)	**32.**	(d)
33.	(b)	**34.**	(c)	**35.**	(a)	**36.**	(b)
37.	(a)	**38.**	(b)	**39.**	(b)	**40.**	(b)
41.	(c)	**42.**	(d)	**43.**	(c)	**44.**	(a)
45.	(a)	**46.**	(a)	**47.**	(b)	**48.**	(b)
49.	(c)	**50.**	(b)	**51.**	(c)	**52.**	(a)
53.	(d)	**54.**	(a)	**55.**	(b)	**56.**	(a)
57.	(d)	**58.**	(c)	**59.**	(a)	**60.**	(b)
61.	(b)	**62.**	(c)	**63.**	(a)	**64.**	(b)
65.	(a)	**66.**	(d)	**67.**	(c)	**68.**	(a)
69.	(b)	**70.**	(c)	**71.**	(b)	**72.**	(a)
73.	(b)	**74.**	(a)	**75.**	(b)	**76.**	(c)
77.	(a)	**78.**	(c)	**79.**	(b)	**80.**	(a)
81.	(a)	**82.**	(b)	**83.**	(a)	**84.**	(b)
85.	(b)	**86.**	(b)	**87.**	(c)	**88.**	(b)
89.	(d)	**90.**	(a)	**91.**	(d)	**92.**	(b)
93.	(b)	**94.**	(a)	**95.**	(c)	**96.**	(c)

SHORT QUESTIONS

6.1 Explain what do you understand by the term viscosity?

Ans. **Viscosity:** The frictional effect between different layers of a flowing fluid is described in terms of viscosity of the fluid. Viscosity measures, how much force is required to slide one layer of the liquid over another layer. It is denoted by η. The SI unit of viscosity is Ns/m^2.

6.2 What is meant by drag force? What are the factors upon which drag force acting upon a small sphere of radius r, moving down through a liquid, depend?

Ans. **Drag Force:** An object moving through a fluid experiences a retarding force called drag force. This force increases as the speed of object through the fluid increases. In case of a spherical object moving through a fluid, the expression of drag forces is:

$$F = 6\pi\eta r v$$

This shows that drag force depends on the following factor:

(i) Radius r of the spherical body.

(ii) Speed v of the body.

(iii) Coefficient of viscosity η.

6.3 Why fog droplets appear to be suspended in air?

Ans. As we know that the expression for the terminal velocity is

$$v_t = \frac{mg}{6\pi\eta r}$$

where $\frac{g}{6\pi\eta r}$ is constant so

$$v_t \propto m$$

This shows that terminal velocity is directly proportional to mass.

As the mass of the fog droplet is very small therefore the terminal velocity is very small. So the droplet appears to be suspended in air.

6.4 Explain the difference between laminar flow and turbulent flow.

Ans. **Laminar Flow:** The fluid, flow is said to laminar if every particle of the fluid that passes a point moves along the same path as followed by particles which passed that point earlier.

Turbulent Flow: The irregular or unsteady flow of the fluid is called turbulent flow. In turbulent flow, there is a great disorder and constantly changing flow path.

6.5 State Bernoulli's relation for a liquid in motion and describe some of its applications.

Ans. **Bernoulli's Theorem:** This theorem states that "the sum of pressure, kinetic energy per unit volume and potential energy per unit volume in a steady flow of an incompressible and non-viscous fluid remains constant at any point of its path".

Mathematically it is expressed as

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{Constant}$$

where ρ is the density of the liquid and g is the acceleration due to gravity.

Applications of Bernoulli's Theorem: Following are the applications of Bernoulli's theorem:

(i) Operation of paint sprayer or perfume sprayer.

(ii) Swing of a cricket ball.

(iii) Working of a carburetor of a car.

(iv) Working of a filter pump.

6.6 A person is standing near a fast moving train. Is there any danger that he will fall towards it?

Ans. We know that according to Bernoulli's principle "the pressure will be low where the speed of the fluid is high and vice versa therefore when a person is standing near a fast moving train the speed of air between person and train is very high and pressure will be low while the speed of air behind the person is low so pressure is high, thus a force will act from high pressure to low pressure therefore the person will be in danger.

6.7 Identify the correct answer. What do you infer from Bernoulli's theorem?

(i) Where the speed of the fluid is high the pressure will be low.

(ii) Where the speed of the fluid is high the pressure is also high.

(iii) This theorem is valid only for turbulent flow of the liquid.

Ans. (i) is correct where the speed of the fluid is high, the pressure will be low.

6.8 Two row boats moving parallel in the same direction are pulled towards each other. Explain.

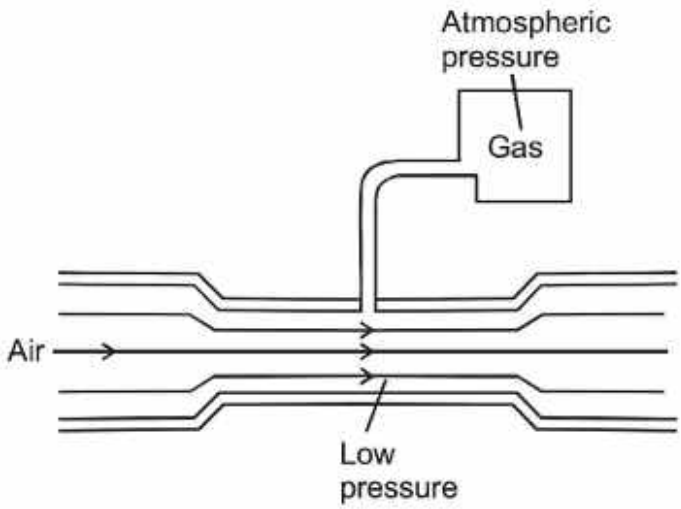
Ans. We know that according to Bernoulli's principle "the pressure will be low where the speed of fluid is high and vice versa therefore when two row boats are moving parallel in the same direction then the speed of water between the boats will be fast and pressure will be low while on the opposite sides of the boats the speed of water will be small so pressure will be high, thus a force will act from high pressure to low pressure therefore two boats are pulled towards each other.

6.9 Explain, how the swing is produced in a fast moving cricket ball.

Ans. We know that according to Bernoulli's principle "the pressure will be low where the speed of the fluid is high and vice versa". Therefore when a cricket ball is thrown by a fast bowler, the speed of air on the shining side will be fast and pressure will be low while on the rough side the speed of air is less and pressure is high. So a face will act from high pressure to the low pressure and the ball moves in a curved path called swing.

6.10 Explain the working of a carburetor of a motorcar using Bernoulli's principle and non viscous liquid is constant; thus.

Ans. Carburetor of car engine uses a venturi duct to feed the correct mixture of air and petrol to the cylinders. Air is drawn through the duct along a pipe to the cylinders. A tiny inlet at the side of duct is fed with petrol. The air through the duct moves very fast, creating a low pressure in the duct, which draws petrol vapour into air stream as shown in figure.



6.11 For which position will the maximum blood pressure in the body have the smallest value. (a) Standing up right (b) Sitting (c) Lying horizontally (d) Standing on one's head?

Ans. The blood pressure is measured at the level of heart. When lying horizontally heart does not has to work as hard as to pump against gravity because all parts of the body are in level with heart. So (c) is correct.

6.12 In an orbiting space station, would the blood pressure in major arteries in the leg ever be greater than the blood pressure in major arteries in the neck?

Ans. No, under weightlessness condition the blood pressure will be equal in major arteries of leg and neck in an orbiting space station.

PROBLEMS WITH SOLUTIONS

PROBLEM 6.1

Certain globular protein particle has a density of 1246 kg m^{-3}. It falls through pure water ($\eta = 8.0 \times 10^{-4}$ $Nm^{-2}s$) with a terminal speed of 3.0 cm h^{-1}. Find the radius of the particle.

Data

Density of protein particle $= \rho = 1246\ kg/m^3$

Viscosity $= \eta = 8.0 \times 10^{-4}\ Ns/m^2$

Terminal speed $= v_t = 3.0\ cm/h$

$= 0.03\ m/h$

$= \dfrac{0.03}{3600}$

$= 8.33 \times 10^{-6}\ m/s$

To Find

Radius of the particle $= r = ?$

SOLUTION

By formula

$$v_t = \frac{2gr^2\rho}{9\eta}$$

$$\boxed{r^2 = \frac{v_t \times 9\eta}{2\rho g}}$$

$$= \frac{8.33 \times 10^{-6} \times 9 \times 8.0 \times 10^{-4}}{2 \times 1246 \times 9.8}$$

$$= \frac{599.77 \times 10^{-4-6}}{24421.6}$$

$$r^2 = 0.024 \times 10^{-10}$$

$$r = 0.156 \times 10^{-5}$$

$$r = 1.56 \times 10^{-6}\ m$$

Result

Radius of the particle $= r = 1.56 \times 10^{-6}\ m$

PROBLEM 6.2

Water flows through a hose, whose internal diameter is 1 cm, at a speed of 1 ms^{-1}. What should be the diameter of the nozzle if the water is to emerge at 21 ms^{-1}?

Data

Internal diameter of pipe $= d_1 = 1$ cm

$= 0.01$ m

Speed of water in the hose $= v_1 = 1$ m/s

Speed of emerging water $= v_2 = 21$ m/s

To Find

Diameter of the nozzle $= d_2 = ?$

SOLUTION

According to equation of continuity

$$\boxed{A_1 v_1 = A_2 v_2} \qquad \ldots\ldots \text{(i)}$$

But $A = \pi r^2$

So $A_1 = \pi \left(\frac{d_1}{2}\right)^2$

$= \pi \frac{d_1^2}{4}$

and $A_2 = \pi \left(\frac{d_2}{2}\right)^2$

$= \pi \frac{d_2^2}{4}$

Putting in eq. (i)

$$\pi \frac{d_1^2}{4} v_1 = \pi \frac{d_2^2}{4} v_2$$

$$d_1^2 v_1 = d_2^2 v_2$$

$$\boxed{d_2^2 = \frac{d_1^2 v_1}{v_2}}$$

$$= \frac{(0.01)^2 \times 1}{21}$$

$$d_2^2 = 4.76 \times 10^{-6}$$

$$d_2 = \sqrt{4.76 \times 10^{-6}}$$
$$= 2.18 \times 10^{-3}$$
$$= 0.21 \times 10^{-2}\ m$$
$$d_2 = 0.21\ cm$$

Result

Diameter of nozzle $= d_2 = 0.21$ cm

PROBLEM 6.3

The pipe near the lower end of a large water storage tank develops a small leak and a stream of water shoots from it. The top of water in the tank is 15m above the point of leak.

(i) With what speed does the water rush from the hole?

(ii) If the hole has an area of 0.060 cm^2, how much water flows out in one second?

Data

Height of water $= h_1 - h_2 = 15$ m

Area of hole $= A = 0.060\ cm^2$
$= 0.060 \times 10^{-4}\ m^2$

To Find

(a) Speed of water from the hole $= v = ?$

(b) Volume per second of water $= V = ?$

SOLUTION

(a) For speed of water, using Torricelli's theorem

$$\boxed{v = \sqrt{2g(h_1 - h_2)}}$$
$$= \sqrt{2 \times 9.8 \times 15}$$
$$= \sqrt{294}$$
$$v = 17\ m/s$$

(b) For volume per second, by using equation of continuity

$$A_1v_1 = A_2v_2 = \text{Volume per second}$$

or

$$\boxed{\text{Volume per second of water} = Av}$$

So $= 0.060 \times 10^{-4} \times 17$
$= 1.02 \times 10^{-4}\ m^3$

Volume per second of water $= 102\ cm^3$

Result

(a) Speed of water from hole $= v = 17$ m/s

(b) Volume per second of water $= 102\ cm^3$

PROBLEM 6.4

Water is flowing smoothly through a closed pipe system. At one point the speed of water is 3 ms^{-1}, while at another point 3m higher, the speed is 4.0 ms^{-1}. If the pressure is 80 KPa at the lower point, what is pressure at the upper point?

Data

Speed of water at one point $= v_1 = 3$ m/s

Height of upper point $= h_2 = 3$ m

Speed of water at lower point $= v_2 = 4$ m/s

Height of lower point $= h_1 = 0$

Pressure at lower point $= P_1 = 80$ KPa

$= 80 \times 1000$

$= 80{,}000$ Pa

Density of water $= \rho = 1000$ kg/m^3

To Find

Pressure at upper point $= P_2 = ?$

SOLUTION

By using Bernoulli's theorem

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

When $h_1 = 0$

So $$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$\boxed{P_2 = P_1 + \frac{1}{2}\rho v_1^2 - \frac{1}{2}\rho v_2^2 - \rho g h_2}$$

$$= 80000 + \frac{1}{2} \times 1000 \times (3)^2 - \frac{1}{2} \times 1000 \times (4)^2 - 1000 \times 9.8 \times 3$$

$$= 80000 + 4500 - 8000 - 29400$$

$$P_2 = 47100 \text{ Pa}$$

$$P_2 = 47.1 \text{ KPa}$$

Result

Pressure at upper end $= P_2 = 47$ KPa

PROBLEM 6.5

An airplane wing is designed so that when the speed of the air across the top of the wing is 450 ms^{-1}, the speed of air below the wing is 410 ms^{-1}. What is the pressure difference between the top and bottom of the wings? (Density of air = 1.29 kgm^{-3}).

Data

Speed of air above the wing $= v_1 = 450$ m/s

Speed of air below the wing $= v_2 = 410$ m/s

Air density $= \rho = 1.29\ kg/m^3$

To Find

Pressure difference $= P_2 - P_1 = ?$

SOLUTION

According to Bernoulli's equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Since $\rho g h_1 = \rho g h_2$

So $$\boxed{P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2}$$

$$P_2 - P_1 = \frac{1}{2}\rho v_1^2 - \frac{1}{2}\rho v_2^2$$

$$= \frac{1}{2}\rho (v_1^2 - v_2^2)$$

$$= \frac{1}{2} \times 1.29\ (450^2 - 410^2)$$

$$= \frac{1}{2} \times 1.29 \times 34400$$

$$P_2 - P_1 = 22188\ Pa$$

$$P_2 - P_1 = 22.1\ KPa$$

Result

Pressure difference $= P_2 - P_1 = 22.1$ KPa

PROBLEM 6.6

The radius of the aorta is about 1.0 cm and the blood flowing through it has a speed of about 30 cms^{-1}. Calculate the average speed of the blood in the capillaries using the fact that although each capillary has a diameter of about 8×10^{-4} cm, there are literally millions of them so that their total cross section is about 2000 cm^2.

Data

Radius of aorta $= r_1 = 1.0$ cm

$= 0.01$ m

Speed of blood $= v_1 = 30$ cm/s

$= 0.3$ m/s

Area of one capillary = A = 8×10^{-4} cm

= 8×10^{-6} m

Total area of cross-section of capillaries = A = 2000 cm^2

= 0.2 m^2

To Find

Average speed of blood = v_2 = ?

SOLUTION

By using equation of continuity

$$A_1v_1 = A_2v_2$$

But $A_1 = \pi r_1^2$

So $\pi r_1^2 v_1 = A_2v_2$

$$\boxed{v_2 = \frac{\pi r_1^2 v_1}{A_2}}$$

$$= \frac{3.14 \times (0.01)^2 \times 0.3}{0.2}$$

$v_2 = 4.71 \times 10^{-4}$ m/s

$v_2 = 5.0 \times 10^{-4}$ m/s

Result

Average speed of blood = v_2 = 5.0×10^{-4} m/s

PROBLEM 6.7

How large must a heating duct be if air moving 3.0ms^{-1} along it can replenish the air in a room of 300m^3 volume every 15 min? Assume the air's density remains constant.

Data

Speed of air in duct = v_1 = 3.0 m/s

Volume of air = V = 300 m^3

Time = t = 15 min.

= 15×60

= 900 sec.

To Find

Size / Length of duct = r = ?

SOLUTION

As we know that

Volume per second = Av

$$\frac{V}{t} = Av \qquad As \quad A = \pi r^2$$

$$\boxed{\frac{V}{t} = \pi r^2 v}$$

$$\boxed{r^2 = \frac{V}{t \times \pi v}}$$

$$= \frac{300}{900 \times 3.14 \times 3.0}$$

$$r^2 = 0.035$$

$$r = 0.188$$

$$r = 0.19 \text{ m}$$

$$r = 19 \text{ cm}$$

Result

Size / Length of duct = r = 19 cm

PROBLEM 6.8

An airplane design calls for a "lift" due to the net force of the moving air on the wing of about 1000 Nm^{-2} of wing area. Assume that air flows past the wing of an aircraft with streamline flow. If the speed of flow past the lower wing surface is 160 ms^{-1}? The density of air is 1.29 kgm^{-3} and assume maximum thickness of wing be one meter.

Data

Pressure difference = $P_1 - P_2$ = 1000 N/m^2

Speed of air past the lower surface = v_1 = 160 m/s

Density of air = ρ = 1.29 kg/m^3

To Find

Speed of air over the upper surface = v_2 = ?

SOLUTION

By using Bernoulli's equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Since $\rho g h_1 = \rho g h_2$

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

$$\boxed{P_1 - P_2 + \frac{1}{2}\rho v_1^2 = \frac{1}{2}\rho v_2^2}$$

$$1000 + \frac{1}{2} \times 1.29 \times (160)^2 = \frac{1}{2} \times 1.29\ v_2^2$$

$$1000 + 16512 = 0.645\ v_2^2$$

$$v_2^2 = \frac{17512}{0.645}$$

$$v_2^2 = 27150.3$$

$$v_2 = 164.7$$

$$v_2 = 165 \text{ m/s}$$

Result

Speed of air over upper surface $= v_2 = 165$ m/s

PROBLEM 6.9

What gauge pressure is required in the city mains for a stream flow a fire hose connected to the city mains to reach a vertical height of 15 m?

Data

Vertical height $= h_1 - h_2 = 15$ m

Density of water $= \rho = 1000 \text{ kg/m}^3$

To Find

Pressure difference $= P_2 - P_1 = ?$

SOLUTION

By using Bernoulli's equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

Since $\frac{1}{2}\rho v_1^2 = \frac{1}{2}\rho v_2^2$

So $P_1 + \rho g h_1 = P_2 + \rho g h_2$

$$\boxed{P_2 - P_1 = \rho g h_1 - \rho g h_2}$$

$$= \rho g (h_1 - h_2)$$

$$= 1000 \times 9.8 \times 15$$

$$P_2 - P_1 = 147000 \text{ Pa}$$

$$P_2 - P_1 = 147 \text{ KPa}$$

Result

Pressure difference $= P_2 - P_1 = 147$ KPa