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.

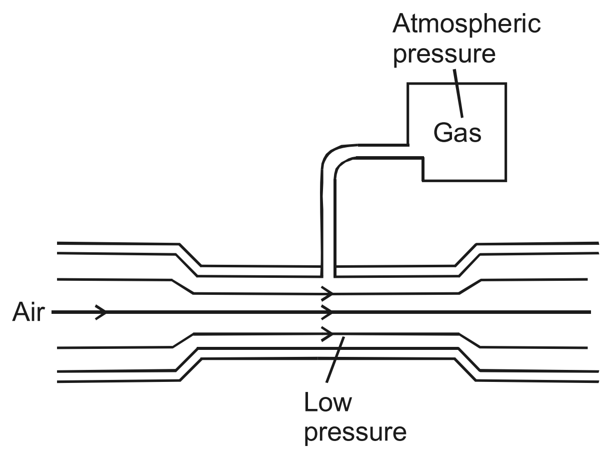
Ans. We know that according to Bernoulli's principle "the pressure will be low where the speed of fluid is high and vice versa therefore when two row boats are moving parallel in the same direction then the speed of water between the boats will be fast and pressure will be low while on the opposite sides 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 (η = 8.0 × 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 = ρ = 1246 kg/m^3

Viscosity = η = 8.0×10^{-4} Ns/m^2

Terminal speed = v_t = 3.0 cm/h

= 0.03 m/h

$$= \frac{0.03}{3600}$$

= 8.33×10^{-6} m/s

To Find

Radius of the particle = r = ?

SOLUTION

By formula

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

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

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

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

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

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

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

Result

Radius of the particle = r = 1.56×10^{-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

$$\boxed{A_1v_1 = A_2v_2} \quad \text{...... (i)}$$

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)

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

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

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

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

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

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

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 × 1000
			=	80,000 Pa
Density of water	=	ρ	=	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 = ρ = 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 $$\boxed{P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2}$$

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

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

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

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

$$P_2 - P_1 = 22188 \text{ Pa}$$

$$P_2 - P_1 = 22.1 \text{ KPa}$$

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 $\pi r_1^2 v_1 = A_2 v_2$

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

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

$v_2 = 4.71 \times 10^{-4}$ 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 $= Av$

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

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

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

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

$$r^2 = 0.035$$

$$r = 0.188$$

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

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

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 $= P_1 - P_2 = 1000 \text{ N/m}^2$

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

Density of air $= \rho = 1.29 \text{ kg/m}^3$

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 = ρ = 1000 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