Viscosity

Fluid Mechanics

Fluid Statics

1. Density of a homogeneous substance is defined as the ratio of its mass to its volume. In other words density is the mass per unit volume.

$d=\frac{m}{v}$, where d=density, m=mass and v=volume

S.I unit: kgm^{-3}.

2. Specific gravity of a material is defined as the ratio of its density to that of water at $4^{o}C$ it is a mere number and has no units. It is also known as relative density.

3. If two liquids of masses m_1 and m_2 and densities d_1 and d_2 respectively are mixed the density of the mixture $d=\frac{(m_1+m_2)d_1d_2}{m_1d_2+m_2d_1}$

If $m_1 = m_2$, then $d=\frac{2d_1d_2}{d_1+d_2}$

4. If two liquids of volumes v_1 and v_2 and density d_1 and d_2 are mixed, then the density of the mixture is $d=\frac{v_1d_1+v_2d_2}{v_1+v_2}$

If $v_1 = v_2$, then $d=\frac{d_1+d_2}{2}$

5. Pressure is defined as the ratio of the normal force acting on the area on which the force acts. Pressure is a scalar quantity.

$P=\frac{F}{A}$ where P = pressure, F = normal component of force and A = area on which force acts.

S.I unit: pascal (Pa).

6. Fluid Pressure

a. The pressure due to a liquid column of height 'h' and density 'd' is given by P = hdg where g = acceleration due to gravity.This is called gauge pressure.

b. The pressure exerted by the atmospheric air at any point is equal to the weight of air contained in a column of unit cross sectional area and extending up to the top of the atmosphere. This is called atmospheric pressure.

c. The total pressure P acting at the bottom of an open liquid column of height 'h' and density 'd' is given by $P=P_a+hdg$ where P_a= atmospheric pressure

d. Atmospheric pressure $=1.013\times10^5$ Pa $=1.013\times10^6$ dynes/cm^2 =76 cm of Hg

7. Pascal's law: When ever pressure is applied on any part of a fluid contained in a vessel, it is transmitted equally in all directions.

8. Archimede's principle: When a body is immersed wholly or partially in a fluid at rest, the fluid exerts an upward force on the body equal to the weight of the fluid displaced by the body.

9. The loss of weight (ΔW) of a solid when immersed in a liquid is given by $\Delta W = vdg$ where v = volume of the displaced liquid, d = density of the liquid and g = acceleration due to gravity.

10. From Archimedes' principle

i) Relative density of solid = $\dfrac{\text{weight of solid in air}}{\text{loss of weight of solid in water}}$

ii) Relative density of a liquid = $\dfrac{\text{loss of weight of sinker in liquid}}{\text{loss of weight of sinker in water}}$

11. The upward force is called the buoyant force or force of buoyancy.

12. Buoyant force depends on the volume of the displaced liquid and not on the volume of the body.

13. Buoyant force depends on the density of the liquid and not on the density of the body.

14. When a body is immersed in a fluid, when

i) If the weight of the body (W) is more than the up thrust (W^I) i.e., $W > W^I$, the body will sink.

ii) If the weight of the body (W) is equal to up thrust (W^I) i.e., $W = W^I$, the body will float, the whole if its volume being inside the liquid and

iii) If the weight of the body (W) is less than the up thrust (W^I) i.e., $W < W^I$, the body will float with a part of it being outside the liquid.

15. When a solid of density 'ρ' floats in a liquid of density 'd', then the volume fraction of solid immersed in liquid is given by

$V_i = \frac{\rho}{d}$ where V_i = volume fraction of the solid inside the liquid.

$V_o = 1 - V_i$ where V_o = volume fraction of the solid outside the liquid.

16. When an ice block floating on water melts, the level of water remains the same.

17. If a floating piece of ice contains an air bubble, the level of water does not change when the ice metals.

18. If a floating ice block contains a piece of cork embedded inside, there is no change in the level of water when the ice melts.

19. A floating block of ice contains a piece of lead. The level of water decreases when the ice melts.

20. When a block of ice floating on a liquid denser than water melts, there is an increase in the level of the liquid.

21. When a block of ice floating on a liquid whose density is less than that of water melts, there is a decrease in the level of the liquid.

22. A man is sitting in a boat which is floating in a pond. If the man drinks some water from the pond, the level of the water remains the same.

23. A boat carrying a number of stones is floating in a water tank. If the stones are unloaded into the water, the water level in the tank decreases.

Fluid Dynamics

24. Streamline flow : The flow of a liquid is said to be streamlined or orderly if the particles of the liquid move along fixed paths known as streamlines and velocity of the particles passing one after the other through a given point on a streamline remains unchanged in magnitude as well as direction at that point.

25. Steady flow or streamline flow :

a. Every particle of the liquid follows the path of its preceding one.

b. The mass of the liquid entering the tube is equal to the mass of the liquid leaving the tube.

c. The path followed by the particle is called streamline.

d. Streamlines may be curves or straight lines.

e. The tangent drawn to the streamline gives the direction of flow of liquid

f. No two streamlines intersect each other

g. No radial flow

h. Pressure at any cross-section is same.

i. A bundle of streamlines having same velocity is called tube of flow.

26. Turbulent Flow

a. The velocity of the particle crossing any particular point of the liquid is not constant in both magnitude and in direction.

b. Velocity varies with time

c. The velocity of the liquid at which streamline flow converts into turbulent flow is called critical velocity (V_c)

27. Critical velocity (V_c)

a. The velocity of the liquid above which the flow becomes streamline is called critical velocity.

b. Critical velocity (V_c) = $\frac{K\eta}{\rho d}$

ρ – Density of the liquid   and d – Diameter of the pipe

c. If K < 2000, the flow is streamline or laminar,

d. If K > 3000 the flow is turbulent.

e. If K is in between 2000 and 3000 the flow is unsteady.

f. High viscous and less dense liquids in narrow pipes have stream line motion.

g. Low viscous and high dense liquids in wider pipes have turbulent motion.

28. Equation of continuity

a. When a non-viscous liquid flows steadily through a tube of uniform bore the product of area of cross section and the velocity of the flow is same at every cross-section of the tube.

Mass flux = constant (or) Avd = constant

Volume flux = constant (or) AV = constant

Or r^2 v = const.

b. If the cross-sectional area is large, the velocity of the flow of the liquid will be less.

c. Water stream narrows as it comes down.

d. If a part of the mouth of a tube through which water is coming out is closed with a finger, the speed of flow increases.

e. Equation of continuity represents the law of conservation of mass in case of moving fluids.

29. Energy of a liquid: The energy at any point in a flowing liquid is of three kinds.

(a) Potential energy, (b) kinetic energy, (c) pressure energy.

a) **Potential energy:** The energy possessed by a liquid by virtue of its height is called potential energy.

Potential energy of mass m of the liquid = mgh

Potential energy per unit mass m = gh

Potential energy per unit volume = ρ gh

b) **Kinetic energy:** The energy possessed by a liquid by virtue of its motion is called kinetic energy.

Kinetic energy per unit mass=$\frac{1}{2}v^2$

Kinetic energy per unit volume = $\frac{1}{2}\rho v^2$

c) **Pressure energy:** The energy possessed by a liquid by virtue of the pressure acting on it is called pressure energy.

Pressure energy = PV

Pressure energy per unit mass =$\frac{P}{\rho}$

Pressure energy per unit volume = P

Where ρ is density of liquid

30. Bernoulli's theorem

a. If an ideal fluid (non viscous, incompressible) is in streamline flow in a tube of non uniform cross-section the sum of the pressure energy, kinetic energy and potential energy at any point per unit mass or per unit volume is constant.

$\frac{P}{\rho}+\frac{V^2}{2}+gh$=constant or $\frac{P}{\rho g}+\frac{V^2}{2g}+h$=constant or $P+\rho gh+\frac{1}{2}\rho V^2$=constant

Here $\frac{P}{\rho g}$ =pressure head

$\frac{V^2}{2g}$ =velocity head

h=gravitational head

P $\rightarrow$ is called static pressure

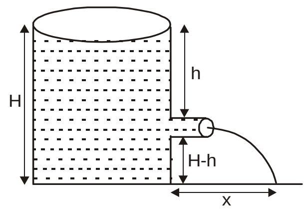
$\frac{1}{2}\rho V^2 \rightarrow$ Dynamic pressure

b. This obeys the law of conservation of energy.

Ex: Spinning motion of a cricket ball (Magnus Effect), Aerodynamic lift, Atomizer etc.

31. Applications of Bernoulli's theorem

A) **Torricelli's theorem:** The velocity of efflux of a liquid through an orifice of a vessel is equal to the velocity acquired by a freely falling body from a height which is equal to that of liquid level from the orifice. $V = \sqrt{2gh}$



B) Time taken by the efflux liquid to reach the ground is given by

$$t = \sqrt{\frac{2(H-h)}{g}}$$

C) Horizontal range of liquid is given by

$$x = \sqrt{2gh} \times \sqrt{\frac{2(H-h)}{g}} = 2\sqrt{h(H-h)}$$

D) Horizontal range is maximum, when orifice is at the middle of liquid level and bottom.

$h = \frac{H}{2}$; x_{max}=H

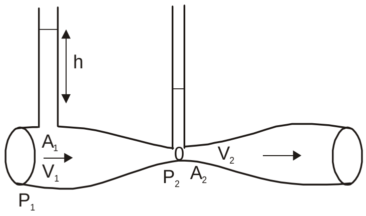
The horizontal range (x) of liquid coming out of the holes at depths h or (H̃h) from its free surface is the same.

E) Time taken for the level to fall from H_1 to H_2 $\quad t = \frac{A}{A_o}\sqrt{\frac{2}{g}}\left[\sqrt{H_1} - \sqrt{H_2}\right]$

Where A_o is area of orifice, A is area of cross-section of container.

32. Venturimeter: Venturimeter is used to measure flow speed and rate of flow in a pipe.

Velocity of flow $V_1 = \sqrt{\dfrac{2gh}{\left(\dfrac{A_1}{A_2}\right)^2 - 1}}$



Rate of flow $Q = A_1\sqrt{\dfrac{2gh}{\left(\dfrac{A_1}{A_2}\right)^2 - 1}}$