CHAPTER

9 Mechanical Properties of Fluids

- Density $= \frac{\text{mass}}{\text{volume}}$ (kg m^{-3})
- Specific weight $= \frac{\text{weight}}{\text{volume}} = \rho g$ (kg m^{-2} s^{-2})
- Relative density $= \frac{\text{density of given liquid}}{\text{density of pure water at 4°C}}$ (Unitless)
- Pressure $= \frac{\text{normal force}}{\text{area}} = \frac{\text{thrust}}{\text{Area}}$ (Nm^{-2})

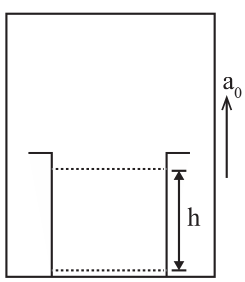
VARIATION OF PRESSURE WITH DEPTH

- Pressure is same at two points at the same horizontal level P_1 and P_2 The difference of pressure between two points separated by a depth h is

  $(P_2 - P_1) = h\rho g$
- Pressure in Case of Accelerating Fluid

Liquid Placed in Elevator

- When elevator accelerates upward with acceleration a_0 then pressure in the fluid, at depth h may be given by, $P = h\rho[g + a_0]$



Steady and Unsteady Flow

- Steady flow is defined as that type of flow in which the fluid characteristics like velocity, pressure and density at a point do not change with time.

Streamline Flow

- In steady flow all the particles passing through a given point follow the same path and hence a unique line of flow. This line or path is called a streamline.

Laminar and Turbulent Flow

- Laminar flow is the flow in which the fluid particles move along well-defined streamlines which are straight and parallel.

Compressible and Incompressible Flow

- In compressible flow the density of fluid varies from point to point i.e, the density is not constant for the fluid whereas in incompressible flow the density of the fluid remains constant throughout.

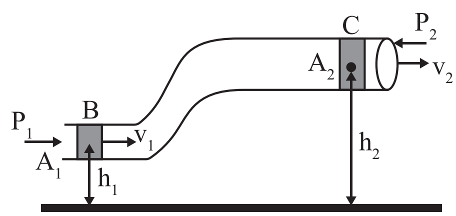
Equation of Continuity

- $A_1v_1 = A_2v_2$ Based on conservation of mass.

Bernoulli's Theorem

- $\boxed{P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}}$

  Based on the conservation of energy.



$$P_1 + \rho gh_1 + \frac{\rho v_1^2}{2} = P_2 + \rho gh_2 + \frac{\rho v_2^2}{2}$$

KINETIC ENERGY

- Kinetic energy per unit volume

  $= \frac{\text{Kinetic Energy}}{\text{volume}} = \frac{1}{2}\frac{m}{V}v^2 = \frac{1}{2}\rho v^2$

Potential Energy

- Potential energy per unit volume

  $= \frac{\text{Potential Energy}}{\text{volume}} = \frac{m}{V}gh = \rho gh$

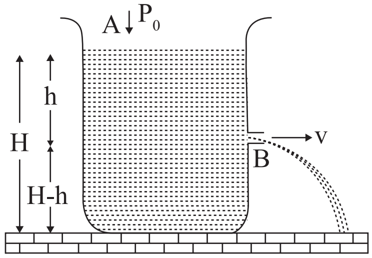
Pressure Energy

- Pressure energy per unit volume $= \frac{\text{Pressure energy}}{\text{volume}} = P$

Rate of Flow

- Volume of water flowing per second $Q = A_1v_1 = A_2v_2$
- Velocity of efflux $V = \sqrt{2gh}$

- Horizontal range $R = 2\sqrt{h(H-h)}$



SURFACE TENSION

- Surface tension is basically a property of liquid. The liquid surface behaves like a stretched elastic membrane which has a natural tendency to contract and tends to have a minimum surface area. This property of liquid is called surface tension. It arises due to intermolecular forces in a liquid.

Intermolecular Forces

(*a*) Cohesive Force

The force acting between the molecules of same substance is called cohesive force.

(*b*) Adhesive Force

The force acting between different types of molecules or molecules of different substances is called adhesive force.

Dependency of Surface Tension

On Cohesive Force: Those factors which increase the cohesive force between molecules increase the surface tension and those which decrease the cohesive force between molecules decrease the surface tension.

(*a*) On mixing detergent in water its surface tension decreases.

(*b*) Surface tension of water is more than (alcohol + water) mixture.

On Temperature

On increasing temperature surface tension decreases. At critical temperature and boiling point it becomes zero.

Note: Surface tension of water is maximum at 4ºC

On Contamination

The dust particles on the liquid surface decreases its surface tension.

Definition of Surface Tension

The force acting per unit length of an imaginary line drawn on the free liquid surface at right angles to the line and in the plane of liquid surface, is difined as surface tension.

For floating needle $2T\ell \sin\theta = mg$

Work = Surface energy = $T\Delta A$

Liquid drop $W = 4\pi r^2 T$

Soap bubble $W = 8\pi r^2 T$

Splitting of bigger drop into smaller droplets $R = n^{1/3} r$

Work done = Change in surface energy = $4\pi R^2 T (n^{1/3} - 1)$

Excess pressure $P_{ex} = P_{in} - P_{out}$

In liquid drop $P_{ex} = \dfrac{2T}{R}$

In soap bubble $P_{ex} = \dfrac{4T}{R}$

ANGLE OF CONTACT (θ_C)

The angle enclosed between the tangent plane at the liquid surface and the tangent plane at the solid surface at the point of contact inside the liquid is defined as the angle of contact.

The angle of contact depends on the nature of the solid and liquid in contact.

Angle of contact $\theta < 90º \Rightarrow$ concave shape, Liquid rise up in capillary

Angle of contact $\theta > 90º \Rightarrow$ convex shape, Liquid falls down in capillary

Angle of contact $\theta = 90º \Rightarrow$ plane shape, Liquid neither rise nor falls

Capillary rise $h = \dfrac{2T\cos\theta}{r\rho g}$

When two soap bubbles are in contact then $r = \dfrac{r_1 r_2}{r_1 - r_2} (r_1 > r_2)$ radius of curvature of the common surface.

When two soap bubbles are combined to form $r = \sqrt{r_1^2 + r_2^2}$ a new bubble then radius of new bubble.

VISCOSITY

Newton's law of viscosity $F = \eta A \dfrac{\Delta V_x}{\Delta y}$

SI UNITS of h : $\dfrac{N \times s}{m^2}$

CGS UNITS: dyne–s/cm^2 or poise (1 decapoise = 10 poise)

Dependency of Viscosity of Fluids on Temperature of Fluid

(*a*) Cohesive forces decrease with increase in temperature. Therefore with the rise in temperature, the viscosity of liquids decreases.

(*b*) The viscosity of gases is the result of diffusion of gas molecules from one moving layer to other moving layer. Now with increase in temperature, the rate of diffusion increasers. So, the viscosity also increases. Thus, the viscosity of gases increase with the rise of temperature.

On Pressure of Fluid

The viscosity of liquid increases with the increase of pressure and the viscosity of gases is practically independent of pressure.

Poiseuille's formula $Q = \dfrac{dV}{dt} = \dfrac{\pi p r^4}{8\eta L}$

Viscous force $F_V = 6\pi\eta r v$

Terminal velocity $V_T = \dfrac{2}{9}\dfrac{r^2(\rho - \sigma)g}{\eta} \Rightarrow V_T \,\alpha\, r^2$

Reynolds number $R_e = \dfrac{\rho V d}{\eta}$

$R_e < 1000$ laminar flow, $R_e > 2000$ turbulent flow