Fluid Mechanics

Topics

1. Properties of Fluid (****) → obj + conv.
2. Fluid Statics →
   - ***Fluid pressure & measurement
   - ***Hydrostatic forces on Plane & Curved Surface
   - ***Liquid in Relative equilibrium
   - ***Buoyancy & Flotation

   } Objective
3. Fluid kinematics ***
4. Fluid Dynamics ***** →
   - Moment equations
   - Energy Equations

   } → obj + conv.
5. Flow measurement → obj
6. Laminar flow *****
7. Turbulent flow**
8. Boundary layer & Drag & Lift *****
9. Model Analysis (obj) ***
10. Pipe flow *****

} Obj + conventional

Introduction

→ A substance in liquid (or) gaseous phase is referred to as "Fluid".

→ They are capable of deforming continuously under the action of shear stress however small the shear stress might be.

in Solids, $\sigma \propto \epsilon$

In fluids, $\tau \propto \frac{d\gamma}{dt}$; $\gamma = \int d\gamma = \int \tau \, dt$.

→ Fluid mechanics deals with properties of fluid at rest as well as in motion.

→ ① Study of fluid at rest → Fluid statics

② Study of fluid in motion when forces responsible for motion are not considered → Fluid Kinematics.

③ Study of fluid in motion by considering the forces responsible for motion is called " Fluid Dynamics".

→ Ideal Fluid :-

→ Ideal fluid is a theoritical conception there is no fluid like Ideal fluid.

→ Ideal fluid does not have surface Tension, Viscosity and are incompressible.

1. Properties of Fluid

Vapour pressure and Cavitation :-

→ Vapour pressure is the pressure excerted by the vapour molecules.

→ whenever in the flow absolute pressure of flow falls below the Vapour pressure, vaporisation starts and Vapours and dissolved gases starts coming out in the form of vapour bubble (or) Air bubble. Thus creating cavity in the flow.

→ these vapour bubbles are swept away from low pressure zone to high Pressure zone due to momentum of flowing fluid.

· In High pressure zone, these vapour bubbles collapse giving rise to highly destructive extremely high pressure waves. this phenomenon is called "Cavitation".

· Cavitation generates Noise, Vibration, Causes surface pitting & fatigue failure.

→ Cavitation occurs when $\boxed{P_{abs} < P_{vapour\ pressure}}$ ** (i.e, pressure at specified points falls below Vapour pressure)

→ vapour pressure increases with temperature, Hence at higher temp. changes of cavitation is more, i.e, there is a greater chance that vapour pressure exceeds the P_{abs}. & Vapour pressure of a liquid is independent of the externally excerted pressure

⇒ Bulk modulus & Compressibility :-

Bulk modulus → $$\boxed{K = -\frac{dP}{\left(\frac{dV}{V}\right)}}$$

(∵ dm=0, because mass is neither created nor destroyed)

$$m = \rho V$$

$$dm^{\,0} = \rho\, dV + V\, d\rho = 0$$

$$-\frac{dV}{V} = \frac{d\rho}{\rho} \qquad \therefore K = \frac{dP}{\left(\frac{d\rho}{\rho}\right)}$$

Compressibility → $\boxed{\frac{1}{K} = \frac{d\rho}{\rho\, dP}}$

if $d\rho = 0$ → incompressible

Isothermal bulk modulus ;

$$P = \rho R T$$

$$\frac{dP}{d\rho} = RT$$

$$K = \rho \frac{dP}{d\rho} = \rho R T = P$$

$$\therefore \boxed{K = P}$$

i.e, Isothermal bulk modulus is equal to pressure.

Adiabatic bulk modulus ;

In adiabatic process → $PV^{\gamma} = \text{constant}$

$$\gamma = \frac{C_p}{C_v} = \text{adiabatic constant}$$

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

$$\frac{P \cdot m^{\gamma}}{\rho^{\gamma}} = \text{constant}$$

$$P = (\text{constant}) \cdot \rho^{\gamma}$$

$$\frac{dP}{d\rho} = \text{constant} \cdot \gamma \rho^{\gamma - 1}$$

$$K = \rho \cdot \frac{dP}{d\rho} = \text{constant} \cdot \gamma \rho^{\gamma} = \gamma P$$

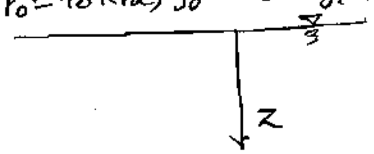
→ check ρ^{γ}

$$\therefore \boxed{K = \gamma P}$$

3) The density of sea water at free surface is 1030 kg/m³ and pressure is 98 KPa. Bulk modulus of sea water is 2.34×10^9 N/m² (constant). The variation of pressure with depth is given by $dP = \rho g\,dz$. Determine the density and pressure at a depth of 2500m. neglect change in temperature

Sol:

$P_0 = 98\,KPa,\ \rho_0 = 1030\,kg/m^3$



for density;

$$dP = \rho g\,dz$$

$$\rho\frac{dP}{d\rho} = K \Rightarrow dP = \frac{K}{\rho}\cdot d\rho$$

$$\Rightarrow \rho g\,dz = \frac{K}{\rho}\cdot d\rho$$

$$\int\frac{d\rho}{\rho^2} = \frac{g}{K}\int dz$$

$$-\frac{1}{\rho} = \frac{gz}{K} + C$$

at $z=0,\ \rho=\rho_0 \Rightarrow C = -\frac{1}{\rho_0}$

$$\rightarrow -\frac{1}{\rho} = \frac{gz}{K} - \frac{1}{\rho_0}$$

$$\frac{1}{\rho} = \frac{1}{\rho_0} - \frac{gz}{K}$$

$$\boxed{\rho = \frac{1}{\frac{1}{\rho_0} - \frac{gz}{K}}}$$

$$\rho_{at\ 2500m} = \frac{1}{\frac{1}{1030} - \frac{9.81\times2500}{2.34\times10^9}}$$

$$\therefore \boxed{\rho_{at\ 2500m} = 1041.24\ kg/m^3}$$

for Pressure ;

$$dP = \rho g\, dz$$

$$dP = \frac{1}{\left(\frac{1}{\rho_0} - \frac{gz}{K}\right)} g\, dz$$

$$\rightarrow \rho \frac{dP}{d\rho} = K$$

$$P = \int dP = K \int \frac{d\rho}{\rho}$$

$$P = K \ln \rho + C$$

at $\rho = \rho_0$, $P = P_0$

$$P_0 = K \ln \rho_0 + C$$

$$\boxed{C = P_0 - K \ln \rho_0}$$

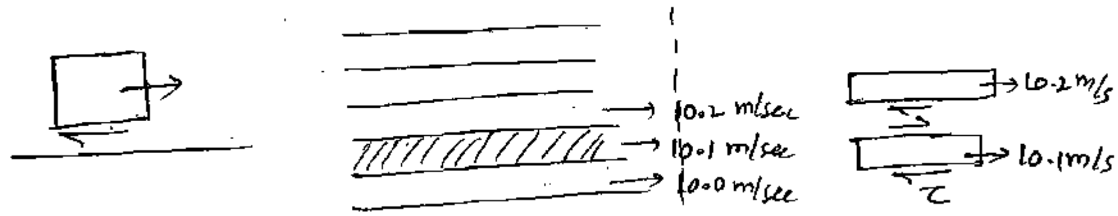
$$\rightarrow P = K \ln \rho + P_0 - K \ln \rho_0$$

$$P = P_0 + K \ln\left(\frac{\rho}{\rho_0}\right)$$

$$P_{at\ 2500m} = 98 \times 10^3 \frac{N}{m^2} + 2.34 \times 10^9 \frac{N}{m^2} \ln\left(\frac{1041.24}{1030}\right)$$

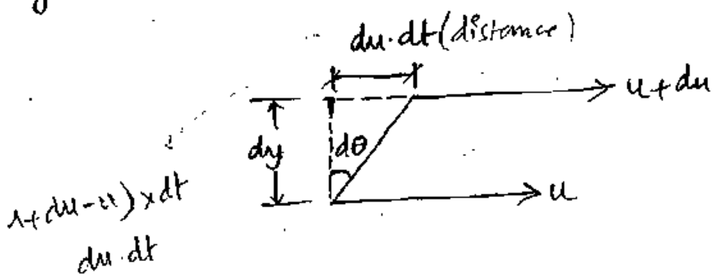
$$\boxed{P_{at\ 2500m} = 25495.209\ KPa}$$

Viscosity :-



→ Viscosity is a measure of resistance of fluid to deformation.

→ It is due to internal friction forces that develop between different layers of fluid that are forced to move relative to each other.



$d\theta = \frac{du \cdot dt}{dy}$ [$d\theta$ → shear strain]

$$\frac{d\theta}{dt} = \frac{du}{dy}$$

$\frac{du}{dy}$ → Velocity gradient

$\frac{d\theta}{dt}$ → Rate of change of shear ~~strain~~.

→ In case of Newtonian fluid, shear stress ∝ rate of shear strain

i.e, $\tau \propto \frac{d\theta}{dt}$

$$\tau \propto \frac{du}{dy}$$

$$\boxed{\tau = \mu \frac{du}{dy}}$$

μ → Dynamic viscosity (or) Absolute viscosity (or) Coefficient of viscosity

→ Unit of Dynamic viscosity (μ) is $\frac{NS}{m^2}$ (or) $\frac{kg}{m.s}$ (or) Poise

$\boxed{10 \text{ Poise} = 1 \frac{NS}{m^2}}$ & $\boxed{\frac{N.S}{m^2} = \frac{kg}{m.sec}} = \frac{gm}{cm.sec}$