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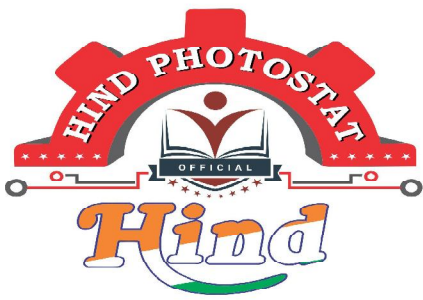
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MADE EASY CIVIL ENGINEERING Fluid Mechanics BY-KAKKAR SIR

- Theory
- Explanation
- Derivation
- Example
- Shortcuts
- Previous Years Question With Solution

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FLUID MECHANICS

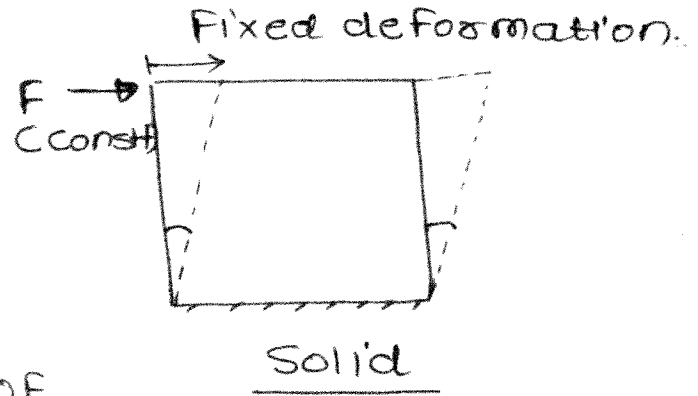
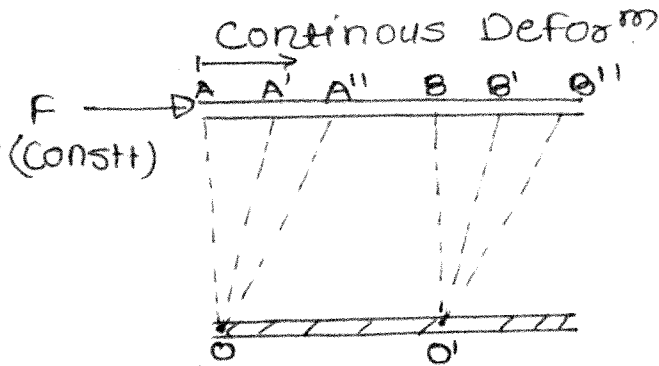
In General →

→ Solid

→ Liquid

→ Gases

→ Fluids



In Fluid the rate of deformation is important

*Fluid →

Fluid is the substance that deforms continuously under the application of tangential force, No matter how small it may be

*Fluid has a Continuum →

In micro system, when the inter molecular distances are negligible as compare to dimension of system we can assume that adjacent to one molecule, there is another molecule without space therefore the entire fluid system can be treated as continuous distribution of mass and such continuous of fluid is known as Continuum.

$$\text{Knudsen No. (Kn)} = \frac{\lambda}{L}$$

Kn < 0.01
"Continuum is valid"

λ = mean free path

L = characteristic Dimension

Not our Study $\left\{ \begin{array}{l} 0.01 < Kn < 0.1 \rightarrow \text{Slip Flow} \\ 0.1 < Kn < 10 \rightarrow \text{Transition Flow} \\ Kn > 10 \rightarrow \text{Free Molecular Flow} \end{array} \right.$

→ Fluid property is such that density etc. can be defined as continuous function of space variable.

→ Continuum is invalid at very low pressure [At High Elevation]

* Fluid Properties

① Density (ρ)

→ It is defined as mass per unit volume of a substance.

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

V = volume
M = mass

units → In MKS - kg/m^3

In C.G.S - gm/cm^3

$$1 \text{ gm/cm}^3 = 1000 \text{ kg/m}^3$$

② Specific Gravity (S)

$$S = \frac{\text{Density of Fluid Substance}}{\text{Density of Standard Fluid Substance}}$$

For Fluids → Std. Fluid → H_2O at 4°C

$$\rho_w = 10^3 \text{ kg/m}^3$$

For Gases → Std. Gas Fluid → Air.

Example } Specific Gravity }

$$\frac{\rho_{Hg}}{\rho_w} = 13.6$$

$$\rho_{Hg} = 13.6 \times 10^3 \text{ kg/m}^3$$

③ Specific weight
or
Weight Density

It is defined as the weight of the substance per unit volume.

$$\left[\text{Specific weight} = \frac{m \times g}{V} \right]$$

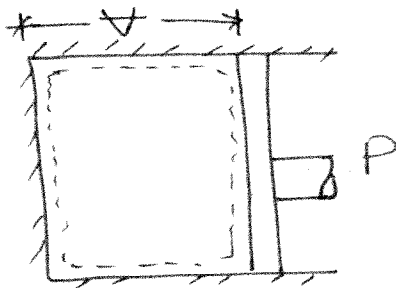
$$\text{Sp. wt.} = \rho g$$

④ Compressibility (β)

It is defined as the reciprocal of bulk modulus of elasticity of fluid.

$$\beta = \frac{1}{K}$$

K = Bulk modulus of elasticity.



$$\left\{ K = - \frac{dP}{\frac{\Delta V}{V}} \right\}$$

$$m = \rho \cdot V$$

$$dm = \rho \cdot \Delta V + \Delta \rho \cdot V$$

$$\rho \Delta V = \Delta \rho \cdot V$$

$$\left\{ - \frac{dV}{V} = \frac{d\rho}{\rho} \right\}$$

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

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

$$\beta = \frac{1}{\rho} \cdot \frac{d\rho}{dP}$$

→ if density is not changing w.r.t pressure

$$\frac{d\rho}{dP} = 0, \quad \beta = 0 \rightarrow \text{(incompressible)}$$

→ if the density is changing w.r.t pressure

$$\frac{d\rho}{dP} \neq 0, \quad \beta \neq 0 \rightarrow \text{(compressible)}$$

* Liquids

$$T = 20^\circ\text{C}$$

$$P = 1 \text{ atm}, \quad \rho_w = 998 \text{ kg/m}^3$$

$$P = 100 \text{ atm}, \quad \rho_w = 1003 \text{ kg/m}^3$$

$$\% \text{ change} = \frac{1003 - 998}{998} \times 100$$

$$\approx 0.5$$

$$\beta \approx 0 \text{ (incompressible)}$$

* Generally, Liquids are treated as incompressible

* Gases

$$P = \rho R T \rightarrow \text{Highly compressible}$$

Note $\left\{ \text{Mach no } (Ma) = \frac{V}{C} \right\}$ → velocity of sound in the medium.

$\left\{ \text{if } Ma \leq 0.3, \text{ the flow is considered as incompressible.} \right.$

* Ideal Gas eqⁿ

① $P \cdot V = n \cdot \bar{R} \cdot T$ Absolute temp

↑ ↑ ↑
Absolute pressure No. of moles Universal Gas Const.

② $P \cdot V = \frac{m}{M} \cdot \bar{R} \cdot T$

$P \cdot V = m \cdot \frac{\bar{R}}{M} \cdot T$

$P \cdot V = m \cdot R \cdot T$

↑
Characteristic Gas Const.

③ $P = \frac{m}{V} \cdot R \cdot T$

$P = \rho R T$

* Isothermal compressibility OF Gases

$P \cdot V = \text{const.}$

$P \rho^{-1} = \text{const.}$

$\rho^{-1} dP - \rho^{-2} P \cdot d\rho = 0$

$\rho^{-1} \left[dP - P \cdot \frac{d\rho}{\rho} \right] = 0$

$dP = P \cdot \frac{d\rho}{\rho}$

$\left(\frac{dP}{d\rho/\rho} \right) = P$

$K_{iso} = P$

$\beta_{iso} = \frac{1}{P}$

* Adiabatic compressibility OF Gases

$P \cdot V^\gamma = \text{const.}$

$P \cdot \left(\frac{m}{\rho} \right)^\gamma = \text{const.}$

$P \rho^\gamma = \text{const.}$

$\rho^{-\gamma} dP - \gamma \cdot \rho^{-\gamma-1} P d\rho = 0$

$\rho^{-\gamma} \left(dP - \gamma \cdot P \frac{d\rho}{\rho} \right) = 0$

$dP = \gamma \cdot P \cdot \frac{d\rho}{\rho}$ For monoatomic Gases $\gamma = 1.67$

$\left(\frac{dP}{d\rho/\rho} \right) = \gamma \cdot P$ For diatomic Gases e.g. Air $(\gamma) = 1.4$

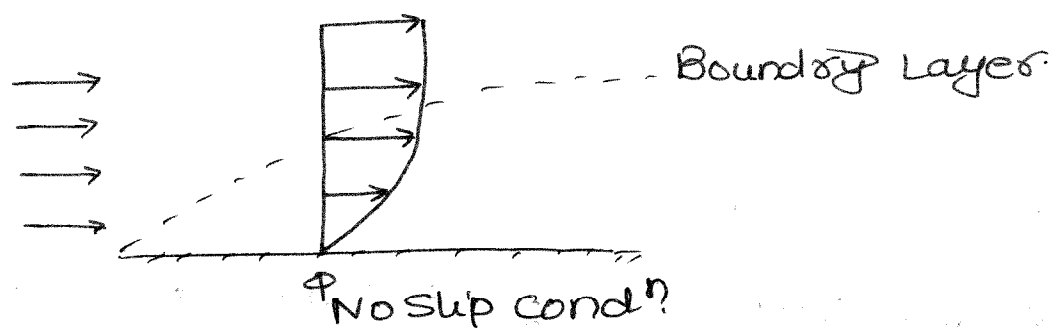
$K_{adia} = \gamma \cdot P$

$\beta_{adia} = \frac{1}{\gamma \cdot P}$

* Flow over a Flat plate

When a real fluid flows over a solid body, the fluid particle at the surface of the body flows with the same velocity as that of the surface to satisfy no slip condition. So the relative velocity of fluid particle at the surface of solid body is 0.

Away from the solid body, in the transverse direction the velocity of fluid particle increases gradually thus the velocity gradient exists in this region close to boundary.



* Viscosity

The two adjacent layers of fluid resist the motion of each other. Such a basic property of fluid is called viscosity.

Cause of viscosity

Liquids

Intermolecular force of attraction "cohesive force"

$$T = 20^\circ\text{C}, P = 1 \text{ atm}$$

$$\mu_w = 0.001 \frac{\text{N}}{\text{m}^2} \cdot \text{sec}$$

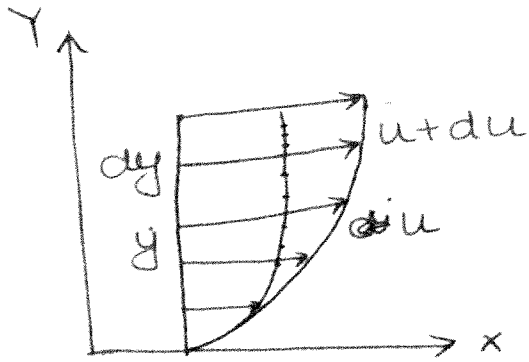
$$\mu_a = 0.00001 \frac{\text{N}}{\text{m}^2} \cdot \text{s}$$

Gases

cohesion almost nil
"Randomness of molecules."

$\mu \rightarrow$ measurement of internal resistance.

a) Angular Deformation

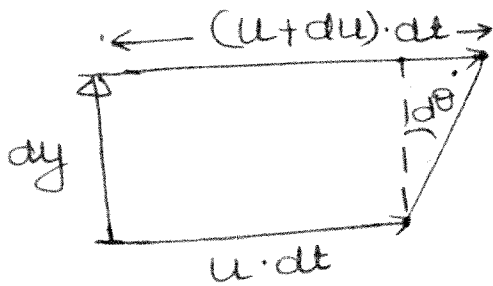


$$\tan \theta = \frac{du \cdot dt}{dy}$$

$d\theta = \text{very very small}$

$$\tan \theta \approx d\theta$$

In dt time interval



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

Rate of shear deformation

b) Newton's Law of Viscosity

The viscous shear stress b/w the two adjacent layers at a distance y from the surface is

$$\tau \propto \frac{d\theta}{dt}$$

$$\left[\frac{d\theta}{dt} = \frac{du}{dy} \right]$$

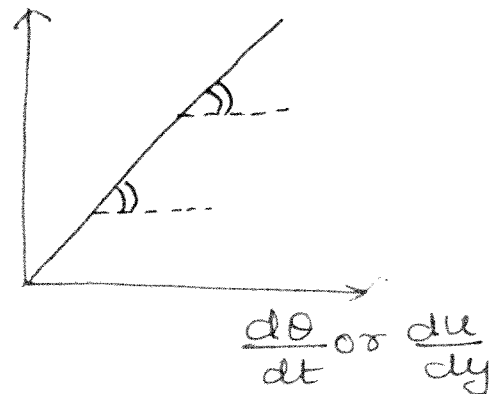
$$\tau \propto \frac{du}{dy}$$

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

dynametic viscosity

or

Coeff of viscosity



Slope of curve = μ

Ex \Rightarrow Air, H_2O , Hg, petrol, kerosine etc

* Fluids Follow Newton's Law of Viscosity is called Newtonian Fluid

c) Unit

Dynamic Viscosity μ

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

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

In SI -

$$\text{Unit of } \mu = \frac{\text{N/m}^2 \times \text{m}}{\text{m/sec}}$$

$$\mu = \frac{\text{N}}{\text{m}^2} \cdot \text{sec}$$

$$1 \frac{\text{N}}{\text{m}^2} \cdot \text{sec} = 1 \text{ Pa} \cdot \text{sec}$$

$$1 \frac{\text{N}}{\text{m}^2} \cdot \text{sec} = 1 \frac{\text{kg}}{\text{m}^2} \times \frac{\text{m}}{\text{s}}$$

$$1 \frac{\text{N}}{\text{m}^2} \cdot \text{sec} = 1 \frac{\text{kg}}{\text{m} \cdot \text{sec}}$$

Dimension of $\mu = [ML^{-1}T^{-1}]$

IN C.G.S

$$\frac{\text{gm}}{\text{cm} \cdot \text{sec}}$$

$$1 \frac{\text{gm}}{\text{cm} \cdot \text{sec}} = 1 \text{ poise}$$

Relation

$$1 \text{ poise} = \frac{1 \text{ gm}}{\text{cm} \cdot \text{sec}} = \frac{10^{-3} \text{ kg}}{10^{-2} \text{ m} \cdot \text{sec}}$$

$$1 \text{ poise} = \frac{1}{10} \frac{\text{kg}}{\text{m} \cdot \text{sec}}$$

Kinematic Viscosity ν

$$\nu = \frac{\mu}{\rho}$$

MKS

$$\text{Unit of } \nu = \frac{\text{kg}}{\text{m} \cdot \text{s}} \frac{\text{m}^3}{\text{kg}}$$

$$\nu = \text{m}^2/\text{sec}$$

C.G.S

$$1 \frac{\text{cm}^2}{\text{sec}} = 1 \text{ stoke}$$

Relation

$$1 \text{ stoke} = \frac{1}{10^4} \text{ m}^2/\text{sec}$$