Toppersnotes

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IES/GATE

CIVIL ENGINEERING

VOLUME – II

Fluid Mechanics

SIERRA INNOVATIONS

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Fluid Mechanics

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Chapter 1 - Study of Motion

Study of motion

(Kinematics) study of motion without the consideration of basic causes of motion i.e. force.

$\vec{v} = \frac{d\vec{s}}{dt}$

$\vec{a} = \frac{d\vec{v}}{dt}$

$\vec{j} = \frac{d\vec{a}}{dt}$

Jerk.

not including mass (directly or indirectly)

unit – m, m/s, m/s², m/s³

Dynamics – study of motion with the cosideration of basic causes of motion. i.e. force.

$\vec{F}_{ex} = \frac{d}{dt}(m\vec{V})$

including mass.

Dynamic Viscosity $(\mu) = \frac{N\text{-}s}{m^2}$

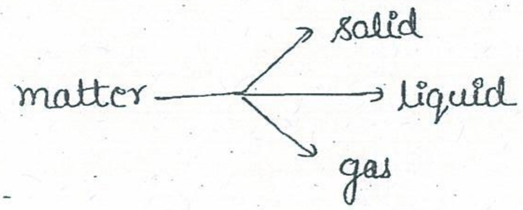
kinematic viscosity $(\nu) = \frac{\mu}{\rho}$ (m^2/s)

Fluid Mechanics :-

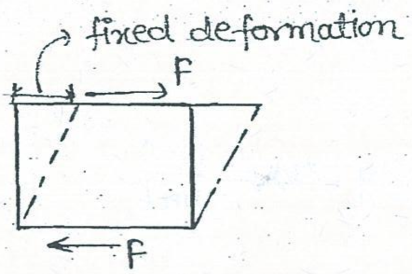
Fluid :- "Liquid & Gases both are having the property of contineous deformation under the action of shear or tongential force. This property of contineously deformation is also known as flow property & Hence Liquid & gases are kept in diffrent catagory which is far away from the solids & this catagory is known as fluid."

A fluid is a substance which is having & ability to flow under the action of shear & tongential forces.

Fluid –



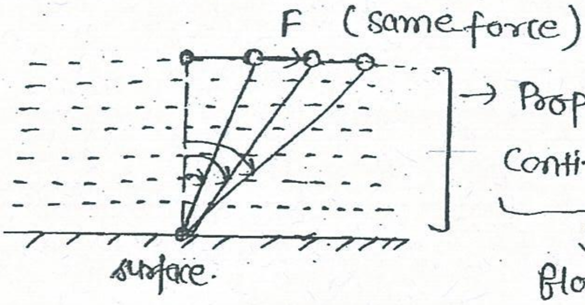
In solid →



deformation change when forces are changes at different-2 time.

In liquid :-

At same force, deformation are changes contineously.



→ Property of Contineous deformation
⇓
Flow property.

Fluid as a Continuum :—

" In macroscopic system, the inter atomic space b/w the molecules of fluid can be treated as neglegible as compared to the dimension of the system therefore we can assume adjacent to one malecule there is a another malecule. & there is no interspace b/w them. Hence the entire fluid malecule system can be treated as contineous distribution of mass system & it is known as Continuum."

 flow.

BASIC FLUID PROPERTY :—

(i) Density (ρ) :— It is defined as mass per unit body of the substance.

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

unit :- kg/m3.

In C.G.S unit —

$$1 gm/c.c = 1 gm/cm^3.$$

$$= \frac{10^{-3} kg}{10^{-6} m^3} = \frac{1000 kg}{m^3}.$$

(2) Specific Weight :- It is the weight of the substance per unit volume.

$$sp.\ wt. = \frac{mg}{V} = \rho.g.$$

$$\boxed{\text{sp. wt.} = \rho g} \quad N/m^3. \qquad \frac{F}{L^3}$$

(3) **Specific Gravity (s.g) :-** A sp. gravity of a fluid is defined as a Ratio of density of fluid to the density of standard fluid.

$$\boxed{(s.g)_{fluid} = \frac{\text{Density of fluid}}{\text{Density of standared fluid}}}$$

for lq. ⇒ Standard fluid ⇒ water ($1000\ kg/m^3$).

for gas ⇒ Standard fluid ⇒ Atm. Air ($1.21\ kg/m^3$).

(4) **Relative density (R.D) :-**

$$\boxed{(R.D.)_{1/2} = \frac{\rho_1}{\rho_2}}$$

(5) **Compressibility (β) :-**

$$\boxed{\beta = \frac{-\frac{d\forall}{\forall}}{dP}} \quad \text{—} \ (1)$$

$$\boxed{m = \rho \times \forall = \text{Constant}}$$

$$\rho \cdot d\forall + \forall \cdot d\rho = 0$$

$$\boxed{\frac{-d\forall}{\forall} = \frac{d\rho}{\rho}}$$

Put these value in eq^n (1)

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

If ρ is not changing w.r.t pressure –

$$\frac{d\rho}{dP} \to 0 \Rightarrow \boxed{\beta = 0}$$

Incompressive

If ρ is changing w.r.t pressure –

$$\frac{d\rho}{dP} \neq 0 \Rightarrow \boxed{\beta \neq 0}$$

Compressive.

Liquid

$\Downarrow$

Compressible

For water :–

at 1 atm $\longrightarrow$ $\rho_{water} = 998\ kg/m^3$

at 100 atm $\longrightarrow$ $\rho_{water} = 1003\ kg/m^3$.

$$\therefore \Delta\rho = 5\ kg/m^3$$

$$\%\ change = \frac{5}{998} \times 100 = \frac{\Delta\rho}{\rho} \times 100$$

$$\approx 0.5\%$$

$$\boxed{\beta_{liq} = 0}$$

Liquid are treated as Incompressible.

Gases

$\Downarrow$

Highly Compressible

$$P = \rho RT$$

$$\boxed{P \propto \rho}$$

NOTE :- The Reciprocal of compressibility is known as Bulk modulus of elasticity.

(6) Isothermal compressibility of gas :-

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

Ideal gas eq^n —

$$P = \rho RT$$

$$\rho = \frac{P}{RT}$$

[Isothermal
T = Constant].

$$\boxed{\frac{d\rho}{dP} = \frac{1}{RT}}$$

$$\therefore \boxed{\beta_{iso} = \frac{1}{\rho} \cdot \frac{1}{RT}}$$

$$\boxed{\beta_{iso} = \frac{1}{\rho RT}}$$

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

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

(7) Adiabatic compressibility of gas :-

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

Adiabatic eqn —

$$PV^{\gamma} = \text{Constant}$$

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

$$\left[\rho = \frac{m}{V} \qquad V = \frac{m}{\rho} \right]$$

$$\therefore \; P\rho^{-\gamma} = \text{Constant}$$

$$P(-\gamma)\,\cancel{\rho^{-\gamma}}{}^{-1}\,d\rho + dP \cdot \cancel{\rho^{-\gamma}} = 0$$

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

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

$$\boxed{\frac{d\rho}{dP} = \frac{\rho}{\gamma P}}$$

$\boxed{\gamma - \text{gama}}$

$$\therefore \; \boxed{\beta_{Adia} = \frac{1}{\rho} \times \frac{\rho}{\gamma \cdot P} = \frac{1}{\gamma \cdot P}}$$

$$\boxed{\beta_{Adia} = \frac{1}{\gamma \cdot P}}$$

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

$$\boxed{\gamma_{Air} = 1.4}$$

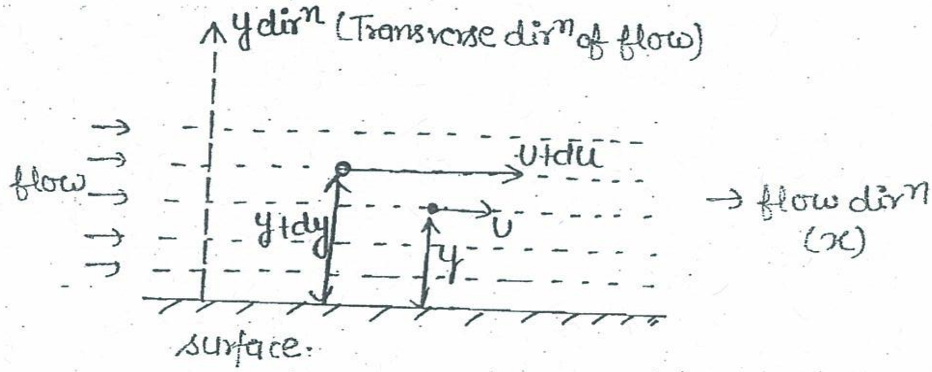
VISCOSITY

"The two adjacent layer of fluid resist the motion of each other such a fundamental property of fluid is known as viscosity."

Basic Reason of Viscosity :– Cohesion ⇒ for liquid
intermolecule attraction

In gases ⇒ Cohesion (negligible)

$(\text{viscosity})_{\text{gases}} <<<< (\text{viscosity})_{\text{liquid}}$

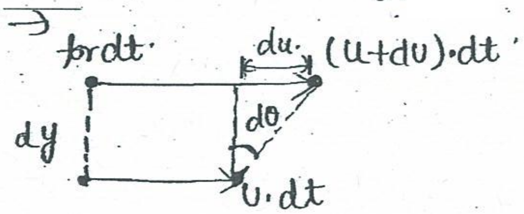


The Relative velocity of the contacting layer = zero.

(No-slip CONDITION)

⇒ There will be the development of velocity gradient in transverse dirⁿ of flow $\left(\frac{du}{dy}\right)$.

In the fig ⇒



Shear deformation b/w adjacent layer =

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

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

Rate of shear deformation →

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

"Rate of shear deformation is same as velocity gradient"
$d\theta/dt$ ... du/dy

Newton's Law of Viscosity

The shear stress b/w the adjacent layer at distance y from the surface will be--

$$\tau \propto \left(\frac{d\theta}{dt}\right)$$

$$\boxed{\tau = \mu\left(\frac{d\theta}{dt}\right)}$$

μ → Constant (But not universal)
⇓
Property of fluid.
as well as depend upon temp.

If μ → high →

$\Rightarrow \frac{d\theta}{dt} \rightarrow$ less

Flow is difficult.

$\Rightarrow$ If $\mu \rightarrow$ less

$\frac{d\theta}{dt} =$ high

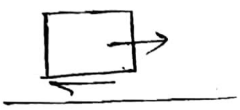
flow is easy.

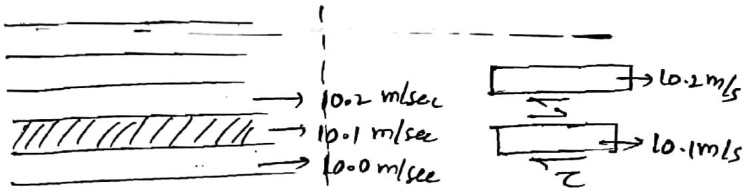
$\mu \Rightarrow$ Direct measurement of internal Resistance b/w the layers of fluid.

$\Downarrow$

dynamic viscosity.

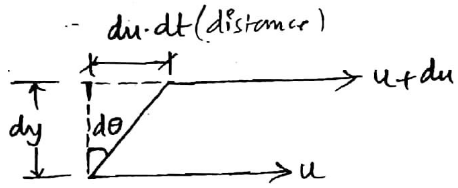
Viscosity :-





→ 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.



$x+(du-u)\times dt$

$du \cdot dt$

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

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

$\frac{du}{dy}$ → Velocity gradient

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

→ In case of Newtonian fluid, $\boxed{\text{shear stress} \propto \text{rate of shear strain}}$

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

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

Note :-

→ Dynamic viscosity of water is approximately 50 times that of Air

→ Examples of Newtonian Fluid ;
Water, Air, Gasoline, oils (Not all oils)

→ Non-Newtonian Fluid :-

for Non-Newtonian fluid, $\boxed{\tau = B + A\left(\frac{du}{dy}\right)^n}$

Dynamic Viscosity (μ) :-

Unit :-

$$\mu = \frac{\tau}{\left(\frac{d\theta}{dt}\right)} = \frac{\tau}{\left(\frac{du}{dy}\right)} = \frac{N}{m^2 \cdot \frac{m}{s \cdot m}} = \frac{N\text{-}s}{m^2}$$

S.I UNIT :-

$\hookrightarrow \frac{N\text{-}s}{m^2} \Rightarrow (Pa\text{-}s)$

M.K.S Unit :-

$\hookrightarrow \frac{kg\text{-}m\text{-}s}{s^2 \cdot m^2} = \frac{kg}{m\text{-}s}.$

$$\boxed{\frac{1\,kg}{m\text{-}s} = 1\,Pa\text{-}s}$$

C.G.S Unit →

Poise.

$$1\text{ Poise} = \frac{1\,gm}{cm\text{-}s}$$

$$= \frac{10^{-3}\,kg}{10^{-2}\,m\text{-}s} = 0.1\,Pa\text{-}s$$

Kinematic viscosity :- (ν)

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

UNIT → m^2/s.

C.G.S UNIT — Stoke.

$$\boxed{\begin{aligned} 1\,\text{stokes} &= \frac{1\ cm^2}{s} \\ &= 10^{-4}\ m^2/s \end{aligned}}$$

<u>Effect of temp. on the Viscosity of the fluid</u> :-

" Basic Reason of Viscosity — Cohesion."

(Cohesion)gas $\Rightarrow$ Almost nill.

$$\boxed{\mu_{gas} <<<< \mu_{lq}}$$

But $\nu_{gas} = \dfrac{\mu_{gas}}{\rho_{gas}}$

It may be $\nu_{gas} > \nu_{lq}$

$\nu_{gas} < \nu_{lq}$

$\nu_{gas} = \nu_{lq}$.

<u>Liquid</u> :-

If $T \uparrow \Rightarrow (\text{Cohesion})_{lq} \downarrow$.

$\Rightarrow (\mu)_{lq} \downarrow$.

$\nu_{lq} = \dfrac{\mu_{lq}}{\rho_{lq}} \Rightarrow \downarrow$.

If $T \uparrow \Rightarrow (\mu)_{lq} \downarrow$ as well as $(\nu)_{lq} \downarrow$.

But Rate of $\downarrow$ in $(\mu)_{lq}$ is None.