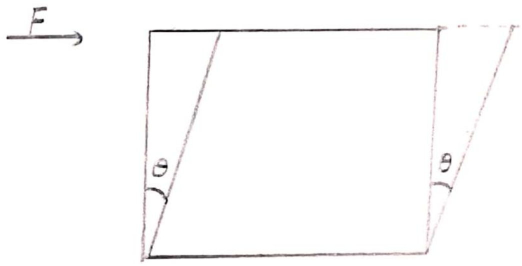
# ⊛ Fluid Mechanics

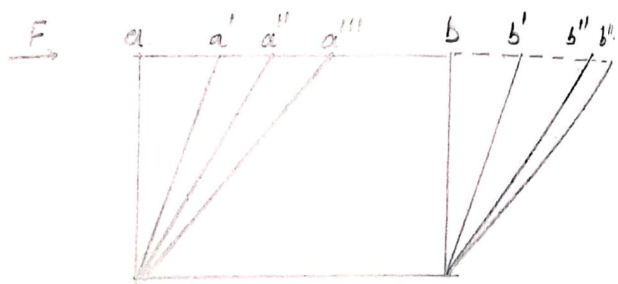
**Mechanics** :- It is a branch of science that deals with state of rest (or) motion of a body.

**Inertia** :- It is an inherent property which opposes (or) which offer resistance. i.e. A object (or) body will continue to be in the state of rest/motion under any disturbance is caused.

**Body** :- Anything which possess inertia is known as Body.

- BODY
  - Rigid Body
    - No deformation
    - $\varepsilon = 0$
    - {Engineering mechanics}
  - Deformable Body
    - Solid Body
      - {SOM}
      - $\varepsilon \neq 0$
    - Fluid
      - {Fluid Mechanics}
      - $\varepsilon \neq 0$




**Solids**

$\tau \propto \theta$

{Shear stress ∝ Shear strain}

$\theta$ = Angular deformation

**Fluids**

$a'b' = t'$, $a''b'' = t''$, $a'''b''' = t'''$

$\tau \propto \frac{d\theta}{dt}$ {Shear stress ∝ Rate of shear strain}

$\frac{d\theta}{dt}$ = Rate of angular deformation.

## Fluid Mechanics :-

→ It is a branch of engineering that deals with properties of fluid in the state of rest/ motion.

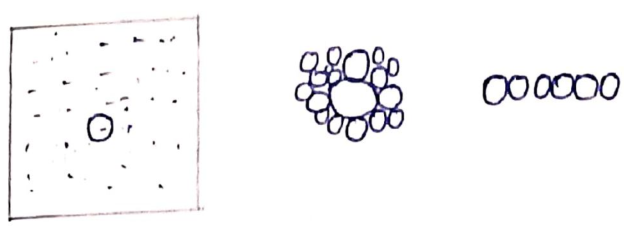
→ (a) Fluid @ Rest :- Fluid Statics.

→ (b) Fluid @ Motion :-

| Fluid Kinematics | Fluid Dynamics |
|---|---|
| Forces responsible to cause motion is not considered. | Forces responsible to cause motion is also considered. |

Hence :- ① Fluid is a deformable Body in which shear stress is directly proportional to Rate of shear strain.

② A fluid is something which is Assumed to be in a of "continuum" {continuous mass distribution}



Truly Speaking, There is a space/vaccum which is created b/w the molecules of fluid, but in continuum analysis, we have considerd that there is no space/ vaccum in b/w adjacent fluid molecules. i.e. there is a continuous Distribution of mass.

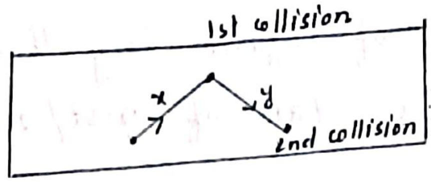
**Note:-** To analyse the fluid in continuum, "Knudsen Number" can be referred. (Kn)

→ If $\boxed{Kn \le 0.01}$, then the subject will be in continuum.

$Kn = \frac{\lambda}{L}$ . $\lambda$ = Mean free Path. i.e statistical Avg. distance b/w two consequetive collisions.

L = characteristic Dimension.

eg. Dia of pipe.




(a) $Kn \leq 0.01$ = Continuum Valid

(b) $0.01 < Kn \leq 0.1$ = Slip flow

(c) $0.1 < Kn \leq 10$ = Transition flow

(d) $Kn > 10$ = Free molecular flow

③ Fluid has got tendency to flow, & it has got no definite shape, it occupies the shape of medium/ container.

⊛ Fluid can be further classified as :-

(i) Liquid

(ii) Gases.

Liquid :- Liquid occupies a particular volume of the container in which it is placed.

→ The volume occupied by the liquid slightly changes, with respect to temperature & Pressure, Hence in most of the cases liquid is assumed to incompressible.

Gas :- Gases are fluid, which occupies volume such that it is equal to entire volume of the container in which is filled.

— Hence gases are compressible & Expensive.

20/02/2023 03:31

Note :- Ideal fluid :-

- Ideal fluid is a one which possess no viscosity, surface tension, & is incompressible.
- Practically no fluid is an ideal fluid, it is assumed for simplicity in calculation.

Real Fluid :- It is a fluid which posses, viscosity, surface tension & compressibility.

- Practically such fluids exists.

## ⊛ Properties of Fluid :-

(1) Mass Density / Specific Mass :- It is the ratio of mass of the fluid to its volume (or) mass occupied by the fluid in a unit volume.

→ It is denoted by "ρ" $\boxed{\rho = \frac{M}{V}}$

→ units :- $Kg/m^3$ (MKS) | $gm/cm^3$ (CGS)

Note :-
Mass Density of fluid depends upon Temperature & Pressure.

(a) With increase in Temperature, Molecular Activity / Inter molecule disturbance increases, Hence over a given volume lesser fluid molecules will be present (i.e mass will reduce over same volume)

→ Density $(\frac{m}{v})$, decreases with increase in temperature.

$$\boxed{\rho \propto \frac{1}{\text{Temperature}}}$$

20/02/2023 03:32

(b) With increase in pressure, More particles / molecules of fluid can occupy the same given volume, Hence leads to increase in overall mass over the same volume, Hence mass density increases.

$\rho \propto \text{Pressure}$

@ STP (1 atm, 0°C) = $\rho_{water} = 999.9\ kg/m^3$
$\rho_{air} = 1.292\ kg/m^3$

## II Specific Weight / Weight Density ($\gamma$)

→ It is defined as Ratio of wt. of the fluid over a given volume.

→ $\gamma = \frac{W}{V} = \frac{mg}{V} = \rho g$ $\{\because \frac{M}{V} = \rho\}$

→ It can also be defined as force exerted by gravity under unit volume of fluid.

Note :- "$\gamma$" depends upon Temp., Pressure & Acc. due to gravity ($\gamma = \rho \cdot g$)

@ STP = $\gamma_{water} = \rho_w \cdot g = 9807\ N/m^3$
$\gamma_{air} = \rho_a \cdot g = 12.67\ N/m^3$

## III. Specific Gravity.

It is a property which signifies, How much heavier (or) lighter is a particle/object w.r.t to standard object.

It is defined as wt. of a given fluid wrt standard fluid @ a same given volume.

$G = \frac{W_f}{W_{SF}}$ at a given volume : $V_f = V_{SF}$  {SF = Standard Fluid}

$$G = \frac{W_f / V_f}{W_{SF} / V_{SF}} = \frac{\gamma_f}{\gamma_{SF}} = \frac{\rho_f \cdot g}{\rho_{SF} \cdot g} = \frac{\rho_f}{\rho_{SF}} = \frac{W_f}{W_{SF}}$$

**Note:-**

① Standard fluid in our case :-

(a) For Fluid = "Water" @ 4°c

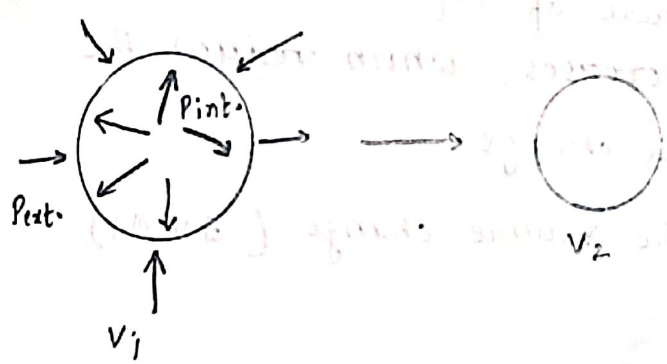
(b) For Gases = "Hydrogen" @ specified temp. & Pressure

② Specific Gravity is also known as "Relative Density".

③ Since Density was dependent on Pressure & Temperature, Hence specific gravity also depends on Temp. & Pressure.

## IV. Compressibility & Bulk Modulus :-

It is the property of fluid, to undergo volume change on application of pressure.




volume change $V_1 \rightarrow V_2$ due to difference In pressure i.e

$P_{ext} - P_{int} = \Delta P.$

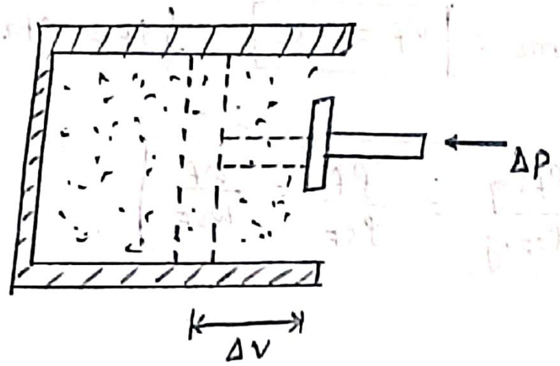
20/02/2023 03:32

— To analyse the above phenomenon Quantitatively, "Bulk Modulus" is used.

⇒ Bulk Modulus (K) :-

$$K = \frac{\Delta P}{-\frac{\Delta V}{V}}$$

, units = $N/m^2$, Pa, $\frac{kg(f)}{m^2}$, $\frac{gm(f)}{cm^2}$, $\frac{dyne}{cm^2}$




Compressibility (β) is Related to Bulk modulus (K) as $\beta = \frac{1}{K}$

$K_{water} = 2.06 \times 10^9 \; N/m^2$ , $K_{air} = 1.03 \times 10^5 \; N/m^2$

Note :- ① $K_{water} > K_{air}$ , Hence $\beta = \frac{1}{K}$ , $\beta_a > \beta_w$

$$\frac{\beta_a}{\beta_w} = \frac{K_w}{K_a} = \frac{2.06 \times 10^9}{1.03 \times 10^5} \simeq 20,000$$

⇒ $\beta_a = 20,000 \, \beta_w$ i.e. air is 20,000 more compressible than air

② Water is assumed to be incompressible. ($\beta \simeq 0 \Rightarrow K \to \infty$)

3) Variation with temperature

ⓐ With increase in temperature of liquid, molecular force of attraction b/w liquid decreases, which reduces the resistance against volume change.

∴ More will be the volume change ($\Delta V \uparrow\uparrow$)

20/02/2023 03:33

→ If $\Delta V \uparrow\uparrow$, Bulk Modulus (K) will decrease. $(K\downarrow\downarrow)$

$$\Rightarrow \boxed{K_{liquid} \propto \frac{1}{\text{Temperature}}}$$

(b) With Respect to Gas :-

With increase in temperature of gas, intermolecular activity (Randomness) increases, Hence they will offer more resistance against volume change, Hence volume change will be less.

→ If $\Delta V \downarrow\downarrow$, Bulk Modulus (K) will increase $(K\uparrow\uparrow)$

$$\Rightarrow \boxed{K_{gas} \propto \text{Temperature}}$$

⊛ General case (for gas) :-

Mass is constant; $M = \rho \cdot V \Rightarrow \boxed{\rho V = \text{constant}}$

$V \cdot \delta\rho + \rho \cdot \delta V = 0 \Rightarrow \boxed{\frac{-\delta V}{V} = \frac{\delta\rho}{\rho}}$ $\quad \delta \rightarrow d$

$$K = \frac{\Delta P}{\frac{-\Delta V}{V}} = \frac{dp}{\frac{-dv}{V}} \quad \therefore \boxed{K = \frac{dp}{\frac{d\rho}{\rho}}}, \quad \boxed{\beta = \frac{d\rho}{\rho \cdot dP}}$$

Spl. case

① For Fluid to be incompressible, $\beta = 0 \Rightarrow d\rho = 0$

$$\Rightarrow \boxed{\rho = \text{constant}}$$

② For Fluid to be compressible, $\beta \neq 0 \Rightarrow d\rho \neq 0$

$$\Rightarrow \boxed{\rho \neq \text{constant}}$$

20/02/2023 03:33

⊛ For gases :- → Isothermal Compressibility
→ Adiabatic Compressibility

(i) Isothermal Compressibility :-

$PV = mRT \Rightarrow P = \frac{m}{V} \cdot RT \Rightarrow \boxed{P = \rho RT} \rightarrow (i)$

We know, $K = \frac{dP}{\frac{d\rho}{\rho}} = \boxed{\rho \cdot \frac{dP}{d\rho} = K} \rightarrow (ii)$

from (i)

$\frac{dP}{d\rho} = RT$  $\therefore$ from (ii) $= \boxed{K = \rho RT}$, $\boxed{\beta = \frac{1}{\rho RT}}$

from (i) $\boxed{K = P}$ & $\boxed{\beta = \frac{1}{P}}$

(ii) For Adiabatic Compressibility :-

$PV^{\gamma} =$ constant  $\because$ Mass is constant $\Rightarrow PV^{\gamma} = M$

$PV^{\gamma} = M^{\gamma} \cdot c$  $\because P = \left(\frac{M}{V}\right)^{\gamma} \cdot c \Rightarrow \boxed{P = C \cdot \rho^{\gamma}} \rightarrow (i)$

$K = \frac{\rho \cdot dP}{d\rho}$, from (i) $= \frac{dP}{d\rho} = C \cdot \gamma \cdot \rho^{\gamma - 1}$

$K = \rho \cdot C \cdot \gamma \cdot \rho^{\gamma - 1} = C\gamma\rho^{\gamma}$, from $C \cdot \rho^{\gamma} = P$

$\therefore \boxed{K = P \cdot \gamma}$ & $\boxed{\beta = \frac{1}{K} = \frac{1}{P\gamma}}$

(V) Viscosity :-

- It is the property of fluid, which opposes the relative motion between two fluid elements {layers of fluid}
- In case of Liquid, Viscosity is because of cohesion b/w the adjacent fluid particles.

20/02/2023 03:34