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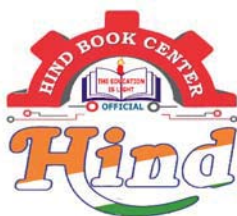
Fluid Mechanics

By-Praveen Kulkarni Sir

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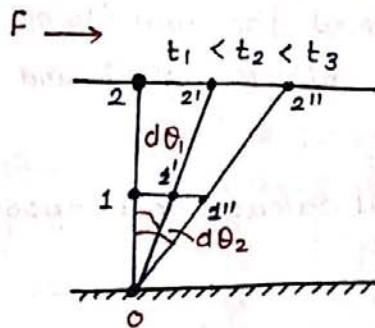
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Fluid:

fluid is a substance which is capable of flowing or deforming under the action of shear force. [however small the shear force may be] This definition of a fluid is also known as a classical definition of a fluid.



As long as there is a shear force fluid flows or deforms continuously. Example: liquids, gases, vapour etc.

Differences between Solids and Fluids:

In case of solids under the action of shear force there is a deformation and this deformation does not change with time. therefore deformation ($d\theta$) is important in solids when this shear force is removed, solids will try to come back to the original position.

In case of fluids the deformation is continuous as long as there is a shear force and this deformation changes with time, therefore in fluids rate of deformation ($d\theta/dt$) is important than deformation ($d\theta$). After the removal of shear force fluid will never ^{try} come back to its original position.

"For a static fluid, the shear force is zero."

chapter: 1 Fluid properties

Any measurable characteristic is a property.

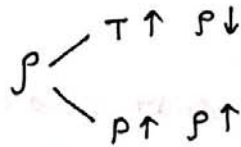
1. Density (Mass density) (ρ):

It is defined as ratio of mass of fluid to its volume. It actually represent the quantity of matter present in a given volume. its unit is kg/m^3 . and its dimensional formula is $[ML^{-3}]$

The density of water for all calculation purpose is taken as 1000 kg/m^3 .

$\rho \uparrow \rho \uparrow, T \uparrow \rho \downarrow$

Density depends on temperature and pressure



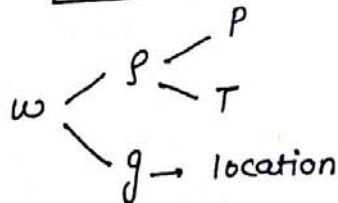
2. Specific Weight (Weight density) : $[\omega]$

It is defined as the ratio of weight of the fluid to its volume, its unit is N/m^3 and its dimensional formula is $[ML^{-2}T^{-2}]$

$$\omega = \frac{\text{Weight of the fluid}}{\text{Vol.}} \quad \text{N/m}^3$$

$$\omega = \frac{mg}{V}$$

$$\boxed{\omega = \rho g}$$



$$\omega = F(P, T, \text{location})$$

$$\left\{ \rho = \frac{m}{V} \right.$$

Specific weight of water

$$\begin{aligned} \omega_{H_2O} &= 1000 \times 9.81 \\ &= 9810 \text{ N/m}^3 \end{aligned}$$

Note: Density is an absolute quantity whereas Specific Weight is not an absolute quantity because it varies from location to location.

3. Specific gravity (S)

It is defined as the ratio of density of fluid to the density of standard fluid.

In case of liquid the standard fluid is water and in case of gases the standard fluid either hydrogen and air at a given temp. and pressure. It is unitless and dimensionless.

$$[M^0 L^0 T^0]$$

✓ s.g. of water is 1. , if s.g. of liquid is less than 1 it is lighter than water, if s.g. of liquid is greater than 1 it is heavier than water.

Note: Though terms Relative density and sp. gravity are used interchangeably, there is a difference between these two. "all specific gravities are relative density but all relative density need not be sp. gravity."

Compressibility (β):

It is the measure of change of volume or change of density with respect to pressure on a given mass of fluid. Mathematically it is defined as reciprocal of bulk modulus.

i.e.

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

k = bulk modulus

$$k = \frac{dp}{-\frac{dv}{v}}$$

$$\beta = -\frac{1}{v} \frac{dv}{dp}$$

$$\boxed{\beta = +\frac{1}{p} \frac{dp}{p}}$$

$$\text{or } k = p \frac{dp}{dp}$$

$$pv = \text{mass}$$

$$p dv + v dp = 0$$

$$-\frac{dv}{v} = \frac{dp}{p}$$

$$dp = 0 ; \beta = 0$$

$$\boxed{p = \text{const}} \text{ (Incompressible fluid)}$$

liquids are generally treated as incompressible and gases are treated as compressible.

A fluid is treated as incompressible fluid if there is no variation of density w.r.t pressure. (i.e. $\frac{d\rho}{dP} = 0$)

Isothermal compressibility of ideal gas:-

$$PV = nRT$$

$$\Rightarrow P = \frac{nRT}{V}$$

$$T = \text{const.}$$

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

$$K = \frac{P dP}{dP} = \frac{P}{P} RT \quad \left\{ \begin{array}{l} P = \frac{nRT}{V} \\ P = \frac{nRT}{V} \end{array} \right.$$

$$\boxed{K_T = P}$$

Isothermal Bulk Modulus is equal to pressure.

$$\boxed{\beta = \frac{1}{P}}$$

$$(\text{unit of compressibility} = \frac{m^2}{N}, \text{ pascal}^{-1})$$

Adiabatic bulk Modulus of an ideal gas:-

$$PV^\gamma = C_1$$

$$P \left(\frac{m}{P} \right)^\gamma = C_1$$

$$\frac{P}{P^\gamma} m^\gamma = C_1 \quad \Rightarrow \quad \frac{P}{P^\gamma} = \frac{C_1}{m^\gamma} = C$$

$$P = C P^\gamma$$

$$\frac{dP}{dP} = C \gamma P^{\gamma-1}$$

$$K = P \frac{dP}{dP}$$

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

$$K = \gamma C P^\gamma$$

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

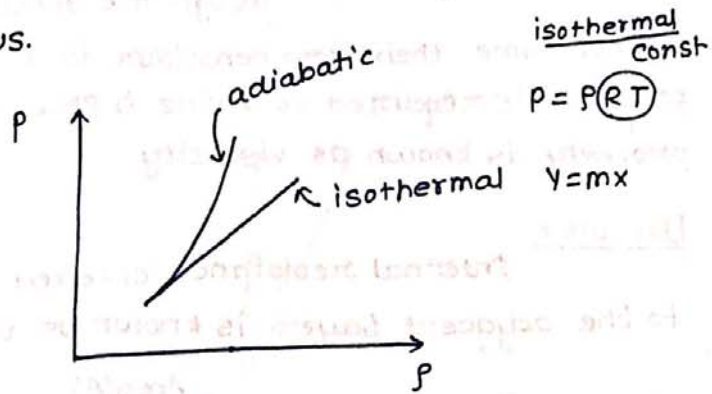
$$\beta = \frac{1}{\gamma p}$$

Note: as $\gamma > 1$ adiabatic bulk Modulus is greater than isothermal bulk Modulus.

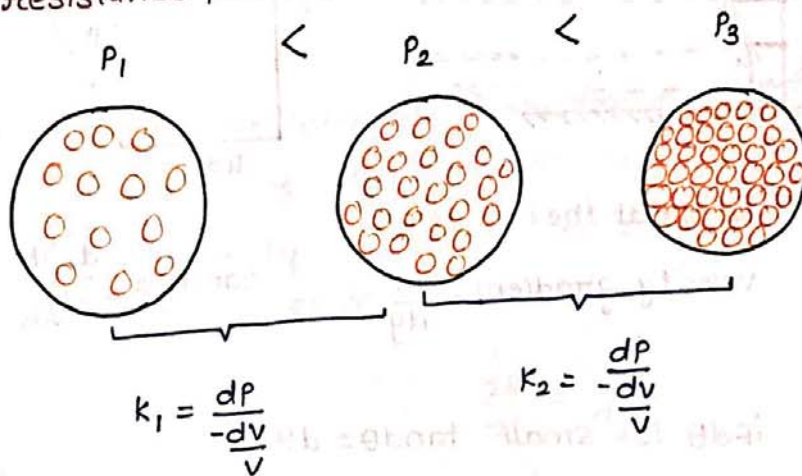
$$k = \frac{dp}{\frac{dv}{v}} \text{ same.}$$

$$k_a > k_t$$

$$dp_a > dp_t$$



Bulk Modulus is not constant and it increases with increase in pressure because at higher pressure the fluid offers more resistance for further compression.



$$k_2 > k_1$$

high speed gas flow, the flow speed is often expressed in term of the dimensionless mach No. defined as $(Ma) = \frac{\text{Speed of Flow}}{\text{Speed of Sound}}$

$$= \frac{v}{c}$$

$$\text{Sonic} = Ma = 1$$

$$\text{Subsonic When } Ma < 1$$

$$\text{Supersonic When } Ma > 1$$

$$\text{Hypersonic When } Ma \gg 1$$

Gas flow can often be approximated as incompressible if the density changes are under 5%, which is usually the case when $Ma < 0.3$.

⇒ In compressible fluids velocity of sound is given as-

$$c = \sqrt{\frac{k}{\rho}}$$

k = Bulk Modulus of fluid ρ = density

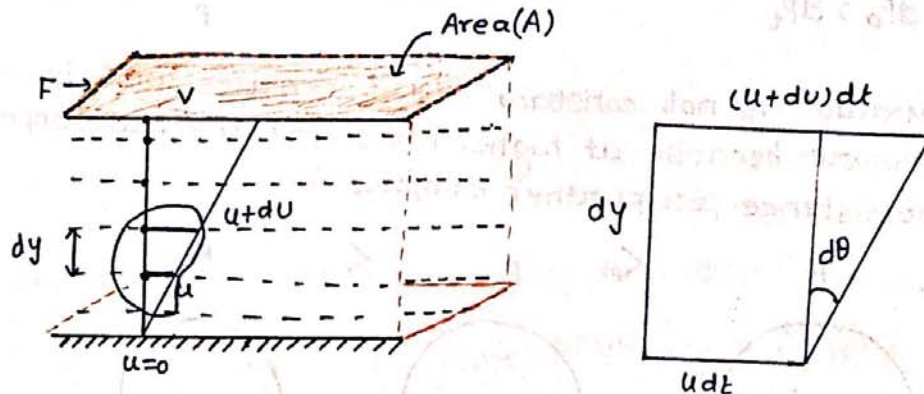
Viscosity

Need to define viscosity:

Though the densities of water and oil almost same, their flow behaviour is not same and hence a property is required to define flow behaviour and this property is known as viscosity.

Definition:

Internal resistance offered by one layer of fluid to the adjacent layer is known as viscosity.



$dt = \text{time}$

(No slip at the boundary)

$$\text{Velocity gradient} = \frac{du}{dy}$$

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

if $d\theta$ is small $\tan d\theta = d\theta$

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

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

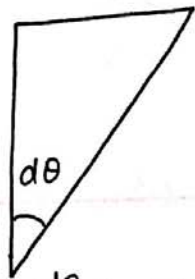
$$\tau = \frac{F}{A} \quad A \rightarrow \text{constant}$$

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

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

$$\tau = \mu \frac{d\theta}{dt}$$

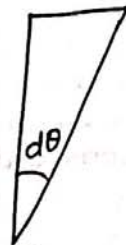
$$\mu = \frac{\tau}{\frac{d\theta}{dt}}$$



$\frac{d\theta}{dt}$ is large

Flow is easy

μ is less, Resistance is less



$\frac{d\theta}{dt}$ is less (small)

Flow is not easy.

μ is more, resistance is more.

$\Rightarrow \mu$ represents the internal resistance offered by one layer of fluid to the adjacent layer and hence μ is known as coefficient of viscosity or absolute viscosity or dynamic viscosity or simply viscosity.

$$\tau = \mu \frac{d\theta}{dt}$$

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

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

$\frac{d\theta}{dt}$ = rate of angular deformation
or

rate of shear strain

$\frac{du}{dy}$ = velocity gradient.

Newtonian Fluid:-

Fluids which obey Newton's law of viscosity are known as Newtonian fluid. A/c to Newton's law of viscosity shear stress is directly proportional to rate of shear strain.

that is

$$\tau \propto \frac{d\theta}{dt} \Rightarrow \tau \propto \frac{du}{dy}$$

\Rightarrow

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

valid for Newtonian fluid equation