Fluid Mechanics

- Matter
  - pressure
  - Continuous deformation under shear stress
- Static & Motion
  - Kinematics
    - v
    - a
    - Types of Flow
    - Flow lines
    - Stream function
    - potential function
  - Dynamics
    - $\boxed{F_p + F_g + F_v = ma}$
    - ↓ Navier Stokes equation
    - If $F_v = 0$
    - $\boxed{F_g + F_p = ma}$
    - ⇓ Eulers Equ [1755]
    - ⇓ application of Bernoulli's equ [1738]

* Topics:-

1. Fluid properties
   - $\rho = m/v$
   - $\omega = \rho g$
   - μ
   - $S.g = \rho_1/\rho_2$
   - $K = \beta$
   - σ = Capillarity
2. pressure measurement
3. Hydrostatic forces on Curved & Flat Surfaces
4. Buoyancy [Body]
5. Fluid kinematics
6. Fluid dynamics
7. Flow through pipes
   - Major
   - Minor
8. laminar pipe flow [ID- Navier Stokes equation]
9. Turbulent pipe flow
10. Boundry layer theory [Flat plate]
11. Dimensional analysis

Fluid properties

*** Fluid Mechanics:-**

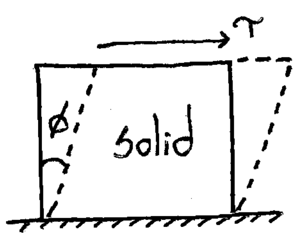
Science which deals the fluid matter [liquid & gas] in static or in motion.

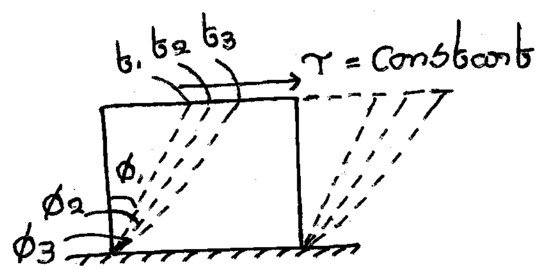
*** Fluid:-**

In solids the deformation is almost constant under stress i.e for the given stress, there is a given strain.

In fluids, fluid shows continuous deformation under shear stress [constant] i.e. the shear deformation is the function of time. So in fluids the rate of shear deformation is more important then deformation.

The property of the fluid which opposes the shear deformation rate is known as viscosity. This property observes when fluid is in motion [layers have relative motion].





$\tau \propto \phi$ [Hook's law]

$\tau = G\phi$

$G = \tau/\phi$

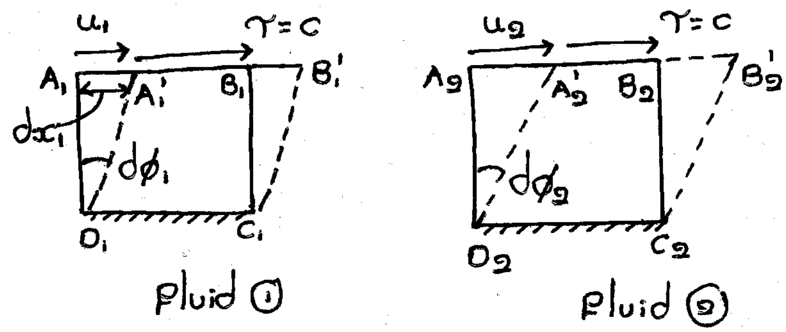
$\tau \propto \dfrac{d\phi}{dt}$ ← Rate of shear deformation

$\tau = \mu \dfrac{d\phi}{dt}$ ← Newton's law of viscosity

Dynamic viscosity $\boxed{\mu = \dfrac{\tau}{\left[\dfrac{d\phi}{dt}\right]}}$ → $\dfrac{1\,N/m^2}{1/sec}$ (or) $\dfrac{N\text{-}s}{m^2}$

$\mu \neq f^n\left[\dfrac{d\phi}{dt}\right]$

$$\frac{d\phi}{dt} \propto \frac{1}{\mu}$$



$$\frac{d\phi_1}{dt} > \frac{d\phi_2}{dt} \qquad \frac{dx_1}{dt} > \frac{dx_2}{dt}$$

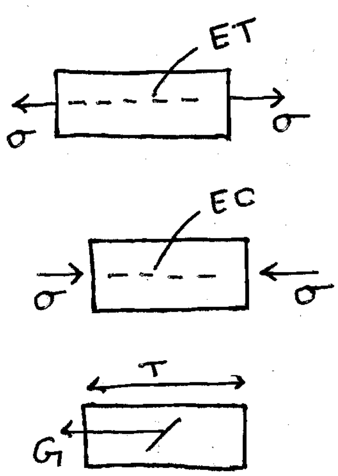
$$\boxed{\mu_1 < \mu_2} \qquad \boxed{u_1 > u_2}$$

$$\boxed{\text{Fluidity} = \frac{1}{\mu}}$$

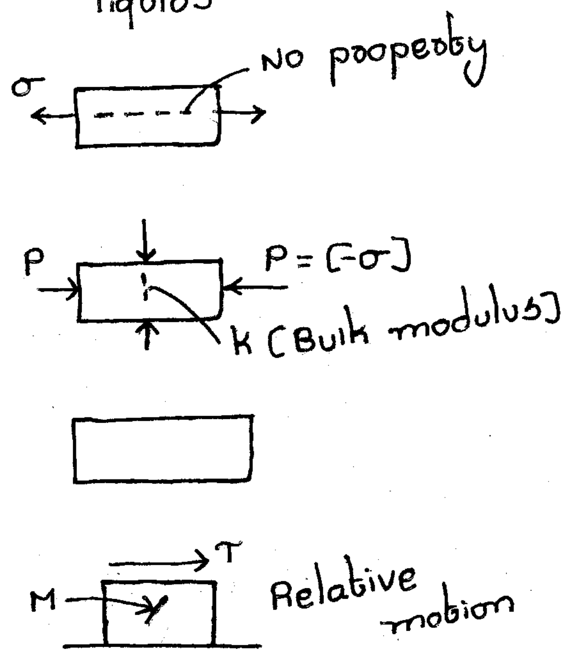
Note:-

- Solids can resist tensile, compressive & shear loads. But fluids have negligible resistance under tensile loads. They resist compressive loads due to Bulk modulus [it is analogous to modulus of elasticity of solids under compression].
- Fluids can resist shear loads due to viscosity. [it is analogous to modulus to rigidity].

Solids

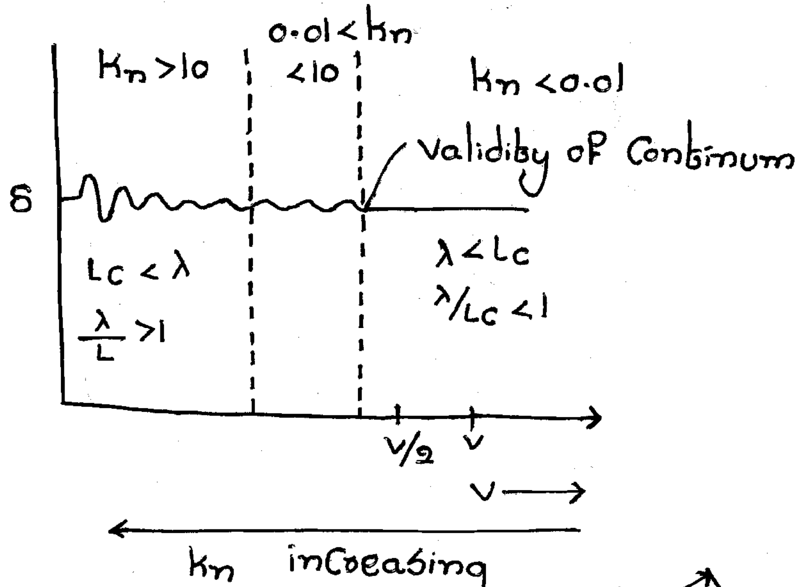


liquids

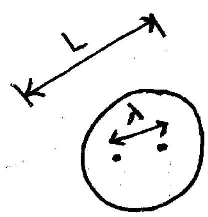


* Concept of Continum: [Macroscopic study]

Macroscopic study to define the properties of the fluid.



$\rho = \frac{m}{V} = \frac{[m/2]}{[V/2]} = \frac{[m/4]}{[V/4]}$



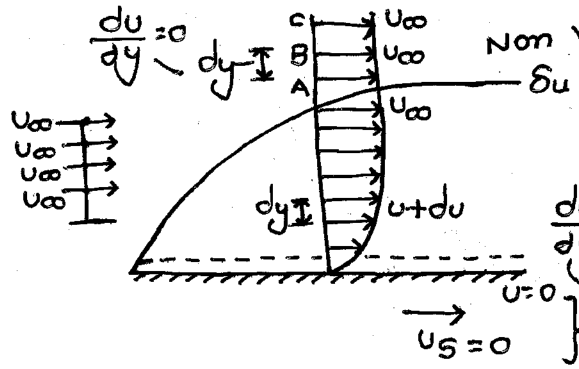
Knudsen number	$K_n = \lambda / L_c$	$= \frac{\text{Mean free path}}{\text{System dimension}}$
Continuum is valid	$K_n < 0.01$	$L_c > 100\lambda$
Transition	$0.01 < K_n < 10$	
Concept of Continuum is not valid	$K_n > 10$	$\lambda > 10 L_c$

* Application of Concept of Continuum:-

- No slip phenomenon:-

when viscous fluid flows over the relative solid surface near the surface. the fluid layer sticks over the solid surface & acquires the velocity of the solid surfaces is known as "No slip phenomenon". It is defined by concept of Continuum for viscous fluids.

No slip is due to neither adhesive forces nor due to surface roughness bcz mercury shows no slip over smooth glass surface.

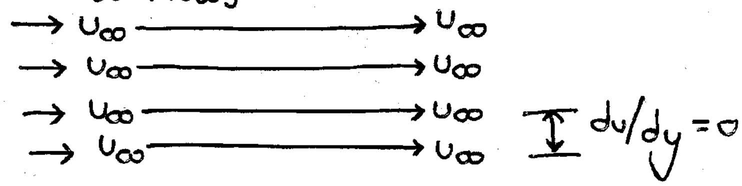


Non viscous flow [ideal flow]

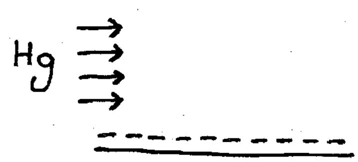
$\tau = \mu \frac{du}{dy} \Rightarrow \mu \neq 0$

$\frac{du}{dy} \neq 0 \Rightarrow \tau \neq 0$
[Viscous flow]

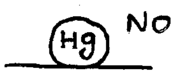
Non-viscous
[Ideal flow]



Ideal fluid $\Rightarrow \mu = 0$. Incompressible
[Concept] cohesive force = 0. surface tension = 0



Glass [Smooth]



No wetting Cohesive force [Hg-Hg] > Adhesive force [Hg-glass]

* Fluid properties:-

1. Density [ρ] / mass density:-

- Mass per unit volume at a specified temperature & pressure.

liquids & solids shows negligible change in density with temp & pressure. But gases density varies with temp & pressure as per ideal gas equation.

$$\rho = \frac{m}{V} \quad [kg/m^3]$$

$$\rho = f^n \, [T, P]$$

For liquids $\rho \neq f^n \, [P, T]$

For Gases $\boxed{P = \rho RT}$

Eg:-

1 atm 4°c => ρ_w = 1000 kg/m³

1 atm 20°c => ρ_w = 998 kg/m³

100 atm 20°c => ρ_w = 1003 kg/m³

From 1 atm -> 100 atm

$d\rho = 1003 - 998 = 5$ kg/m³

% change in density = $\frac{d\rho}{\rho} \times 100 = \left[\frac{1003-998}{998}\right] \times 100$

$= 0.5\% < 5\%$

⇓

Incompressible fluid

Incompressible flow:-

$\boxed{\text{Compressibility} = 0}$ -> [exact]

$\frac{d\rho}{dp} = 0$

$\boxed{\% \frac{d\rho}{\rho} < 5\%}$ -> Approximate
-> Valid for liquids & Gases
-> For any pressure change
[Incompressible fluid in that pressure range]

Specific weight / weight density [ω]:-

wtg per unit volume at specified temp & at specified pressure.

$$\boxed{\gamma \text{ (or) } \omega = \frac{wt}{\text{Volume}}} \quad N/m^3$$

i.e., Gravitational force on volumetric mass.

$$\gamma_{water} = \omega_{water} = \frac{mg}{V} = \rho \times g = 1000 \times 9.81 = 9810 \ N/m^3$$

$1\ kg\text{-}f = 9.81 N$

$\gamma_{water} = 1000 \times \frac{[9.81 N]}{m^3}$

$\boxed{\gamma_{water} = 1000\ kg\text{-}f/m^3}$ force

$\boxed{\rho_\omega = 1000\ kg/m^3}$ Mass

* Relative density / Specific Gravity [S.g]:-

$$\boxed{R.D = \frac{\rho_1}{\rho_2}}$$

Eg:- $\text{Specific gravity} = \frac{\text{density of fluid}}{\text{density of standard fluid}}$

For liquids

$\rho_\omega = 1000 kg/m^3$

For Gases

$\rho_{air} = 1.23 kg/m^3$

Eg:-

$$S.G_f = \frac{\rho_f}{\rho_\omega} \times \frac{g}{g}$$

$$S.G_f = \frac{\omega_f}{\omega_\omega}$$

Eg:- $[S.G]_{Hg} = 13.6$

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

$$\rho_{Hg} = 13.6\, \rho_\omega$$

$$\rho_{Hg} \times g = 13.6\, [\rho_\omega \times g]$$

Eg:- $[S.G]_{gasoline} = 0.75$

$[S.g]_{wood} = 0.6$ => For any solid. reference is water [incompressible]

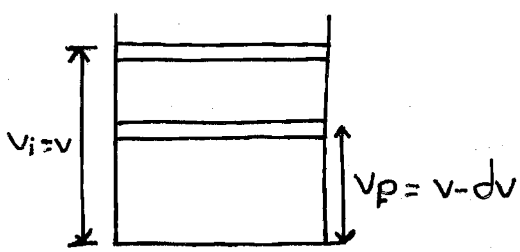
$$\frac{\rho_{wood}}{\rho_{water}} = 0.6$$

* Bulk modulus [K] and Compressibility [β] :-

It is the property of the fluid which defines the opposition for compression under pressure. It is analogous to modulus of elasticity of solids under compression.

liquids have large value of bulk modulus [$K_{\omega} = 2 \times 10^{6} \frac{kN}{m^2}$] then gases. [$K_{air} = 100\, kN/m^2$] so liquid shows more opposition for compression than gases. so liquids are considered as incompressible with respect to gases i.e compressibility is inverse of bulk modulus.

The ability of further compression under pressure at given state is known as "Compressibility".



$$\epsilon_v = \frac{dv}{V_i} = \frac{V_f - V_i}{V_i}$$

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

$$\epsilon_v = \frac{-dv}{v}$$

$$dp \propto \epsilon_v$$

$$dp = K\epsilon_v$$

$$\boxed{K = \frac{dp}{\left[\frac{-dv}{v}\right]} = \frac{dp}{\left[d\rho/\rho\right]}}\ N/m^2$$

valid for both liquids & gases

$$\rho v = mass$$

$$\ln\rho + \ln v = \ln m$$

$$\frac{d\rho}{\rho} + \frac{dv}{v} = 0$$

$$\left[\frac{-dv}{v}\right] = \frac{d\rho}{\rho}$$

Incompressible fluid :-

$$\epsilon_v \to 0 \qquad dp > 0$$

$$K = \frac{dp}{\epsilon_v} \to 0$$

$$K \to \infty$$

Compressibility = 0