



IES/GATE

←————→

MECHANICAL ENGINEERING

VOLUME - 1

**FLUID MECHANICS (FM), REFRIGERATION
AIR CONDITIONING (RAC)**



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RAC

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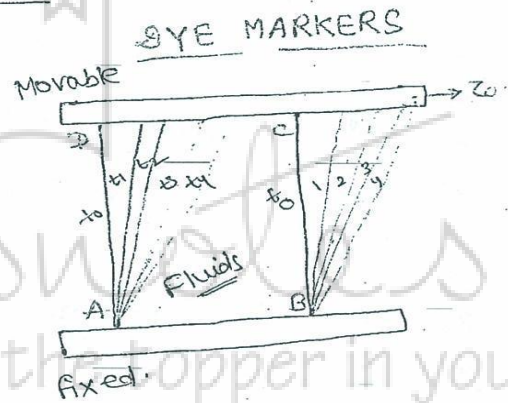
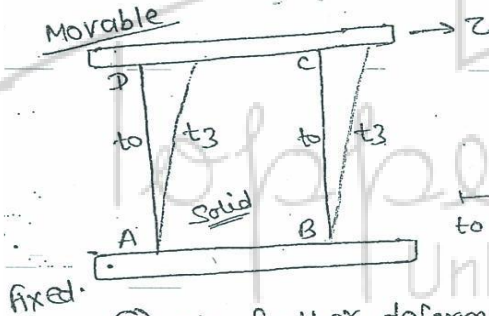
*FLUID
MECHANICS*

Chapter :- 1 Introduction - Fluids & Properties

Behaviour under forces / stresses .

- | | Solid | Fluids . |
|---------------|-------|----------|
| ① Tensile | ✓ | |
| ② Compressive | ✓ | |
| ③ shear: | ✓ | |

Behaviour Under shear stresses



- ① No further deformation (after t_3 upto elastic limit not crossed)
- ② Regains original shape.

Concept of fluid :-

Fluid is defined as a substance which can't sustain shear stress at rest.

Fluid can also be defined as substance which deforms continuously under action of a shear stress, no matter how small the shear stress may be.

Fluid is a substance which is capable of flowing and changing its shape, this is because of the

is inability to resist shearing stresses.

However this does not mean that the fluids do not offer any resistance to the shearing forces. In fact as the fluids flow, there exist tangential or shearing stresses between the layers of the fluid due to viscosity. However as long as the fluid is at rest, no shear stress can exist within it.

IDEAL FLUID :-

It is an imaginary and hypothetical fluid which has

- i.) Zero viscosity.
- ii.) Zero surface tension. and,
- iii.) It is perfectly incompressible

35% fluid ideal still at cyclone fluid still 31% effect of fluid 20% b/c E is conserved.

Because of zero viscosity, the ideal fluid faces or encounters zero resistance to its motion.

Concept of Continuum :-

Continuum implies a continuous distribution of matter with no voids or empty spaces. For mechanical analysis fluids are assumed as continuum because even the gases have a very high molecular density and the distances between them the molecules is very very small.

Concept of Continuum breaks down in

- i) High vacuum condition.
- ii) Rarefied gas flows.
- iii) Shock.

No Slip Condition :-

Fluid in direct contact with the solid boundary has the velocity of the boundary itself, in other words the layers of the fluids sticks to the solid boundary and "there is no slip between the fluid and the solid at the contact".

PROPERTIES OF FLUIDS :-

(1) Mass Density or specific mass (ρ)

$$\rho = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad \rho = \frac{m}{V} \quad \text{kg/m}^3.$$

Effect of temperature on density



(2) Weight Density or specific weight (ω or γ)

$$\omega = \frac{\text{Wt.}}{\text{Volume}} = \frac{N}{\text{m}^3}$$

$$\omega = \frac{mg}{V} = \frac{V\rho g}{V} \quad \text{or} \quad \boxed{\omega = \rho g}$$

(3) Specific volume (v)

$$v = \frac{\text{Vol}}{\text{mass}} \quad \text{m}^3/\text{kg}.$$

$$v = \frac{1}{\rho}$$

(4) Specific gravity or Relative Density (S or sp. gr.) :-

$$S = \frac{\rho_{\text{test fluid}}}{\rho_{\text{std. fluid}}} = \frac{W_{\text{test fluid}}}{W_{\text{std. fluid}}}$$

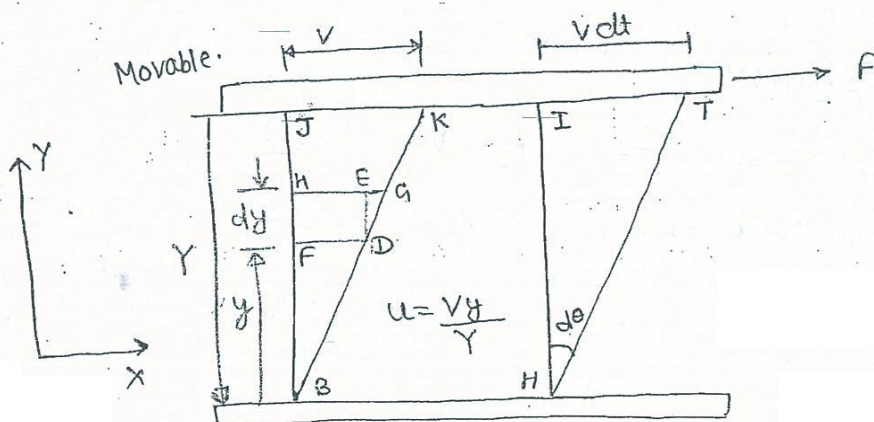
Standard fluid :- liquid — water at 4°C.
 Gas — Air/N₂ at specified Temp. & Press.

(5) Viscosity

It is the property by virtue of which fluid offers resistance to the movement of one layer of fluid over adjacent layers.

It is due to the forces of cohesion and molecular momentum exchange between the layers of the fluid. and as the flow takes place this effects appears as shearing stresses between the layers of the fluids.

Newton's Law of Viscosity :-

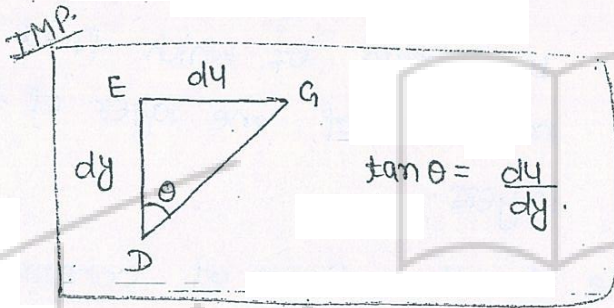


$$FD = HE = u$$

$$EH = DE = dy \quad \quad \quad E_H = du$$

Assumption:

- ① $F =$ shear force on the upper plate.
- ② $A =$ Area of the upper plate in contact with the fluid.
- ③ $V =$ velocity of the upper plate.
- ④ $Y =$ distance b/w the plates
- ⑤ V and Y are not very large. (i.e. the variation to be linear).



∴ Similar Δ BJK & BFD.

$$\frac{JK}{JB} = \frac{FD}{FB} \quad \text{or} \quad \frac{u}{Y} = \frac{U}{Y}$$

or $u = \frac{vY}{Y} \Rightarrow$ linear velocity profile

OBSERVATION $F \propto VY$

- (i) $A, Y = \text{const.} \Rightarrow F \propto V \rightarrow$ ①
- (ii) $Y, V = \text{const.} ; F \propto A \rightarrow$ ②
- (iii) $A \& V = \text{const.} ; F \propto \frac{1}{Y} \rightarrow$ ③

Combining (1) (2) & (3)

$$F \propto \frac{AV}{Y} \quad \text{or} \quad \frac{F}{A} \propto \frac{V}{Y}$$

$$\tau \propto \frac{V}{Y} \quad \text{--- (4)}$$

In similar triangle BJK and DEG ;

$$\frac{JK}{JB} = \frac{EG}{ED}$$

$$\frac{V}{Y} = \frac{dy}{dy} \quad \text{--- (5)}$$

velocity gradient

Using (5) in (4) :

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

IMP

$$\tau = \mu \frac{dy}{dy} \quad \text{--- (6)}$$

Newton's law.

μ = Constant of Proportionality
 = Dynamic / Absolute viscosity.

UNITS :- SI UNIT

$$* \frac{N \cdot s}{m^2} \text{ or } Pa \cdot sec = kg/m \cdot sec$$

$$* 1 \text{ Poise} = 0.1 Pa \cdot sec$$

μ It is the Shear stress required to produce unit velocity gradient or deformation rate.

Kinematic viscosity (ν)

$$\nu = \frac{\mu}{\rho} \quad m^2/sec$$

cgs unit

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

In Δ HIT;

$$\tau = v dt = \gamma \cdot d\theta$$

$$\boxed{\frac{d\theta}{dt} = \frac{v}{\gamma}} \quad \text{--- (7) using (5) in (7)}$$



IMP:

$$\boxed{\frac{d\theta}{dt} = \frac{dv}{dy}} \quad \text{--- (8)}$$

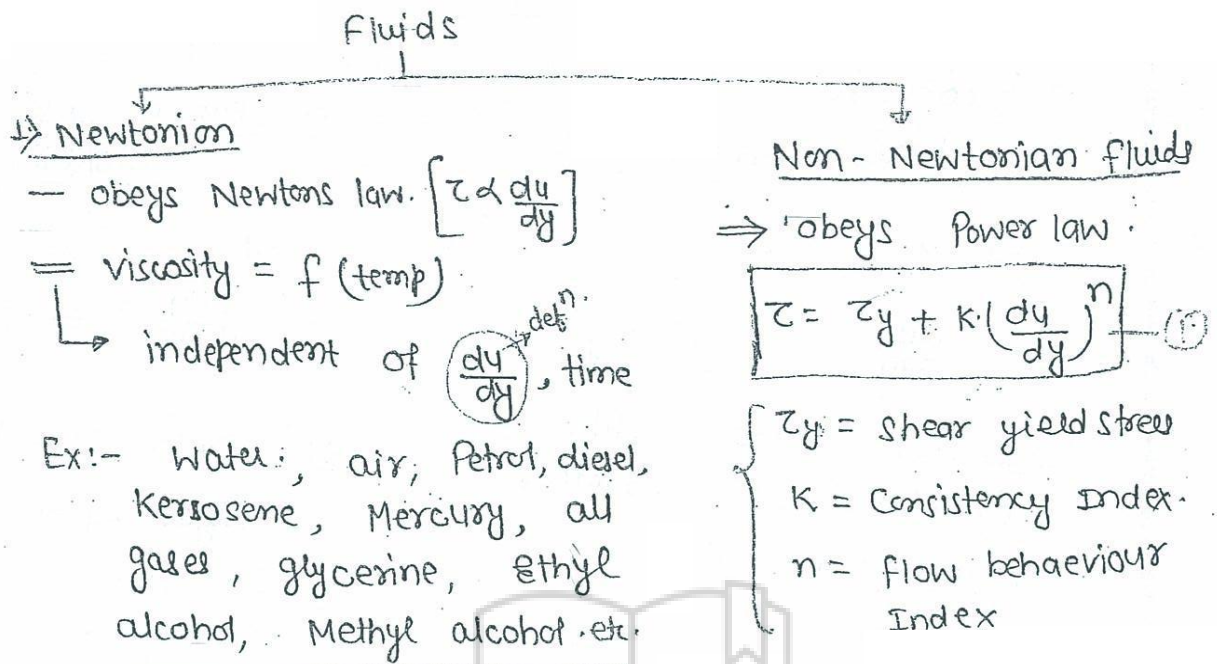
$$\Rightarrow \boxed{\text{deformation rate} = \text{velocity gradient}}$$

Shear stress is always associated with deformation rate.

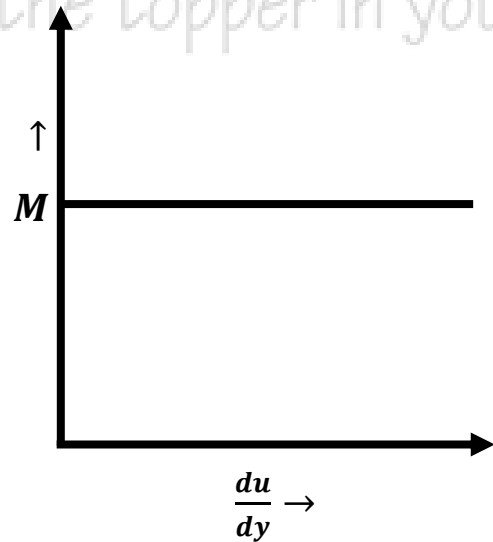
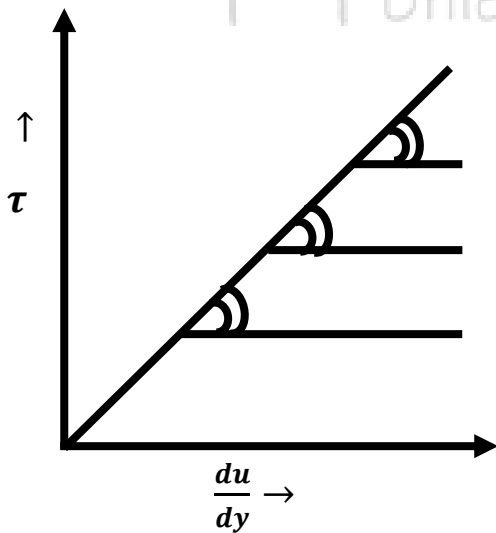
Effect of Temp. \uparrow on viscosity =

	μ	ν
liquid	\downarrow	\downarrow
gases	\uparrow	\uparrow

★ Classification of fluids on the basis of relation between τ and $\frac{dv}{dy}$.



Newtonian finical



⇒ Time Independent

Pseudoplastic
or, Shear thinning.

⇒ $\tau_y = 0, n < 1$

As: $\frac{du}{dy} \uparrow \Rightarrow \text{visco.} \downarrow$

Ex:- Paint, Blood, Milk,
Polymer solution, Colloids,
Paper pulp in water,
Ketch up etc.

Dilatant or Shear
Thickening :-

$\tau_y = 0, n > 1$

As: $\frac{du}{dy} \uparrow \Rightarrow \text{visco.} \uparrow$

Ex:- Butter solution,
Sugar Syrup,
Corn flour,
Quick Sand. (2m2m)

(ii) Time Dependent Non-Newtonian Fluids

$\tau_y > 0$; $\text{viscosity} = f(\text{temp.}, \frac{du}{dy}, \text{time})$

Thixotropic

$\tau_y > 0, n < 1$

As time $\uparrow = \text{visc.} \downarrow$

Ex:- Ice cream,
YOGHURT,
MARRINIC,
PRINTER INK etc.

Rheopectic

$\tau_y > 0; n > 1$

As time $\uparrow \Rightarrow \text{visc.} \uparrow$

Ex:- Gypsum paste,
Bentonite solution
etc.

Rheology

↳ study of Non-Newtonian Fluids.

Bingham or Ideal Plastic :-

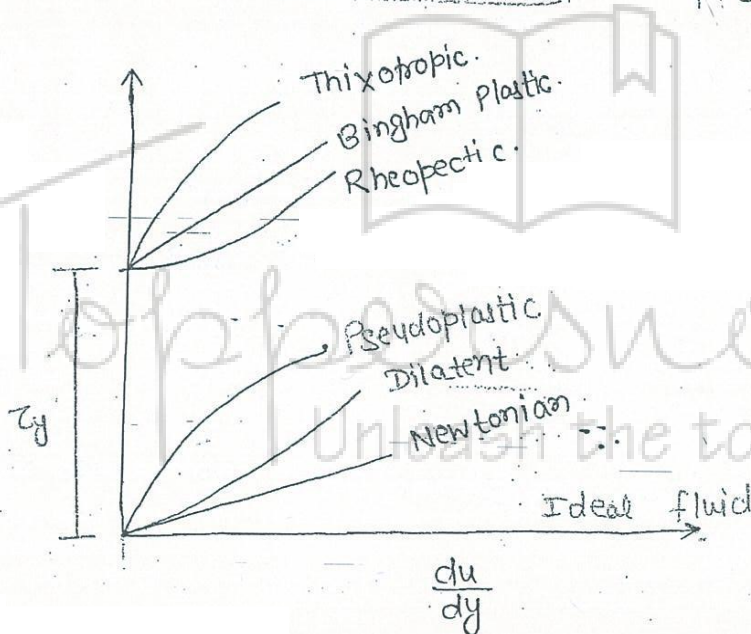
- Ex:- Tooth Paste.
 Drilling mud.

Power law; $\tau = \tau_y + K \cdot \left(\frac{du}{dy}\right)^n$

for Bingham Plastic.

$\tau_y > 0$; $K = \mu$, $n = 1$

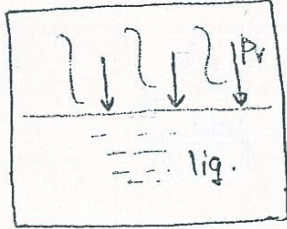
$\tau = \tau_y + \mu \cdot \left(\frac{du}{dy}\right)$ — Power law for Bingham plastic.



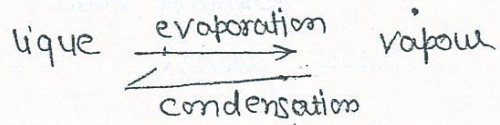
Bingham plastic is a fluid which behaves like a solid - until τ_y is exceeded and after that it behaves like a Newtonian fluid.

Drilling mud is used to disperse the mud from the oil well during extraction.

⑥ Vapour Pressure :-



Phase equilibrium.



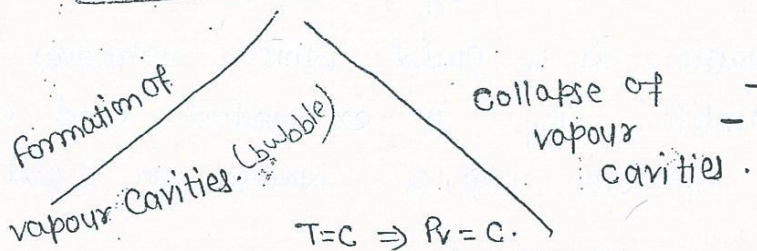
All liquids have a tendency to vapourise. Vapour pressure is defined as the pressure exerted by vapour of a liquid which are in phase equilibrium with the liquid itself.

Vapour pressure increases with temperature.

If the external absolute pressure exerted on the liquid and the vapour pressure of the liquid become equal, then the phenomenon of Boiling starts taking place.

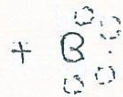
Boiling is not spontaneous but evaporation is even at 0°C

CAVITATION :-



$$P_A < P_v$$

$$45 < 50$$



$$P_B > P_v$$

$$52 > 50$$

P_v can be more is achieved by the arrangement of tube.



Collision of water at the cavity centre

↓
generation of pressure pulses.

↓
Formation of Pits on the surface.

↓
Failure due to Pitting erosion.

Methods to Prevent Cavitation

Outlet of Reaction turbine

↓
draft tube is provided.

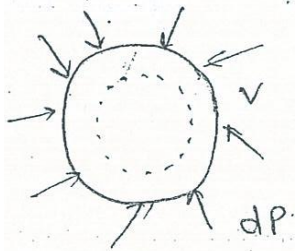


Inlet of centrifugal pumps.

↓
NPSH (Net Pump suction head)

7) Compressibility β and Elasticity :-

$$\beta = \frac{1}{K} \quad \text{--- (1)}$$



$$K = \frac{dP}{-\frac{dv}{V}} \quad \text{--- (2)}$$

$$K = -\frac{V dP}{dV} \quad \text{--- (3)}$$

$$\text{mass } (m) = \rho V = \text{Const.}$$

$$V d\rho + \rho dV = 0$$

$$\boxed{\frac{dV}{V} = -\frac{d\rho}{\rho}} \rightarrow (4)$$

using (4) in (3)

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

or

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

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

or

$$\boxed{\beta = \frac{d\rho}{\rho dP}} \quad (5)$$

if $d\rho = 0 \Rightarrow \beta = 0 \Rightarrow$ Incompressible fluid.

$$K = 0.103 \text{ MPa (Air)}$$

$$K = 2060 \text{ MPa (H}_2\text{O)}$$

$$K = 2060,00 \text{ MPa (steel)}$$

for water the value of β is very less so under normal condition the water is Incompressible.

C_p = Compressibility factor.

$$= 1 + \frac{M^2}{4} + \frac{2-\gamma}{24} M^4 +$$

where: γ = Ratio of specific heats

$$M = \text{Mach. No} = \frac{V}{c} \quad \frac{\text{velocity of air}}{\text{velocity of sound in air}}$$

if $\gamma = 1.4$.

$$C_p = 1 + \frac{M^2}{4} + \frac{M^4}{40} +$$

$$\left. \begin{array}{l} M \\ \% \text{ error or} \\ \% \text{ change in} \\ \text{density} \end{array} \right\} = (C_p - 1) \times 100$$

0.1	0.25
0.2	1.00
0.3	2.3
0.4	4.1
...	...
1.0	27.5

IMP:

$$M < 0.2 - 0.3$$

When the Mach no lies in b/w 0.2 - 0.3 then the %age change in density is less than 5%.

IMP: - Generally the liquids are taken as Incompressible because their value of K is very high.

Even the gases can be taken as Incompressible if the value of Mach No. "M" is less than $M < 0.2 - 0.3$ because for this range the percentage change in density is much less than 5%.

Q. 8. W.B.

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

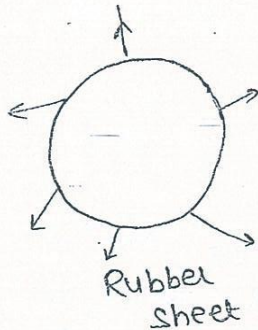
$$\begin{aligned}
 K &= \rho \cdot \frac{1750}{\rho^{1/2}} \\
 &= \rho^{1 - 1/2} \cdot 1750 \\
 &= \rho^{1/2} \times 1750 \\
 &= 48750 \, \text{N/m}^2
 \end{aligned}$$

$$P = (3500 \rho^{1/2} + 2500)$$

$$\begin{aligned}
 \frac{dP}{d\rho} &= \frac{3500 \cdot \frac{1}{2}}{\rho^{1/2}} \\
 &= \frac{1750}{\rho^{1/2}}
 \end{aligned}$$

$$\begin{aligned}
 (100 \text{ kPa}) &= (3500 \rho^{1/2} + 2500) \frac{\text{N}}{\text{m}^2} \\
 \rho &= 776
 \end{aligned}$$

* SURFACE TENSION :- (σ)



Pulling \rightarrow



Stretched Rubber
Same as liquid surface.

Defination :-

It is the property by virtue of which a liquid tends to minimize its own surface area.

Concept of Surface Tension :-

Drops of liquid behave like small spherical balloons filled with liquid and the surface of the drops acts like stretched elastic membrane under tension. The pulling force which causes this tension is due to the force of cohesion and acts parallel to the surface. It is the intensity of these forces per unit length of the surface that gives the value of surface tension.