ToppersNotes

IES/GATE

MECHANICAL ENGINEERING

FLUID MECHANICS
&
RAC, REFRIGERATION, AIR CONDITIONING

VOLUME-I

Sierra Innovations Pvt. Ltd.

Contents

FLUID MECHANICS (FM)

↓

Study of behaviour of FUIDS
- At rest
- In Motion
- Interaction of fluids with
  - other fluid
  - Solid
  - → At the BOUNDARIES

Syllabus :- FM

① Introduction — Fluids and Properties.

② Pressure & its Measurement.

③ Hydrostatic forces on surfaces.

④ Buoyancy and floatation.

(② – ④] Fluid statics.)

⑤ Fluid Kinematics. → Motion Greek word.

⑥ Fluid Dynamics. → Power. $P = F \times u$

⑦ Flow through Pipes.

⑧ Laminar flow.

⑨ Turbulent flow through Pipes.

⑩ Boundary layer Theory.

⑪ Dimensional Analysis.

Study Material

① Class Notes.

②

BOOKS

MANOJ NAUDIYAL.

Foreign	Indian
— Fox & Mc Donald	— R.K Bansal
— Cengell	— Modiseth
— Shames	— Kumar
	— Subramaniam (Que^n).

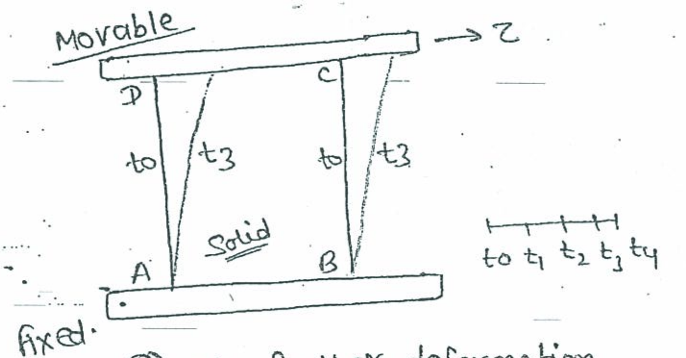
CHAPTER- 1 :-

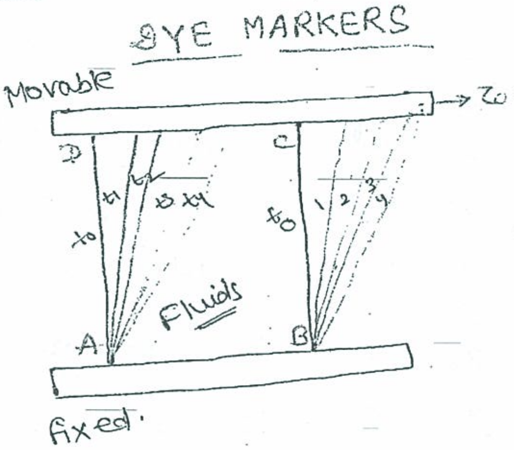
INTRODUCTION – FLUIDS & PROPERTIES

Behaviour under forces / stresses.

	Solid	Fluids.
① Tensile	✓	
② Compressive	✓	
③ Shear	✓	

Behaeviour Under shear stresses





① No further deformation (after t3 upto elastic limit not crossed)

② Regains original shape.

Concept of fluid :-

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

Fluid can also be defined as substances 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 its inability to resist shearing stresses.

However this does not mean that the fluids donot 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

अगर fluid ideal होती तो cyclone hudhud आदि ~~नहीं~~ और effect होते जाती ~~Delhi 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 vaccum condition.
- ii) Rarefied gas flows
- iii) Shock

No Slip Condition :-

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

PROPERTIES OF ~~FD~~ FLUIDS :-

⟨1⟩ **Mass Density or specific mass (ρ)**

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

$P\uparrow \Rightarrow \rho\uparrow$

$T\uparrow \Rightarrow \rho\downarrow$

⟨2⟩ **Weight Density or specific weight (ω or γ)**

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

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

⟨3⟩ **Specific volume (ϑ)**

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

$$\boxed{\vartheta = \frac{1}{\rho}}$$

⟨4⟩ Specific gravity or Relative Density (S or sp. gra.) :-

$$\boxed{S = \frac{\rho_{\text{test fluids}}}{\rho_{\text{std. fluids}}} = \frac{\omega_{\text{test fluid}}}{\omega_{\text{std. fluid}}}}$$

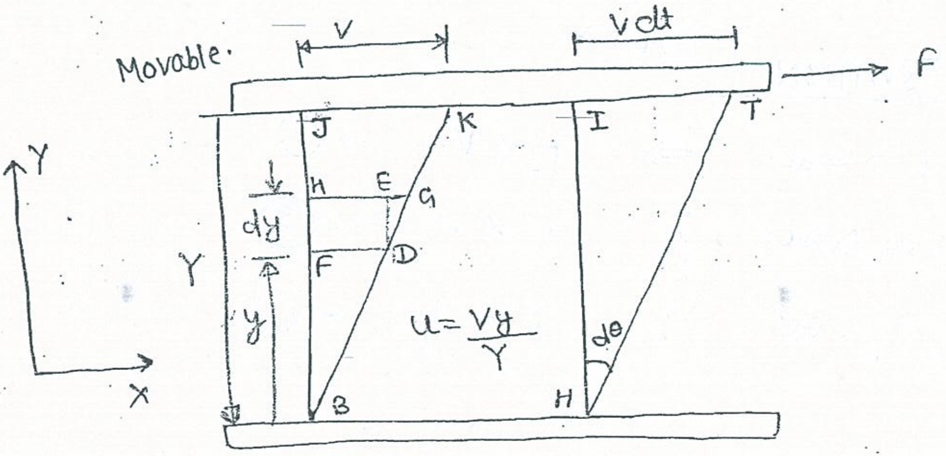
Standard fluid :- liquid — Water at 4°C.
Gas — Air / N_2 at specified Temp. & Pres.

⟨5⟩ Viscosity.

It is the property by virtue of which fluid offers resistance to the movement of one layer of fluids 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 affects appears as Shearing stresses between the layers of the fluids.

Newton's Law of Viscosity :-



FD = HE = u

EH = DE = dy EG = du

Assumption :-

① F = shear force on the upper plate.

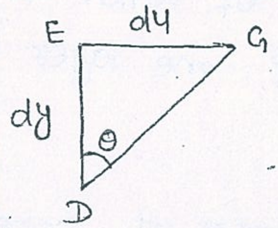
② A = Area of the upper plate in contact with the fluid.

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).

IMP.



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

In similar Δ^{le} BJK & BFD

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

$$\text{or} \quad \boxed{u = \frac{Vy}{Y}} \Rightarrow \text{linear velocity Profile.}$$

F A V Y.

OBSERVATION

(i) A, Y = Const. ⇒ $F \propto V \rightarrow$ ①

(ii) Y, V = Const. ; $F \propto A \rightarrow$ ②

(iii) A & V = Cost ; $F \propto \frac{1}{Y}$ — ③

Combining ① ② & ③

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

$$\boxed{\tau \propto \frac{V}{Y}} \longrightarrow (4)$$

In similar triangle BJK and DEG ;

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

$$\boxed{\frac{V}{Y} = \frac{dy}{dy}} \longrightarrow (5)$$

velocity gradient.

Using ⑤ in ④ ;

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

IMP

$$\boxed{\tau = \mu \frac{du}{dy}} \longrightarrow (6)$$

Newton's law.

μ = Constant of Proportionality.

= Dynamic / Absolute viscosity.

UNITS :- SI UNIT

* $\frac{N\text{-}S}{m^2}$ or Pa. sec = Kg/m-sec.

* 1 Poise = ·1 Pa.sec.

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

Kinematic viscosity (ν)

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

cgs unit $\boxed{1 \text{ stoke} = 1\ cm^2/sec.}$

In $\triangle HIT$;

$$IT = Vdt = Y \cdot d\theta$$

$$\boxed{\frac{d\theta}{dt} = \frac{V}{Y}} \quad \text{— ⑦}$$

using ⑤ in ⑦

IMP:

$$\boxed{\frac{d\theta}{dt} = \frac{du}{dy}} \quad \text{— ⑧}$$

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

Shear stress is always associated with deformation rate.

Effect of Temp. ↑ on viscosity :—

	μ	ν
Liquid	↓	↓
gases	↑	↑

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

Fluids

1) Newtonion

— obeys Newtons law. $\left[\tau \propto \frac{du}{dy}\right]$

= viscosity = f (temp)

↳ independent of $\left(\frac{dy}{dy}\right)^{\text{def}^n}$, time

Ex:- Water, air, Petrol, diesel, Kerrosene, Mercury, all gases, glycerine, Ethyl alcohol, Methyl alcohol etc.

Non - Newtonian fluids

⇒ obeys Power law.

$$\boxed{\tau = \tau_y + K\cdot\left(\frac{du}{dy}\right)^n} \quad (1)$$

τ_y = shear yield stress

K = Consistency Index.

n = flow behaeviour Index

eq^n ① can be written as;

$$\tau = \tau_y + \underbrace{\left\{K\cdot\left(\frac{du}{dy}\right)^{n-1}\right\}}_{\eta}\left(\frac{du}{dy}\right)$$

eta η = Apparent viscosity.

$$\boxed{\tau = \tau_y + \eta\,\frac{du}{dy}}$$

Non- Newtonian fluids :-

i) Time Independent :-

$\tau_y = 0$; viscosity = $f\left(\text{Temp}, \frac{du}{dy}\right)$

↳ independent of time.

ii) Time Dependent.

1.) Time Independent

Pseudoplastic or; Shear thinning.

⇒ $\tau_y = 0$, $n < 1$

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

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

Dilatant or Shear Thickening :-

$\tau_y = 0$, $n > 1$

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

Ex:- Butter solution.
Sugar syrup,
Corn flour,
Quick Sand. (दलदल)

(ii) Time Dependent Non-Newtonion Fluids

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

Thixotropic

$\tau_y > 0$, $n < 1$

As time ↑ = visc. ↓

Ex:- Ice cream.
YOGHURT.
MARGARINIC.
PRINTER INK etc.

Rheopectic

$\tau_y > 0$; $n > 1$

As time ↑ ⇒ visc. ↑

Ex:- Gypsum park.
Benotonite solution
etc.

Rheology
↳ study of Non. Newtonion Fluids.

Bingham or Ideal Plastic :-

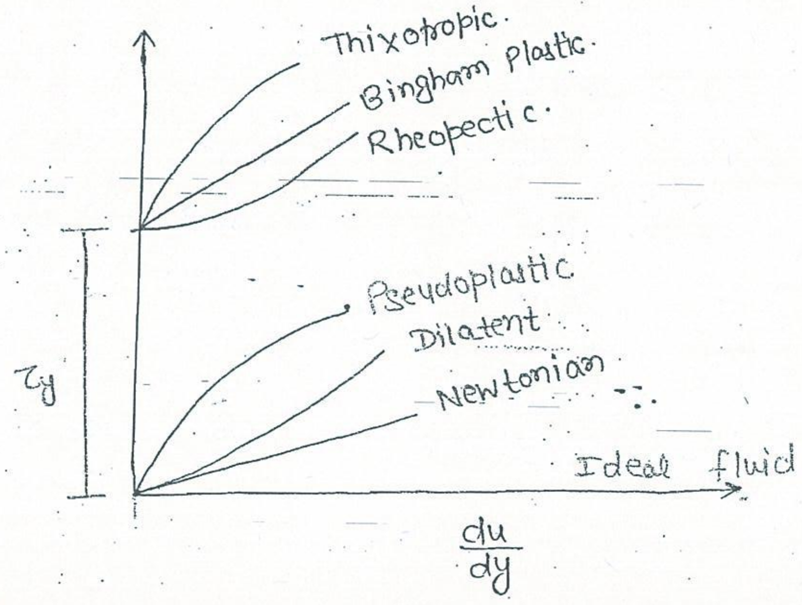
Ex :- Tooth Paste
- Drilling mud.

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

For Bingham Plastic.

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

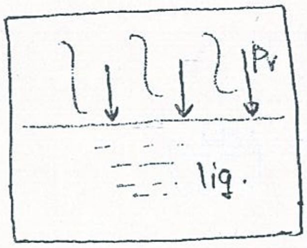
$\therefore$ $\boxed{\tau = \tau_y + \mu \cdot \left(\frac{du}{dy}\right)}$ — Power law for Bingham Plastic.



Bingham plastic is a fluid which behaeves like a Solid - untill τ_y is exceeded and after that it behaeves like a Newtonian fluid.

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

⟨6⟩ Vapour Pressure :-



Phase equilibrium.

lique $\underset{\text{condensation}}{\overset{\text{evaporation}}{\rightleftharpoons}}$ vapour

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

vapour preuesure increases with temperature.

If the External absolute pressure exerted on the liquid and the vapour pressure of the liquid become equal, then the phenemenon of Bioling starts taking place.

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

CAVITATION :-

Formation of vapour Cavities. (bubble)

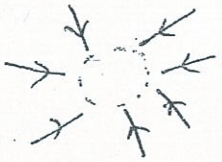
collapse of vapour cavities.

$T=C \Rightarrow P_V = C.$

$P_A < P_V$ $\quad$ $P_B > P_V$

$\boxed{45 < 50}$ $\quad$ $52 > 50$

Pv 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.
गड्ढे

↓

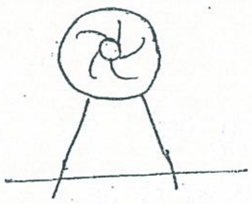
Failure due to Pitting erosion.

Methods to Prevent Cavitation

Outlet of Reaction turbine

↓

Draft tube is provided.



Inlet of centrifugal pumps.

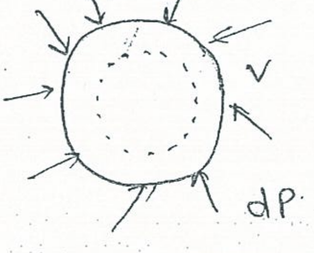
↓

NPSH
(Net Pump suction head)

7. Compressibility (β) and Elasticity (K) :-

(K) → Bulk modulus of Elasticity.

$$\boxed{\beta = \frac{1}{K}} \quad \text{——} \; ①$$



$$K = \frac{dP}{-\frac{dV}{V}} \quad \text{——} \; ②$$

$$K = -\frac{VdP}{dV} \quad \text{——} \; ③$$

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

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

$$\boxed{\frac{dV}{V} = -\frac{d\rho}{\rho}} \longrightarrow ④$$

using ④ in ③

$$K = \frac{dP}{\frac{d\rho}{\rho}} \quad \text{or} \quad \boxed{K = \frac{\rho dP}{d\rho}}$$

$$\beta = \frac{1}{K} \quad \text{or} \quad \boxed{\beta = \frac{d\rho}{\rho dP}} \text{ --- } ⑤$$

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

$K = 0.103$ MPa. (Air).

$K = 2060$ MPa (H2O)

$K = 2060,00$ MPa (Steel)

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

C_p = Compressibility factor.

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

where; γ = Ratio of specific heats

M = Mach. NO $= \frac{V}{C}$. $\frac{\text{velocity of air}}{\text{velocity of sound in air}}$

If $\gamma = 1.4$.

$$C_P = 1 + \frac{M^2}{4} + \frac{M^4}{40} + \text{-----}$$

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

M	% error or; % change in Density
0.1	.25
0.2	1.00
0.3	2.3
0.4	4.1
⋮	⋮
1.0	27.5

IMP.

$$\boxed{M < 0.2 - 0.3}$$

when the Mac. 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 $M < .2 - 0.3$. because for this range the percentage, change in density is much less than 5%.

Q.8. W.B.

$$K = \frac{\rho \, dP}{d\rho} \qquad P = (3500 \rho^{1/2} + 2500)$$

$$K = \rho \cdot \frac{1750}{\rho^{1/2}} \qquad \frac{dP}{d\rho} = \frac{3500 \times \frac{1}{2}}{\rho^{1/2}}$$

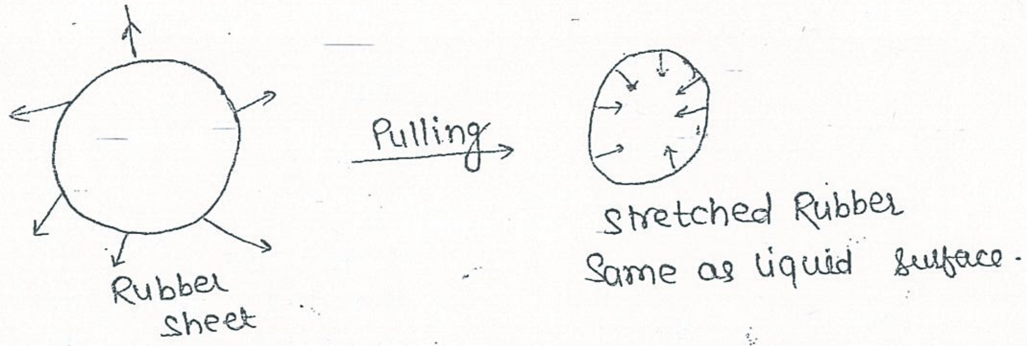
$$= \rho^{1-\frac{1}{2}} . 1750 \qquad = \frac{1750}{\rho^{1/2}}.$$

$= ~~1000~~$

$$(776)^{1/2} \times 1750 \qquad (100 \text{ kPa}) = (3500 \rho^{1/2} + 2500) \frac{N}{m^2}$$

$$= 48750 \ N/m^2 \qquad \rho = 776.$$

* SURFACE TENSION :- (σ)



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 behaeve like small spherical ballons 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 cohession 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.

Surface Energy :-

Surface Tension can also be defined as surface energy. In this case it represents the amount of work required to be done in order to increase the area of the surface by unit amount.

σ always act along the length.