LECTURE NOTE
ON
HYDRAULIC AND IRRIGATION
3^{RD} SEMESTER

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INTRODUCTION
Chapter - 1

Fluid Mechanics

Any substance which can flow called fluid.

Flow

Relative change of position of particle wrt time

Fluid

- → Fluid may be liquid or gas, or both.
- → Fluid doesn't have any certain shape.
- → It occupies shape of vessel.
- → Fluid can flow under it own weights.

Mechanics

It is study of force and effect of force.

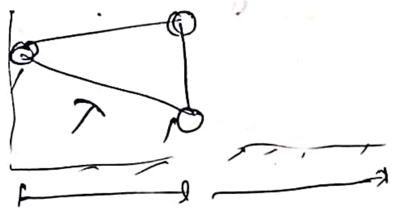
Macroscopic Approach to Fluid

Continuous distribution of mass

Assumption: "There are no voids betn molecules"

It is applied in

$$\text{Knudsen Number } (K_n) = \frac{\text{mean free path}}{\text{characteristic length}} = \frac{\lambda}{L}$$



If $K_n < 0.01$, i.e continuous distribution of mass, means there is no voids.

If $0.01 < K_n < 10$, i.e slip flow

If $K_n > 10$, free molecular flow

Fluid Mechanics

→ It is the branch of science which deals with the behaviour of the fluids (liquids or gases) at rest as well as in motion.

→ The study of fluids at rest is called fluid statics.

→ The study of fluids in motion, where pressure forces are not cosidered, is called fluid kinematics and if the pressure forces are also considered for the fluids in motion, is called fluid dynamics.

(1) Properties of Fluid

(i) Density or mass Density (ρ)

It represents heaviness of fluid.

(rho) $\rho = \frac{m}{V}$, $\rho \uparrow$ $m \uparrow$ (Structure is compact i.e dense medium)

$\rho \downarrow$ $m \downarrow$

Temp ↑ $\rho \downarrow$
Pressure ↑ $\rho \downarrow$

SI unit of density . kg/m^3, ~~g/cm^3~~

CGS unit of " gm/cm^3 ρ of oil = $850\ kg/m^3$

NOTE ρ of ~~water~~ air = $1.21\ kg/m^3$ at standard temp

Density of water is $1000 kg/m^3$ at 4°C OR $1\ gm/cm^3$

(ii) Weight density (γ) / specific weight (w)

w or $\gamma = \frac{weight}{volume} = \frac{W}{V} = \frac{mg}{V} = \rho g$

Temp. ↑ $\gamma \downarrow$
Pressure ↑ $\gamma \downarrow$

weight = mg

g = gravitational pull force in N
m = mass of fluid

SI Unit of weight density is N/m^3

mks unit is kg/m^2s^2
cgs " gm/cm^2s^2

Weight density of water is $9.81 \times 1000\ N/m^3$

(iii) Specific Gravity or Relative Density

$$G = \frac{\text{Density of fluid}}{\text{density of standard fluid at standard temp.}}$$

$$\text{Specific Gravity of Liquid} = \frac{\text{Density of Liquid}}{\text{Density of water at } 4°C}$$

$$G \text{ of Gas} = \frac{\text{Density of Gas}}{\text{Density of air at Standard temp \& Pressure}}$$

H_2 / Air at 15°C

∴ Specific gravity of mercury is 13.6

(iv) Specific Volume (v)

$v = \frac{volume}{mass} = \frac{1}{\rho}$ m^3/kg

Q. If G of mercury is 13.6 then find Density of ?

$$\text{Specific gravity of liquid} = \frac{\text{Density of liquid}}{\text{density of water at } 4^\circ C}$$

$$(SG)_{L} = \frac{\rho_{mg}}{1000}$$

$$\Rightarrow 13.6 = \frac{\rho_{mg}}{1000}$$

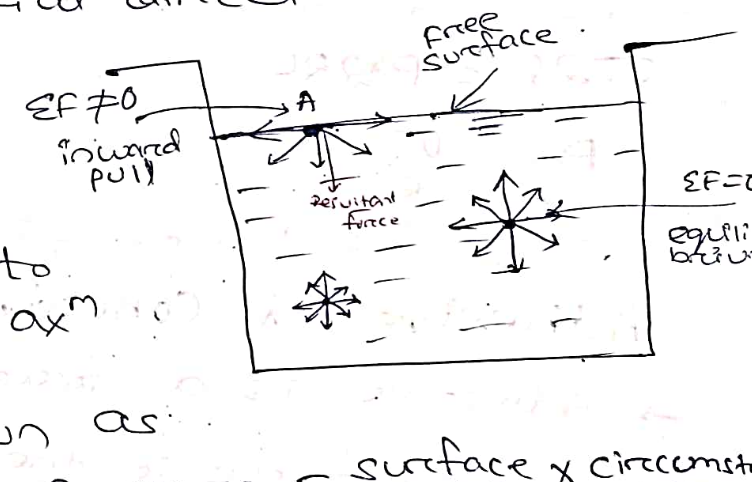
$$\Rightarrow \rho_{mg} = 13600\ kg/m^3$$

(iv) Surface Tension

Free surface is a surface with constant normal stress and zero shear stress. No external force in tangential direction.

Free surface of liquid behaves like a stretched membrane and it tries to minimize its area, upto max^m possible extent.

This property is known as surface tension.



Pressure (P) intensity = surface tension (σ) × circumstances

$= \sigma \times \pi d$

$$\text{Surface Tension } (\sigma) = \frac{\text{Force}}{\text{Unit length}} \quad N/m$$

Surface Energy

Work done in contracting the free surfaces is called surface energy.

$W = \sigma n$

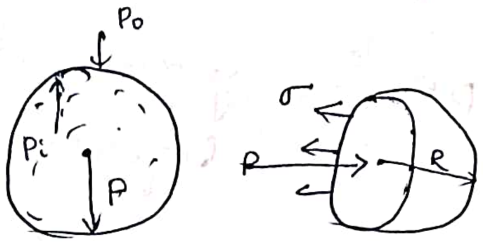
$$\text{Surface Tension} = \frac{\text{Force}}{L} \times \frac{\Delta L}{\Delta L} = Nm/m^2 = J/m^2$$

Surface Tension in Different Cases

(1) Water Droplet

P_i : inside pressure

P_o : Outside pressure



Resultant Pressure = $P_i - P_o$ = Excess pressure

For equilibrium, $P\pi R^2 = \sigma \times 2\pi R$

$\Sigma F = 0$

$P \rightarrow \quad \leftarrow \sigma$

$$P = \frac{2\sigma}{R}$$

(2) Soap bubble

$P\pi R^2 = \sigma 2 \times 2\pi R$

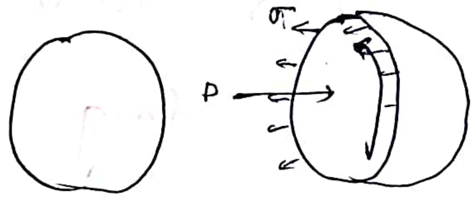
$P = \frac{8\sigma}{R}$ = $\frac{8\sigma}{}$

$P = \frac{4\sigma}{R}$

$P \times \frac{\pi}{4} d^2 = 2 \times (\sigma \times \pi d)$

$P = \frac{\sigma 2\pi d}{\frac{\pi}{4} d^2}$

$P = \frac{8\sigma}{d}$



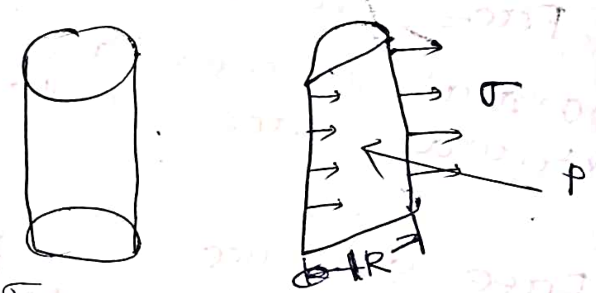
(3) Water Jet

$F = P \times area = P \times L \times d = PL2R$

Force due to tension $= \sigma \times 2L$

$\sigma 2l = P \times 2RL$

$$P = \frac{\sigma}{R}$$



OR $P \cdot Ld = \sigma 2L \Rightarrow P = \frac{\sigma 2L}{Ld} = \frac{2\sigma}{d}$

Adhesive & Cohessive Force

→ Adhesive is a force acting betⁿ two surfaces of different medium.

→ Cohession force is the force acting betⁿ molecules of same medium.

Wetting or Non-wetting Liquids

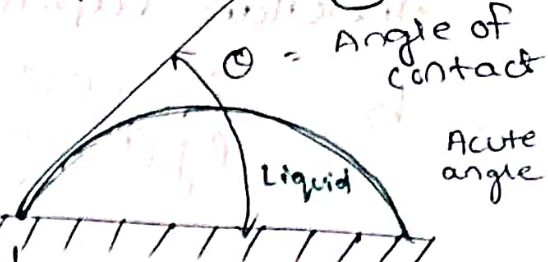
Case-1

Adhesion Force > Cohesion force i.e liquid will wet the solid boundary i.e Wetting Liquid

Case-2

Cohesion Force > Adhesion force i.e Non-wetting liquid.

For Wetting Liquid

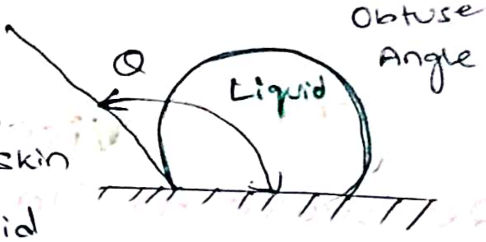


Adhesive Force > Cohesive Force

e.g water & glass, copper & silver & gold

If $\theta < 90°$ or $\frac{\pi}{2}$ i.e Wetting liquid
i.e acute angle i.e 8'

For Non-wetting Liquid



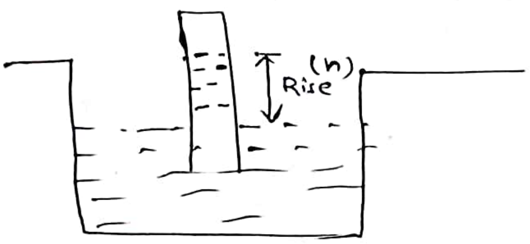
Cohesive force > Adhesive force

e.g mercury & glass, water & leaf, mercury & human skin

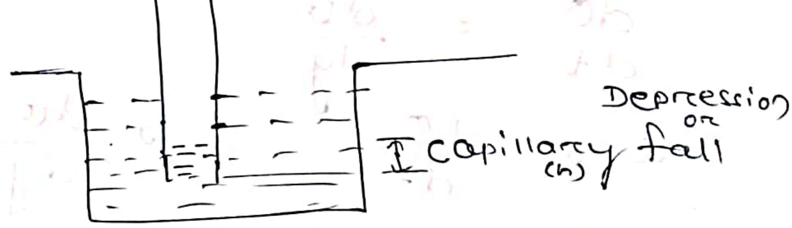
If $\theta > 90°$ or $\frac{\pi}{2}$ i.e non wetting liquid
i.e is obtuse angle e.g 130°

Capillarity

→ A phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid.

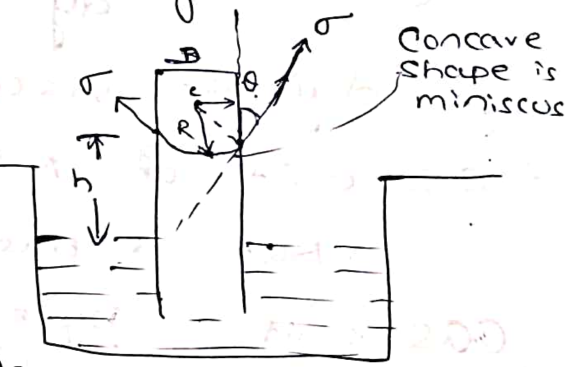


Wetting Liquid



Non-wetting liquid

Capillary Rise/Depression (h)



$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

where, σ = surface Tension (N/m)
d = dia of capillary tube (m)
ρ = density of liquid (kg/m³)
θ = angle of contact

For water glass, $\theta = 0$
For mercury glass, $\theta = 128°$

Weight of liquid of height (h) = (Area of tube × h) ρg
$= \frac{\pi}{4} d^2 h \rho g$

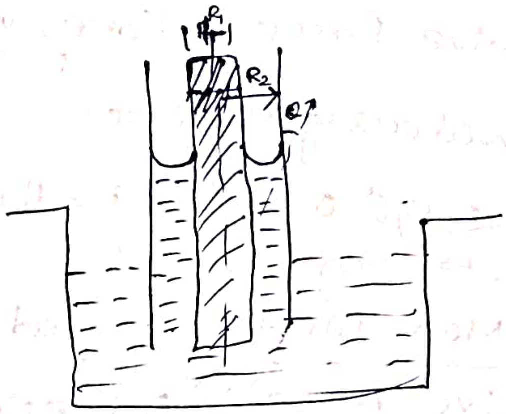
$$h = \frac{4\sigma}{\rho g d}$$

→ Rise of liquid surface called capillary rise, fall of liquid surface known as capillary depression.

Vertical component of the surface tensile force = (σ × circumference × $\cos\theta$)
$= \sigma \pi d \cos\theta$

Annular capillarity

$$h = \frac{2\sigma\cos\theta}{\rho g (r_2 - r_1)}$$



Viscosity

Resistance to flow of a fluid. It is occur due to (i) cohesive force and (ii) inter molecular momentum transfer.

$$\mu = \frac{\text{shear stress}}{\frac{\text{change of velocity}}{\text{change of distance}}} = \frac{\text{Force/Area}}{\left(\frac{\text{Length}}{\text{time}}\right) \times \frac{1}{\text{length}}}$$

Newton's Law of Viscosity

Shear stress ∝ Rate of shear strain

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

$$\tau \propto \frac{d\theta}{dt} \quad \text{i.e } \tau \propto \frac{du}{dy}$$

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

μ = dynamic viscosity of the fluid

SI-unit of Ns/m^2 / Pascal·S i.e Pas

N/m^2 is pascal

CGS unit. $\frac{\text{Dyne}\cdot S}{Cm^2}$ / Poise

Relation bet^n poise & Pas

$$1 \text{ Poise} = \frac{1}{10} \text{ Pas or } \frac{NS}{m^2}$$

$$1 \frac{NS}{m^2} = 10 \text{ Poise} = 1 \text{ Pascal}$$

Fluid is a substance which deform continuously under the action of very small SF (or shear stress)

Kinematic Viscosity

It is ability of fluid to difuse a disturbance in molecular momentum.

OR

Defined as the ratio betⁿ the dynamic viscosity and density of fluid. Denoted by 'ν'

$$\nu = \frac{\mu}{\rho}$$

SI unit is m^2/s

CGS unit cm^2/s ; Stokes

1 Stoke = $10^{-4} m^2/s$

Effect of Temp. on Dynamic Viscosity

(i) Liquid

Temp ↑ μ_{Liquid} ↓

$$\mu = \frac{\mu_0}{1 + \alpha T + \beta T^2}$$

where,
μ = dynamic viscosity of liquid
μ_0 = " " at 0°C
α, β = constant, $\alpha > \beta$

(ii) Gases

Temp ↑, Viscosity ↑

$$\mu = \mu_0 + \alpha T - \beta T^2$$

with increase in temp, molecular momentum transfer increases and hence viscosity increases.

Newton's Law of Viscosity

It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain constant of proportionality is called the co-efficient of viscosity.

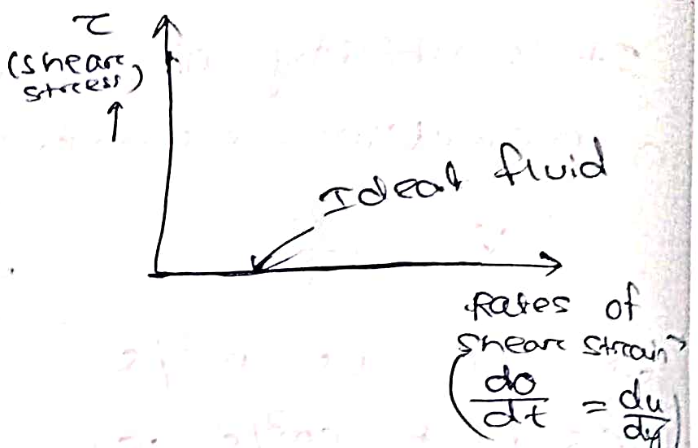
$$\tau = \mu \frac{du}{dy}$$

Fluid which obey the this relation is known as Newtonian fluid otherwise it is known as non-Newtonian fluid

Rehological Behaviour of Fluid

Branch of science which deal with behaviour of fluid

(i) Ideal Fluid



→ No viscosity

→ incompressible

→ No shear stress

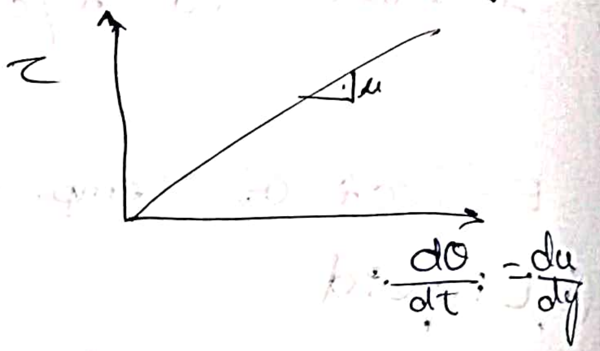
→ Constant normal stress

(ii) Newtonian Fluid

Fluid which obey's Newton's law of viscosity

Newton's Law of viscosity

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



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

$$y = mx + c$$

(iii) Non-Newtonian Fluid

Fluid which isn't obey Newton's Law of viscosity

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

m = consistency index

n = flow index

If $n > 1$. Then Non-Newtonian fluid is called Dillatent fluid.

If $n < 1$, then it is Pseudoplastic fluid

(iv) Real fluid :-

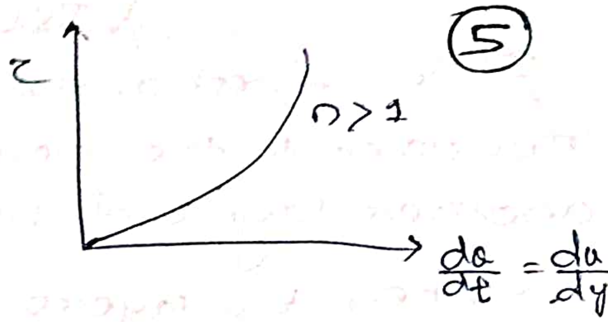
which possesses viscosity, is known as real fluids.

(v) Ideal Plastic fluid :- Which shear stress is more than the yield value and shear stress ∝ rate of shear strain

Dilatent fluid

→ shear thicking fluid

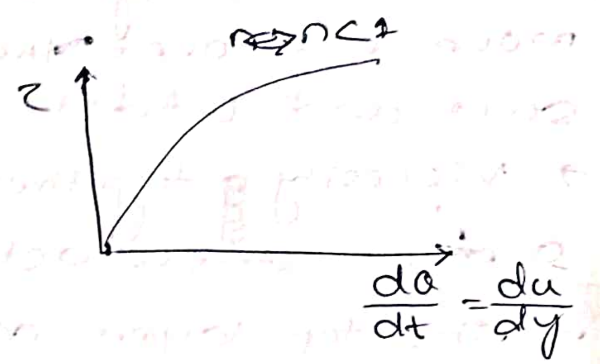
e.g starch suspension



pseudo. plastic fluid

shear Thinning fluid

e.g Blood



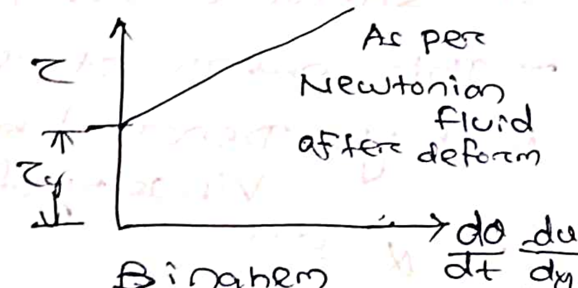
(iv) Binghem Plastic & Hasschal Buckley Fluid

$$\tau = \tau_y + m\left(\frac{du}{dy}\right)^n$$

τ_y = yield shear stress

For Binghem Plastic,

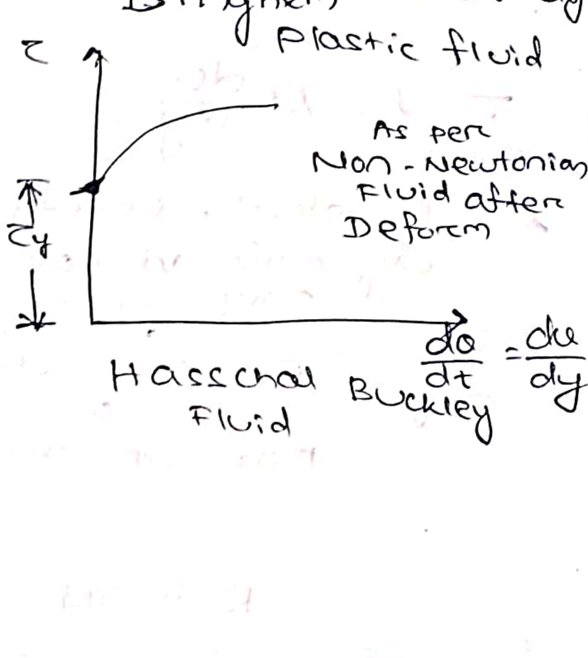
$$\tau = \tau_y + \mu\left(\frac{du}{dy}\right)$$



Binghem Plastic fluid

For Hasschal Buckley fluid

$$\tau = \tau_y + m\left(\frac{du}{dy}\right)$$



Hasschal Buckley Fluid

VISCOSITY

It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another layer of fluid.

→ When two layers of a fluid, a distance 'dy' apart, move one over the another at different velocities, say u and u+du.

→ Viscosity together with relative velocity causes a shear stress acting bet^n the fluid layers.

→ The top layer causes a shear stress on the adjacent lower layers while the lower layer causes a shear stress on the adjacent top layer.

→ This shear stress is $\propto$ rate of change of velocity w.r.t y. Denoted by τ

Viscosity of Liquid

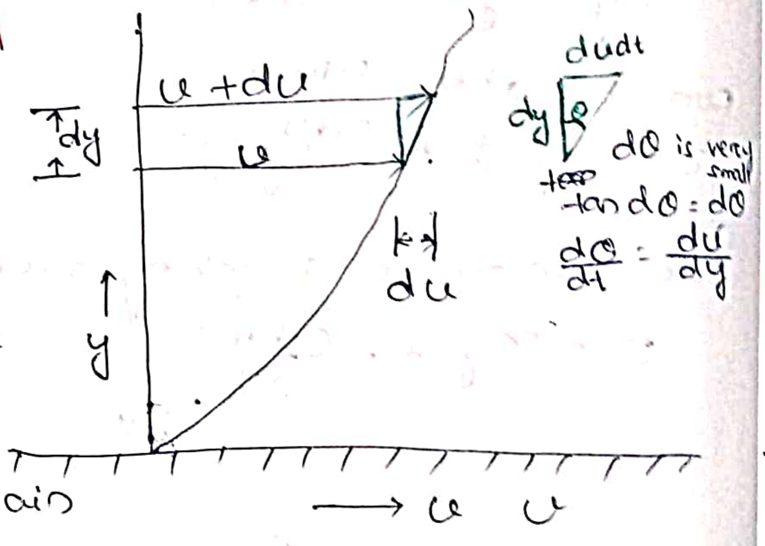
$$\tau \propto \frac{du}{dy}$$

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

where,

μ = constant, co-efficient of dynamic viscosity or only viscosity

$\frac{du}{dy}$ = rate of shear strain OR rate of shear deformation or velocity gradient



REASON

→ The reason for viscosity is relative motion and cohesion.

→ The liquid at rest or relative rest, the concept of viscosity is not valid.

Due to Cohesion & relative motion

Finding shear stress when velocity profile is given:- (6)

$u = ay^2 + by + c$

find shear stress at $y = k$, $u = u(y)$ only, $\tau = \mu \frac{du}{dy}$

$$\frac{du}{dy} = \frac{d}{dy}[ay^2 + by + c]$$

$$= \frac{d}{dy}(ay^2) + \frac{d}{dy}(by) + \frac{d}{dy}(c) \Rightarrow 2ay + b = \frac{du}{dy}$$

=)

This eqⁿ applicable for linear velocity only with uniform shear stress throughout the c/s in normal direction.

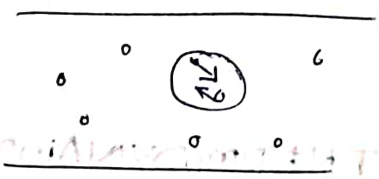
1) Linear velocity profile, $\tau = \mu \frac{\Delta U}{Y}$

2) Some random velocity profile, $\tau = \mu \frac{du}{dy}$

3) ~~Nothing~~

Viscosity of Gases

Viscosity of gases occurs due to molecular collision



when, Temp. ↑ viscosity of Gas ↑

due to molecules increases its randomness which further increases molecular collisions.

Cavitation

→ Phenomenon which occurs within a moving liquid when the static pressure at some location falls to or below the vapour pressure of the liquid.

→ occurs when fluid pressure reduced to the local vapour pressure & boiling occurs.

→ Cavitation occurs at locations where the velocity is high

Causes

→ when static & dynamic pressure meet. like in turbines

→ during vapour pressure formation

→ near first moving blades of turbines, also exit of the turbines.

THERMODYNAMIC PROPERTIES

~~But~~ gases are compressible fluids and hence thermodynamic properties. With the change of pressure and temp., the gases undergo large variation in density.

Isothermal Process

If the change in density occurs at constant temp. then the process in called isothermal.

$$\frac{p}{\rho} = \text{constant}$$

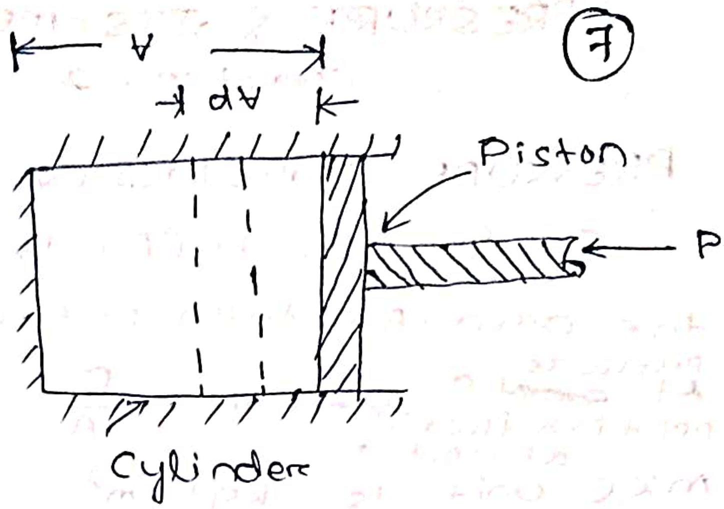
Adiabatic Process

If the change in density occurs with no heat exchange to and from the gas, the process is called adiabatic.

$$\frac{p}{\rho^{k}} = \text{constant}$$

COMPRESSIBILITY

It is the reciprocal of the bulk modulus of elasticity, K which is defined as the ratio of compressive stress to volumetric strain



increase in pressure $= dp$ kgf/m²

Decrease in volume $= d\forall$

Volumetric strain $= -\frac{d\forall}{\forall}$

Bulk modulus $(K) = \frac{\text{Increase of pressure}}{\text{Volumetric strain}}$

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

NOTE: Raindrops are spherical in shape bcoz for a given volume sphere has min^m surface area. Surface area is max^m for sphere leading to min^m surface energy & max^m stability. $E_s = \sigma A$

SURFACE ENERGY

→ During stretching of an interface, work is done to move liquid molecules from the interior parts to the surface against the attraction force of other liquid molecules.

→ The work done is stored as potential energy of the molecules available on this interface.

→ This potential energy of molecules on the interface is known as surface energy.

Work done If ① of a rod converted stretching to ②

$A_1 = 2Lx, \; A_2 = 2L(x + \Delta x)$

$\Delta A = 2L\Delta x$

At equilibrium

$F = F_{st}$

$F = \sigma(2L)$ —— ①

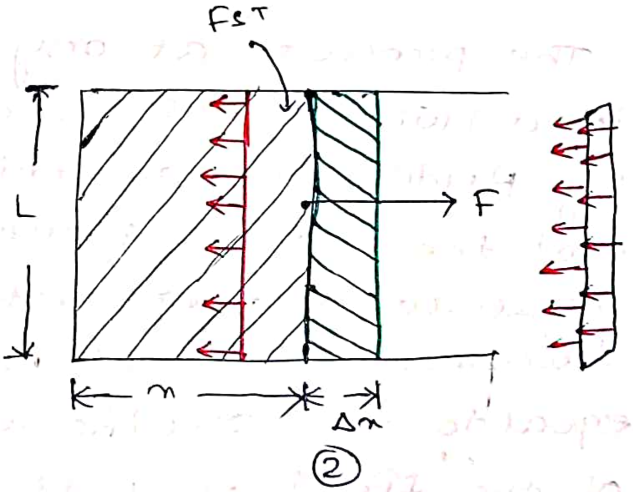
$W = F\,\Delta x \cos 0°$

$W = F\,\Delta x$

$W = \sigma(2L)\Delta x$

$W = \sigma(2L\Delta x)$

$W = \sigma\Delta A$



①

$\Delta E_s = W$

$\Delta E_s = \sigma\Delta A$

$E_{s2} - E_{s1} = \sigma(A_2 - A_1)$

$E_s = \sigma A$

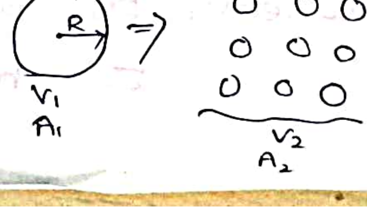
$\sigma = \frac{E_s}{A}$

If $A = 1\,m^2$,

$\sigma = E_s$

Workdone in converting a large spherical droplet into 'n' number of small spherical droplets.

$V_1 = V_2$, $A_2 > A_1$



$V_1 = V_2$

$\frac{4}{3}\pi R^3 = n \times \frac{4}{3}\pi r^3$

$nr^3 = R^3 \Rightarrow r = \frac{R}{n^{1/3}}$

$\Delta A = A_2 - A_1$

$\Delta A = 4\pi[nr^2 - R^2]$

$\Delta A = 4\pi[n(\frac{R}{n^{1/3}})^2 - R^2]$

$\Delta A = 4\pi R^2(n^{1/3} - 1)$