10/6/19 [Mon]

UNIT-1 * FLUID & THEIR PROPERTIES *

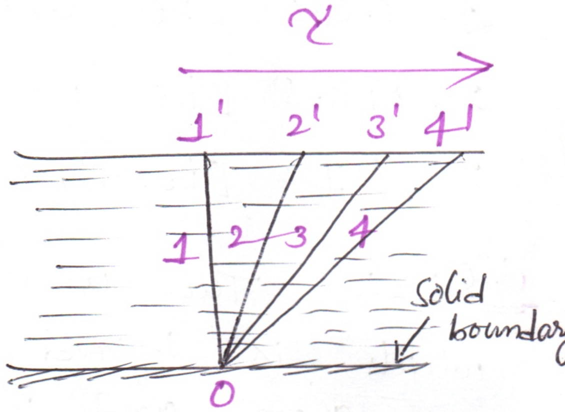
Introduction :-

⇒ Fluid mechanics is the branch of science which deals with the behaviours of the fluids [liquid (or) gases] at rest as well as in motion

* Both liquid & gases come under the category of fluids

Fluids at rest	Fluids in motion [Pressure forces are not considered]	Fluid in motion [pressure forces are also considered]
1) Fluid statics	2). Fluid ~~ki~~ kinematics	3. Fluid dynamics

Fluid :- A fluid is a substance which deforms continuously when subjected to external shear stress however smaller the shear stress may be



→ The continuous deformation of fluid under the action of shear stress causes a flow.

→ Fig shows shear stress applied at certain location in a fluid, the element O11' which is initially at rest, will move to O22' then to O33' and to O44' and so on.

→ If a fluid is at rest, no shear stresses will act on it. The forces acting in the fluid will be normal to the planes on which they act.

Difference b/w Liquid & gases :-

→ **Solid :-** It offers resistance to the shear stress/forces because of very strong intermolecular attraction. It has a definite shape & volume

Ex :- Metals, wood etc.,

→ **Liquid :-** It has definite volume but no shape for all practical purposes;

liquids have free surface liquids have less compressibility

Ex :- water, oils etc.,

Gas :- has no definite shape and volume. It has highly compressible. Gas has no free surface Ex :- Air and other gases

Vapour :- It is a gas very nearer to liquid states Ex :- steam

System of units :-

The following system of units are mostly used.

1. C.G.S (i.e., Centimetre - Gram - second) system of units
2. M.K.S [i.e., Metre - Kilogram - second) system of units
3. S.I [i.e, International] system of units

C.G.S :- The unit of force in this system is dyne which is defined as the force acting on a mass of one gram and producing an acceleration of one centimetre per second square

M.K.S :- The unit of force in this system is expressed as kilogram force and is represented as kgf

S.I :- The system of International units

The system is Newton and → The unit force in this system is Newton and it is represented "N". Newton is the force acting on a mass of one kilogram and producing an acceleration of one metre per second square. The relation b/w Newton (N) and dyne is obtained as

One Newton = one kilogram mass × $\frac{\text{one metre}}{s^2}$

$= 1000\,gm \times \frac{100\,cm}{s^2}$ [1 kg = 1000 gm]

$= 1000 \times 100 \times \frac{gm \times cm}{s^2}$

$= 10^5$ dyne

⇒ one kilo-newton = 10^3 Newton & one mega Newton = 10^6 N

1 kN = 10^3 N

⇒ kilo = 10^3 -- k
⇒ Mega = 10^6 -- M
Giga = 10^9 -- G
Tera = 10^{12} -- T

→ Mega newton = 10^6 N = MN
Giga Newton = 10^9 N = GN
Tera Newton = 10^{12} N = TN

⇒ Milli = 10^{-3} -- m
⇒ Micro = 10^{-6} -- μ
Nano = 10^{-9} -- n
Pico = 10^{-12} -- p

→ milli Newton = 10^{-3} newton = mN
micro Newton = 10^{-6} newton = μN

⇒ The relation b/w kilogram force (kgf) & Newton is given by one kgf = 9.81 N

W = m×g Newtons

$W = 1kg \times 9.81 \frac{m}{s^2} = 9.81\,N$ $\left[N = kg\frac{m}{s^2}\right]$

Basic units :-

physical quantity	Notation of unit	Dimension or Symbol
Length	metre	m
Mass	kilogram	kg
Time	Second	s
Electric current	Ampere	A
Temperature	kelvin	K
Luminous intensity	Candella	cd

⇒ Supplementary units :-

plane angle	Radian	rad
Solid angle	Steridian	Sr

⇒ Derived units :-

Acceleration	metre / sec^2	m/s^2
Angular velocity	radian / sec	rad/s
Angular acceleration	radian / sec^2	rad/s^2
Force	Newton	N = kg m/s^2
moment of force	Newton metre	Nm
works, Energy	Joule	$J = Nm = kg\frac{m^2}{s^2}$
Torque	Newton metre	Nm
power	watt	W = J/s
pressure	pascal	Pa = N/m^2
Frequency	Hertz	Hz = s^{-1}

Properties of fluids :-

(i) **Mass density** (ρ) :- It is the mass of the matter occupied in unit volume at a std temp & pressure
It is denoted by ρ

$\rho = \frac{M}{V}$ Dim :- ML^{-3}
unit :- kg/m^3

⇒ If temp increases "ρ" decreases
Exception :- Density of water at 0°C to 4°C

⇒ pressure ↑ ρ ↑

* Mass density is independent of acc" due to gravity
So it is constant everywhere

Air :- 1.2 kg/m^3 mercury :- 13600 kg/m^3
water : 1000 kg/m^3

Specific weight :- [γ (or) w (or) ρg]: weight of the matter per unit volume

$\Rightarrow \gamma = \frac{W}{V} = \frac{Mg}{V} = \rho g$

$\Rightarrow$ Dim :- $ML^{-2}T^{-2}$
units :- N/m^3

$N = Kg\frac{m}{s^2}$ $M \cdot L \cdot T^{-2}$ & $V = L^3$

$\gamma = \frac{MLT^{-2}}{L^3} = ML^{-2}T^{-2}$ $Kg\frac{m}{s^2} = \left(Kg\frac{m}{s^2}\right)/m^3$

$\Rightarrow$ units : N/m^3

* It is not Absolute quantity and varies from place to place from place to place as g changes from place to place

$g_{poles} \simeq 9.83\ m/s^2$ $g_{equator} \simeq 9.78\ m/s^2$

Air = $11.77\ N/m^3$; water :- $9.81 kN/m^3$

Specific volume :- (V_s)

* volume occupied by unit mass of fluid

$V_s = \frac{1}{\rho}$ (m^3/kg)

* It is the reciprocal of mass density

Specific gravity (s) (or) **Relative density** :-

It is the ratio of the mass density of any matter to the mass density of a std fluid water

$(S) = \frac{\rho}{\rho_{water}} = \frac{\gamma}{\gamma_{water}}$

unit : No

Air :- 0.0012 wood :- 0.6

water :- 1.0 Mercury :- 13.6

Pressure :- It is the compressive stress on the fluid for uniform pressure

Pressure, $P = \frac{\text{Normal force } (F)}{\text{Area of surface } (A)}$

$P = \frac{F}{L^2} = FL^{-2} \Rightarrow ML^{-1}T^{-2} \Rightarrow SI = N/m^2$

$\Rightarrow 1\ Pa = 1\ N/m^2$, $1\ kpa = 1000\ N/m^2$

$\Rightarrow 1\ bar = 100\ kpa = 10^5\ N/m^2$

1) calculate the specific weight, density, & specific gravity of one litre of a liquid which weighs 7N

Sol:- Given

volume = 1 litre = $\frac{1}{1000}$ m^3 [∵ 1 litre = $\frac{1}{1000}$ m^3 or 1 litre = 1000 cm^3

weight = 7N

(i) Specific weight (w) = $\frac{\text{weight}}{\text{volume}} = \frac{7N}{\left(\frac{1}{1000}\right)m^3} = 7000\ N/m^3$

(ii) Density (ρ) = $\frac{w}{g} = \frac{7000}{9.81}\ kg/m^3 = 713.5\ kg/m^3$

(iii) Specific gravity = $\frac{\text{Density of liquid}}{\text{Density of water}} = \frac{713.5}{1000} = 0.7135$

(2) calculate the density, specific weight & weight of one litre of petrol of specific gravity = 0.7

Sol:- Given:- volume = 1 litre = $1 \times 1000\ cm^3 = \frac{1000}{10^6}\ m^3 = 0.001\ m^3$

$S = 0.7$

Density = $\rho = S \times 1000\ kg/m^3 = 0.7 \times 1000 = 700\ kg/m^3$

Speci weight = $w = \rho \times g = 700 \times 9.81\ N/m^3 = 6867\ N/m^3$

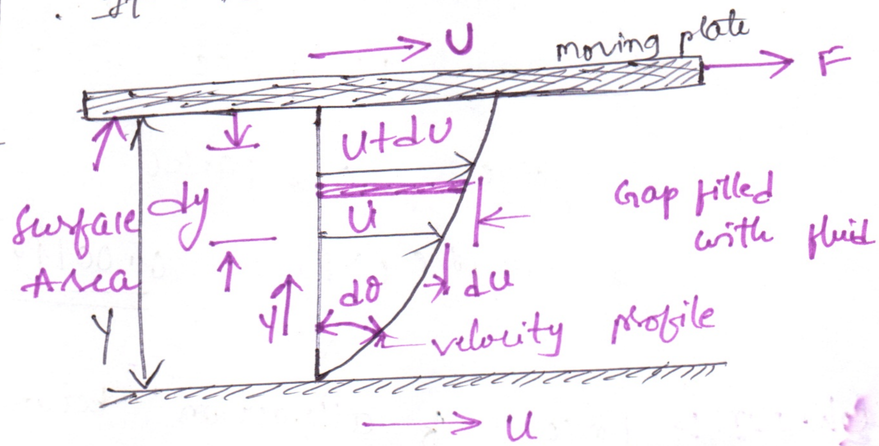
Speci weight = $\frac{\text{weight}}{\text{volume}}$ = $w = \frac{W}{0.001}$ or $6867 = \frac{W}{0.001}$

$W = 6867 \times 0.001 = 6.867\ N$

Viscosity :- Viscosity is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid. * when two layers of a fluid, a distance "dy" apart, move one over the other at different velocities, say u & $u+du$ as shown in fig. * The viscosity together with relative velocity causes a shear stress acting between the fluid ~~layers~~ layers

* The top layer causes shear stress on the adjacent lower layer while the lower layer causes a shear stress on adjacent top layer

* The shear stress is proportional to the rate of velocity w.r.to "y". It is denoted by symbol (τ)



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

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

⇒ μ is called constant proportionality & is known as the coefficient of dynamic viscosity (or) only viscosity

$\frac{du}{dy}$ represents the rate of shear strain (or) rate of shear deformation (or) velocity gradient. $\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}$

Dim :- $\mu = F \cdot T \cdot L^{-2} = ML^{-1}T^{-1}$

Dim:-

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

$$\frac{\text{Force}/(\text{Length})^2}{\left(\frac{1}{\text{Time}}\right)} = \frac{\text{Force} \times \text{Time}}{(\text{Length})^2}$$

In MKS — $\frac{kgf - sec}{m^2}$ $\left[\frac{Force \times Time}{(Length)^2}\right]$

In C.G.S — $\frac{dyne - sec}{cm^2}$ = 1 poise ✓

In S.I — $\frac{N \cdot S}{m^2}$ = Pa.s

* Dynamic viscosity at 20°
For water ≃ 1.005×10^{-3} Pa.s
For air ≃ 1.81×10^{-5} Pa.s

⇒ C.G.S $1N = 10^5$ dynes

$1 N \cdot S/m^2 = 10^5 \text{ dynes} \cdot \text{sec} / 10^4 cm^2$

$= 10 \text{ dyne} \cdot \text{sec}/cm^2$

= 10 poise = $\underline{\underline{1 \text{ pa.s}}}$

1 poise = 0.1 pa.sec

1 centipoise (C.P) = $\underline{\underline{0.001 \text{ Pa - sec}}}$

Cohesion:- Force of attraction between the molecules of the same liquid

Adhesion:- Force of attraction b/w the molecules of different liquids (or) between the liquid molecules and solid boundary containing the liquid

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. The constant of proportionality is called the coefficient of viscosity

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

Kinematic viscosity :- (ν):- It is the ratio of dynamic viscosity and mass density

$$\nu = \frac{\text{Dynamic viscosity}}{\text{mass density}} = \frac{\mu}{\rho}$$

$$\nu = \frac{\frac{\text{Force} \times \text{Time}}{(\text{Length})^2}}{\frac{\text{mass}}{(\text{Length})^3}} = \frac{\frac{\text{Force} \times \text{Time}}{\text{mass}}}{\text{Length}}$$

$$\nu = \frac{\text{mass} \times \frac{\text{Length}}{(\text{Time})^2} \times \text{Time}}{\frac{\text{mass}}{\text{Length}}} = \frac{(\text{Length})^2}{\text{Time}} \quad \left[\begin{aligned} \text{force} &= \text{mass} \times \text{Acc} \\ &= \text{mass} \times \frac{\text{Length}}{\text{Time}^2} \end{aligned}\right]$$

Dim :- $L^2 T^{-1}$

⇒ S.I & M.K.S = m^2/sec

⇒ C.G.S = cm^2/sec

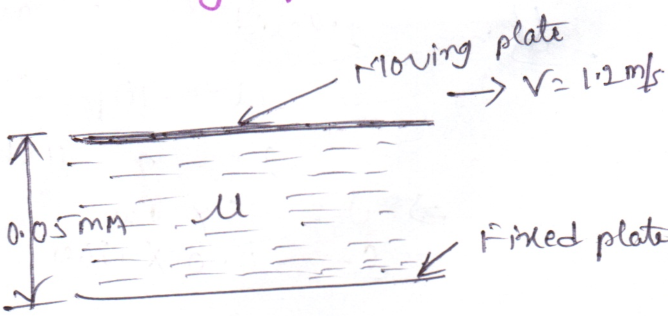
⇒ 1 stoke = $1\ cm^2/sec = 10^{-4}\ m^2/sec$

⇒ $\nu_{air} \simeq 15 \times 10^{-6}\ m^2/sec$

⇒ $\nu_{water} \simeq 1 \times 10^{-6}\ m^2/sec$

⇒ 'ν' of air is approximately 15 times that of water at 20°C

1) A plate 0.05 mm distance from a fixed plate moves at 1.2 m/s and requires a shear stress of 2.2 to maintain this velocity. Find the viscosity of the fluid between in the plates.



Sol:-

$V = 1.2\ m/s$

$Y = 0.05\ mm = 0.05 \times 10^{-3}\ m$

$\tau = 2.2\ N/m^2$

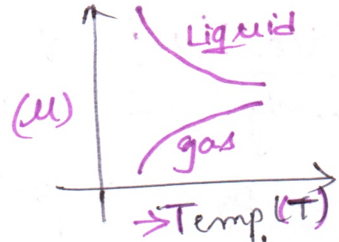
$\mu = ?$

By Newton's law of viscosity $\tau = \mu \cdot \frac{V}{y}$

$$2.2 = \mu \times \frac{1.2}{0.05 \times 10^{-3}} \Rightarrow \mu = 9.16 \times 10^{-5}\ N \cdot s/m^2$$

Note:-

Factors affecting of viscosity :-



Effect of temp :-

Liquids:- In liquids viscosity is due to intermolecular cohesion. As temp increases, cohesion reduces and hence viscosity decreases

For liquids $\mu = D.e^{B/T}$ --- Andrade's eqⁿ

D & B are constants & T is Abs. temp

Gases:- transfer of molecular momentum (Interchange between layers) is the reason for resistance against motion in gases become more dynamic, more collision leading to more transfer of molecular momentum b/w different layers. Hence as temp increases, viscosity gases increases

For gases $\mu = \dfrac{aT^{1/2}}{1+b/T}$ --- [Sutherland eqⁿ]

where a & b are empirical constants & "t" is Absolute temp

(2) A liquid Specific gravity $S = 0.8$ & dynamic viscosity is $= 10$ prise from this it to calculate kinematic viscosity (ν)?

Sol: liquid $S = 0.8$

$\mu = 10$ proise

$\nu = ?$ stokes

$\Rightarrow \rho = S \times \rho_w$

$S = 0.8 \times 1000 = 800\ kg/m^3$

[$\because$ 1 poise $= 10^{-1}\ \dfrac{N \cdot Sec}{M^2}$]

$\mu = 10$ poise $= 10 \times 10^{-1}\ \dfrac{N \cdot sec}{m^2}$ ✓

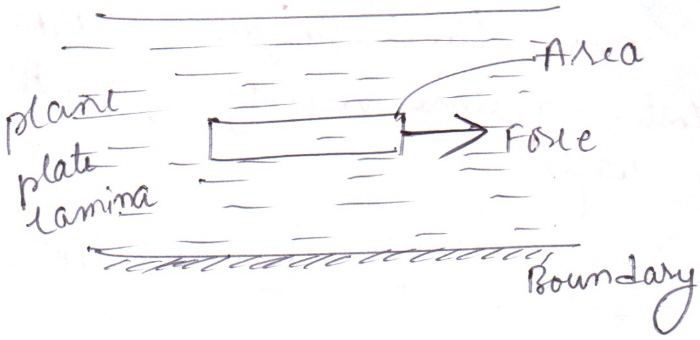
$\nu = ?$ $\quad \nu = \dfrac{\mu}{\rho} = \left[\dfrac{10 \times 10^{-1}}{800}\right] m^2/sec$

$\left(\dfrac{10 \times 10^{-1}}{800}\right) \times 10^4\ cm^2/sec$

$= 12.5$ stokes

Newton Experiment

when fluid is passed in certain boundary



$\boxed{F \propto A \text{ (Area)}}$

Area is low $\propto$ Force is low

like that

$\boxed{F \propto V}$ $\boxed{F \propto \frac{1}{y}}$

$F \propto \frac{AV}{y} \Rightarrow F = \mu \frac{AV}{y}$

$$\Rightarrow \frac{F}{A} = \frac{\mu V}{y} \Rightarrow \boxed{\tau = \mu \frac{V}{y}}$$

3) A circular shaft of 500mm dia was rotating inside a sleeve (or) bearing of 502mm dia is running at 200 R.P.M the Annular space was filled with lubricant viscosity 5 poise. calculate power loss due to friction for sleeve length of 100mm

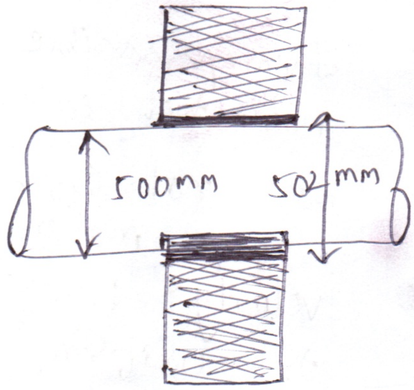
Sol: shaft $\rightarrow$ 500 mm dia

sleeve $\rightarrow$ 502 mm dia

N = — 200 RPM

Annular space $\mu = 5$ poise

$\mu = 5 \times 10^{-1} \frac{N\text{-sec}}{m^2}$



$\Rightarrow P_{loss\,(friction)} = ?$

$l = 100\,mm$

$\Rightarrow$ Area under shear $= \pi d L$

$\Rightarrow \boxed{V = \frac{\pi d N}{60}}$ $\Rightarrow y = \frac{D_0 - D_i}{2} = 1\,mm = 1 \times 10^{-3}\,m$

$P_{loss} = F \times \text{velocity} \Rightarrow \boxed{P = \left(\frac{\mu A V}{y}\right) \cdot V}$

$$P = \frac{5 \times 10^{-1} \times [\pi \times 0.5 \times 0.1] \times \left[\frac{\pi \times 0.5 \times 200}{60}\right]^2}{1 \times 10^{-3}}$$

$P = 2.153\,kN$

2) A lubricated shaft rotates inside a concentric sleeve (Journal) bearing at 1200 RPM. The radial clearance is 0.1 mm and diameter of the shaft is 40 mm and its length in contact with oil sleeve is 60 mm and dynamic coefficient of viscosity of oil is 0.2 N-s/m²

(a) The shear stress acting over the surface in kN/m² is

(b) The approximate power lost against viscosity of oil is (in watt)

Sol:
$$\tau = \frac{\frac{0.2 \times \pi \times 0.04 \times 1200}{60}}{0.1 \times 10^{-3}} \approx 5 \times 10^{3}\ N/m^2 \text{ say } 5\ kN/m^2$$

Torque(T) = Tangential force (F_t) × Radius of the shaft (r)

$$T = \underset{(\tau)}{\text{shear stress}} \times \underset{\pi . d . L}{\text{Area of contact}} \times \frac{\text{dia of shaft}}{2}$$

$$T = 0.754\ Nm \quad \& \quad P = \frac{2\pi N T}{60} = \underline{\underline{95\ watt}}$$

Classification of fluids :-

(i) Ideal (or) perfect fluid:-

* Non viscous (Frictionless) * No surface tension
* Incompressible
* Does not exist in reality
* Does not offer shear resistance when fluid is in motion
* velocity distribution in motion : Rectangular or uniform at a cross section

(ii) Real fluids :-

* possess the properties such as viscosity, surface tension & compressibility etc.,

⇒ Newtonian fluids :-

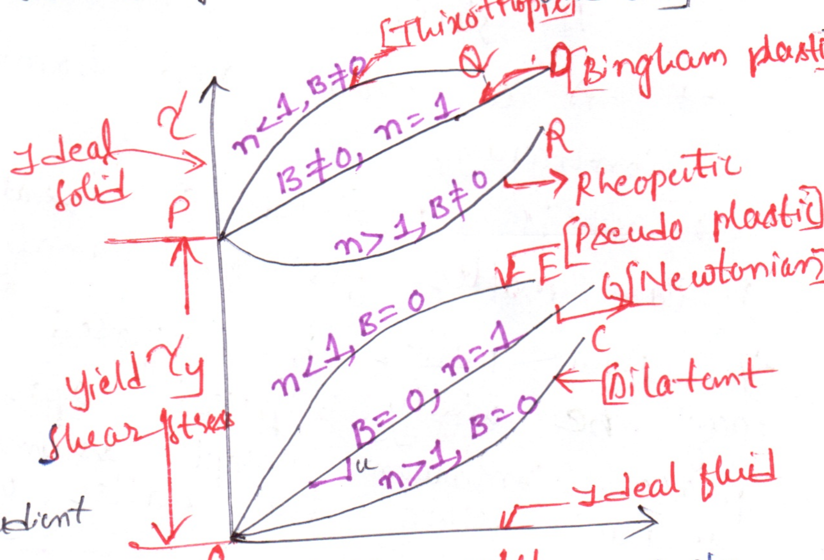
Fluids which obey Newton's law of viscosity

* Newtonian fluids have constant viscosity
viscosity is independent of rate of deformation

* There will be linear releationship between shear stress and resulting rate of deformation
Ex: Air, water, light oils & gasoline [It indicated line OG]

Non - Newtonian fluids:-

* Do not follow the Newton's law of viscosity. The study of Non Newtonian fluids is called Rheology



* Relationship b/w shear stress and velocity gradient

$$\boxed{\tau = \tau_y + A\left[\frac{du}{dy}\right]^n} \quad (\text{or}) \quad \boxed{\tau = A\left(\frac{du}{dy}\right)^n + B}$$

$\frac{du}{dy}$ → velocity gradient

where

τ_y = minimum yield stress to start deformation

A = a Constant depending upon the type of fluid and Conditions imposed on flow

Based on power index "n" and constant "A", Non-Newtonian fluids are

Classification of fluids

- Ideal
- Real
  - [Fluid mechanics] $\left[\tau = \mu\frac{du}{dy}\right]$ Newtonian
    [Air, water, light oil, & gasoline]
    [OG line]
  - (Rheology) $\tau = A\left[\frac{du}{dy}\right]^n + B$ Non Newtonian
    - Time dependent
      - Thixotropic [OPQ]
        [Ex: printers ink, lipstick]
        [Butter, Sugar Solⁿ, Suspension of Rice starch, & Sand]
      - Rheopatic [OPR]
        [Gypsum]
    - Time independent
      - [OE] Pseudo plastic
        [Blood, milk, paper, pulp]
      - [OPD] Ideal plastic (or) Bingham plastic
        [Ex: Sewage sludge, Drilling mud, tooth paste]
      - [OC] Dilatent

Ex: Dilatent

Fluid Continuum Concept :-

A fluid is assumed to be continuum.

* A continuous and homogeneous medium is called continuum.

* It is a kind of idealization of the properties of the matter for flow analysis

* Any matter is composed of several molecules which may be widely spaced apart, especially in the gas phase continuum concept assumes a continuous distribution of mass within the matter with no empty space or voids

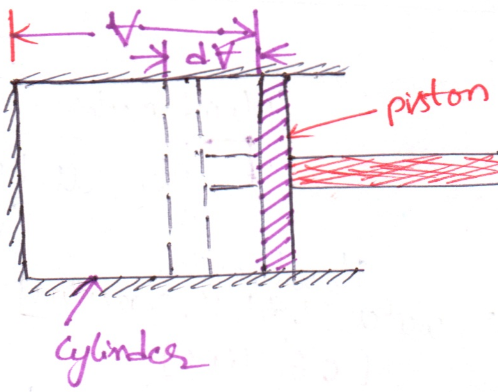
* $\boxed{Kn = \frac{\lambda}{L} = \frac{\text{Mean free path}}{\text{characteristic length of flow}}}$

* Fluid can be treated as ~~characteristic~~ length continuous when knudsen number is $< 1\%$ $(Kn < 0.01)$

eg :- Liquid gases in compressed state [high dense gases] will satisfy the continuum concept.

Compressibility & Bulk modulus :-

* Compressibility is the reciprocal of the bulk modulus of elasticity "K" which is defined as the ratio of compressive stress to volumetric strain



* consider a cylinder fitted with a piston as shown in fig

Let ∀ = volume of a gas enclosed in the cylinder

P = pressure of gas when volume is ∀

Let the pressure is increased to $p + dp$, the volume of gas decreases from ∀ to ∀ − d∀.

Then increase in pressure = dP kgf/m^2

Decrease in volume $= d\forall$

$\therefore$ volumetric strain $= -\dfrac{d\forall}{\forall}$

– ve sign indicates the volume decreases with increase of pressure

$\therefore$ $\boxed{\text{Bulk modulus } k = \dfrac{\text{Increase of pressure}}{\text{volumetric strain}}}$

$$k = \frac{dP}{\frac{-d\forall}{\forall}} = \frac{-dP}{d\forall}\forall$$

* 20°C & 1 atm (or) 101.325 kpa
* for water $\simeq 2.06 \times 10^9$ Pa
  Air $\simeq 1.03 \times 10^5$ Pa
  For steel $\simeq 2.06 \times 10^{11}$ Pa

$\therefore$ $\boxed{\text{Compressibility} = \dfrac{1}{k}}$

1) On a given mass of fluid if the pressure increases from 3 M.Pas to 3.5 M.Pas causing the density to increases from 500 kg/m³ to 501 kg/m³. The bulk modulus of fluid (k) ______

Sol:- $P = 3.0$ M.Pas

$= 3.5$ MPas

$k = ?$

$\rightarrow \rho = 500$ kg/m³

501 kg/m³

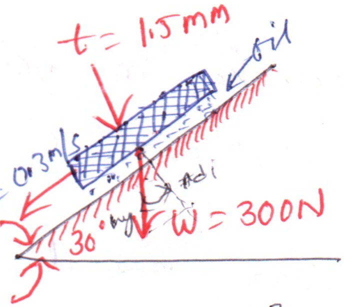
$$\boxed{\Rightarrow k = \frac{dP}{\left[\frac{d\rho}{\rho}\right]}} = \frac{[3.5 - 3.0] \times 10^6}{\left[\frac{501 - 500}{500}\right]}$$

$\Rightarrow k = 250 \times 10^6 = \underline{250 \text{ MPa}}$

(2). Calculate the dynamic viscosity of an oil, which is used for lubrication b/w a square plate of size 0.8 m × 0.8 m and an inclined plane with angle of inclination 30° as shown in figure. The weight of the square plate is 300 N and it slides down the inclined plane with a uniform velocity of 0.3 m/s. The thickness of oil film is 1.5 mm.

~~Sol~~ Given:

Area of plate: $A = 0.8 \times 0.8 = 0.64\, m^2$



~~Angle~~ of plane: $\theta = 30^\circ$

weight of plate: $W = 300N$

velocity of plate: $u = 0.3\, m/s$

Thickness of oil film $t = dy = 1.5\, mm = 1.5 \times 10^{-3}\, m$

Let the viscosity of fluid b/w plate and inclined plane is μ

Component weight W, along the plane $= W\cos 60^\circ = 300\cos 60^\circ = 150N$

Thus the shear force, F, on the bottom surface of the plate $= 150N$

and shear stress $\tau = \dfrac{F}{Area} = \dfrac{150}{0.64}\, N/m^2$

Now using eq^n where $\tau = \mu \dfrac{du}{dy}$.

where du = change of velocity $= u - 0 = u = 0.3\, m/s$

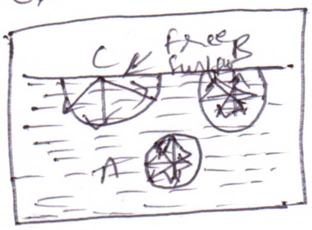
$dy = t = 1.5 \times 10^{-3}\, m$

$$\frac{150}{0.64} = \mu \frac{0.3}{1.5 \times 10^{-3}}$$

$$\mu = \frac{150 \times 1.5 \times 10^{-3}}{0.64 \times 0.3} = 1.17\, Ns/m^2$$

$$\mu = 1.17 \times 10 = \underline{11.7 \text{ poise}}$$

Surface tension :- Surface tension is defined as the tensile force acting on the surface of a liquid in contact with gas (or) on the surface b/w two immiscible liquids such that the contact surface behaves like a membrane under tension



* The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area.

$\Rightarrow$ It is denoted by σ (sigma) SI :- N/m

In MKS : kgf/m, Dim :- MT^{-2} (or) FL^{-1}

$\Rightarrow$ $\sigma = \frac{W \text{ (or) } F}{A}$

* A liquid forms an interface with a second liquid (or) gas. This liquid – air interface behaves like a membrane under tension

* A Tensiometer and stalagmometer are the experimental instruments used to measure the surface tension (σ) of liquids

* Temp ↑ surface tension σ (↓) [Bcz cohesion ↓]

Ex :- ~~Soaps~~ Soaps & detergents lowers the surface tension of water and enable it to penetrate into the small openings b/w fibers for more effective washing.

Std values :- 0.073 N/m at 30°c = σ_{water}

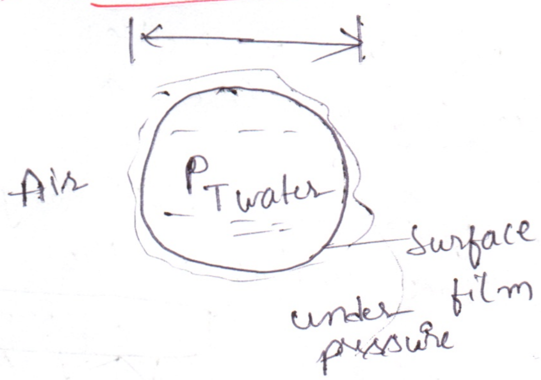
0.589 N/m at 100°c = σ_{water}

σ_{Hg} = 0.49 N/m at 30°c

* **water droplet :-** Pressure intensity $P_I > P_{atm}$

* In water droplet is more than atm. pressure its stage is burst.

1) water droplet :-



For eqn in equillibrium No Burst

$\Rightarrow F_{Bursting} = F_{resisting}$

$P \times A = F \times \sigma$

$P \times A = \sigma \times L$

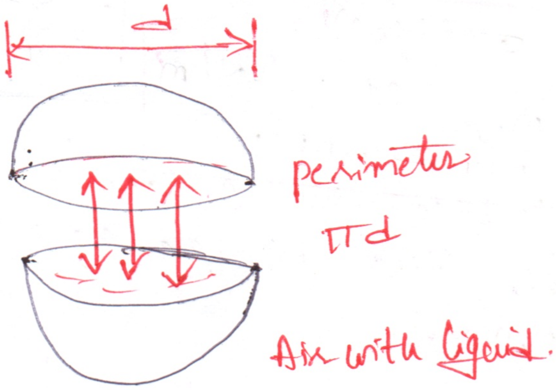
$\boxed{\text{Surface tension} = F/A}$

$\cancel{\sigma} = F/L$

$F_\sigma = \sigma \times L$

$F_p = P \times A$

$P = F/A$



$F_{Burst} = F_{resisting}$

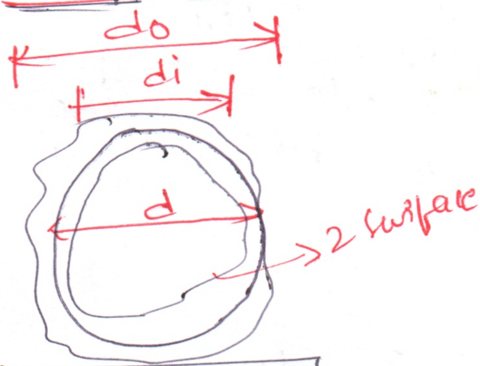
$F_p = \sigma \times \underbrace{L}_{\pi d}$

$P \times A = \sigma \times \pi d$

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

$$\boxed{P = \frac{4\sigma}{d}}$$

(2) Soap bubble :-



$\boxed{d_o = d_i = d}$

Soap bubble two interface water & Air

$F_p = F_\sigma$

$P \times A = \sigma \times L$

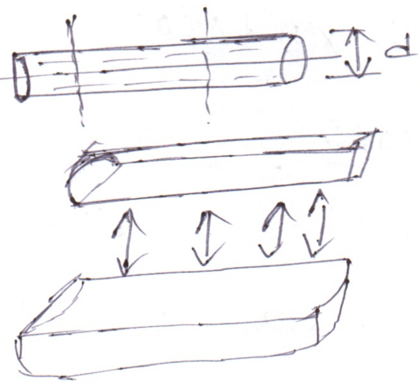
$P \times \frac{\pi d^2}{4} = \sigma [\pi d_o + \pi d_i]$

$= \sigma \cdot 2\pi d$

$P = \frac{4\sigma}{d} \times 2 = \frac{8\sigma}{d}$

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

③ Liquid jet :-



Liquid is contact with in the surface

$F_p = F_L$

$P \times A = \sigma \times L$

$P \times L \times d = \sigma [2L]$

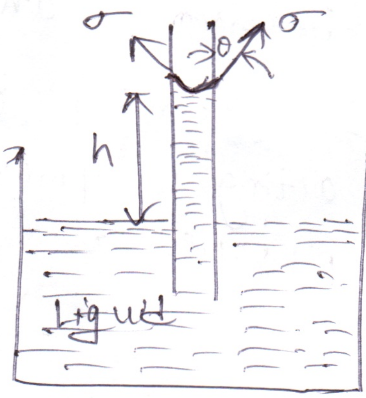
So we can consider only length

$$* \boxed{P = \frac{2\sigma}{d}}$$

Capillarity :- Capillarity is defined as 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. The rise of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary depression. It is expressed in terms of cm (or) mm of liquid.

* Its value depends upon the specific weight of the

⟹ capillary rise :-



Let σ = surface tension of liquid

θ = Angle of contact b/w liquid and glass tube

The weight of liquid of height "h" in the tube = [Area of tube × h] × ρ × g

$$\frac{\pi}{4} d^2 \times h \times \rho \times g \text{ ——— (i)}$$

where ρ = Density of liquid

vertical component of the surface tensile force

$= (\sigma \times \text{circumference}) \times \cos\theta$

$= \sigma \times \pi d \times \cos\theta$ ——— (ii)

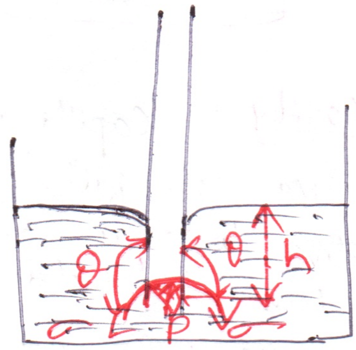
$$\frac{\pi}{4} d^2 \times h \times \rho \times g = \sigma \times \pi d \times \cos\theta$$

$$h = \frac{\sigma \times \pi d \times \cos\theta}{\frac{\pi}{4} d^2 \times \rho \times g} = \frac{4\sigma \cos\theta}{\rho \times g \times d}$$

The value of θ b/w water & clean glass tube
$\theta = 0$

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

Capillary fall :-



If the glass tube is dipped in mercury

Let h = height of depression

⇒ Then in equilibrium two forces are acting on the mercury inside the tube. First one is due to surface tension acting in the downward direction and is equal to $\sigma \times \pi d \times \cos\theta$

⇒ Second force is due to hydrostatic force acting upward and is equal to intensity of pressure at a depth h × Area

$$= P \times \frac{\pi}{4} d^2 = \rho g \times h \times \frac{\pi}{4} d^2 \qquad \boxed{P = \rho g h}$$

Equating the two we get

$$\sigma \times \pi d \times \cos\theta = \rho g h \times \frac{\pi}{4} d^2$$

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

θ mercury glass tube 128°

FACTORS AFFECTING CAPILLARITY

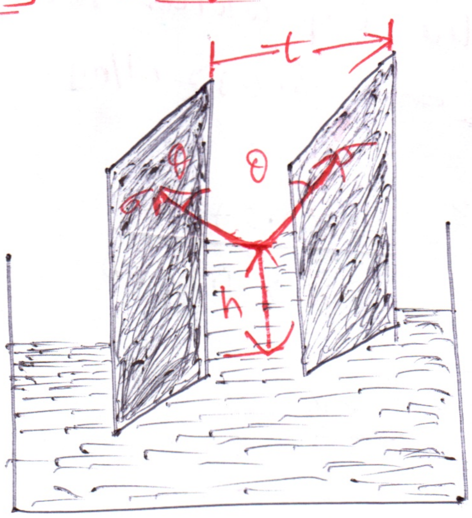
* Capillarity is inversely proportional to the diameter of the tube. Therefore, the thinner the tube is, the greater the rise (or fall) of the liquid in the tube. In practice, the capillarity effect for water is usually negligible in tubes whose diameter is greater than 10mm when pressure measurements are made using manometers and barometers, it is important to use sufficiently large tubes to minimize the capillary effect.

* The capillarity is inversely proportional to the density of the liquid. Hence lighter liquids have greater capillary rise

* Capillarity depends upon the type of liquid [wetting or non wetting] and the material of the tube including cleanliness

* The impurities present in the liquid. If detergent is added to the water, the surface tension reduces and hence capillarity gets affected

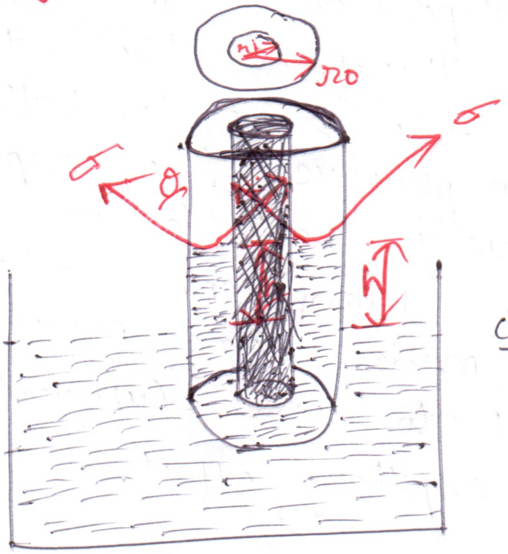
Capillarity through parallel plates :-



$$\boxed{h = \frac{2\sigma \cos\theta}{\rho \cdot g \cdot t}}$$

t = The uniform gap b/w the vertical plates partially immersed in a fluid.

Capillarity through an annular space



$$h = \frac{2\sigma\cos\theta}{\rho g(r_0 - r_i)}$$

where: r_0 = outer radius of annular space

r_i = inner radius of annular space

⇒ Capillarity through a circular tube of radius (r) are inserted in mercury (S_m) above which a liquid specific gravity (S_0) lies:

$$h = \frac{2\sigma\cos\theta}{\rho g r (S_m - S_0)}$$

practical examples for capillarity :-

* The rise of kerosene through a cotton wick
* Rise of water to the top of tall trees

(1) what diameter of glass tube is required if the capillary effects of the tap water not to exceed capillary rise 10mm [$\sigma = 0.072$ N/m]

Sol: $h = \frac{4\sigma\cos\theta}{\rho g D} \Rightarrow 10\times10^{-3} = \frac{4\times0.072\times1}{1000\times9.81\times D}$

$D = 0.003$ m $= \underline{3mm}$

Vapour pressure & cavitation

* In a closed vessel at a constant temp the liquid surface liquid molecules break away from the liquid surface and enter the air space in vapour state

* when the air above the liquid surface is saturated with liquid vapour molecules then the pressure on liquid surface is called vapour pressure.

* vapour pressure is the pressure at which a liquid boils and is in equilibrium with its own vapour

* As a temp increases vapour pressure increases

* Mercury has very low vapour pressure and hence it is an excellent fluid to be used in a barometer

* volatile liquids like Benzene have high vapour pressure

* At boiling point of the liquid vapour pressure equals atm. pressure equals Atmospheric pressure

* If any flow system, the pressure at any point in the liquid approaches the vapour pressure, vapourization of liquid starts, resulting in the pockets of dissolved gases and vapours

* Alternatively, the dissolved air present in liquids is released as the pressure is reduced and thus air pockets (or) bubbles are formed in liquid.

* these air pockets are often termed as air locks due to which air cavitation occurs.

Cavitation:-

when a vapour bubble collapses, a cavity is formed resulting in rushing of surrounding fluid to fill the space. The formation of vapour bubbles and their collapse is called cavitation

* collapse of bubbles gives rise to high impact pressure. The pressure developed by the collapsing bubbles repeatedly is so high that the material ~~gets~~ from the adjoining boundaries gets eroded and cavities are formed on them.

It results in

1. Erosion of blades of turbines and pumps, surrounding parts of machines also called pitting
2. Reduction of efficiency of a machine
3. Lot of vibrations & noise
4. Fatigue failure.

* cavitation occurs in a flow system dissolved gases (vapour bubbles) carried into a region of high pressure and their subsequent collapses gives rise to high pressure, which leads to noise, vibrations & erosion

* → cavitation observed in
1. Turbines runners exit
2. pump suction pipes & impellers
3. Hydraulic structures like spillways & sluice gates
4. syphon pipes

(σ_c) cavitation Number:-

$$\boxed{\sigma_c = \frac{p - p_v}{\rho V^2/2}}$$

p = pressure at a point under consideration (Absolute)

p_v = vapour pressure of the liquid

ρ = Mass density of fluid

V = velocity of the fluid flow

① calculate the capillary effect in millimeters in a glasstube of 4 mm diameter, when immersed in ① water ② mercury. The temparature of the liquid is 20°c and the values of the surface tension of water and mercury at 20°c in contact with air are 0.073 N/mm² and 0.51 N/mm² respectively. The angle of contact for water is zero and that for mercury is 130°. Take density of water at 20°c is equal to 998 kg/m³.

Sol) Given,

Diameter of Glass tube, $d = 4mm = 4\times10^{-3}m$

$\sigma_{water} = 0.073\ N/m$

$\sigma_{mercury} = 0.51\ N/m$

$\rho_{water} = 998\ kg/m^3$

$\theta_w = 0°,\ \theta_m = 130°$

capillary rise :- (Water)

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

$$h = \frac{4\times0.073\times1}{998\times9.81\times4\times10^{-3}}$$

$h = 7.48\times10^{-3}m$

$h = 7.48\ mm.$

capillary fall:- (Mercury)

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

$$h = \frac{4\times0.51\times\cos(130)}{13600\times9.81\times4\times10^{-3}}$$

$h = 2.45\times10^{-3}m$

$h = 2.45\ mm.$

② The dynamic viscosity of an oil used for lubrication between a shaft and sleave is 6 poise. The shaft diameter is 0.4m and rotates at 190 rpm. calculate the power loss in the baring for a sleave length of 90mm, the thickness of oil film is 1.5mm.

Sol) Given,

Length of sleave, $L = 90mm = 90\times10^{-3}m$

thickness of oil film, $t = 1.5\ mm = 1.5\times10^{-3}m$

diameter of shaft, $d = 0.4m$

$N = 190\ rpm$

Viscosity of oil $= 6\times10^{-1}\ N\text{-}s/m = 6\times10^{-2}\ N\text{-}s/mm$

$$\tau = \frac{\mu \times \frac{\pi d N}{60}}{t} = \frac{6\times10^{-1} \times 3.979}{1.5\times10^{-3}} = 1591.6 N$$

$$\because \frac{\pi d N}{60} = \frac{\pi \times 0.4 \times 190}{60}$$

$$= 3.979$$

$$\tau = \frac{F}{A} \Rightarrow F = \tau \times A$$

$$F = 1591.6 \times \pi \times d \times L$$

$$F = 1591.6 \times \pi \times 0.4 \times 90 \times 10^{-3}$$

$$F = 180.005 N$$

T = tangential force x radius of shaft

T = F_t x radius of shaft

$$T = 180.005 \times \frac{0.4}{2}$$

$$T = 36.001 \text{ N-m.}$$

power loss $(P) = \frac{T \times 2\pi N}{60} = \frac{36 \times \pi \times 2 \times 190}{60} = 716.283$ watts.