2. PROPERTIES OF FLUIDS

MASS DENSITY/ SPECIFIC MASS(ρ): Mass of substance per unit volume at given condition. $\rho(kg/m^3) = m/V$

$\rho_{water} = 1000\ kg/m^3$	$\rho_{kerosene} = 810\ kg/m^3$	$\rho_{mercury} = 13600\,kg/m^3$

FACTOR	FACTOR ⇑	Remarks
T	$\rho \Downarrow$	Except Water form 0° C to 4°C & $T_{stp} = 4°C\ for\ water\ and\ 20°C\ for\ Gas$
P	$\rho \Uparrow$	$P_{stp} = 1\ atm = 101.325\ KPa$
Height	$\rho = constant$	

SPECIFIC WEIGHT (γ or ω or ρ_g)/ WEIGHT DENSITY: Weight per unit volume. $\gamma\ (N/m^3) = \rho g$

FACTOR	FACTOR ⇑	Remarks
g	$\gamma \Uparrow$	At polls, γ is higher & $g_{moon} = g_{earth}/6$

SPECIFIC/ RELATIVE GRAVITY (S_g)	SPECIFIC VOLUME (v)
It's ratio of density of fluid to the standard fluid.	It's reciprocal of mass density.
$S_g(Unitless) = \rho_{fluid}/\rho_{water} = \gamma_{fluid}/\gamma_{water}$	$v(m^3/kg) = 1/\rho$

PRESSURE: Compressive force per unit area. It's scalar function.

P_{abs} or $P_{total}(+ve)$	$P_{local}(+ve)$	$P_{gage}(+ve\ or\ -ve)$

BULK MODULUS (K) AND COMPRESSIBILITY (β):

$K(in\ Pa) = \dfrac{Change\ in\ pressure}{Volumetric\ Strain} = \dfrac{\Delta P}{dV/V} = \dfrac{-P}{\varepsilon_V} = \dfrac{P}{d\rho/\rho}$	$\beta\ (in\ Pa^{-1}) = \dfrac{1}{K}$		K is more $\Rightarrow$ difficult to compress $\Rightarrow \beta$ decreases
At 20°C & 1 atm	$K_{air} = 1.013 * 10^5\ Pa$	$K_{water} = 2.06 * 10^9\ Pa$	$K_{steel} = 2.06 * 10^{11}\ Pa$

Compressibility are considered in hammering effect.

PRESSURE WAVE VELOCITY IN FLUIDS:

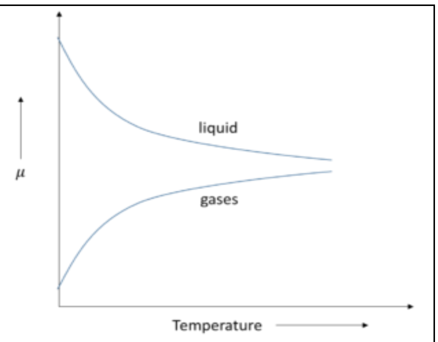
$C = \sqrt{K/\rho}$	C = Pressure Wave Velocity = Velocity of Sound
In isothermal conditions, $K = P = \rho RT$ $C = \sqrt{RT}$	In adiabatic conditions, $K = (C_P/C_V)P$ $C = \sqrt{(C_P/C_V)RT}$

MECH NUMBER (M_a)		$M_a = \dfrac{V}{C}$		V = Velocity of Fluid or body C = Sound/ Sonic Velocity	
Incompressible	Subsonic	Transonic	Sonic	Supersonic	Hypersonic
< 0.3	< 1	$\approx 1 (0.8 < M_a < 1.2)$	1	$1 < M_a < 3$	$M_a > 3$

DYNAMIC VISCOSITY (μ): The viscosity of a fluid is a measure of its resistance to deformation at a given rate.

Unit	SI System: $Pa - s$ or $kg/(m\ s)$ CGS System: $Poise$ or $gm/(cm\ s)$	$1\ Pa - s = 10\ Poise$
$\mu_{gas} = \dfrac{aT^{1/2}}{1 + \frac{b}{T}} \propto \sqrt{T}$		$\mu_{liquid} = a\left[10^{b/(T-C)}\right]$

Viscosity is caused by intermolecular forces of cohesion and due to transfer of molecular momentum between fluid layer of which in liquids the former and in gases the layer contributes the major part towards viscosity.



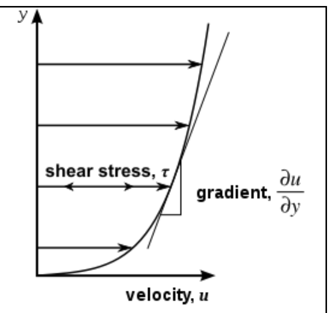
NEWTON'S LAW OF VISCOSITY: It's valid for two parallel plate,

$$\tau = \mu \frac{du}{dy}, Where\ u = f(y)$$

Condition for linear profile: 1) Gap (y) is smaller, 2) $dP/dx = 0$

ASSUMPTIONS IN NEWTONS LAW OF VISCOSITY:

1. Fluid particles move in such a direction maintaining straight and parallel lines
2. No slip condition at surface & other fluid particles slid over each other retarded the motion because of interaction between faster and slower moving fluid.
3. $\tau \propto du/dy$, du/dy = Slope or rate of shear strain or distance rate of velocity diff.



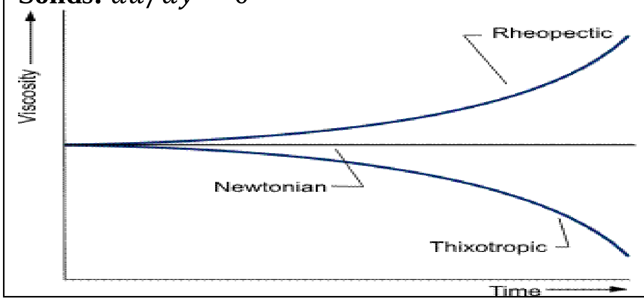
NON-NEWTONIAN FLUIDS (RHEOLOGY):

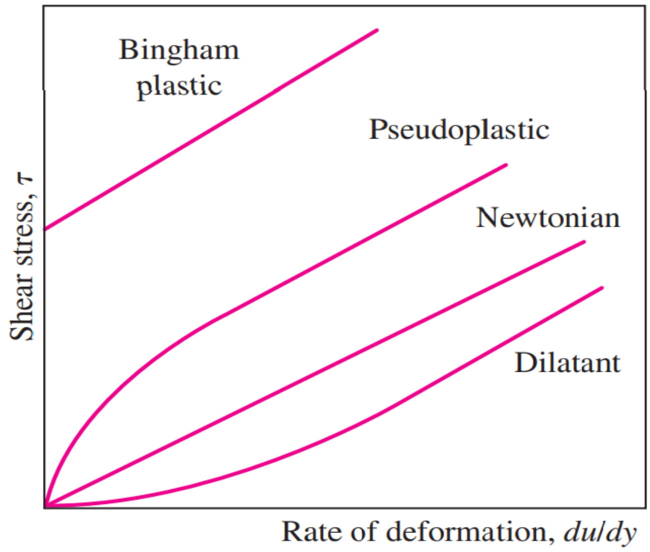
NON-NEWTONIAN FLUIDS	NEWTONIAN FLUIDS
$\mu = Slope = Constant\ (Linear\ Relationship)$	$\mu = Slope \neq Constant(Non - Linear\ Relationship)$

POWER LAW: $$\tau = \tau_y + A\left(\frac{du}{dy}\right)^n$$	τ_y = Minimum Yield Stress to start Deformation, A = Multiplying factor, n = Power Index,

TYPES OF NON-NEWTONIAN FLUIDS

TIME INDEPENDENT	TIME DEPENDENT
Pseudoplastic/ Shear Thinning: $\tau_y = 0, n < 1$ $\mu_{app} = A\left(\frac{du}{dy}\right)^{n-1}$ — E.g. Blood, Milk, Paper Pulp, etc…	**Thixotropic:** $\tau_y > 0, n < 1$ E.g. Printer's ink, leaps sticks, Etc…
Dilatant/ Shear Thickening: $\tau_y = 0, n > 1$ $\mu_{app} = A\left(\frac{du}{dy}\right)^{n-1}$ — E.g. Starch, Sand, etc…	**Rheopectic:** $\tau_y > 0, n > 1$ E.g. Gypsum, Etc…
Bingham Plastic: $\tau_y > 0, n = 1$ $\mu_{app} = A$ — E.g. Toothpaste (Dual Behaviour), etc…	
Newtonian Fluid: $\tau_y = 0, n = 1$	
Ideal Fluids: $\tau_y = 0, n = 1, A = 0$	
Solids: $du/dy = 0$	





VISCOELASTIC FLUIDS: Fluids can regain their shape (Partially) are called viscoelastic fluids.
E.g. Biological Fluids, Mixture of Liquids and solid partials

IDEAL FLUIDS OR PREFECT FLUID	REAL OR PRACTICAL FLUIDS
• Non-Viscous (Frictionless)/ Inviscid • Incompressible ($K = \infty$ & $\beta = 0$) • No surface tensions • Doesn't exist in reality • Doesn't offer shear resistance when fluid is in motion • Velocity distribution in motion is rectangular or uniform at a cross section	• Viscous (Friction) • Compressible • Surface Tension

$\boldsymbol{KINEMATIC\ VISCOSITY\ \vartheta}(in\ Stokes\ or\ m^2/s) = \frac{\mu}{\rho}$		$1\ Stokes = 1\ cm^2/s$	
At $20°C$ & $1\ atm$	$\vartheta_{water} = 1 * 10^{-6}\ m^2/s$	$\mu_{water} = 1.005 * 10^{-3}\ Pa\ s$	
	$\vartheta_{air} = 15 * 10^{-6}\ m^2/s \approx 15 * \vartheta_{water}$	$\mu_{air} = 1.81 * 10^{-5}\ Pa\ s$	
$\mu_{water} = (50\ to\ 55)\mu_{air} @\ 20°C = (100)\mu_{air} @\ 0°C$			
EFFECT OF TEMPERATURE ON ϑ	$\boldsymbol{\vartheta \propto T^{3/2}}$		

$$\boldsymbol{SURFACE\ TENSION\ \sigma_s(J/m^2\ or\ N\ m^{-1})} = \frac{Force}{Surface\ Length} = \frac{F}{2b} = \frac{Surface\ Energy}{Area\ Change} = \frac{\sigma_s\,(2bx)}{(2bx)}$$

FACTORS AFFECTING SURFACE TENSION:

1. $Cohesion \uparrow \Rightarrow \sigma_s \uparrow$
2. $Temperature \uparrow \Rightarrow Cohesion \downarrow \Rightarrow \sigma_s \downarrow$
3. Pressure effect is negligible
4. $Impurity \uparrow \Rightarrow \sigma_s \downarrow$
5. Beyond Critical Point there is no surface tension

Surface Tension of Some Fluid in Air At 1atm

Fluid	$\boldsymbol{\sigma_s(N\ m^{-1})}$
Water at $0°C$	0.076
Water at $20°C$	0.073
Water at $100°C$	0.059
Soap Solution at $20°C$	0.025
Mercury at $20°C$	0.440

EXCESSIVE HYDROSTATIC PRESSURE OR GAGE PRESSURE INSIDE A DROPLET/ BUBBLE:

$$Pressure\ force = Surface\ tension$$

CASE-I (EXCESS PRESSURE IN LIQUID JET): $\Delta P(LD) = \sigma_s(2L)$

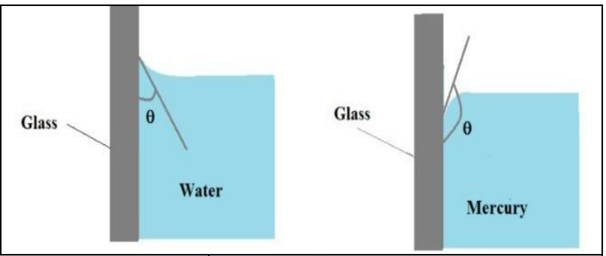
CASE-II (LIQUID DROP): $\Delta P\ \pi R^2 = \sigma_s(2\pi R)$

CASE-III (EXCESS PRESSURE IN SOAP BUBBLE): $\Delta P\ \pi R^2 = \sigma_s(2 * 2\pi R)$

ANGLE OF CONTACT ($\boldsymbol{\theta}$): Tangent between the solid towards liquid make angle with vertical surface.

For Wetting fluid,	For Non-Wetting fluid,
Water, $\theta < 90°$	Mercury, $\theta > 90°$
Cohesion < Adhesion	Cohesion > Adhesion
Capillary rise	Capillary fall

FACTORS AFFECTING $\boldsymbol{\theta}$: 1) Liquid, 2) Solid, 3) Impurities



CAPILLARITY: It's ability to rise or fall liquids in tubes of small diameter.

$$Surface\ Tension = Weight\ of\ Vol.of\ water \Rightarrow \sigma_s \cos\theta\,(2\pi R) = \pi R^2 h\,\gamma$$

$$h = \frac{2\,\sigma_s \cos\theta}{\gamma R}, Where\ \gamma = \rho g$$

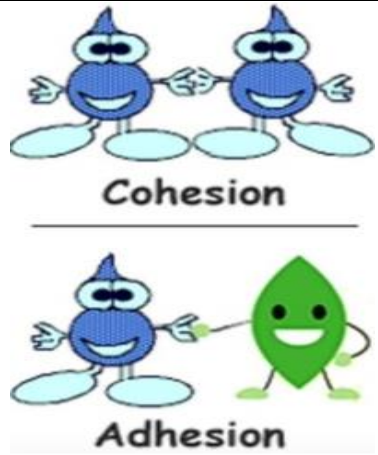
Obtuse angle: $\theta > 90°$	Acute angle: $\theta < 90°$

CAPILLARITY THROUGH PARALLEL PLATES:

$$Surface\ Tension = Weight\ of\ Vol.of\ water \Rightarrow \sigma_s \cos\theta\,(2L) = Lth\,\gamma$$

$$h = \frac{2\,\sigma_s \cos\theta}{\gamma t}$$

CAPILLARITY THROUGH ANNULAR TUBES	CAPILLARITY THROUGH DIFFERENT FLUIDS
$h = \frac{2\,\sigma_s \cos\theta}{\gamma(R_o - R_i)}$	$h = \frac{2\,\sigma_s \cos\theta}{\gamma R(S_1 - S_2)}$



PRACTICAL EXAMPLES OF CAPILLARITY:

- Rise of oil in a cotton wick
- Rise of sap in trees
- Blotting Paper
- Cotton Shirts used in Summer
- Water rising from one end of towel to the other end.

When length of tube is cut or less than the height of capillary rise, the liquid molecules on reaching top of the capillary meet horizontal surface of the tube. The surface tension becomes horizontal. There is no vertical force to pull the liquid up and it stops rising. Also, at each point at the capillary edge there exists a point diametrically opposite at which the surface tension is equal and opposite. Thus, and equilibrium is established and the liquid does not spill over.

VAPOUR PRESSURE: Pressure excreted by it's own molecules on the surface when there is thermodynamic equilibrium (Evaporation rate = Condensation rate) is called vapour pressure.

$Evaporation = f(T)$	$Condensation = f'(Density\ of\ Vapour\ molecules)$

FACTORS AFFECTING VAPOUR PRESSURE:

FACTOR	FACTOR ⇑	Remarks	@ $20°C$	$P_v(kPa)$
T	P_v ⇑	@ Boiling point $P_v = 1\ atm\ for\ water$	Water	2.4
Cohesion	P_v ⇓		Mercury	$0.17 * 10^{-3}$
Volatility of Fluid	P_v ⇑		Petrol	70

Boiling: It's volumetric phenomenon.	**Evaporation:** It's Surface phenomenon.

CAVITATION: It's the formation of bubbles in liquid flow when the local pressure falls below vapour pressure.

- These bubbles are traveling by the flow to high pressure region and collapse to the surface and Torus & micro jects are formed. Due to striking of micro jets deterioration (Pitting) of the martial takes place.

E.g. 1) Cavitation occurs in pump before entering pump, 2) In the turbine, cavitation occurs in the draft tube, 3) In blades of hydraulic machine, convex side pressure is less may causes the cavitation.