KULKARNI ACADEMY

Mechanical Engineering

Toppers Handwritten Notes

Fluid Mechanics

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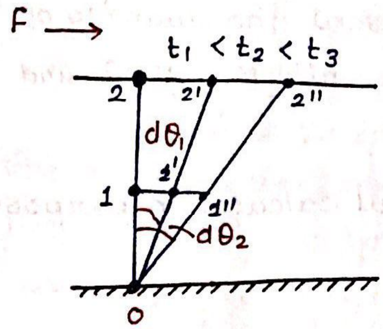
Fluid:

Fluid is a substance which is capable of flowing or deforming under the action of shear force. [however small the shear force may be] This defination of a fluid is also known as a classical definition of a fluid.



As long as there is a shear force fluid flows or deform continuously. Example: liquids, gases, vapour etc.

Differences between solids and fluids:

In case of solids under the action of shear force there is a deformation and this deformation does not change with time. therefore deformation ($d\theta$) is important in solids when this shear force is removed, solids will try to comeback to the original position.

In case of fluids the deformation is continuous as long as there is a shear force and this deformation changes with time, therefore in fluids rate of deformation ($d\theta/dt$) is important than deformation ($d\theta$). After the removal of shear force fluid will never try come back to its original position.

"For a static fluid, the shear force is zero."

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chapter: 1 Fluid properties

Any measurable characterstic is a property.

1. Density (Mass density) (ρ):

It is defined as ratio of mass of fluid to its volume. It actually represent the quantity of matter present in a given volume. it's unit is kg/m3. and its dimensional formula is $[ML^{-3}]$

The density of water for all calculation purpose is taken as 1000 kg/m3.

$P\uparrow \ \rho\uparrow, \quad T\uparrow \ \rho\downarrow$

Density depends on temperature and pressure

ρ → $T\uparrow \ \rho\downarrow$
ρ → $P\uparrow \ \rho\uparrow$

2. Specific Weight (Weight density): [w]

It is defined as the ratio of Weight of the fluid to it's volume, its unit is N/m3 and it's dimensional formula - $[ML^{-2}T^{-2}]$

$$w = \frac{\text{Weight of the fluid}}{\text{Vol.}} \quad N/m3$$

$$w = \frac{mg}{V}$$

$$\boxed{w = \rho g} \qquad \left\{ \rho = \frac{m}{V} \right.$$

Specific weight of water

$w_{H_2O} = 1000 \times 9.81$

$= 9810\ N/m3$

w → ρ → P, T
w → g → location

$w = F(P, T, \text{location})$

Note: Density is an absolute quantity whereas Specific Weight is not an absolute quantity because it varies from location to location.

3. **Specific gravity: (S)**

It is defined as the ratio of density of fluid to the density of standard fluid.

In case of liquid the standard fluid is water and in case of gases the standard fluid either hydrogen and air at a given temp. and pressure. It is unitless and dimensionless.

$[M^0 L^0 T^0]$

✓ s.g. of water is 1. , if s.g. of liquid is less than 1 it is lighter than water, if s.g. of liquid is greater than 1 it is heaviour than water.

Note: Though terms Relative density and sp. gravity are used interchongably, there is a difference between these two. "all specific gravities are relative density but all relative density need not be sp. gravity."

Compressibility (β): It is the measure of change of volume or change of density with respect to pressure on a given mass of fluid.

Mathematically it is defined as reciprocal of bulk Modulus.

i.e.

$$\beta = \frac{1}{k} \qquad k = \text{bulk Modulus}$$

$$\text{or } k = \frac{\rho \, dP}{d\rho}$$

$$k = \frac{dP}{\frac{-dV}{V}}$$

$$\beta = -\frac{1}{V}\frac{dV}{dP}$$

$$\boxed{\beta = +\frac{1}{\rho}\frac{d\rho}{dP}}$$

$$\rho V = \text{mass}$$

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

$$-\frac{dV}{V} = \frac{d\rho}{\rho}$$

$$d\rho = 0 \;;\; \beta = 0$$

$\boxed{\rho = \text{const}}$ (Incompressible Fluid) liquids are generally treated as incompressible and gases are treated as compressible.

A fluid is treated as incompressible fluid if there is no variation of density wrt pressure. (i.e. $\frac{d\rho}{dP}=0$)

Isothermal compressibility of ideal gas:-

$PV = mRT$

$\Rightarrow P = \rho RT \qquad T = \text{const.}$

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

$K = \rho\frac{dP}{d\rho} = \rho RT \quad \{ \; P = \rho RT$

$\boxed{K_T = P}$

Isothermal Bulk Modulus is equal to pressure.

$\boxed{\beta = \frac{1}{P}}$ (unit of compressibility $= \frac{m^2}{N}$, / pascal^{-1})

Adiabatic bulk Modulus of an ideal gas:-

$PV^{\gamma} = C_1$

$P\left(\frac{m}{\rho}\right)^{\gamma} = C_1$

$\frac{P}{\rho^{\gamma}} m^{\gamma} = C_1 \Rightarrow \frac{P}{\rho^{\gamma}} = \frac{C_1}{m^{\gamma}} = C$

$P = C\rho^{\gamma}$

$\frac{dP}{d\rho} = C\gamma\rho^{\gamma-1}$

$K = \rho\frac{dP}{d\rho} \qquad K = \rho . C\gamma\rho^{\gamma-1}$

$K = \gamma C\rho^{\gamma} \qquad \boxed{K = \gamma P}$

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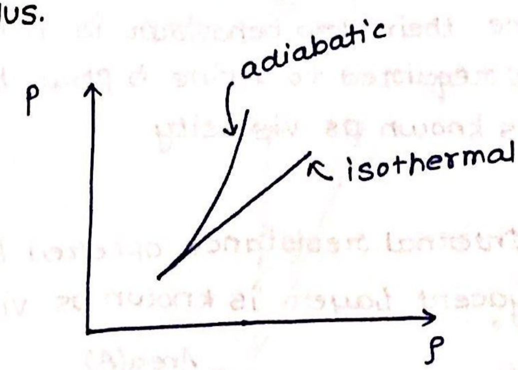
$$\boxed{\beta = \frac{1}{\gamma P}}$$

Note: as $\gamma > 1$ adiabatic bulk Modulus is greater than isothermal bulk Modulus.

$$k = \frac{dP}{\left(\frac{dV}{V}\right)} \quad \text{same.}$$

$k_a > k_t$

$dP_a > dP_t$



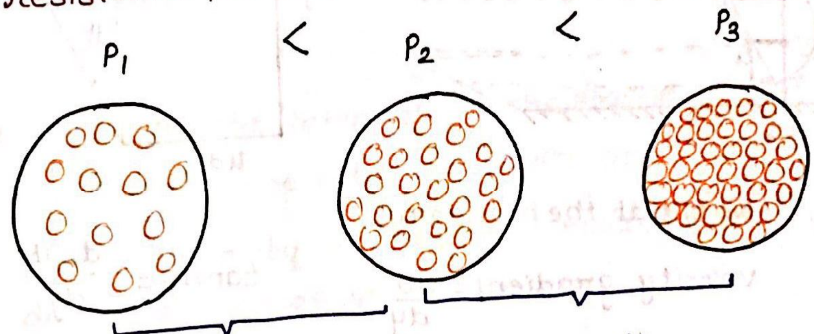
isothermal

Const

$P = \rho (RT)$

$Y = mx$

Bulk Modulus is not constant and it increases with increase in pressure because at higher pressure the Fluid offer's more resistance for further compression.



$$k_1 = \frac{dP}{-\frac{dV}{V}} \qquad k_2 = \frac{dP}{-\frac{dV}{V}}$$

$\underline{k_2 > k_1}$

high speed gas flow, the flow speed is often expressed in term of the dimensionless mach No. defined as $(Ma) = \frac{\text{Speed of Flow}}{\text{Speed of Sound}} = \frac{V}{c}$

Sonic = $Ma = 1$

Subsonic when $Ma < 1$

Supersonic when $Ma > 1$

Hypersonic when $Ma >> 1$

Gas flow can often be approximated as incompressible if the density changes are under 5%, which is usually the case when $Ma < 0.3$.

⇒ In compressible fluids velocity of sound is given as-

$c = \sqrt{K/\rho}$ $\quad K$ = Bulk Modulus of fluid $\quad \rho$ = density

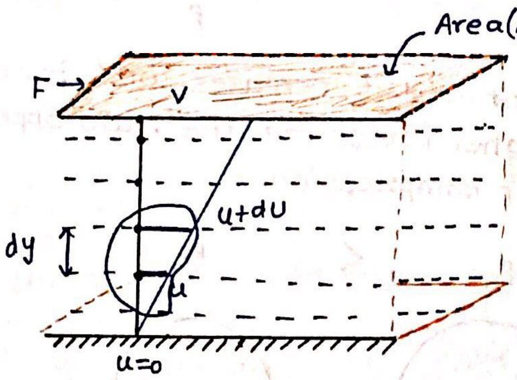
Viscosity

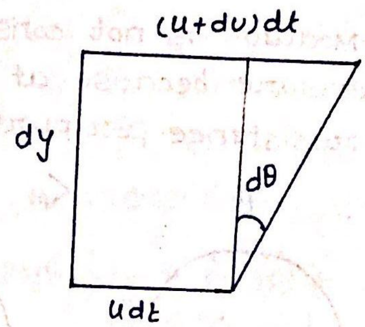
Need to define viscosity:

Though the densities of water and oil almost same, their flow behaviour is not same and hence a property is required to define flow behaviour and this property is known as viscosity.

Definition:

Internal resistance offered by one layer of fluid to the adjacent layer is known as viscosity.





dt = time (No slip at the boundary)

Velocity gradient $= \frac{du}{dy}$

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

if $d\theta$ is small $\tan d\theta = d\theta$

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

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

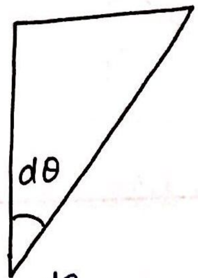
$\tau = \frac{F}{A}$ A → constant

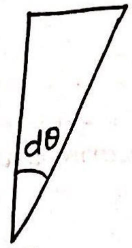
$\tau \propto F \propto \frac{d\theta}{dt}$

$$\tau \propto \frac{d\theta}{dt}$$

$$\tau = \mu \frac{d\theta}{dt}$$

$$\boxed{\mu = \frac{\tau}{\frac{d\theta}{dt}}}$$





$\frac{d\theta}{dt}$ is large

Flow is easy

μ is less, Resistance is less

$\frac{d\theta}{dt}$ is less (small)

flow is not easy.

μ is more, resistance is more.

⇒ μ represents the internal ~~er~~ resistance offered by one layer of fluid to the adjacent layer and hence μ is known as coefficient of viscosity or absolute viscosity or dynamic viscosity or simply viscosity.

$$\tau = \mu \frac{d\theta}{dt} \quad ; \quad \frac{d\theta}{dt} = \frac{du}{dy}$$

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

$\frac{d\theta}{dt}$ = rate of angular deformation or rate of shear strain

$\frac{du}{dy}$ = velocity gradient.

Newtonian Fluid:-

Fluids which obey Newton's law of viscosity are known as Newtonian fluid. A/c to Newtons law of viscosity shear stress is directly preportional to rate of shear strain. that is

$$\tau \propto \frac{d\theta}{dt} \Rightarrow \tau \propto \frac{du}{dy} \Rightarrow \boxed{\tau = \mu \frac{du}{dy}}$$

Valid for Newtonian fluid equation

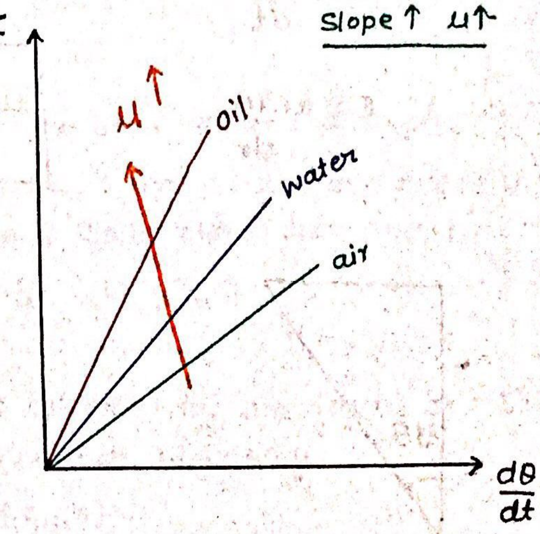
Slope ↑ μ↑

$\tau \propto \frac{d\theta}{dt}$

$\tau = \mu \frac{d\theta}{dt}$ μ = const.

$y = m\,x$

$m = \mu$ = slope = constant.



Examples of Newtonian fluid:

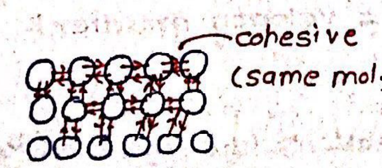
→ Air, water, petrol, diesel, keroscene, oil, Mercury etc.

Note: for a Newtonian fluid viscosity does not change with rate of deformation.

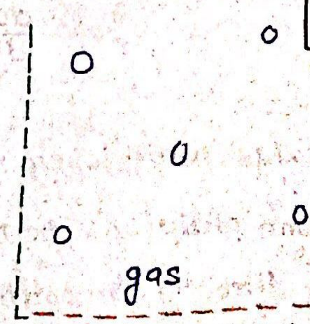
Variation of viscosity with temperature:

In case of liquids the intermolecular distance is small and hence cohesive forces are large with increase in temp. cohesive forces decrease and the resistance of the flow is also decreases, therefore "viscosity of a liquid decreases with increase in temp".

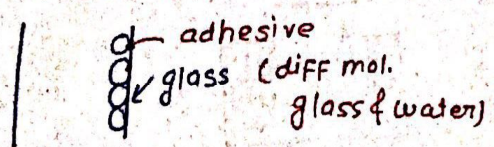
In case of gases intermolecular distance is large and hence cohesive forces are Negligible with increase in temp. Molecular disturbance increases and hence resistance to the flow also increases "Therefore viscosity of gas increase with increase in temperature."



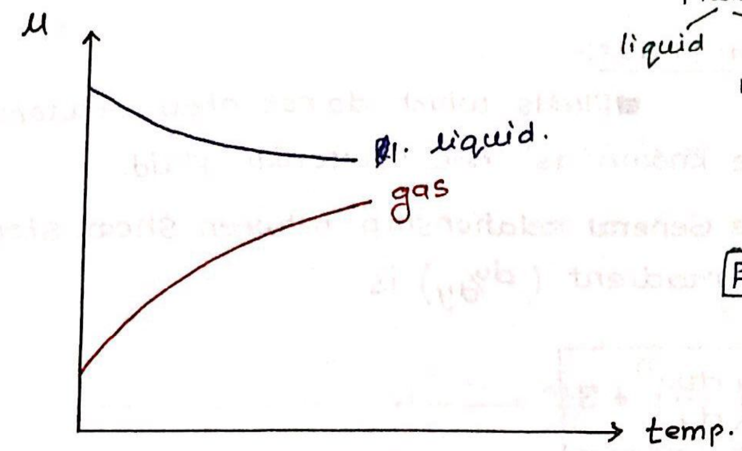
water/liquid Molecules



[In gas T↑, molecular agitation (disturbance ↑ so viscosity increases with ↑ in temp.]



In liquid T↑ cohesive force ↓ so viscosity ↓ with increase in temp.



Fluid → liquid, gas

molecular agitation ↓ disturbance

Fluid = F(CF, MA)

liquid → F(CF)

gas → F(MA)

Unit of viscosity:-

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

$$\frac{N}{m^2} = \mu \cdot \frac{m}{s} \cdot \frac{1}{m}$$

$$\mu = \frac{N\text{-}S}{m^2} = \text{pascal-sec.}$$

$$\frac{N\text{-}S}{m^2} = \frac{\frac{kg \cdot m}{s^2} \cdot s}{m^2} = \frac{kg}{m\text{-}s.}$$

in MKS → kgf/m^2

Dimensional Formula of $\mu = [M^1 L^{-1} T^{-1}]$

unit of viscosity in cgs system:

$$\frac{kg}{m\text{-}s} \Rightarrow 1 \frac{gm}{cm\text{-}sec} = 1 \text{ poise}$$

$$\Rightarrow 1 \frac{kg}{m\text{-}s} = \frac{10^3\ gm}{10^2\ cm\text{-}sec} = 10 \frac{gm}{cm\text{-}sec} = 10 \text{ poise}$$

$$1 \frac{N\text{-}S}{m^2} = 10 \text{ poise}$$

$1 \text{ poise} = 0.1 \frac{N\text{-}S}{m^2} = 0.1 \text{ pascal-sec}$

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Non-Newtonian Fluids:-

Fluids which do not obey Newton's law of viscosity are known as non-newtonian fluid.

The General relationship between shear stress (τ) and velocity gradient (du/dy) is

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

Case: 1 $B=0$; $n>1$ Dilatent Fluids (non-collidal)

A fluid is said to be dilatent fluid for which the apparent (similiar) viscosity increases with rate of deformation.

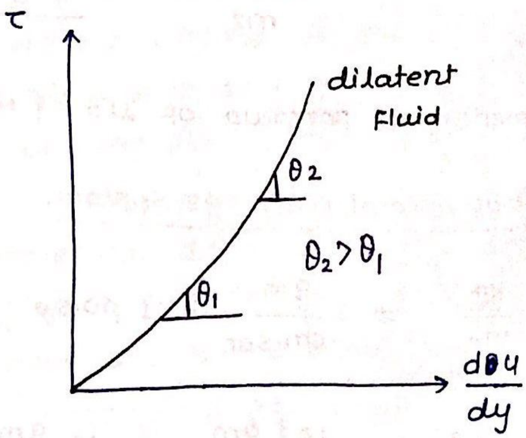
Ex: Ricestarch, Sugar in water.

"As the $\mu_{app.}$ is increasing with deformation, these fluids is also known as shear thickenning fluid.

$$\tau = A\left(\frac{du}{dy}\right)^n + 0$$

$$\tau = \underbrace{A\left(\frac{du}{dy}\right)^{n-1}}_{\mu_{app.}} \cdot \left(\frac{du}{dy}\right)$$

$$\tau = \mu_{app.}\left(\frac{du}{dy}\right)$$

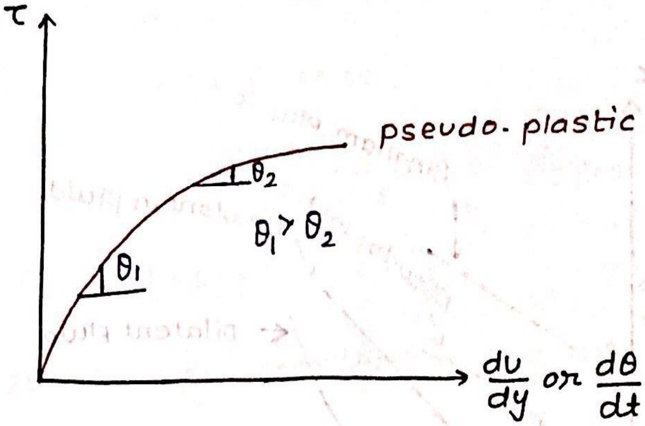


Case 2: $B=0$; $n<1$ pseudo plastic Fluids (collidal)

For a pseudoplastic fluid apparent viscosity decreases with rate of deformation.

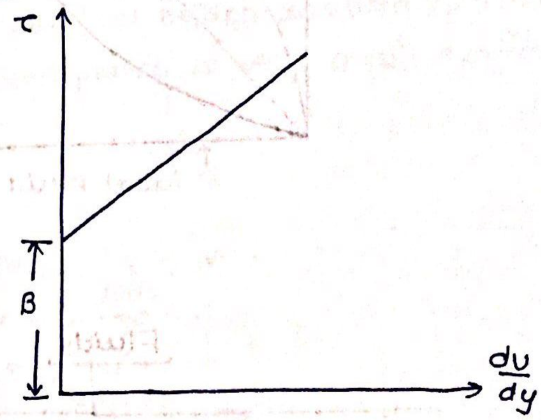
Ex: Milk, blood, collidal solutions.

"as the $\mu_{app.}$ is ↓ with deformation, these fluids is also known as Shear thinning fluid.



case:3: Bingham plastic Fluid.

$B \neq 0 \; ; \; n = 1$



Ex: Toothpaste

"Such Fluids are comes under Rahelogy."

Note: In case of bingham plastic Fluid certain min. shear stress is required for causing the Flow of Fluid. below this shear stress there is no Flow therefore it acts like a solid, After that it behaves like a fluid. such ~~Fluids~~ substances which behaves both Fluids and solids are known as Rheological substances. and study of these substances is known as rhelogy.

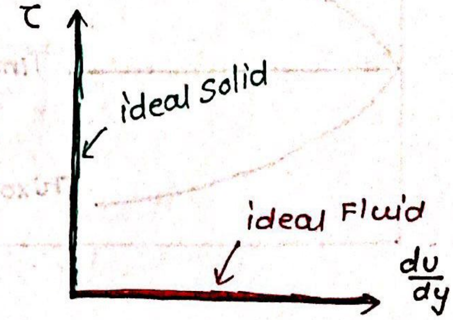
Ideal Fluid:

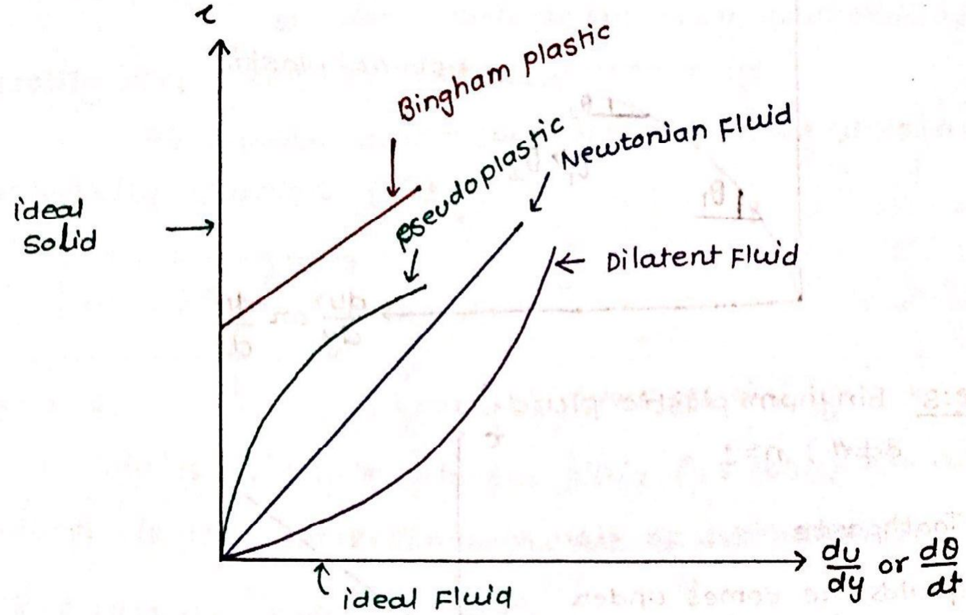
A fluid which is non-viscous and incompressible is known as an ideal Fluid. Though there is no ideal Fluid It is introduced for bringing simplicity of ~~anc~~ in the analysis.

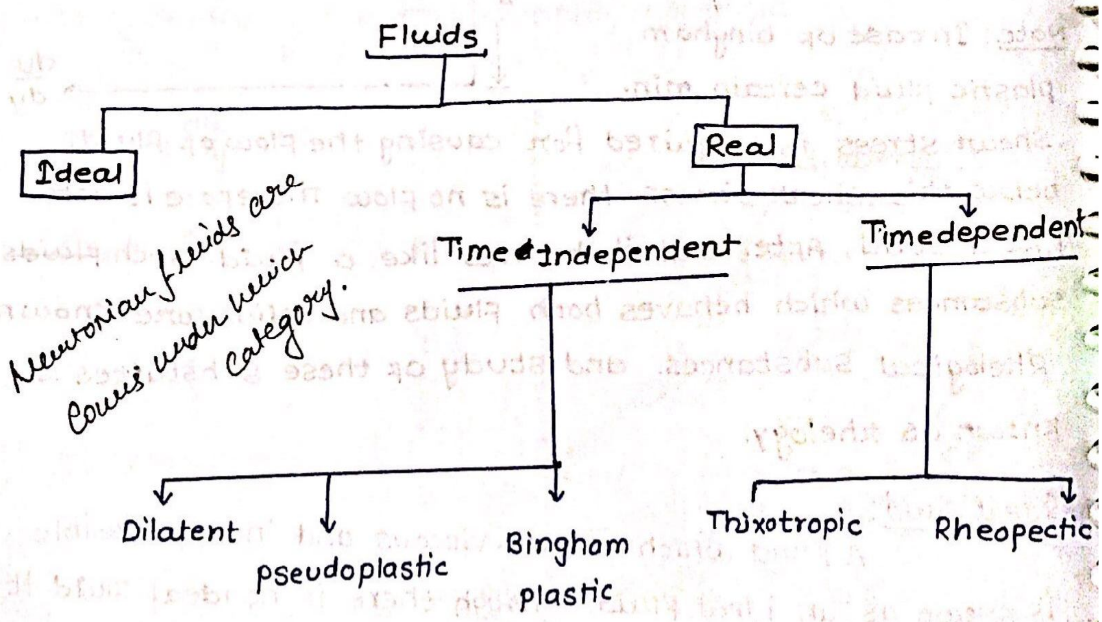
$\tau = \mu \frac{du}{dy}$

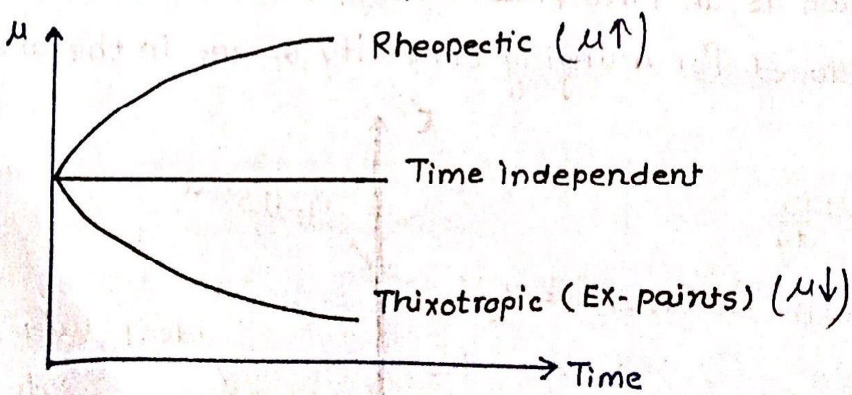
$\mu = 0$ for ideal Fluid

$\tau = 0$




τ
Bingham plastic
pseudoplastic
Newtonian Fluid
ideal solid
Dilatent Fluid
ideal Fluid
du/dy or dθ/dt


Fluids
Ideal
Real
Time Independent
Timedependent
Dilatent
pseudoplastic
Bingham plastic
Thixotropic
Rheopectic
Newtonian fluids are comes under which category.


μ
Rheopectic (μ↑)
Time Independent
Thixotropic (EX- paints) (μ↓)
Time