EWCE 261
Fluid Mechanics

Cr Hr: 3

Sec A

Before mid: 2 Class per week
After mid: 2 Class per week

Sec B by Lec Atiq

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- Pabs w r t zero datum
- Pg w r t Patm datum
- Newton law of viscosity

COURSE OUTLINE

- **Development and Scope of Fluid Mechanics**
- **Fluid Properties**
- **Fluid Statics**
- **Kinematics of Fluid Flow**
- **Fluid Flow Concepts and Basic Equations: Continuity**
- **Equation, Bernoulli's Equation, Energy Equation**
- **Momentum Equation and Forces in Fluid Flow**
- **Similitude and Dimensional Analysis**
- **Steady Incompressible Flow in Pressure Conduits: Laminar**
- **Flow and Turbulent Flow**
- **General Equation for Fluid Friction**
- **Empirical Equation for Pipe Flow**
- **Minor Losses in Pipe Flow**
- **Fluid Measurement: pitot tube, orifice, mouthpiece, nozzle, venturimeter, weir.**
- **Pipe Flow Problems: Pipes in Series and Parallel, Branching Pipes, Pipe Networks.**

Reference Books

1. Fluid Mechanics with Engineering Application by Franzini
2. Fluid Mechanics by Md. Abdul Halim

Development and Scope of Fluid Mechanics

There is air and water in rivers and seas near us. The air and water of rivers and seas are always moving. Such a movement of gas or liquid (collectively called ‘fluid’) is called the ‘flow’, and the **study of this is flow ‘fluid mechanics**’.

While the flow of the air and the water of rivers and seas are flows of our concern, so also are the flows of water, sewage and gas in pipes, in irrigation canals, and around rockets, aircraft, express trains, automobiles and boats.

Fluid Mechanics is the branch of engineering science that deals with the behavior of fluids (liquids and gases) at rest and in motion.

Development and Scope of Fluid Mechanics

The science of flow has been classified into hydraulics and hydrodynamics

Hydraulics developed from experimental studies. Hydraulics developed as a purely empirical science with practical techniques beginning in prehistoric times. it is believed that hydraulics was born in the utilisation of water channels and ships.

Hydrodynamics developed through theoretical studies.

In recent years, however, both have merged into the single discipline called fluid mechanics. hydrodynamics, which tackles fluid movement both mathematically and theoretically. hydrodynamics was thought to be without practical use.

SCOPE OF FLUID MECHANICS

- Knowledge and understanding of the basic principles and concepts of fluid mechanics are essential to analyze any system in which a fluid is the working medium.

- The design of almost all means transportation requires application of fluid Mechanics.

- Air craft for subsonic and supersonic flight, ground effect machines, hovercraft, vertical takeoff and landing requiring minimum runway length, surface ships, submarines and automobiles requires the knowledge of fluid mechanics.

- The design of all types of fluid machinery including pumps, fans, blowers, compressors and turbines clearly require knowledge of basic principles fluid mechanics.

- Other applications include design of lubricating systems, heating and ventilating of private homes, large office buildings, shopping malls and design of pipeline systems

Definition of Fluid and its Type

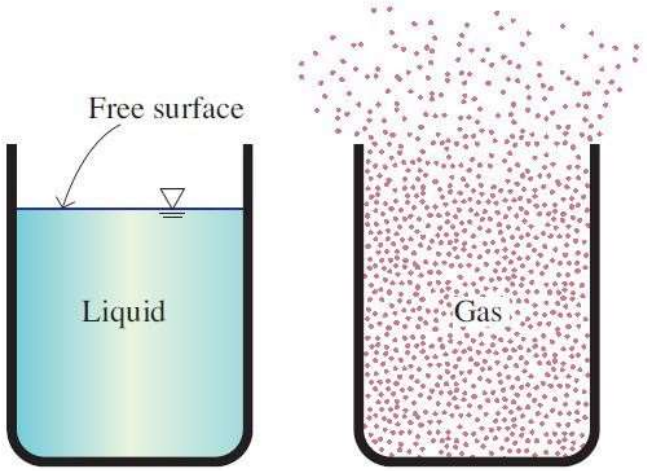
Fluid is a substance that deforms continuously under the application of shear (tangential) stress no matter how small the stress may be.

Alternatively, we may define a fluid as a substance that cannot sustain a shear stress when at rest.

Fluids are divided into liquids and gases.

A liquid is hard to compress, volume remains relatively constant because of the strong cohesive forces between the molecules and it changes its shape according to the shape of its container with an upper free surface.

Gas is easy to compress, and fully expands to fill its container because the gas molecules are widely spaced and the cohesive forces between them are very small. There is thus no free surface.



Unlike a liquid, a gas does not form a free surface, and it expands to fill the entire available space

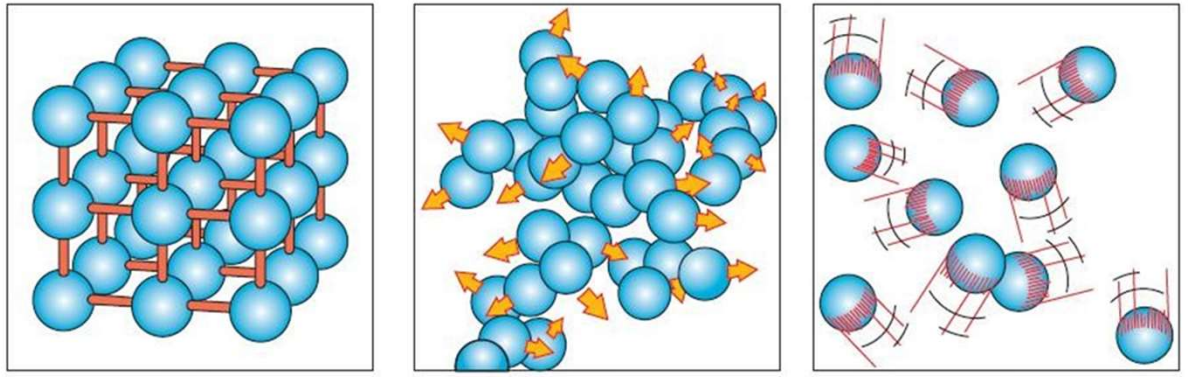
Definition of Fluid and its Type

Intermolecular bonds are strongest in solids and weakest in gases.

Solid: The molecules in a solid are arranged in a pattern that is repeated throughout.

Liquid: In liquids molecules can rotate and translate freely.

Gas: In the gas phase, the molecules are far apart from each other, and molecular ordering is nonexistent.



The arrangement of atoms in different phases: (*a*) molecules are at relatively fixed positions in a solid, (*b*) groups of molecules move about each other in the liquid phase, and (*c*) individual molecules move about at random in the gas phase.

Definition of Fluid and its Type

Liquids are called incompressible fluids and gases compressible fluids.

An important characteristic of a fluid: compressibility and its viscosity.

Whereas a solid shows its elasticity in tension, compression or shearing stress, a fluid does so only for compression. In other words, a fluid increases its pressure against compression, trying to retain its original volume. This characteristic is called compressibility.
Furthermore, a fluid shows resistance whenever two layers slide over each other. This characteristic is called viscosity.

Fluid Mechanics

Fluid mechanics is that branch of engineering science which deals with the behavior of fluids (liquid and gasses) at rest and in motion

Fluid Mechanics may be divided into three branches

1.Fluid Statics: which deals with the cases in which the fluid is at rest and the forces on a fluid element are in equilibrium

2.Fluid Kinematics: which deals with the velocities, accelerations and the patterns of flow without considering the forces or energy

3. Fluid Dynamics: which deals with the relations between velocities and accelerations of fluid with the forces or energies causing them

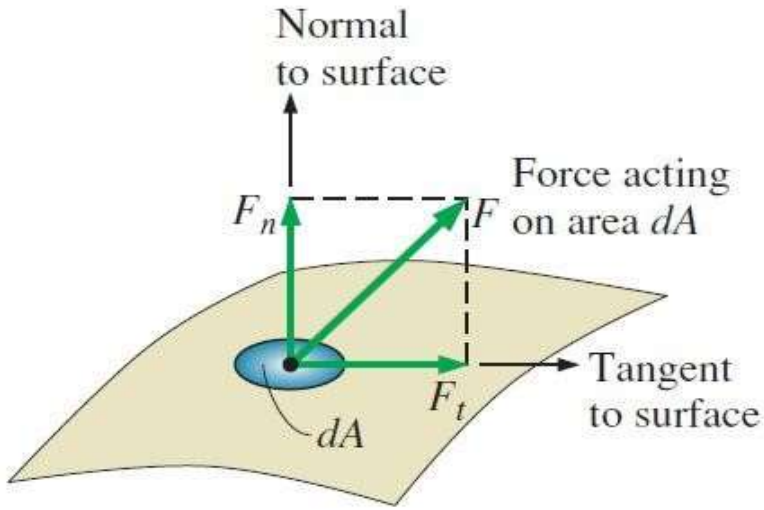
Stress: Force per unit area.

Normal stress: The normal component of a force acting on a surface per unit area.

Shear stress: The tangential component of a force acting on a surface per unit area.

Pressure: The normal stress in a fluid at rest.

Zero shear stress: A fluid at rest is at a state of zero shear stress.



$$\text{Normal stress: } \sigma = \frac{F_n}{dA}$$

$$\text{Shear stress: } \tau = \frac{F_t}{dA}$$

Normal stress and shear stress at the surface of a fluid element

For fluids at rest, the shear stress is zero and pressure is the only normal stress

Difference Between Vapour and Gas

Vapour	Gas
Vapours are in solid or liquid state in ordinary conditions, but change into gaseous state under specific conditions. It is not a state of matter.	Gases are in gaseous state under ordinary conditions (at room temperature and one atmospheric pressure). Gas is a state of matter.
Vapours experience a phase change, i.e., from liquid to vapour form or from solid to vapour form.	Gases do not experience a phase change. Any change in phase will change the state of gas into liquid.
Natural state of vapor is not gaseous, but can be solid or liquid.	Natural state of a gas is the gaseous form.
Vapour is a substance that is a combination of gaseous and liquid phase in ordinary conditions.	Gas is a substance that has a single thermodynamic state in ordinary conditions.
Vapour is made of atoms and molecules that move randomly	Gases are made of atoms and molecules that move randomly
Examples: Iodine exists in a solid form under ordinary conditions, but upon heating, it changes to the vapour form.	Examples: Oxygen, Nitrogen, and Argon.

FLUID PROPERTIES

Density: It is defined as mass of the fluid per unit volume.

$$\rho = \frac{m}{V}, \text{ SI unit is kg/m}^3$$

Density of water , ρ = 1000 kg/m³

Application:

1. Oil floats on water because it is less denser.
2. Boat Floats on water as boat is less denser than water.

Specific weight or weight density:

The specific weight, γ, of a fluid is defined as weight of fluid to it's volume.

$$\gamma = \frac{W}{V} = \frac{mg}{V} = \left(\frac{m}{V}\right) g = \rho g$$

SI unit is N/m^3 while the English unit is lb/ft^3

FLUID PROPERTIES

Specific Volume:

Specific volume is the volume occupied by unit mass of the fluid. It is represented by V_s. It is the reciprocal of density.

$V_s = \frac{V}{M} = \frac{1}{\rho}$, **UNIT: m^3 / Kg**

Specific Gravity:

It is the ratio of density of a substance to the density of reference substance. Denoted by S

$$S = \frac{\text{Density of fluid}}{\text{Density of reference fluid}}$$

It is a dimensionless quantity.

The ratio of the density of a material p to the density of water p, is called the specific gravity

FLUID PROPERTIES

Viscosity

Viscosity is the **property of fluid by virtue of which it offers resistance to shear or angular deformation**. So, the viscosity of fluid is a measure of its resistance to flow.

For a viscous fluid at low velocities, the fluid flows in parallel layers and for this type of flow, Newton postulated that shearing or frictional stress is proportional to the spatial rate of change of velocity (i.e velocity gradiant) normal to the flow, $\boldsymbol{\tau \propto \frac{du}{dy}}$

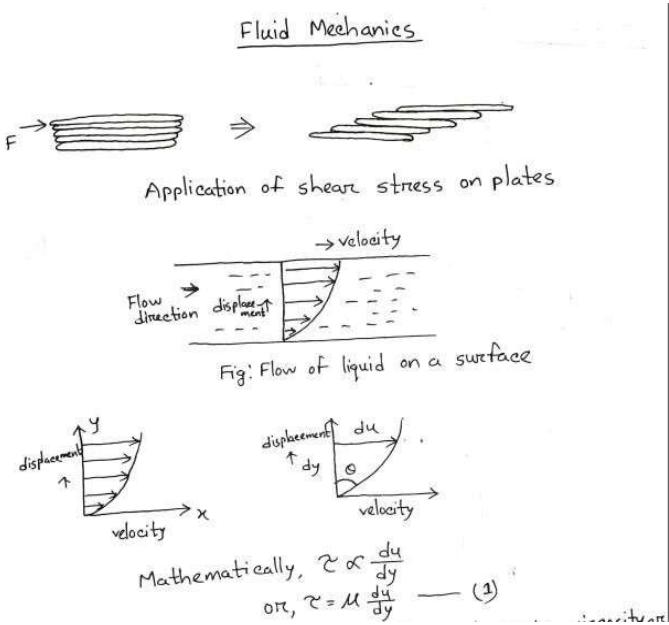
Or, The shear stress on a surface tangent to the flow direction is proportional to the rate of change of shear strain, $\tau \propto \frac{d\alpha}{dt}$

FLUID PROPERTIES

Viscosity

Newton Law of viscosity $\tau \propto \frac{du}{dy}$

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



The proportional constant μ is called the viscosity, the **coefficient of viscosity or the dynamic viscosity**.

FLUID PROPERTIES

Dynamic Viscosity

Unit:

Pa s (pascal second) in SI, and **g/(cm s)** in the CGS unit.

1 g/(cm s) in the absolute system of units is called 1 **P (poise),** while its **1/100**th part is 1 **CP (centipoise).**

Thus, **1 P = 100 cP = 0.1 Pas**

Unit:

$$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{\text{shear stress}}{\frac{\text{velocity}}{\text{displacement}}} = \frac{\frac{N}{m^2}}{\frac{m/s}{m}} = \frac{N/m^2}{\left(\frac{m}{s} \times \frac{1}{m}\right)} = \frac{N.s}{m^2} = N s m^{-2}$$

C.G.S. unit $\mu = \frac{\text{dyne.sec}}{cm^2}$ (1 poise)

$$1 \text{ poise} = \frac{\text{dyne.sec}}{cm^2} = \frac{10^{-5} N.sec}{\left(\frac{1}{100} m\right)^2} = \frac{10^{-5}}{\frac{1}{10^4}} N.s/m^2 \quad [1 \text{ dyne} = 10^{-5} N]$$

$$= 10^{-5} \cdot 10^4 \; N.s/m^2$$

$$= 10^{-1} \; N.s/m^2$$

$$\therefore 1 \text{ poise} = \frac{1}{10} N.s/m^2$$

FLUID PROPERTIES

Kinematic Viscosity

Kinematic viscosity or the coefficient of kinematic viscosity, v is the ratio of dynamic viscosity of fluid μ to its density ρ,

$$\boldsymbol{v = \frac{\mu}{\rho}}$$

Since the effect of viscosity on the movement of fluid is expressed by v, the name of kinematic viscosity is given.

Unit:

$\frac{m^2}{s}$ regardless of the system of units.

In the CGS system, $1\ \frac{cm^2}{s}$ is called 1 **St (stokes)** while its 1 / 100th part is **1 cSt (centistokes).**

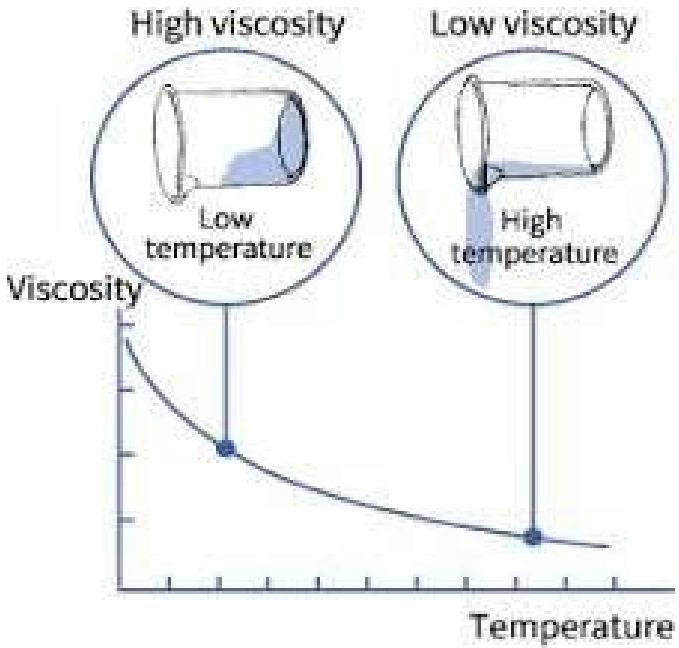
Thus, $1\ \text{St} = 1\ \times 10^{-4}\ \frac{m^2}{s}$, $1\ \text{cSt} = 1\ \times 10^{-6}\ \frac{m^2}{s}$

$$\boldsymbol{v = \frac{\mu}{\rho} = \frac{N.s.m^{-2}}{kg.m^{-3}}}$$
$$= \frac{kg.m.s^{-2}.s.m^{-2}}{kg.m^{-3}}$$
$$= \frac{m^2}{s}$$

Temperature vs Viscosity

As the **temperature of the liquid/ fluid increases its viscosity decreases.**

When the liquid is heated the cohesive forces between the molecules reduce thus the forces of attraction between them reduce, which eventually reduces the viscosity of the liquids.

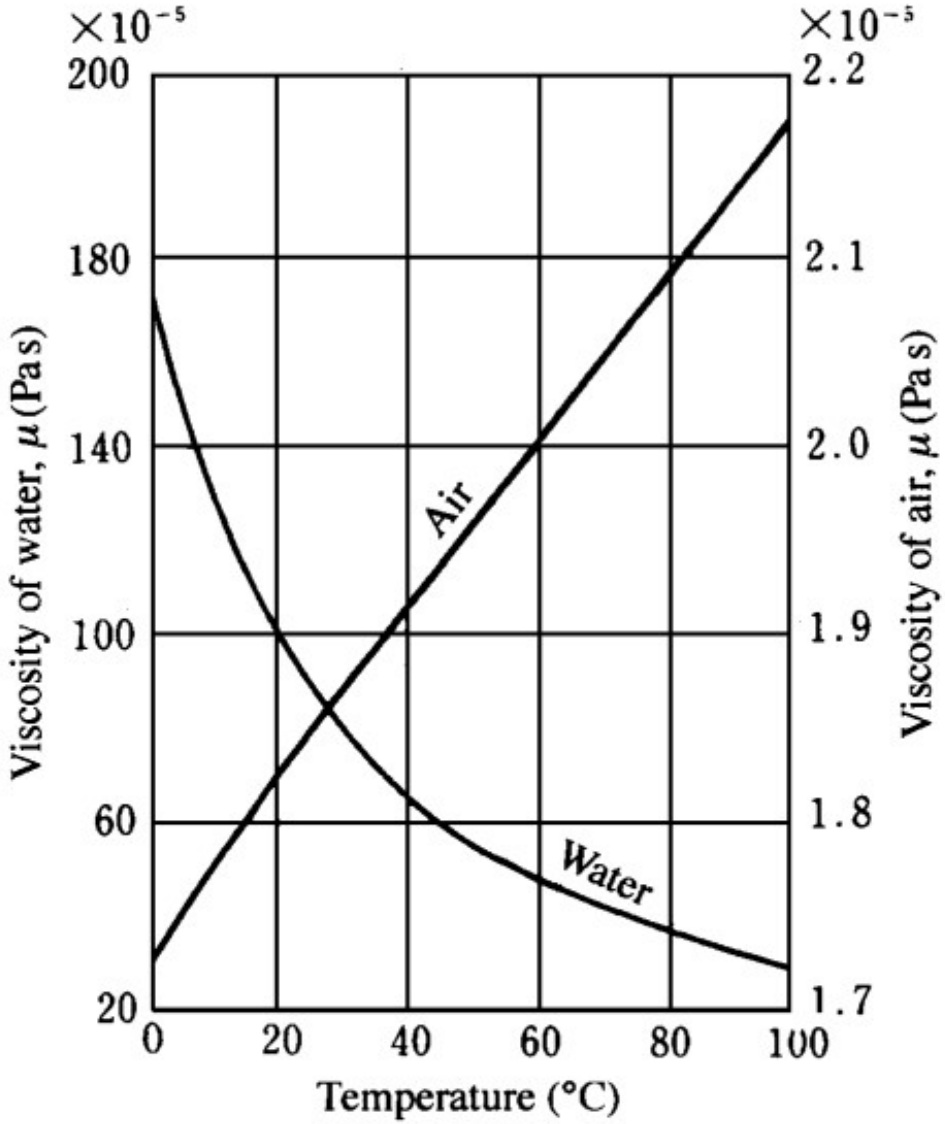


Effects of temperature on viscosity

The **viscosity of the gases increases as the temperature of the gas increases**.

In the gases the cohesive forces between the molecules is lesser, when we increase the temperature the collision between the molecules will be high as because the kinetic energy will be high, so molecular momentum transfer will be high. As a result viscosity will increase

Temperature vs Viscosity



Causes of Viscosity: The causes of viscosity in a fluid are possibly due to two factors
(i) intermolecular force of cohesion
(ii) molecular momentum exchange.

Due to strong cohesive forces between the molecules, any layer in a moving fluid tries to drag the adjacent layer to move with an equal speed and thus produces the effect of viscosity. #The individual molecules of a fluid are continuously in motion and this motion makes a possible process of momentum exchange between layers. Such migration of molecules causes forces of acceleration or deceleration to drag the layers and produces the effect of viscosity. Although the process of molecular momentum exchange occurs in liquids, the intermolecular cohesion is the dominant cause of viscosity in a liquid. Since cohesion decreases with increase in temperature, the liquid viscosity decreases with increase in temperature. In gases the intermolecular cohesive forces are very small and the viscosity is dictated by molecular momentum exchange. As the random molecular motion increases wit a rise in temperature, the viscosity also increases accordingly

FLUID PROPERTIES

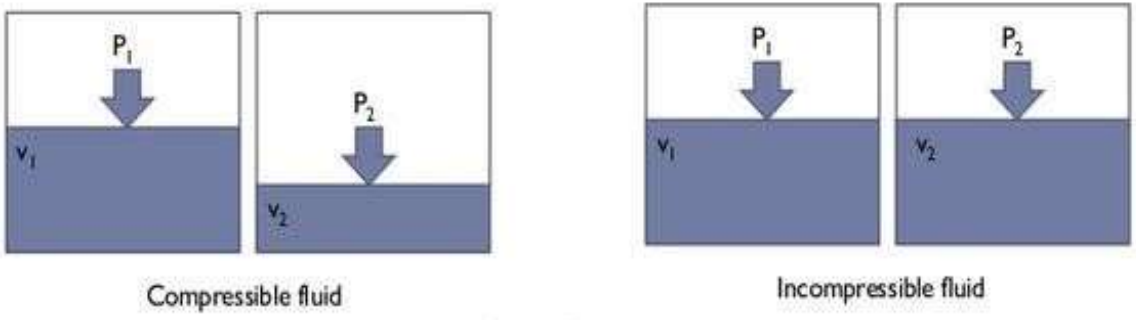
Compressibility

For solids its tight so **solids cannot be compressed**. For gases, the atoms are loosely packed and it is easily compressible.

Generally all fluids are compressible and in case of liquids, the compressibility is less. For most practical problem, **water is considered to be incompressible**.

But in case of water flowing through pipes, when sudden or larger changes in pressure occur, the compressibility can not be neglected

Compressible and Incompressible flows



FLUID PROPERTIES

Compressibility and Bulk/volume Modulus of Elasticity

Fluids may be compressed by an external pressure applied to a volume of fluid. Gases, however, are compressed by an external pressure to a much greater degree than liquids.

The compressibility of a fluid may be defined as the variation of its volume with the variation of pressure and is inversely proportional to its bulk modulus of elasticity.

Consider that a force is applied to any fluid so that the volume of the fluid V decreases by an amount ΔV. The decrease per unit volume is proportional to the force per unit area (i.e. pressure) of the fluid.

$$\text{So, } \mathrm{d}p \propto \frac{-dV}{V} \qquad \text{or, } \mathrm{d}p = -K\frac{dV}{V} \qquad \text{or, } K = -\frac{V dp}{dV}$$

FLUID PROPERTIES

Compressibility and Bulk/volume Modulus of Elasticity

$$\text{So, } \mathrm{d}p \propto \frac{-dV}{V} \qquad \text{or, } \mathrm{d}p = -K\frac{dV}{V} \qquad \text{or, } K = -\frac{V\,dp}{dV}$$

Here K **is the volume or bulk modulus of elasticity** which has the dimensions of pressure i.e. force per unit area (N/m^2).
The value of K for water at any temperature increases with pressure.

Its reciprocal β,
$\beta = 1/K$ is called the **compressibility**, whose value directly indicates how compressible the fluid is.

Difference between Ideal and Real Fluid

Ideal Fluid	Real Fluid
1. Incompressible(constant density)	1.Compressible
2. Have laminar flow Laminar flow-fluid flows parallel	
Turbulent flow-fluid does not flow in	
parallel	2. Have turbulent flow
3.Non viscous flow	3. Viscous flow

Newtonian fluid and non Newtonian fluid

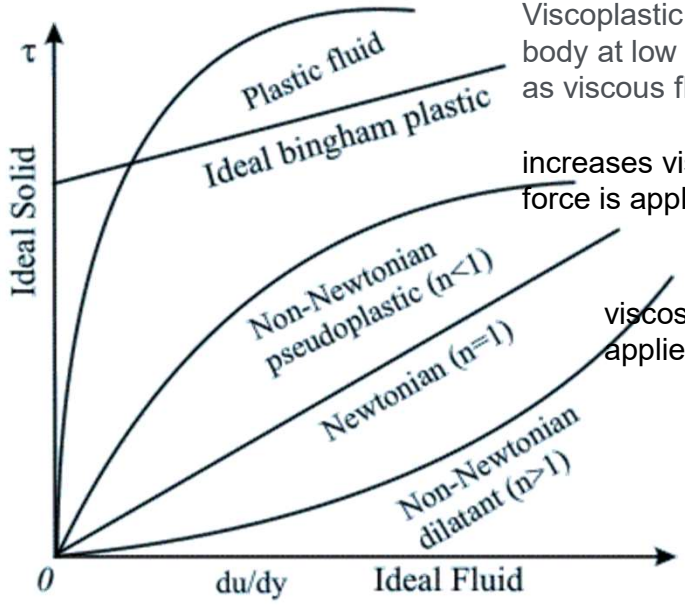
Newtonian fluid follows Newton's law of viscosity but non Newtonian fluid does not follow the law of viscosity

For water, oil or air, the shearing stress z is proportional to the velocity gradient $\frac{du}{dy}$. Such fluids are called Newtonian fluids.

Liquid pulp, a high-molecular-weight solution or asphalt, is called a non-Newtonian fluid.

These fluids are further classified as shown in Fig by the relationship between the shearing stress and the velocity gradient, i.e. a rheological diagram.

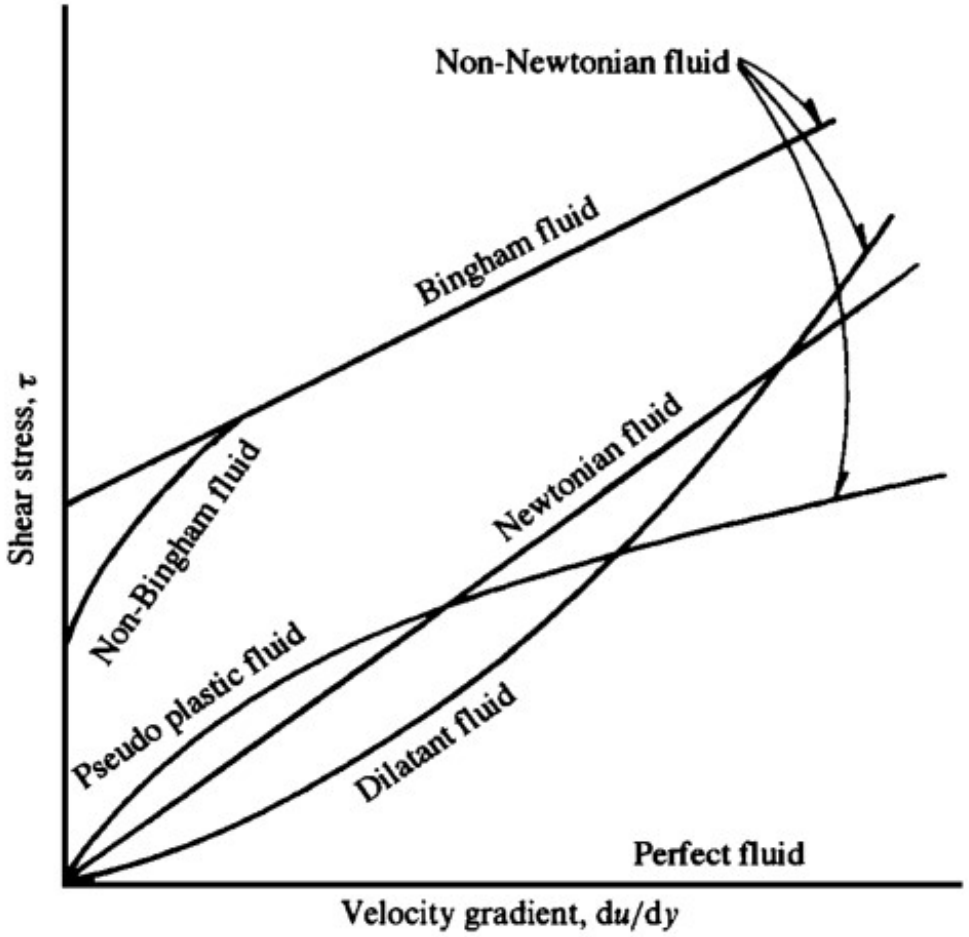
FLUID PROPERTIES



Viscoplastic, behaves as rigid body at low stresses but flows as viscous fluid at high stress

increases viscosity as force is applied

viscosity increases with applied shear stress.



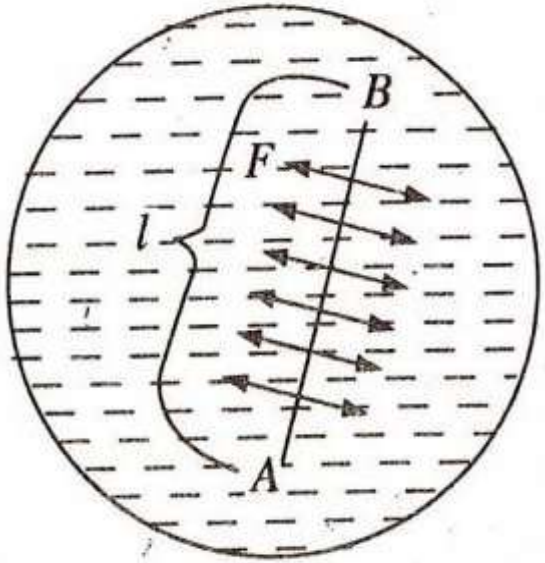
Graph showing Relationship of shear stress and velocity gradient of different fluid

FLUID PROPERTIES

Surface Tension

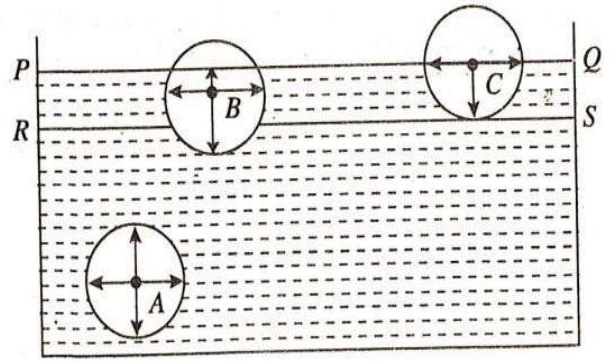
The surface of a liquid is apt to shrink, and its free surface is in such a state where each section pulls another as if an elastic film is being stretched.

The tensile strength per unit length of assumed section on the free surface is called the surface tension.



Mathematical expression, $T = \frac{F}{l}$

F is the force per unit length l is the length in which force act T is the surface tension of the liquid



Molecular Theory of surface Tension

FLUID PROPERTIES

Cohesion and Adhesion:

Cohesion is the property of fluid by which **molecules of the same fluid are attracted**. This property enables the liquids to resist small tensile stress.

Adhesion is a property of fluid by which **molecules of different liquids are attracted to each other or molecules of a liquid are attracted to another body.** This enables the two different liquids to adhere to each other or to a liquid to adhere to another body.

FLUID PROPERTIES

Capillarity: It can be defined as the tendency of a liquid in a capillary tube to rise or fall as a result of surface tension.

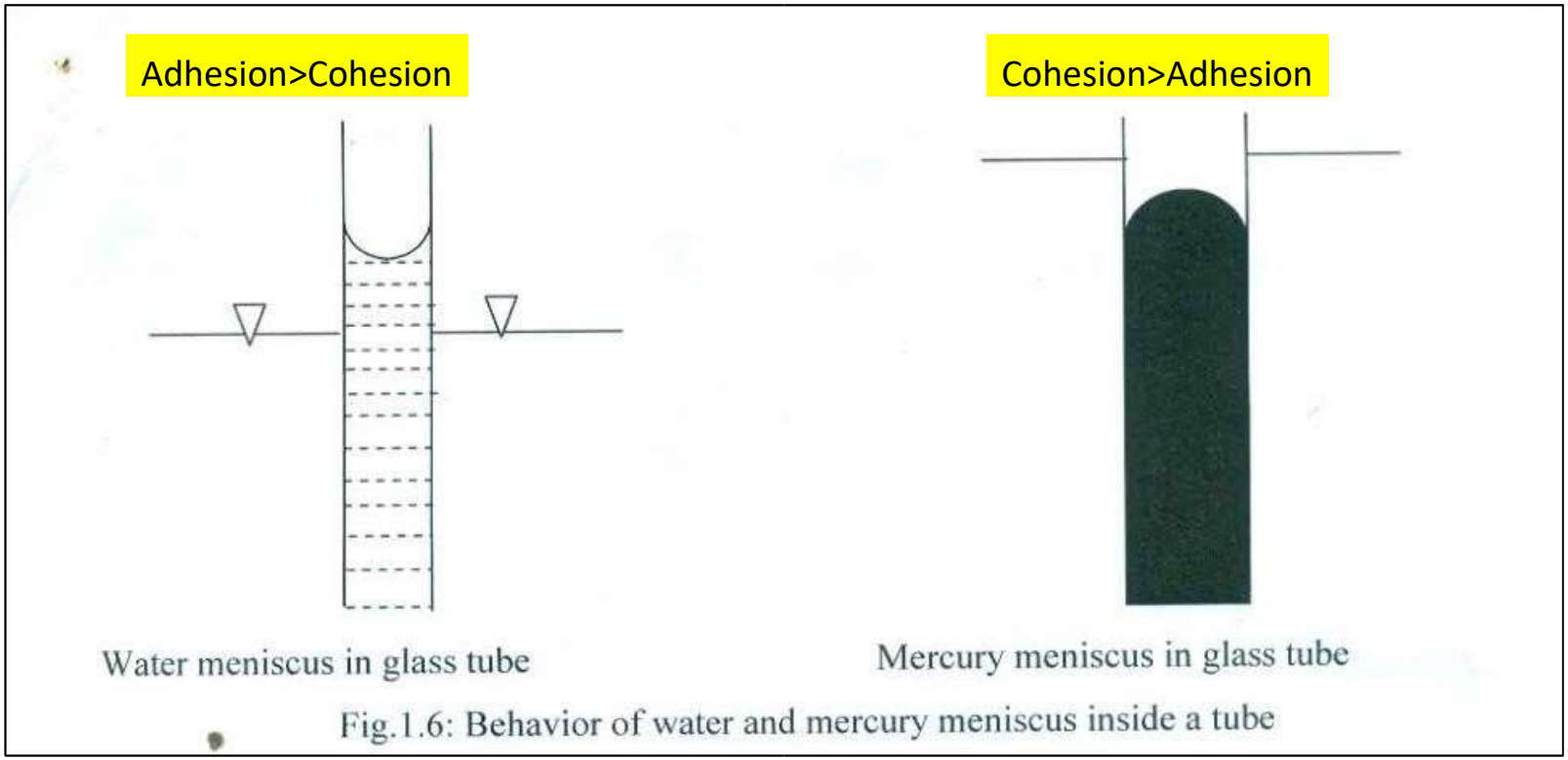
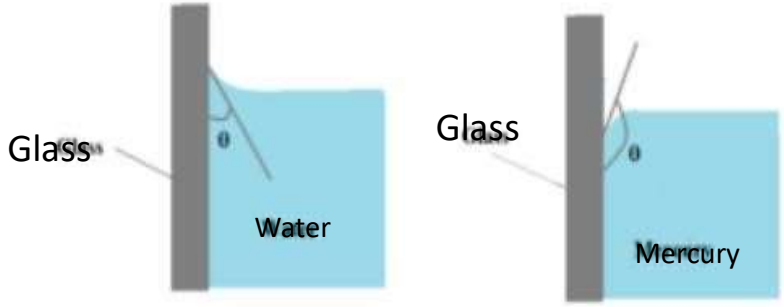


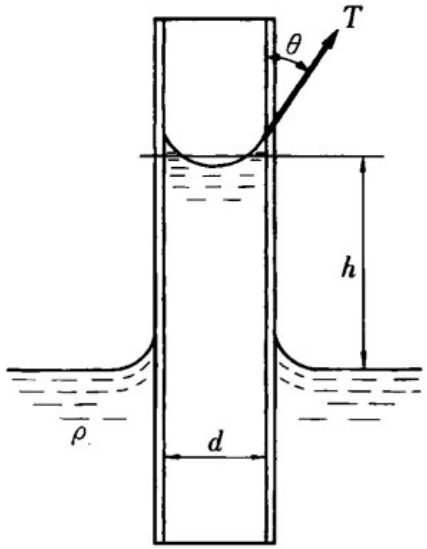
Fig.1.6: Behavior of water and mercury meniscus inside a tube

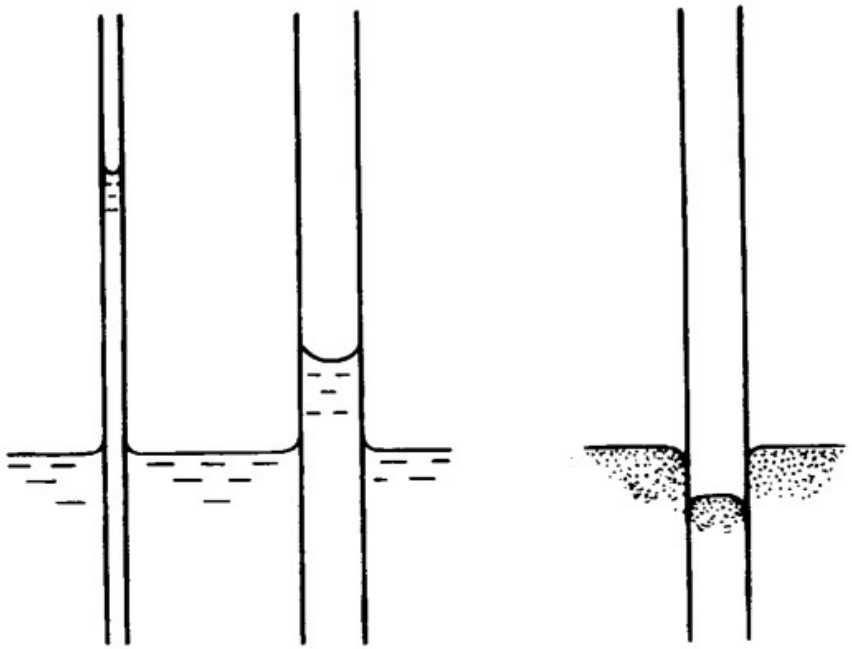
FLUID PROPERTIES

Angle of Contact: If water is taken in a vessel, the free surface of water near the glass wall is curved concave upward.
If mercury is taken, we see convex upward.



When the liquid is contact with solid, the angle between the solid surface and the tangent to the free surface of the liquid at the point of contact measured from inside the liquid is called angle of contact.





(a) Water (b) Mercury

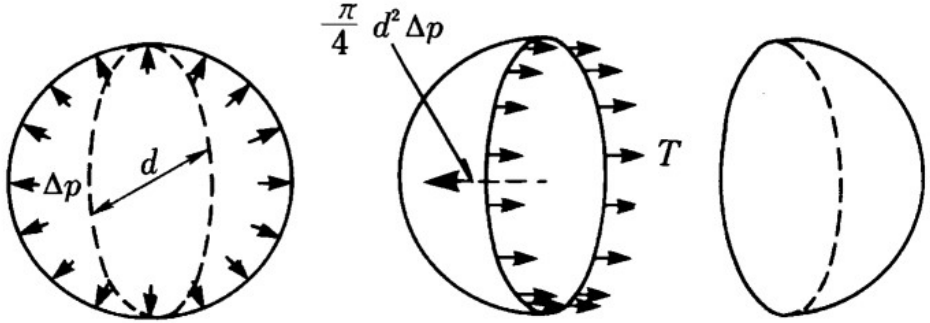
Change of liquid surface due to capillarity

A dewdrop appearing on a plant leaf is spherical in shape. This is also because of the tendency to shrink due to surface tension.
Consequently its internal pressure is higher than its peripheral pressure.

Putting d as the diameter of the liquid drop, T as the surface tension, and p as the increase in internal pressure, the following equation is obtained owing to the balance of forces

$$\pi dT = \frac{\pi d^2}{4}\Delta p$$

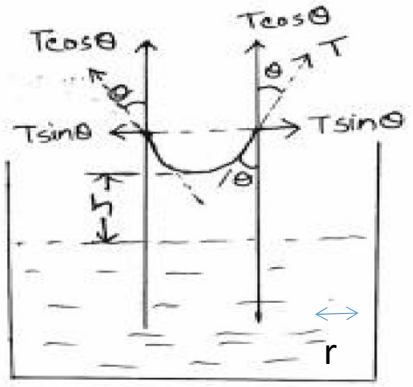
$$\Delta p = \frac{4T}{d}$$



$$\pi dT\cos\theta = \frac{\pi d^2}{4}\rho g h \qquad h = \frac{4T\cos\theta}{\rho g d}$$

Equation of Capillarity

Capillarity:



T = surface tension in unit force per unit length

θ = wetting angle

γ = specific weight of liquid

h = capillary rise

r = radius of tube

Here,

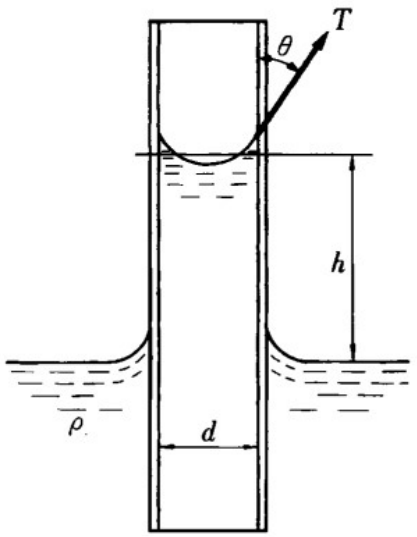
$$2\pi r T\cos\theta = \pi r^2\left(h+\frac{1}{3}r\right)\rho g$$

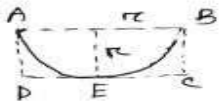
$$\Rightarrow T = \frac{r\rho g\left(h+\frac{1}{3}r\right)}{2\cos\theta}$$

If θ is very small, we can neglect and r is very small compared to h so $\frac{1}{3}r$ can be neglected.

$$\therefore T = \frac{r\rho g h}{2}$$

→ T (surface tension is also expressed as σ)





vol^m of ABCD = $\pi r^2 \times r = \pi r^3$

vol^m of AEB = $\frac{\frac{4}{3}\pi r^3}{2} = \frac{2}{3}\pi r^3$

∴ remaining vol^m

$= \pi r^3 - \frac{2}{3}\pi r^3$

$= \frac{1}{3}\pi r^3$

$\rho = \frac{m}{V}$

$\Rightarrow m = \rho V$

$= \rho\left(\frac{1}{3}\pi r^3 + \pi r^2 h\right)$

total downward force

$= \pi r^2\left(h+\frac{1}{3}r\right)\rho g$

- Zero memory substances
- Continuum concept: laminar/L<0.01
- Contineus function in spce w r t space