Fluid mechanics

Unit-I

{ Introduction of fluid }

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Fluid: A substance in the liquid or gas phase.

A solid can resist an applied shear stress by deforming.
A fluid deforms continuously under the influence of a shear stress, no matter how small

Ideal fluids- An ideal fluid is one which has no viscosity, surface tension and is incompressible. In true sense no such fluid exists in nature. However fluids which have low viscosities such as water and air can be treated as ideal fluids under certain conditions. The assumption of ideal fluids help in simplifying the mathematical analysis

Real fluids - A real practical fluid is one which has viscosity, surface tension and compressibility in addition to the density. The real fluids are actually available in nature.

❑ Types Of Fluid Flow:-

1) Steady & Unsteady Flows.

2) Uniform & Non-uniform Flows.

3) Laminar & Turbulent Flows.

4) Compressible & Incompressible Flows.

5) Rotational & Irrotational Flows.

6) One , Two & Three Dimensional Flows.

❖ Steady & Unsteady Flows:-

➢ **Steady Flows:-**

In which the fluid Characteristics Like velocity, pressure, density , etc. At a Point do not change with time.

➢ Unsteady Flow:-

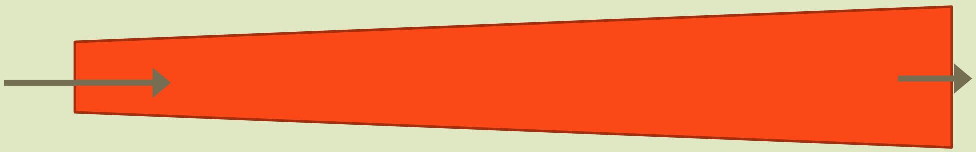
- In which the fluid velocity , pressure or density at a point changes with respect to time.

Uniform & Non-uniform Flow :-

➢Uniform Flow:-

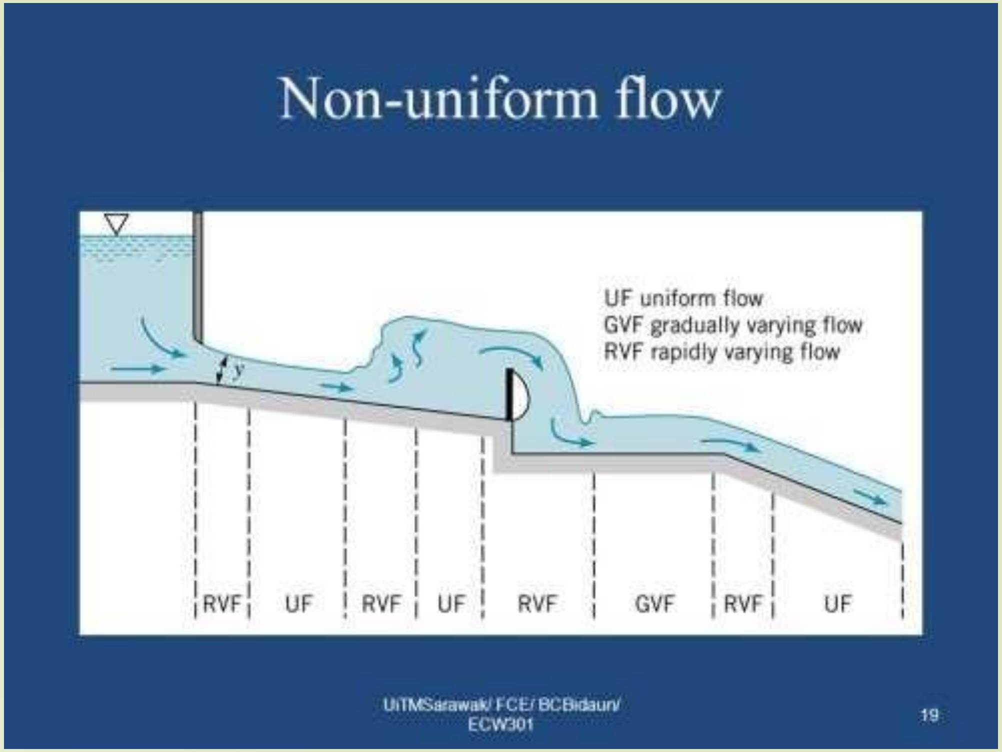
In which the velocity at given time does not change with respect to space (length of direction of the flow).

➢ **Non-Uniform Flow:-**



Changing in space

In which the velocity at any time changes with respect to space.



❑ Laminar & Turbulent flows:-

- **Laminar Flow:-**
  - in which the fluid particles move along well defined paths or stream line.

Fig. Laminar Flow

Turbulent Flow:-

- ✓ fluid moves in very irregular paths or zig – zag Way.
- ✓ velocity at a point fluctuates.

Compressible & Incompressible Flows:-

➢Compressible Flows:-

✓In which the density of the fluid changes from point to point.
✓The density is not constant for the fluid.

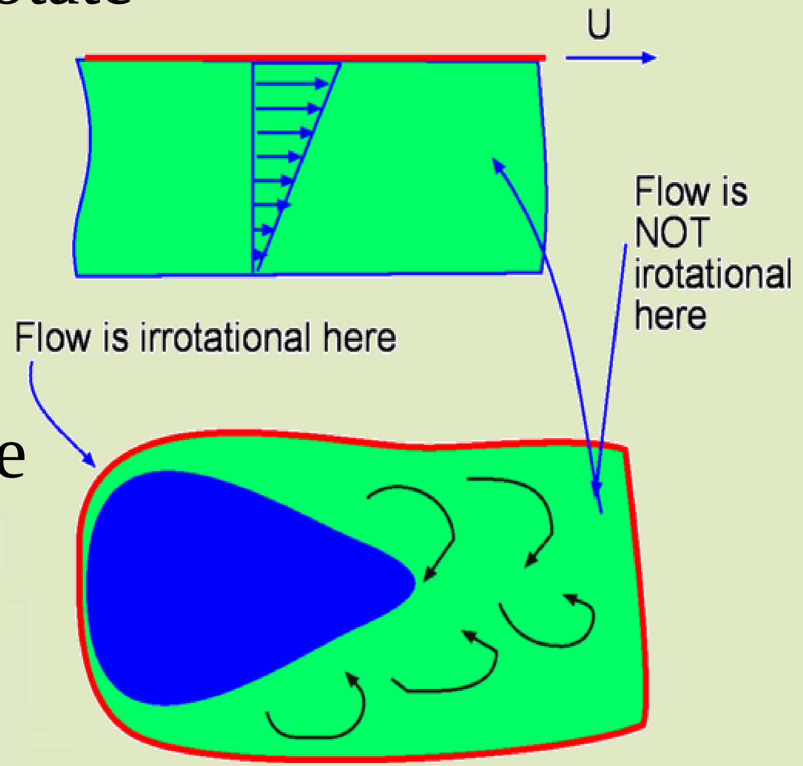
➢Incompressible Flows:-

✓ In which the density of fluid changes from point to point.
✓ the density is constant for the fluid.

Rotational & Irrotational Flows:-

❖Rotational Flow :-

➢In which the fluid particles while flowing along stream lines, Also rotate about their own axis.



❖ Irrotational Flow:-

➢In which the fluid particles while flowing along stream lines, do not rotate about their own axis.

One , Two & Three Dimensional Flows:-

One Dimensional Flow:-

- In which the flow parameter such as velocity is a function of time and
- one space co-ordinate only.

Two Dimensional Flow:-

- In which the velocity is a function of time and

- two rectangular space co-ordinates.

Three Dimensional Flow:-

- In which the velocity is the function of time and

- Three mutually perpendicular directions.

Hydrodynamics: The study of the motion of fluids that can be approximated as incompressible (such as liquids, especially water, and gases at low speeds).

Hydraulics: A subcategory of hydrodynamics, which deals with liquid flows in pipes and open channels

Fluid mechanics: The science that deals with the behavior of fluids at rest (*fluid statics*) or in motion (*fluid dynamics*), and the interaction of fluids with solids or other fluids at the boundaries

Thank

You

Fluid mechanics

Unit-II

{ Properties of fluid }

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Concept of Continuum

- Air is made of particles - molecules.
- We are tempted to treat each of these particles individually, and study its motion as Newton did.
- This approach fails when there are millions of particles to deal with, which randomly collide with each other millions of times per second.
- When we deal with such large number of particles, we can describe their characteristics only in terms of statistical averages.
- In other words, we treat the fluid as a continuous medium, which has certain average properties at any point in space and time.

Physical properties of liquid

- Mass density
- Specific weight
- Specific volume
- Relative density
- Specific gravity
- Vapor pressure
- Cavitation
- Cohesion and adhesion
- Surface tension
- Capillarity

Physical properties of liquid

- **Mass density**
- Density is the **mass of the fluid per unit volume**
- It is designated with symbol of ρ (rho). ρ =mass/volume =M/L^3
- Unit : Kg/m^3
- Density of water at 4°C=$1000 kg/m^3$, $1 g/cm^3$

- Specific weight
- The **specific weight** (also known as the **unit weight**) is the **weight** per **unit** volume of a material.
- The symbol of **specific weight** is γ (the Greek letter Gamma).
- A commonly used value is the **specific weight** of water on Earth at 4°C which is $9.807 kN/m^3$.
- γ= weight/volume=$M/L^2T^2 = \rho g$

Physical properties of liquid

- Specific Volume

- The **specific volume** of a substance is the ratio of the substance's volume to its mass.
- It is the reciprocal of density .
- Specific volume is defined as the number of cubic meters occupied by one kilogram of a particular substance.
- Unit: m^3/kg
- It is designated with v= volume / mass= L^3 / M

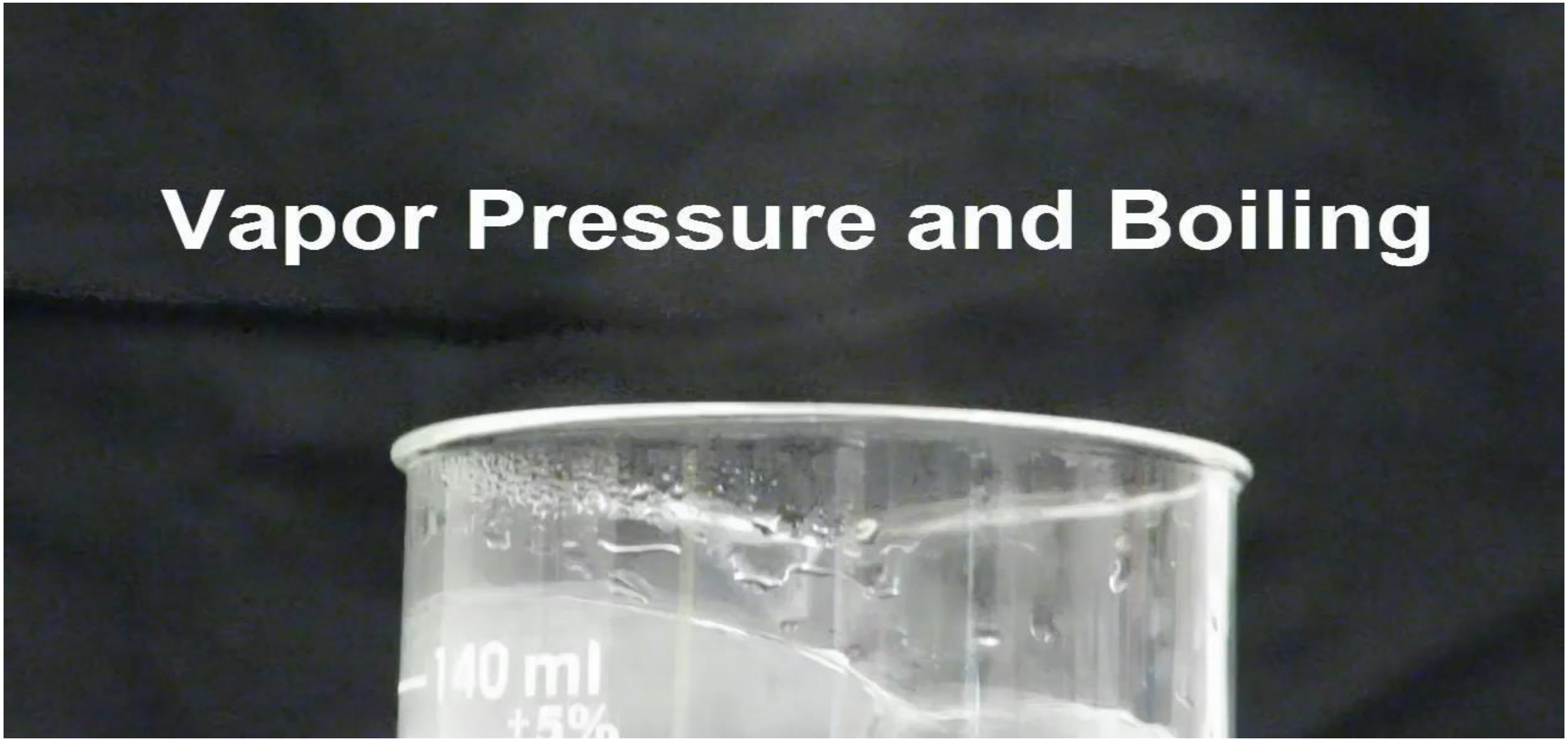
Physical properties of liquid

Specific gravity(sp.gr/s)

- The specific gravity is the **ratio of the density or specific weight of the fluid to the density or specific weight of water, at a temperature of 4°C**
- For Gases the standard fluid is taken either air at 0^0C or Hydrogen at the same temperature.
- It is dimensionless quantity.
- **A Statement that the specific gravity of mercury is 13.6 implies that its weight (or mass) is 13.6 times that of the same volume of water.**
  In simple words, mercury is 13.6 times heavier than water.
- $s = \rho_{fluid} / \rho_{\text{water at } 4^{o}C}$

Physical properties of liquid

- **Vapor pressure**



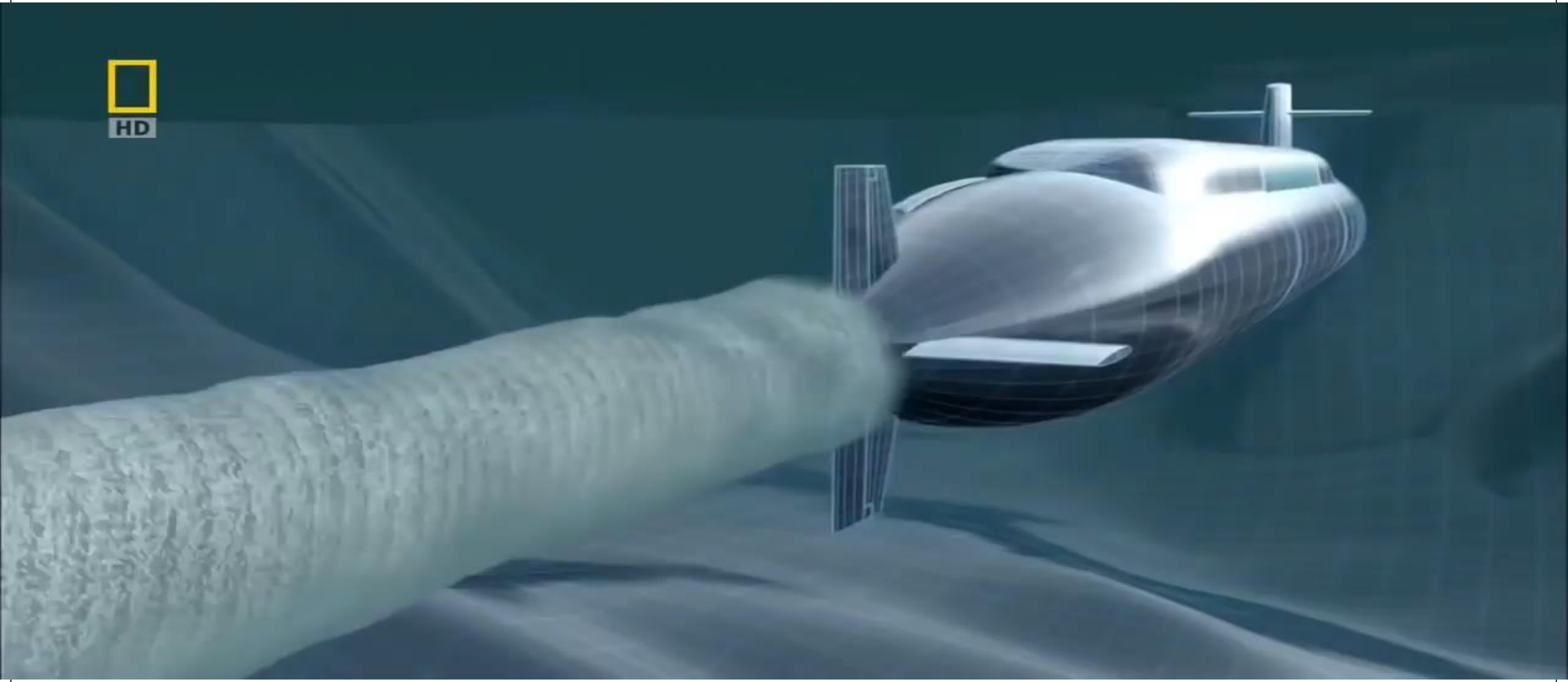
Physical properties of liquid

Vapor pressure

- the pressure exerted by a vapor at a given temperature in a closed system
- Pressure=F/A=N/m^2

Physical properties of liquid

- Cavitation



Physical properties of liquid

Cavitation

- If the pressure of the liquid falls below the vapour pressure, P_v, the liquid boils, generating vapour bubbles or cavities-cavitation.
- The bubbles are swept into higher pressure regions by the liquid flow, where they collapse creating pressure waves and cause mechanical damage to solid surfaces.

Physical properties of liquid

Cohesion and Adhesion

- In cohesion, water sticks to other water molecules often via Hydrogen bonds
- In adhesion, water sticks to non-water molecules via hydrogen bonds e.g. dew on leaves of plant

Physical properties of liquid

- **Cohesion and Adhesion**

Physical properties of liquid

❑Surface tension

Physical properties of liquid

❑ Surface tension

- Surface tension is the tensile force acting on the liquid surface in contact with gas or another immiscible(different type)of liquid
- Surface tension=tensile force/length =N/m
- Surface tension allows insects, usually denser than water, to float and stride on a water surface.
- At liquid–air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion).
- Represented by σ(sigma)
- Decreases with increase in temperature
- Thick liquids have higher surface tension than thin liquids

Physical properties of liquid

- **Capillarity**

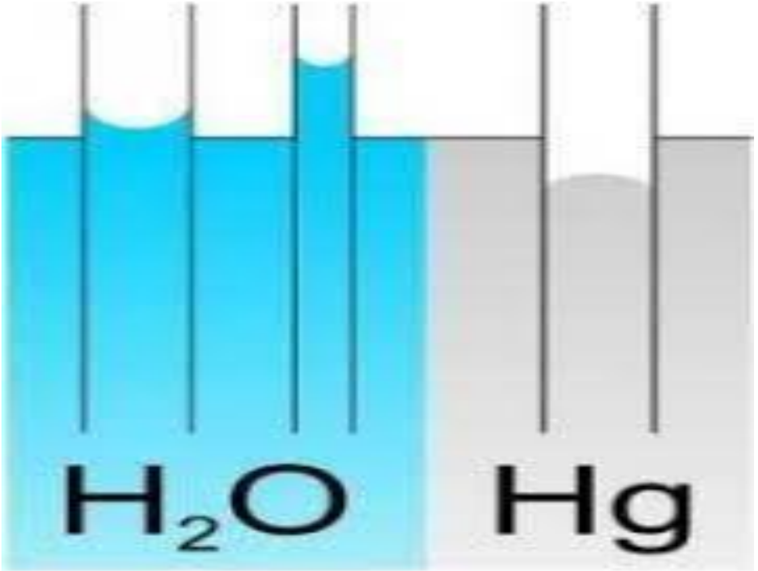
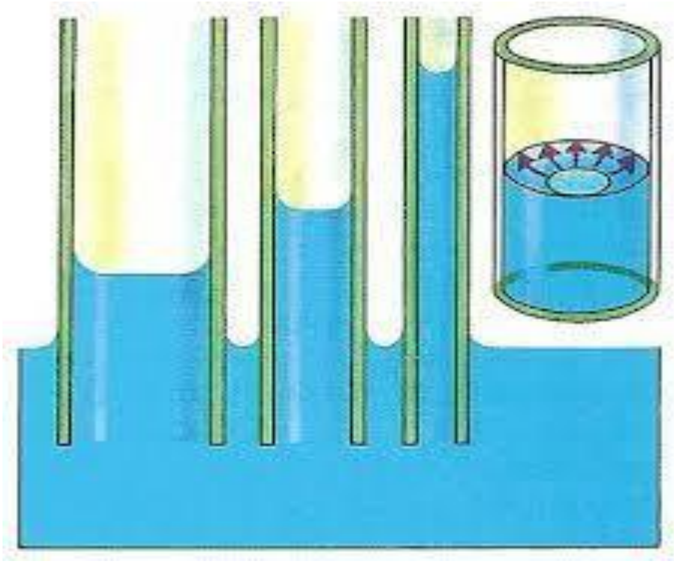


Fig: Capillary Tube



Physical properties of liquid

- **Capillarity**
  - It is defined as the rise or fall in the level of the liquid in a tube when it is immersed in a liquid in comparison with the adjacent level of liquid.
  - If the liquid level rises in the tube, it is called capillary rise
  - If the liquid level falls in the tube, it is called capillary fall/depression

Physical properties of liquid

Capillarity

$$\sigma = \frac{\gamma h D}{4\cos\theta} \quad or \quad h = \frac{4\sigma\cos\theta}{\gamma D}$$

- D= diameter of tube
- γ=specific weight of liquid
- h=capillary rise
- θ=angle of contact or contact angle
- σ=force of surface tension per unit length

- The above equation is used to compute capillary rise/fall.
- Note: Fall has –ve sign

Viscosity

- It is the property of a fluid by virtue of which it offers resistance to deformation under the influence of external forces.
- It can also be defined as internal resistance offered by fluid to flow.
- It is denoted by μ.
- Molasses, tar, glycerin are highly viscous fluids.
- Water, air, petrol have very small viscosity and are called thin fluids.
- It is also termed as coefficient of viscosity or absolute viscosity or dynamic viscosity or molecular viscosity.

Factors affecting viscosity

1. Cohesion:

- It is the attraction between molecules of fluid.
- With increase in molecular attraction (cohesion), viscosity (resistance to flow) also increases in a fluid.
- It is dominant in liquids.

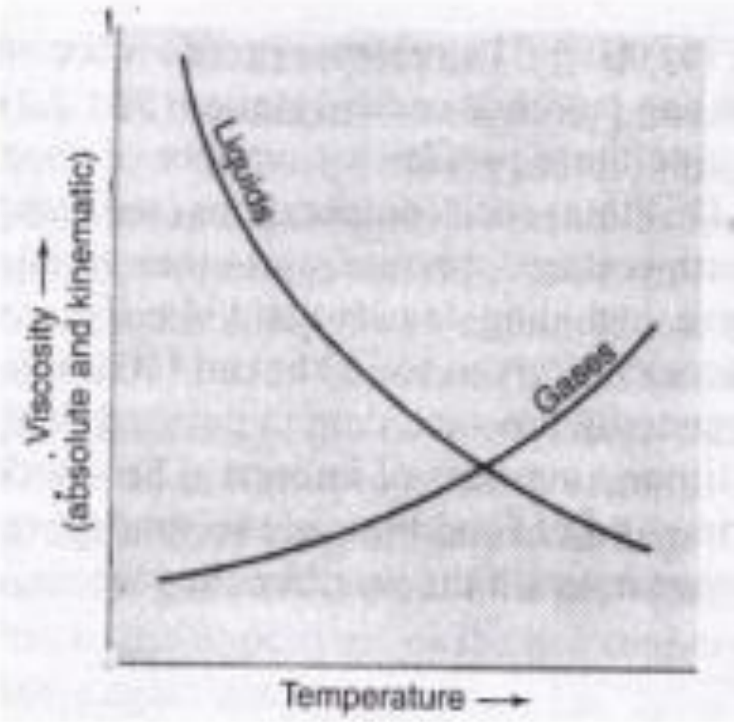
2. Molecular momentum:

- Molecules in any fluid change their position with time and is known as molecular activity. More the molecular activity more will be viscosity of the fluid.
- It is dominant in gases

Effect of temperature on viscosity

- **For Liquids:**
- In case of liquids, cohesion (molecular attraction is dominant). Therefore, if the temperature of liquid is increased, its cohesion and hence viscosity will decrease.

$$\mu = \frac{1}{T}$$



- **For Gases:**
- In gases momentum exchange is dominant. Therefore, if the temperature of gases is increases, its momentum exchange will increase and hence viscosity will increase.

$$\mu = T$$

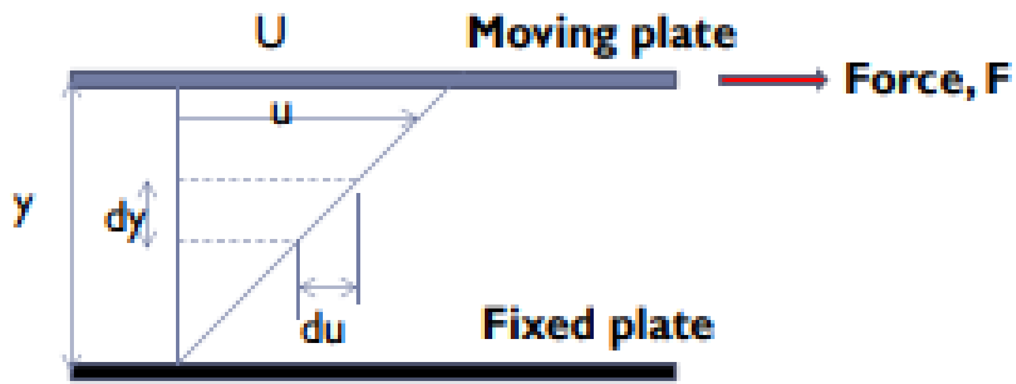
Kinematic Viscosity

- It is ratio of absolute viscosity and density of fluid.
- It is denoted by ν (nu)

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

Newton's Equation of Viscosity

- Consider two parallel plates, in which lower plate is fixed and upper is moving with and uniform velocity 'U' under the influence of force 'F'. Space between the plates is filled with a fluid having viscosity, μ.



- F= Applied force (shearing force)
- A= Contact area of plate(resisting area)
- y=gap/space between plates
- U=Velocity of plate
- As the upper plate moves, fluid also moves in the direction of applied force due to adhesion.

Newton's Equation of Viscosity

- **<u>Factor affecting Force, F</u>**

$$(i)\,F \propto A; \quad (ii)\,F \propto U; \quad (iii)\,F \propto \frac{1}{y}$$

- Hence,

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

- **Where,** μ *is coefficient of viscosity*

- **Assuming linear velocity profile (as shown in figure)**

$$\tau = \frac{F}{A} = \mu \frac{U}{y} = \mu \frac{du}{dy}$$

Newton's Equation of Viscosity

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

- The above equation is called as **Newton's equation of viscosity.**
- The equation shows that the shearing stress is directly proportional to the velocity gradient and its is known as **Netwon's law of viscosity.**

- In the above equation
- du/dy= velocity gradient or rate of change of deformation
- μ = absolute viscosity
- τ=shear stress

Newton's law of viscosity

- Following Observations can be made from Newton’s viscosity

  • Max. shear stress occur when velocity gradient is largest and shear stress disappears where velocity gradient is zero.
  • Velocity Gradient becomes small with distance from the boundary. Consequently the max value of shear stress occurs at the boundary and it decreases from the boundary.

Unit of Viscosity

- **Viscosity** $\mu = M / LT$

	SI	CGS
	N-s/m^2	Dyne-s/cm^2 (Poise, P)
	Kg/(m-s)	g/(cm-s)

Widely used unit is Poise =0.1N.s/m^2

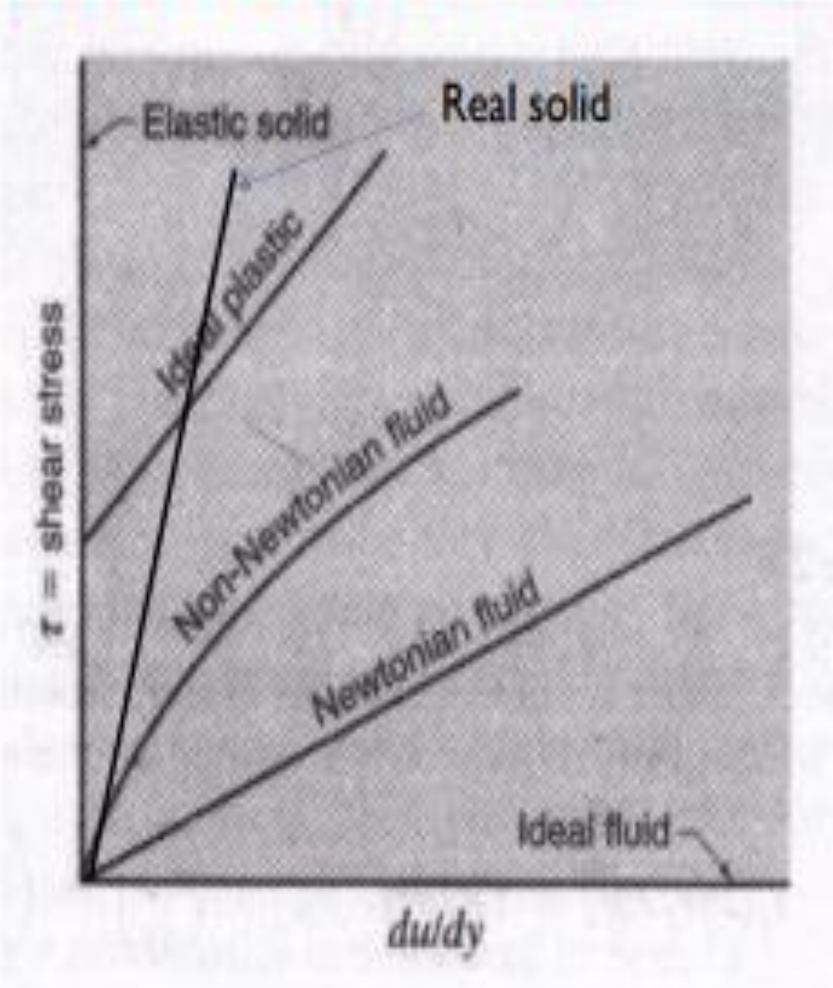
- **Kinematic Viscosity** $\nu = L^2 / T$

	SI	CGS
	m^2/s	cm^2/s (stoke)

Widely used unit is Stoke=10^{-4}m^2/s

Shear Stress ~ Velocity gradient curve

- Ideal fluid
- Newtownian Fluid
- Non-Newtownian fluid
- Ideal plastic
- Real solid
- Ideal solid/elastic solid



Shear Stress ~ Velocity gradient curve

- **Ideal Fluid:** The fluid which does not offer resistance to flow

$$\mu = 0 \Rightarrow \tau = 0$$

- **Newto nian Fluid:** Fluid which obey Newto n's law of viscosity

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

slope of curve ($\tau \sim du/dy$)is constant

- **Non-Newtonian fluid:** Fluid which does not obey Newto n's Law of viscosity

$$\tau \not\propto \frac{du}{dy}$$

slope of curve ($\tau \sim du/dy$)changing continuously

IMPORTANCE OF DIMENSIONS AND UNITS

- Any physical quantity can be characterized by **dimensions.**
- The magnitudes assigned to the dimensions are called **units.**
- Some basic dimensions such as mass *m*, length *L*, time *t*, and temperature *T* are selected as **primary** or **fundamental dimensions**, while others such as velocity *V*, energy *E*, and volume *V* are expressed in terms of the primary dimensions and are called **secondary dimensions**, or **derived dimensions.**
- **Metric SI system:** A simple and logical system based on a decimal relationship between the various units.

- **English system:** It has no apparent systematic numerical base, and various units in this system are related to each other rather arbitrarily.

TABLE 1–1

The seven fundamental (or primary) dimensions and their units in SI

Dimension	Unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Temperature	kelvin (K)
Electric current	ampere (A)
Amount of light	candela (cd)
Amount of matter	mole (mol)

TABLE 1–2

Standard prefixes in SI units

Multiple	Prefix
10^{24}	yotta, Y
10^{21}	zetta, Z
10^{18}	exa, E
10^{15}	peta, P
10^{12}	tera, T
10^{9}	giga, G
10^{6}	mega, M
10^{3}	kilo, k
10^{2}	hecto, h
10^{1}	deka, da
10^{-1}	deci, d
10^{-2}	centi, c
10^{-3}	milli, m
10^{-6}	micro, μ
10^{-9}	nano, n