Fluid Mechanics

For

ME / CE

By

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Syllabus for Fluid Mechanics

Fluid Properties; Fluid Statics, Manometry, Buoyancy, Forces on Submerged Bodies, Stability of Floating Bodies; Control-Volume Analysis of Mass, Momentum and Energy; Fluid Acceleration; Differential Equations of Continuity and Momentum; Bernoulli's Equation; Dimensional Analysis; Viscous Flow of Incompressible Fluids, Boundary Layer, Elementary Turbulent Flow, Flow Through Pipes, Head Losses In Pipes, Bends and Fittings.

Previous Year GATE Papers and Analysis

GATE Papers with answer key

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Subject wise Weightage Analysis

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"If you don't set goals, you can't regret not reaching them."
......Yogi Berra

CHAPTER 1

Fluid Properties

Learning Objectives

After reading this chapter, you will know:

1. Fluids, Properties of Fluids
2. Types of Fluids

Fluids

It is defined as a substance which deforms continuously even with a small amount of shear force exerted on it, whereas a solid offers resistance to the force because very strong intermolecular attraction exists in it.

Both liquids and gases come under the fluids.

1. **Liquid**
   It has definite volume but no shape for all practical purposes considered incompressible.
2. **Gas**
   It has no shape and volume highly compressible.
3. **Vapour**
   A gas whose temperature and pressure are such that it is very near to the liquid phase.
   E.g.: Steam

Properties of Fluids

Mass Density (ρ)

It is defined as mass per unit volume. Unit: kg/m^3, Dimension: M/L^3

Absolute quantity i.e., does not change with location.

As pressure increases mass density increases (as large number of molecules are forced into a given volume)

Specific Weight (γ)

Weight of the substance per unit volume. Also represents force exerted by gravity on a unit volume fluid.

Mass density and specific weight of a fluid are related as $\gamma = \rho g$;

Where, g = Acceleration due to gravity

Units: N/m^3, Dimensions: $ML^{-2}T^{-2}$ or FL^{-3}

It is not an absolute quantity, varies from place to place, because g (acceleration due to gravity) is changing from place to place primarily latitude and elevation above M.S.L.

Specific weight of water, $\gamma = 1000 \times 9.81 = 9810\ N/m^3$

Specific Volume (v)

Specific volume of a fluid is the volume of the fluid per unit weight.
$v = 1/\rho$ (Reciprocal of density)
Units: m^3/kg

Specific gravity (G)

It is a ratio of specific weight (mass density) of a fluid to the specific weight (mass density) of a standard fluid.

$$G = \frac{\text{Specific weight (or mass density)of a fluid}}{\text{Specific weight (or mass density)of a standard fluid}}$$

For liquids, standard fluid is water at 4 ^{o}C
For gases, standard fluid is hydrogen or air
Units: No units (as it is a ratio of two quantities having same unit)
Specific gravity of water = 1.0, Mercury = 13.6
Since the density of fluid varies with temperature, specific gravity must be determined and specified at a particular temperature.

Viscosity

A measure of fluids resistance to shear. A property of a fluid by virtue of which it offers resistance to the movement of one layer of fluid over the adjacent layer. It is due to intermolecular cohesion and transfer of molecular momentum between layers.

- **Dynamic Viscosity (μ)**
  Units: SI: Pa.sec or N.sec/m^2; MKS: kg/(m.sec)
  CGS: poise = dyne.sec/cm^2
  Conversion: 1 poise = 0.1 Pa.sec
  Dimensions: $ML^{-1}T^{-1}$ or $FL^{-2}T$

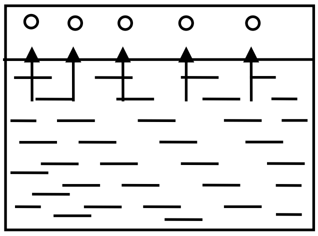
- **Kinematic Viscosity (ν)**
  It is dependent on pressure. For liquids dynamic viscosity decreases with gases increase in temperature because density of liquid decreases with increase in temperature for it decreases with increase in temperature because molecular momentum increases and cohesion is negligible in gases.

  $$\text{Kinematic Viscosity } (\nu) = \frac{\text{Dynamic viscosity}}{\text{Mass density}} = \frac{\mu}{\rho}$$

  Units: SI: m^2/sec; CGS: cm^2/sec or stokes
  Dimensions: L^2T^{-1}
  Kinematic viscosity depends on both pressure and temperature.

Vapour Pressure

In a closed vessel at a constant temperature, the 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 exerted on liquid surface is called vapour pressure. Vapour pressure increases with temperature. The low vapour pressure of mercury (along with high density) makes it very suitable for use in barometers and other pressure measuring devices.



Cavitation

Occurs in a flow system, dissolved gases (vapour bubbles) carried into a region of high pressure and their subsequent collapse gives rise to high pressure, which leads to noise, vibrations and erosion. Cavitation occurs in,

1. Turbine runner
2. Pump impellers
3. Hydraulic structures like spillways and sluice gates
4. Ship propellers

Compressibility

Change in volume (or density) due to change in pressure. Compressibility is inversely proportional to Bulk Modulus K.

$$K = \frac{-dP}{\left(\frac{dv}{V}\right)} \text{ or } \frac{-dP}{\left(\frac{d\rho}{\rho}\right)}$$

(Negative sign indicates a decrease in volume with increase in pressure)

Coefficient of compressibility, $\beta = \frac{1}{K}$

Surface Tension

It is defined as the tensile force acting on surface of liquid in contact with gas or on the surface between two immiscible liquid such that the contact surface behaves like a memberance.

There are mainly two types of force:

- **Cohesion:** Force of attraction between the molecules of the same liquid.
- **Adhesion:** Force of attraction between the molecules of different liquids (or) between the liquid molecules and solid boundary containing the liquid. A liquid forms an interface with a second liquid or gas. This liquid – air interface behaves like a membrane under tension. The surface energy per unit area of interface is called Surface Tension. It can also be expressed as a line force. Force per unit length.
  Units: N/m
  Dimensions: FL^{-1} or MT^{-2}

Surface tension is due to cohesion between liquid molecules. As temperature increases → Surface tension decreases (because cohesion decreases)

Due to cohesion, surface tension pressure changes occur across a curved surface of

1. **Liquid Jet:** Increase in pressure inside and outside of liquid jet.

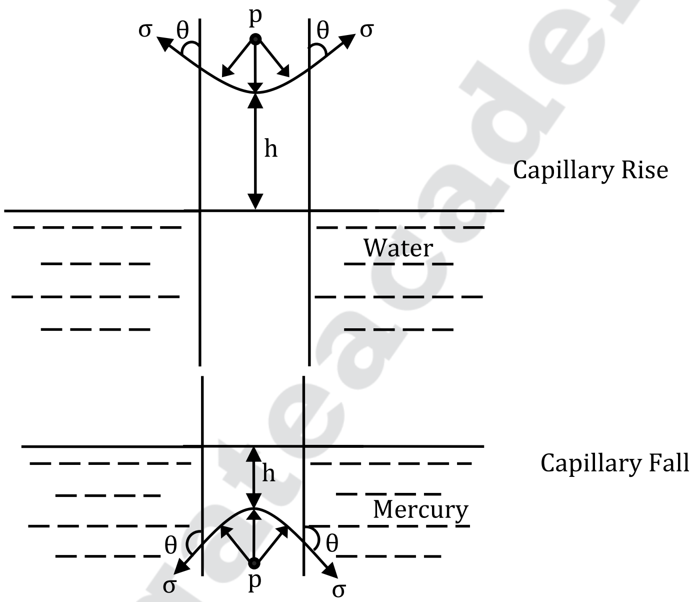
$$\Delta P = \frac{2\sigma}{d};\ \text{Where, d} = \text{Dia of jet}, \Delta P = \text{Pressure intensity inside the liquid}$$

2. **Liquid Drop**: $\Delta P = \frac{4\sigma}{d}$; Where, d = Dia of drop let

3. **Soap Bubble**: $\Delta P = \frac{8\sigma}{d}$; Where, d = Dia of bubble

Capillarity

The phenomenon of rise or fall of a liquid surface relative to the adjacent general level of liquid in small diameter tubes. The rise of liquid surface is designated as capillary rise and lowering is called capillary depression. Capillary rise happens when adhesive is stronger than cohesive for example in water capillary depression happens when cohesive is stronger than adhesive for example in mercury.



E.g.: Mercury depressive with convers upwards capillary (Rise or Fall)

Units: cm or mm of liquids.

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

σ = Surface tension

θ = Angle of contact between liquid and boundary

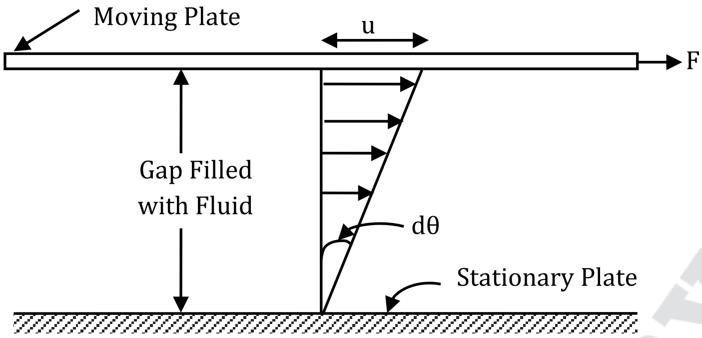
d = Dia. of tube

$\theta = 0° \rightarrow$ Water and glass

$\theta = 130° \rightarrow$ Mercury and gases

For tube dia. > 12 mm capillary effects are negligible. Hence the dia. of glass tubes used for measuring pressure (manometers, piezometer etc.) should be large enough.

Newton's Law of Viscosity



Shear stress ∝ Time rate of deformation (shear deformation)

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

Where, F is the Force required to move the surface area 'A'

$\frac{F}{A} \propto \frac{u}{y}$ or $\tau = \mu\left(\frac{u}{y}\right)$

Differential form: $\tau = \mu\left(\frac{du}{dy}\right)$

Where, τ = Shear stress

(du / dy) = Velocity gradient

μ = Dynamic viscosity

According to Newton's law of viscosity, for a given shear stress acting on fluid (τ), the rate at which fluid deforms (u/y) is inversely proportional to viscosity (μ).

Types of Fluids

Ideal Fluid or Perfect Fluid

- Non viscous (frictionless) and incompressible.
- Used in the mathematical analysis of flow problems.
- Does not exist in reality.
- Does not offer shear resistance when fluid is in motion.

Real Fluid

- Possess the properties such as viscosity, surface tension and compressibility.
- Resistance is offered when they are set in motion.

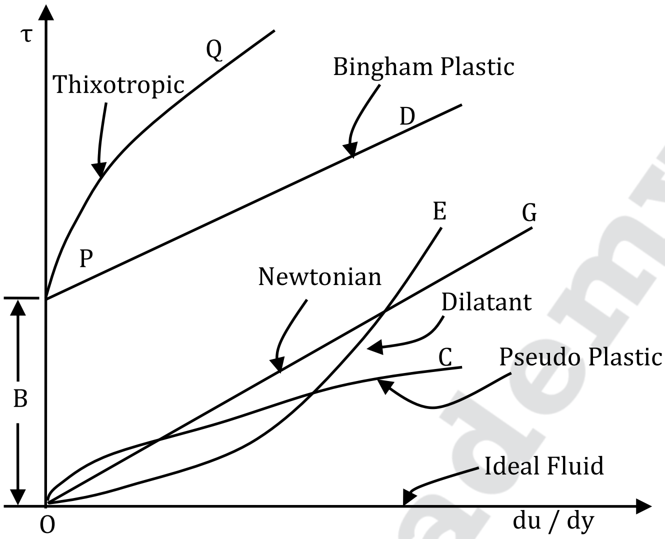
Newtonian Fluid

- This obeys Newton's Law of Viscosity.
- Newtonian fluid has constant viscosity (Viscosity is independent of shear stress).
- There will be linear relationship between shear stress and resulting rate of deformation.
  E.g.: Air, Water, Light Oils and Gasoline.

Non – Newtonian Fluids

- Do not follow the Newton's law of viscosity
- Relationship between shear stress and velocity gradient

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



Where A and B are constants depend upon the type of fluid and conditions imposed on flow. Based on power index 'n' and constant B Non – Newtonian fluids are

(i) $B = 0$ and $n > 1$ (represented by OE in Figure)
  Dilatant Fluids, **E.g.:** Butter, Quick sand.

(ii) $B = 0$ and $n < 1$ (represented by OC in Figure) Pseudo plastic.
  E.g.: Blood, Paper Pulp, Polymeric solutions such as rubber, suspension paints.

(iii) $B = \tau_y$ and $n = 1$(represented by PD in the Figure)
  Bingham plastic **E.g.:** Sewage sludge, Drilling mud.
  - Certain minimum shear stress τ_y known as yield stress that needs to be applied before they start flowing.

(iv) Thixotropic Fluids: Printers ink, Lipstick.
  - Time dependent fluid i.e., viscosity depends upon both shear stress and duration of application.
  - Viscosity increases or decreases with time.
    E.g.: Paints and enamels, when subjected to high shear by the brush during application of paints, the apparent viscosity is reduced the paint covers the surface smoothly and brush marks disappears subsequently.