



METHODIST
COLLEGE OF ENGINEERING & TECHNOLOGY
(An UGC-AUTONOMOUS INSTITUTION)



Estd : 2008

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FLUID MECHANICS (M24PC303CE)

UNIT-I: PROPERTIES OF FLUIDS

Student Notes

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1. Introduction to Fluid Mechanics

Fluid mechanics is the branch of science concerned with the behaviour of fluids, mainly liquids and gases. The study is commonly organized into three aspects: fluids at rest, fluids in motion without considering pressure forces, and fluids in motion where pressure forces are also considered.

Branch	Main idea
Fluid statics	Study of fluids at rest.
Fluid kinematics	Study of fluid motion without considering the forces causing the motion.
Fluid dynamics	Study of fluid motion in which pressure forces and other forces are considered.

2. Properties of Fluids

The important properties covered in this unit are density, specific weight, specific volume, specific gravity, viscosity, compressibility/bulk modulus, surface tension, capillarity and vapour pressure.

2.1 Density or Mass Density

Density is the mass of fluid contained in unit volume. It is denoted by ρ .

$$\rho = m / V$$

SI unit: kg/m^3 . For liquids, density may be treated as approximately constant, whereas the density of gases varies with pressure and temperature. The density of water used in the reference material is 1000 kg/m^3 .

2.2 Specific Weight / Weight Density

Specific weight is the weight of fluid contained in unit volume. It is denoted by γ (also written as w in the reference material).

$$\gamma = W / V = \rho g$$

SI unit: N/m^3 . For water, $\gamma \approx 9.81 \text{ kN/m}^3$.

Key relation: $\gamma = \rho g$

2.3 Specific Volume

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

$$v = V / m = 1 / \rho$$

SI unit: m^3/kg . The property is particularly useful in dealing with gases.

2.4 Specific Gravity / Relative Density

Specific gravity is the ratio of the density (or specific weight) of a fluid to that of a standard fluid. For liquids, water is used as the standard; for gases, air is used.

For a liquid: $S = \rho_{\text{liquid}} / \rho_{\text{water}}$

$$\text{Therefore, } \rho_{\text{liquid}} = S \times 1000 \text{ kg/m}^3$$

Specific gravity is dimensionless.

Example: If $S = 0.7$, density = $0.7 \times 1000 = 700 \text{ kg/m}^3$.

Worked Example 1: Liquid of known weight

A liquid occupies 1 litre and weighs 7 N. Determine its specific weight, density and specific gravity.

Given: $V = 1 \text{ L} = 0.001 \text{ m}^3$; $W = 7 \text{ N}$.

Specific weight, $\gamma = W/V = 7/0.001 = 7000 \text{ N/m}^3$.

Density, $\rho = \gamma/g = 7000/9.81 \approx 713.5 \text{ kg/m}^3$.

Specific gravity, $S = 713.5/1000 = 0.7135$.

Worked Example 2: Petrol with known specific gravity

One litre of petrol has specific gravity 0.7. Determine its density, specific weight and weight.

Density = $0.7 \times 1000 = 700 \text{ kg/m}^3$.

Specific weight = $700 \times 9.81 = 6867 \text{ N/m}^3$.

Weight = $\gamma V = 6867 \times 0.001 = 6.867 \text{ N}$.

3. Viscosity

Viscosity is the property of a fluid that offers resistance to the relative movement of one fluid layer over an adjacent layer. When neighbouring layers move at different velocities, viscous action produces shear stress.

For a fluid layer, the shear stress is related to the velocity gradient by:

$$\tau = \mu (du/dy)$$

where τ = shear stress, μ = coefficient of dynamic viscosity, and du/dy = velocity gradient (rate of shear deformation).

Thus, dynamic viscosity may be understood as the shear stress required to produce unit rate of shear strain.

3.1 Dynamic Viscosity

Dynamic viscosity is denoted by μ . In SI units its unit is Pa·s (equivalently N·s/m²).

3.2 Kinematic Viscosity

Kinematic viscosity is the ratio of dynamic viscosity to density. It is denoted by ν (nu).

$$\nu = \mu / \rho$$

SI unit: m²/s. In CGS units it is cm²/s, commonly called stoke.

1 stoke = 10⁻⁴ m²/s; 1 centistoke = 10⁻² stoke.

3.3 Newton's Law of Viscosity

Newton's law states that, for a Newtonian fluid, shear stress is directly proportional to the rate of shear strain or velocity gradient.

$$\tau \propto du/dy \rightarrow \tau = \mu(du/dy)$$

Fluids that obey this relation are called Newtonian fluids. Fluids that do not obey it are called non-Newtonian fluids.

3.4 Effect of Temperature on Viscosity

Temperature affects viscosity differently for liquids and gases. According to the supplied reference material, the viscosity of liquids decreases as temperature increases, whereas the viscosity of gases increases as temperature increases.

Fluid	Effect of increasing temperature	Reason described in reference
Liquids	Viscosity decreases	Cohesive forces reduce as temperature increases.
Gases	Viscosity increases	Molecular momentum transfer becomes more significant with increasing temperature.

3.5 Classification of Fluids

Type	Description
Ideal fluid	An imaginary fluid that is incompressible and has no viscosity.
Real fluid	A fluid possessing viscosity; fluids encountered in practice are real fluids.
Newtonian fluid	A real fluid for which shear stress is directly proportional to the rate of shear strain/velocity gradient.
Non-Newtonian fluid	A real fluid for which shear stress is not proportional to the rate of shear strain/velocity gradient.
Ideal plastic fluid	A fluid for which shear stress must exceed a yield value, after which shear stress is proportional to the rate of shear strain/velocity gradient.

4. Compressibility and Bulk Modulus

Compressibility is the reciprocal of the bulk modulus of elasticity. Bulk modulus is defined as the ratio of compressive stress (increase in pressure) to volumetric strain.

For a volume V subjected to an increase in pressure dp , the volume decreases by dV . Therefore:

$$K = - dp / (dV/V) = -V(dp/dV)$$

The negative sign indicates that volume decreases when pressure increases.

$$\text{Compressibility} = 1/K$$

The reference material also introduces the relationship between bulk modulus and pressure for gases under different compression processes, including isothermal compression.

5. Surface Tension

Surface tension is associated with the tensile force acting along the surface of a liquid in contact with a gas or at the interface of immiscible liquids. The free surface behaves like a thin membrane under tension. Surface tension is denoted by σ .

SI unit: N/m.

Molecular explanation: molecules within the liquid experience attractions in all directions. Molecules near the free surface experience an unbalanced resultant attraction, which causes the free surface to behave as though it were an elastic membrane under tension.

5.1 Surface Tension on a Liquid Droplet

For a spherical liquid droplet of diameter d , equilibrium of pressure force and surface-tension force gives:

$$p \times (\pi d^2/4) = \sigma \times \pi d$$

$$\text{Therefore: } p = 4\sigma/d$$

The relation shows that, for a given surface tension, the excess pressure inside a droplet increases as its diameter decreases.

5.2 Surface Tension on a Hollow Bubble

A hollow/soap bubble has two surfaces in contact with air. Therefore, the surface-tension effect occurs on both surfaces.

$$\text{Excess pressure: } p = 8\sigma/d$$

5.3 Surface Tension on a Liquid Jet

For a liquid jet of diameter d , equilibrium of pressure force and surface-tension force gives:

$$p \times L \times d = \sigma \times 2L$$

$$\text{Therefore: } p = 2\sigma/d$$

6. Capillarity

Capillarity is the phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general liquid level. Rise is called capillary rise; fall is called capillary depression. It is generally expressed in mm or cm.

The magnitude depends on the surface tension, specific weight/density of the liquid, tube diameter and angle of contact.

6.1 Capillary Rise

For a small tube of diameter d , the weight of the liquid column is balanced by the vertical component of surface tension.

$$h = 4\sigma \cos\theta / (\rho g d)$$

For water in a clean glass tube, θ is approximately 0° , so $\cos\theta \approx 1$:

$$h = 4\sigma / (\rho g d)$$

6.2 Capillary Depression

When a liquid such as mercury is depressed in a glass tube, the surface-tension force acts downward. The magnitude of depression is obtained from equilibrium:

$$h = 4\sigma \cos\theta / (\rho g d)$$

For depression, the sign/direction is interpreted according to the angle of contact and the direction of the surface-tension component.

7. Vapour Pressure

Vaporization is the change of a liquid into the gaseous state. Molecules continuously escape from the free liquid surface. In a closed vessel, the accumulated vapour exerts pressure on the liquid surface; this is called vapour pressure.

A liquid can boil when the pressure acting on its surface is reduced to a value equal to or below its vapour pressure at the prevailing temperature. Thus, boiling does not necessarily require the liquid to reach its normal boiling temperature if the surrounding pressure is sufficiently reduced.

8. Cavitation

Cavitation occurs in a flowing liquid when the pressure at a location falls to or below the vapour pressure. Vapour bubbles form in the low-pressure region. These bubbles are carried by the flow into a higher-pressure region, where they collapse suddenly.

The collapse produces very high local impact pressures. Repeated bubble collapse can cause pitting and erosion of the adjoining solid/metallic surfaces, producing cavities.

Stage	What happens
1. Low pressure	Local liquid pressure falls to or below vapour pressure.
2. Bubble formation	Liquid vaporizes locally and vapour bubbles form.

3. Bubble transport	Flow carries the bubbles toward a higher-pressure region.
4. Collapse	Bubbles collapse rapidly in the higher-pressure region.
5. Damage	High impact pressure can cause pitting, erosion and cavities on surfaces.

9. Quick Formula Sheet

Property / phenomenon	Formula	Typical SI unit
Density	$\rho = m/V$	kg/m^3
Specific weight	$\gamma = W/V = \rho g$	N/m^3
Specific volume	$v = V/m = 1/\rho$	m^3/kg
Specific gravity (liquid)	$S = \rho/\rho_{\text{water}}$	Dimensionless
Newton's law of viscosity	$\tau = \mu(du/dy)$	τ : Pa; μ : Pa·s
Kinematic viscosity	$\nu = \mu/\rho$	m^2/s
Bulk modulus	$K = -dp/(dV/V)$	Pa
Compressibility	$1/K$	Pa^{-1}
Droplet excess pressure	$p = 4\sigma/d$	Pa
Hollow bubble excess pressure	$p = 8\sigma/d$	Pa
Liquid jet excess pressure	$p = 2\sigma/d$	Pa
Capillary rise magnitude	$h = 4\sigma\cos\theta/(\rho g d)$	m

10. Key Points for Examination

- Differentiate fluid statics, fluid kinematics and fluid dynamics.
- Define density, specific weight, specific volume and specific gravity and state their SI units.
- Derive/use the relationships $\gamma = \rho g$ and $v = 1/\rho$.
- Explain viscosity and state Newton's law of viscosity.
- Distinguish dynamic viscosity from kinematic viscosity.
- Classify fluids as ideal, real, Newtonian, non-Newtonian and ideal plastic fluids.
- Explain why viscosity changes differently with temperature for liquids and gases.
- Define compressibility and bulk modulus and explain the negative sign in the bulk-modulus expression.
- Explain surface tension using molecular attraction and derive excess pressure for a droplet, hollow bubble and liquid jet.
- Define capillarity and derive the expression for capillary rise.
- Explain vapour pressure and the condition for boiling under reduced pressure.
- Explain the mechanism of cavitation and its effect on engineering surfaces.

11. Self-Check Questions

1. Define fluid mechanics and distinguish its three main branches.
2. A liquid weighs 7 N and occupies 1 litre. Find its specific weight, density and specific gravity.
3. A liquid has specific gravity 0.7. Determine its density and specific weight.
4. Define viscosity and explain the physical meaning of the velocity gradient.

5. State Newton's law of viscosity and explain Newtonian and non-Newtonian fluids.
6. Define kinematic viscosity and derive its relation with dynamic viscosity and density.
7. Explain the effect of temperature on the viscosity of liquids and gases.
8. Define bulk modulus and compressibility. Why is a negative sign used in the bulk-modulus relation?
9. Derive the expression for excess pressure inside a liquid droplet.
10. Derive the expression for excess pressure inside a hollow bubble.
11. Derive the expression for capillary rise in a small tube.
12. Differentiate vapour pressure and cavitation.
13. Explain the sequence of events leading to cavitation and its effect on hydraulic/metallic surfaces.

End of Unit-I Notes