FLUID MECHANICS

Topic: UNIT I - Capillarity & Surface Tension Mechanics

Fluid vs Solid: Fundamental Distinction

- Fluids deform continuously under the application of shear stress, no matter how small.
- Solids undergo a finite, static deformation proportional to the applied shear force.
- Fluids lack a fixed shape and assume the contours of their containment vessels.
- Dynamic behavior in fluids is driven primarily by molecular interaction and continuous strain rates.

Mass Density, Specific Weight & Specific Gravity

- Mass Density (ρ): The mass of fluid per unit volume ($\rho = m/V$, standard units: kg/m^3).
- Specific Weight (γ): Gravitational force exerted on a unit volume ($\gamma = \rho g$, units: N/m^3).
- Specific Gravity (S): Dimensionless ratio of fluid density compared to standard pure water at 4°C.
- These foundational parameters govern hydrostatic pressure distributions across all vertical depth profiles.

Viscosity Mechanics: Dynamic vs Kinematic

- Dynamic Viscosity (μ): Internal fluid resistance to shear deformation ($\mu = \tau / (du/dy)$).
- Standard dimensional units for dynamic viscosity are expressed in $N \cdot s/m^3$ or Poise.
- Kinematic Viscosity (v): The ratio of dynamic viscosity to fluid mass density ($v = \mu / \rho$).
- Kinematic metrics match momentum diffusivity fields and are quantified in m^2/s or Stokes.

Newton's Law of Viscosity

- Asserts that shear stress (τ) varies linearly with the spatial rate of shear strain (du/dy).
- Governing Equation: $\tau = \mu \cdot (du/dy)$, where μ acts as the constant coefficient of dynamic viscosity.
- Newtonian Fluids: Maintain constant viscosity values independent of variations in strain rates.
- Non-Newtonian Fluids: Exhibit variable viscosity profiles under fluctuating shear application stresses.

Thermal Impact on Viscosity Variations

- Liquids: Dynamic viscosity decreases markedly as absolute temperature parameters rise.
- Intermolecular cohesive forces dominate liquid structures and break down under thermal expansion.
- Gases: Dynamic viscosity increases proportionally with rising absolute temperature cycles.
- Molecular momentum transfer via rapid kinetic collisions governs gas resistance dynamics.

Vapor Pressure, Boiling & Cavitation

- Vapor Pressure: Pressure exerted by fluid vapor in thermal equilibrium phase changes.
- Boiling occurs when local liquid vapor pressure parameters equal ambient environmental pressures.
- Cavitation: Rapid formation and collapse of vapor bubbles due to highly localized low-pressure drops.
- Structural damage occurs as vapor bubbles implode violently against metallic hydraulic boundary walls.

Surface Tension Principles

- Surface Tension (σ): Intensity of molecular attraction per unit length along liquid boundaries (N/m).
- Driven by unbalanced, inward-directed cohesive forces acting on surface-level fluid molecules.
- Creates a localized tensile membrane layer capable of resisting minor external loading weights.
- Critical parameter governing drop dynamics, meniscus configuration, and multi-phase interfaces.

Capillarity: Rise and Depression Mechanics

- Capillarity: The elevation or depression of a liquid column inside small-diameter conduits.
- Controlled by relative balance between fluid cohesion forces and fluid-solid adhesion properties.
- Capillary Rise: Occurs when adhesion forces dominate (e.g., water on clean glass grids).
- Capillary Depression: Occurs when internal cohesion forces dominate (e.g., liquid mercury on glass).

Mathematical Derivation of Capillary Height

- Derived by equating upward vertical tensile forces directly against liquid column weights.
- Governing Formula: $h = (4 \sigma \cos \theta) / (\rho g d)$.
- Where θ represents contact angle, σ is surface tension, and d is structural tube diameter.
- Engineering Requirement: Manometer tube diameters must exceed 10mm to completely eliminate capillary errors.

Bulk Modulus & Fluid Compressibility

- Bulk Modulus of Elasticity (K): Measures a fluid's volumetric resistance to external uniform pressure.
- Formula: $K = -\, dp / (dV/V) = dp / (d\rho/\rho)$ (standard units: N/m^2 or Pascals).
- Compressibility (β): The reciprocal metric representing fluid volumetric changes ($\beta = 1/K$).
- Liquids are modeled as incompressible ($\beta \approx 0$) across conventional low-velocity civil engineering designs.

Fluid Statics: Pascal's Law & Pressure Variation

- Pascal's Law: Intensity of static pressure at any given coordinate point is equal in all spatial directions.
- Hydrostatic Equation: $dp/dz = -\rho g = -\gamma$, tracking variations with vertical altitude columns.
- Compiles pressure variations across variable temperature, absolute density, and local altitude profiles.
- Forms the analytical baseline for calculating total forces on horizontal, vertical, and inclined surfaces.

UNIT I Summary & High-Yield Viva-Voce Key

- Comprehensive tracking of Unit I core syllabus parameters and theoretical frameworks.
- High-yield focus on governing mathematical derivations and mechanical configurations.

 VIVA-VOCE ASSESSMENT CORE QUESTIONS:

1. Why must manometer tubes have an internal diameter greater than 10mm?
2. Contrast how dynamic viscosity varies with temperature in liquids versus gases.
3. State the criteria required for cavitation to initiate in dynamic flow systems.

Thank You..