Fluid Mechanics I – Expanded Lecture Notes

Based on R.K. Bansal | CUSAT B.Tech Naval Architecture & Shipbuilding (2024 Scheme)

Complete detailed notes covering all 5 modules with derivations, concepts, and explanations suitable for 8- and 16-mark university questions.

MODULE I – Properties of Fluids

Fluid mechanics is the branch of engineering science that deals with the behavior of fluids (liquids and gases) at rest and in motion. A fluid is defined as a substance that deforms continuously when subjected to shear stress, no matter how small that stress may be.

1. Properties of Fluids

Density (ρ): mass per unit volume (kg/m^3). Specific weight (γ): ρg (N/m^3). Specific gravity: ratio of a fluid's density to that of water.

Dynamic viscosity (μ) defines internal resistance to flow: $\tau = \mu(du/dy)$.

Kinematic viscosity ($\nu = \mu/\rho$) expresses viscosity per unit density.

Compressibility (β) is the fractional change in volume per unit pressure change: $\beta = -(1/V)(dV/dp)$.

Surface tension (σ) is the tensile force per unit length acting on a liquid surface, responsible for capillary effects: $h = (4\sigma\cos\theta)/(\rho g d)$.

Newton's Law of Viscosity

Shear stress τ is proportional to velocity gradient du/dy. Newtonian fluids obey $\tau = \mu(du/dy)$; non-Newtonian fluids (e.g., paints, blood) deviate from this behavior.

Capillarity

When a small-diameter tube is dipped in a liquid, the liquid rises or falls. Rise $h = (4\sigma\cos\theta)/(\rho g d)$. This principle helps measure surface tension.

MODULE II – Fluid Statics

1. Pressure Variation in a Fluid

Pressure increases with depth: $dp/dz = -\rho g$. Integrating, $p = p$■ $+ \rho g h$.

Pascal's Law: Pressure at a point in a static fluid acts equally in all directions.

2. Hydrostatic Forces on Surfaces

For a plane surface submerged in a liquid, the total pressure force is $F = \rho g A h_c$, acting at the center of pressure $h_{cp} = h_c + (I_G / (h_c A))$.

3. Buoyancy and Stability of Floating Bodies

Buoyant force F_B = weight of displaced fluid = $\rho g V_{displaced}$.

Metacentric height $GM = BM - BG$, where $BM = I/V$. Stable if G lies below M, neutral if at same level, unstable if above M.

4. Manometers

Used to measure pressure difference. U-tube and differential manometers follow $\Delta p = (\rho_m - \rho_f)gh$. Piezometer measures gauge pressure directly as $p = \rho g h$.

MODULE III – Fluid Kinematics and Dynamics

1. Types of Flow: Steady/unsteady, uniform/non-uniform, laminar/turbulent, rotational/irrotational.
Flow Lines: Streamline (tangent to velocity vector), pathline, streakline.
2. Continuity Equation: For incompressible flow, A■V■ = A■V■ or $\partial u/\partial x + \partial v/\partial y + \partial w/\partial z = 0$.
3. Bernoulli's Equation:
Derived from Euler's equation of motion, integrating along a streamline gives $(p/\rho g) + (V^2/2g) + z =$ constant. It represents the conservation of energy of a fluid particle.
Applications: Venturimeter, Orifice meter, Pitot tube, flow through pipes and over notches.
4. Momentum Equation: F = ■(V■ – V■). Used to compute forces due to fluid jets on vanes and bends.
5. Head Losses:
Major loss $h_f = f(L/D)(V^2/2g)$ (Darcy–Weisbach).
Minor losses $h_m = K(V^2/2g)$ for fittings, bends, expansions.

MODULE IV – Flow Measurement

1. Venturimeter: Based on Bernoulli’s theorem, measures discharge using pressure difference between converging and diverging sections:
$Q = Cd\ (A\blacksquare A\blacksquare\ /\ \sqrt{(A\blacksquare^2 – A\blacksquare^2)})\ \sqrt{(2gh)}$.
2. Orifice Meter: A simple opening in a pipe wall measuring discharge as $Q = Cd\ a\sqrt{(2gh)}$.
3. Pitot Tube: Measures velocity directly from stagnation head: $V = C\sqrt{(2gh)}$.
4. Notches and Weirs:
Rectangular weir: $Q = (2/3)Cd\ b\sqrt{(2g)}H^{3\blacksquare 2}$.
Triangular (V-notch): $Q = 1.417Cd\ H^{\blacksquare\blacksquare 2}$.
Used for open-channel flow measurement.

MODULE V – Dimensional Analysis and Similitude

1. Dimensional Homogeneity: Each term in an equation must have the same dimensions. This ensures physical consistency.
2. Buckingham π Theorem: For a phenomenon involving n variables and k fundamental dimensions, number of dimensionless groups = n – k.
3. Dimensionless Numbers:
$Re = \rho VL/\mu$ – ratio of inertia to viscous forces.
$Fr = V/\sqrt{(gL)}$ – ratio of inertia to gravity forces.
$We = \rho V^2L/\sigma$ – ratio of inertia to surface tension forces.
$Eu = p/(\rho V^2)$ – ratio of pressure to inertia forces.
$Ma = V/a$ – compressibility effect.
4. Similitude and Model Laws:
Geometric similarity: same shape ratios.
Kinematic similarity: velocities and accelerations in ratio.
Dynamic similarity: Forces ratios same (Re, Fr, We equal).
Used in ship model testing, hydraulic structures, and aircraft design.

Exam-Oriented Notes:

8 Mark Questions: Derive Bernoulli’s theorem, explain metacentric height, derive continuity equation, Venturimeter derivation.
16 Mark Questions: Flow through pipes and losses, dimensional analysis, forces on submerged surfaces, jet impact problems.