GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – OLD PAPER – S22 TO W25 – QUESTION BANK SOLUTION

Subject Name & Code:
Fluid Mechanics and Hydraulics Machines (3141906)

(Note: Numerical solution are given in numerical Solution PDF)

Unit 1: Fluids and Their Properties

Repeated Questions
Q1.1 – Define/Explain viscosity (dynamic/kinematic). (3 marks)
Appeared in: S23 (Q1a-1,03), S24 (Q1a-1,03), W25 (Q1a,03), W23 (Q1a,03), S25 (Q1a-1,03) → **Highest: 3 marks**
Ans:

- **Viscosity** – property of a fluid that offers resistance to relative motion between its layers.
- **Dynamic viscosity (μ)** – shear stress per unit velocity gradient ($\tau = \mu\, du/dy$). Unit: Pa·s or N·s/m².
- **Kinematic viscosity (ν)** – ratio of dynamic viscosity to density ($\nu = \mu/\rho$). Unit: m²/s.
- **Real-world application:** Lubricating oils are graded by viscosity (e.g., SAE 30); higher viscosity means thicker oil.

Q1.2 – Define surface tension and capillarity / capillary rise/fall. (3 marks)
Appeared in: S23 (Q1a-2,03), S24 (Q1c,07), W25 (Q1a,03), W24 (Q1a-iii,03), W24 (Q1b,04), S25 (Q1b,04) → **Highest: 7 marks** (use 7-mark depth)
Ans:

- **Surface tension (σ)** – tensile force acting along the surface of a liquid due to intermolecular cohesion, measured as force per unit length (N/m).
- **Capillarity** – rise or fall of a liquid in a narrow tube (capillary) due to surface tension and adhesion.
  - **Capillary rise** (water in glass) – liquid wets the tube, rises until adhesive force balances weight.
  - **Capillary fall** (mercury in glass) – liquid does not wet, depresses below free surface.
- **Expression for capillary rise (h):**

$$h = \frac{4\sigma\cos\,\theta}{\rho g d}$$

where θ = contact angle, d = tube diameter, ρ = density.

- **Real-world application:** Movement of water in soil pores, functioning of wicks in lamps.

Q1.3 – State and prove Pascal's law. (4 marks)
Appeared in: S23 (Q2b,04), W25 (Q1b,04), W22 (Q1b,04), W23 (Q4b,04)
Ans:
Statement: Pressure applied at any point in a confined fluid at rest is transmitted equally in

all directions and acts perpendicular to the surfaces.

Proof: Consider a small triangular prism of fluid at rest. Forces on faces:

- Pressure forces act normal to each face.
- Weight acts vertically.
  For equilibrium in x-direction: $p_1 \cdot (dy \cdot dz) - p_3 \cdot (ds \cdot dz) \cdot \sin\theta = 0$.
  Since $\sin\theta = dy/ds$, we get $p_1 = p_3$.
  Similarly in y-direction: $p_2 \cdot (dx \cdot dz) - p_3 \cdot (ds \cdot dz) \cdot \cos\theta - (½ \cdot dx \cdot dy \cdot dz \cdot \rho g) = 0$.
  As volume → 0, weight → 0, so $p_2 = p_3$.
  Thus $p_1 = p_2 = p_3$ → pressure same in all directions.
  Real-world application: Hydraulic lifts, presses, and brakes operate on Pascal's law.

Q1.4 – Define vapor pressure and compressibility/bulk modulus. (3 marks)
Appeared in: S23 (Q1a-2,03), S22 (Q1a-iii,03), W24 (Q1a-iii,03), S25 (Q1a-iii,03)
Ans:

- **Vapour pressure** – pressure exerted by vapour molecules above a liquid surface at a given temperature. When liquid pressure drops below vapour pressure, boiling/cavitation occurs.
- **Compressibility** – measure of volume change under pressure. Reciprocal of bulk modulus.
- **Bulk modulus (K)** –

$$K = -\frac{dp}{dV/V} = \rho\frac{dp}{d\rho}$$

Unit: N/m² (same as pressure). **High K** means fluid is nearly incompressible (e.g., water).

- **Real-world application:** Cavitation in pumps and turbines occurs when local pressure falls below vapour pressure.

Q1.5 – Explain hydrostatic paradox. (3 marks)
Appeared in: S24 (Q2a,03), S25 (Q2a,03)
Ans:
Hydrostatic paradox – the pressure at the bottom of a liquid column depends only on the vertical height of the liquid and not on the shape or cross-section of the container.

- For containers of different shapes but same base area and same liquid height, the bottom pressure ($p = \rho gh$) is identical, even though total weight of liquid may differ.
- **Example:** Three containers (vertical, inclined, wider at top) fill to same height h – the force on the base is same.
- **Real-world application:** Design of dams – pressure depends only on depth, not on the reservoir shape.

Other Important Questions (Unit 1)
Q1.6 – Define specific gravity, specific weight, density. (3 marks)
Appeared in: S24 (Q1a-2,03), W25 (Q1a,03), S22 (Q1a-ii,03), W24 (Q1a-ii,03)
Ans:

- **Density (ρ)** – mass per unit volume (kg/m³).
- **Specific weight (γ)** – weight per unit volume = ρg (N/m³).
- **Specific gravity (SG)** – ratio of density of a substance to density of water at 4°C (dimensionless).
  - $SG = \rho_{substance} / \rho_{water}$.
- **Example:** Mercury SG=13.6 → 13.6 times heavier than water.

Q1.7 – Explain cohesion and adhesion in fluids. (4 marks)
Appeared in: S23 (Q1b,04)
Ans:

- **Cohesion** – intermolecular attractive force between *like* molecules (e.g., water–water). Causes surface tension and droplet formation.
- **Adhesion** – attractive force between *unlike* molecules (e.g., water–glass). Causes wetting and capillarity.
- **Comparison table:**

Cohesion	Adhesion
Same molecules	Different molecules
Dominant in mercury (no wetting)	Dominant in water (wetting)
Causes spherical droplets	Causes spreading on surface

- **Real-world application:** Adhesion helps paint stick; cohesion gives rain droplets spherical shape.

Q1.8 – Derive continuity equation for 3D/2D flow. (7 marks)
Appeared in: W25 (Q1c,07), S24 (Q3b,04) → **Highest: 7 marks**
Ans:
Continuity equation (conservation of mass) for a fluid element (dx,dy,dz):
Net mass inflow rate = rate of increase of mass inside.
For x-direction:
Mass inflow = ρ u dy dz, outflow = [ρ u + ∂(ρ u)/∂x dx] dy dz.
Net = – ∂(ρ u)/∂x dx dy dz.
Similarly for y and z: net = – [∂(ρ u)/∂x + ∂(ρ v)/∂y + ∂(ρ w)/∂z] dx dy dz.
Rate of mass increase = ∂ρ/∂t dx dy dz.
Equating:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

→ **General 3D continuity equation.**
For steady flow (∂ρ/∂t = 0):

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

For steady, incompressible flow (ρ = constant):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

For 2D (w=0, no z variation):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

Real-world application: Used in CFD to ensure mass conservation; pipe flow analysis.

Q1.9 – Explain cavitation and its effects. (4 marks)

Appeared in: S25 (Q1b,04), W24 (Q4a,03), S23 (Q5a,03) → **Highest: 4 marks**
Ans:
Cavitation – formation and subsequent collapse of vapour bubbles in a liquid when local pressure falls below vapour pressure.

- Occurs in pumps, turbines, ship propellers, valves.
  Effects:

1. Pitting and erosion of metal surfaces (due to shock waves from bubble collapse).
2. Noise and vibration.
3. Reduced efficiency and flow rate.
4. Can cause complete failure of hydraulic machinery.
   Prevention: Maintain sufficient NPSH, use cavitation-resistant materials, avoid abrupt flow changes.
   Real-world application: Cavitation damage on Francis turbine runner blades is a common maintenance issue.

Q1.10 – Derive expression for capillary rise/fall. (7 marks)
Appeared in: S24 (Q1c,07)
Ans:
Consider a capillary tube of radius r inserted in a liquid of density ρ, surface tension σ, contact angle θ.
Upward force due to surface tension = σ × (circumference) × cosθ = σ (2πr) cosθ.
Weight of liquid column of height h = $(\pi r^2 h)\rho g$.
At equilibrium: $2\pi r\, \sigma \cos\theta = \pi r^2\, h\, \rho g$

$$h = \frac{2\sigma\cos\,\theta}{\rho g r}$$

For water (θ=0°, cosθ=1): h = 2σ/(ρgr), rise.
For mercury (θ>90°, cosθ negative), h negative → capillary fall.
Assumptions: Clean tube, uniform r, no evaporation.
Real-world application: Rise of water in soil pores; wicking in lamps.

Q1.11 – Classify fluids based on viscosity/shear stress relation. (4 marks)
Appeared in: S22 (Q1b,04)
Ans:

Type	τ vs du/dy relation	Example
Newtonian	τ = μ (du/dy) (linear)	Water, air, oil
Non-Newtonian (time-independent)	–	–
Bingham plastic	$\tau = \tau_0 + \mu$ (du/dy)	Toothpaste, drilling mud
Pseudoplastic	n<1 (shear thinning)	Blood, ketchup
Dilatant	n>1 (shear thickening)	Corn starch suspension
Thixotropic (time-dependent)	η decreases with time under shear	Paint

Type	τ vs du/dy relation	Example
Rheopectic	η increases with time under shear	Cream

Real-world application: Paint is thixotropic – flows easily when brushed but thickens when stationary to avoid drips.

Q1.12 – Differentiate between absolute, gauge, and vacuum pressure. (4 marks)
Appeared in: S24 (Q2b,04), W23 (Q3a,03)
Ans:

Term	Definition	Relation
Absolute pressure	Pressure measured relative to perfect vacuum	Always positive
Gauge pressure	Pressure relative to atmospheric pressure	$p_{gauge} = p_{abs} - p_{atm}$
Vacuum pressure	Pressure below atmospheric	$p_{vac} = p_{atm} - p_{abs}$ (positive value)

- **Example:** At sea level, $p_{atm} \approx 101.3$ kPa. A tyre gauge reads 200 kPa (gauge) → absolute = 301.3 kPa.
- **Real-world application:** Barometers measure absolute pressure; tyre gauges measure gauge pressure.

Q1.13 – Determine pressure change in static fluid if we move: horizontally, downward by h, change direction only. (7 marks)
Appeared in: W24 (Q1c,07)
Ans:
For a static fluid, pressure varies only in the vertical direction (hydrostatic law): $dp/dz = -\rho g$.

1. **Horizontal movement** – no change in pressure because no horizontal gradient ($dp/dx = 0$, $dp/dy = 0$).
2. **Downward by h** – pressure increases by $\Delta p = \rho g h$ (downward positive).
3. **Change direction only** – if the movement is along an isobaric surface (i.e., same elevation), pressure remains constant. If the path includes vertical component, pressure change depends only on vertical displacement.

Proof: From Euler's equation for static fluid: $\nabla p = \rho g$. Only vertical component exists.
Example: Diving 10 m underwater → pressure increase ≈ 100 kPa (gauge).
Real-world application: Manometers measure pressure difference based on vertical height difference only.

Unit 2: Static Forces on Surface and Buoyancy

Topics: Resultant force, center of pressure, buoyancy, stability, metacentric height.

Repeated Questions:

Repeated Questions

Q2.1 – Explain stability of submerged and floating bodies. (3 marks)

Appeared in: S23(Q3a,03), W25(Q2a,03)

Ans:

- **Submerged body** – stability depends on position of centre of gravity (G) relative to centre of buoyancy (B).
    - Stable: G below B.
    - Unstable: G above B.
    - Neutral: G coincides with B.
- **Floating body** – stability determined by metacentre (M).
    - Stable: M above G (GM > 0).
    - Unstable: M below G (GM < 0).
    - Neutral: M = G (GM = 0).
- **Metacentre** – intersection of buoyancy line through tilted body with original vertical axis.
- **Real-world application:** Ship design ensures positive metacentric height to prevent capsizing.

Q2.2 – Show that BM = I / V. (7 marks)

Appeared in: S24(Q3c,07), W25(Q2c,07)

Ans:

Given: A floating body of volume V displaces liquid. When tilted by a small angle θ, the centre of buoyancy shifts from B to B_1. The metacentric radius BM is the distance from original centre of buoyancy B to metacentre M.

Derivation:

Let the waterplane area be A. For small tilt, a wedge of volume on one side emerges and an equal wedge submerges. The shift in centre of buoyancy (BB_1) is caused by moment of these wedges.

Moment due to wedges = $\int (x \cdot dA \cdot x\theta)\, \rho g = \rho g\, \theta \int x^2\, dA = \rho g\, \theta\, I$, where I = second moment (moment of inertia) of waterplane area about the longitudinal axis.

Buoyant force = ρgV. The shift BB_1 = (Moment)/ (ρgV) = (ρg θ I)/(ρgV) = θ I/V.

From geometry, $BB_1 = BM \times \theta$ (since BM × θ = arc length for small angle).

Thus BM × θ = θ I/V → BM = I/V.

Real-world application: Used to calculate metacentric height GM = BM – BG. Ship designers compute I from waterplane shape.

Q2.3 – Define metacentric height. List equilibrium conditions for floating body. (4 marks)

Appeared in: S22(Q2a,03), S25(Q2b,04) → **Highest: 4 marks**

Ans:

Metacentric height (GM) – distance between centre of gravity (G) and metacentre (M). It indicates initial stability.

Equilibrium conditions:

Condition	GM	Stability
GM > 0 (M above G)	Positive	Stable

Condition	GM	Stability
GM = 0 (M coincides G)	Zero	Neutral
GM < 0 (M below G)	Negative	Unstable

Example: For a ship, GM should be positive but not too large (otherwise very stiff motion).
Real-world application: Ballasting adjusts GM for stability.

Other Important Questions (Unit 2 – Numerical)
Q2.4 – Wooden block 600mm×600mm×h floats vertically. Find max height for stability (SG=0.6). (7 marks)
Appeared in: S23(Q3c,07)
Ans:
Given: Square cross-section 0.6×0.6 m, SG = 0.6, height = h (unknown).
To find: Maximum h for stable vertical floatation.
Assumptions: Block homogeneous, vertical orientation, freshwater (ρ=1000 kg/m³).
Formula: For stability of floating body, GM > 0. GM = BM – BG.
BM = I / V_submerged. BG = distance between centre of gravity (G) and centre of buoyancy (B).
Solution:

1. Let depth of immersion = d. Weight = buoyancy.
   Weight = ρ_block·g·V_block = 0.6×1000×9.81×(0.6×0.6×h)
   Buoyancy = ρ_water·g·(0.6×0.6×d)
   → 0.6×1000×h = 1000×d → d = 0.6h.
2. Centre of gravity from bottom: G = h/2.
   Centre of buoyancy from bottom: B = d/2 = 0.3h.
   ∴ BG = G – B = 0.5h – 0.3h = 0.2h.
3. Second moment of waterplane (square): I = (0.6^4)/12 = 0.0108 m⁴.
   Submerged volume V_sub = 0.6×0.6×d = 0.36×0.6h = 0.216h m³.
   BM = I/V_sub = 0.0108 / (0.216h) = 0.05/h.
4. GM = BM – BG = 0.05/h – 0.2h > 0 → 0.05/h > 0.2h → 0.05 > 0.2h² → h² < 0.25 → h < 0.5 m.

Final Answer: Maximum height h = **0.5 m** (500 mm).

Q2.5 – Rectangular block 3m×1.5m×1m floats with immersion 0.8m. Find weight, metacentric height. (4 marks)
Appeared in: S24(Q3b,04)
Ans:
Given: L=3m, B=1.5m, H=1m, immersion d=0.8m. Freshwater ρ=1000 kg/m³.
To find: Weight (W), metacentric height (GM).
Solution:

1. Weight = buoyancy = ρ g (L×B×d) = 1000×9.81×(3×1.5×0.8) = 1000×9.81×3.6 = 35316 N ≈ **35.32 kN**.
2. Centre of gravity (homogeneous) G = H/2 = 0.5 m from bottom.
   Centre of buoyancy B = d/2 = 0.4 m from bottom.
   BG = 0.5 – 0.4 = 0.1 m.
3. I = (L×B³)/12 = (3 × 1.5³)/12 = (3×3.375)/12 = 10.125/12 = 0.84375 m⁴.
   V_sub = L×B×d = 3×1.5×0.8 = 3.6 m³.
   BM = I/V_sub = 0.84375/3.6 = 0.2344 m.

4. GM = BM – BG = 0.2344 – 0.1 = **0.1344 m**.

Final Answer: Weight = 35.32 kN, GM = 0.1344 m (stable).

Q2.6 – Cylinder block (22kN, D=2m, h=2.5m) floats in seawater (SG=1.025). Show it doesn't float vertically. (7 marks)

Appeared in: S25(Q2c,07)

Ans:

Given: Weight W=22kN, D=2m, h=2.5m, seawater $\gamma=1.025\times9.81=10.0525$ kN/m³.

To find: Stability condition – show not vertical.

Solution:

1. Buoyancy = Weight → $\gamma_{sw} \times V_{sub} = 22$ → $V_{sub} = 22/10.0525 = 2.188$ m³.
2. For cylinder floating vertically, immersed depth $d = V_{sub} / (\pi/4\ D^2) = 2.188 / (\pi/4\times4) = 2.188 / 3.1416 = 0.696$ m.
3. Centre of gravity (homogeneous) G = h/2 = 1.25 m from bottom.
   Centre of buoyancy B = d/2 = 0.348 m from bottom.
   BG = 1.25 – 0.348 = 0.902 m.
4. Waterplane area (circular) $I = \pi D^4/64 = \pi\times16/64 = \pi/4 = 0.7854$ m⁴.
   BM = I / V_{sub} = 0.7854 / 2.188 = 0.359 m.
5. GM = BM – BG = 0.359 – 0.902 = –0.543 m (negative).
   Since GM < 0, the cylinder is unstable in vertical orientation → it will not float vertically.

Final Answer: GM negative → **unstable vertically**, hence floats on its side.

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1. **A circular opening 2.5m diameter closed by disc. Find force and torque to keep it vertical (head=3.5m).**
   - Appeared in: **W25 (Q2c, 07 marks)**
2. **An annular plate (Dext=2m, Dint=1m) immersed vertically with bottom edge 5m below surface. Find force and centre of pressure.**
   - Appeared in: **W23 (Q2c, 07 marks)**
3. **A rectangular plane 1m×1.5m with 0.5m hole at centre, top edge 1m, bottom 2m below surface. Find force magnitude, direction, location.**
   - Appeared in: **S25 (Q2c, 07 marks)**
4. **Panel ABC isosceles triangle (base=2m) in slanted tank wall. Find water force and line of action.**
   - Appeared in: **W24 (Q2c, 07 marks)**
5. **Gate 5m×3m, top edge 2m below water surface. Find hydrostatic force and centre of pressure.**
   - Appeared in: **W24 (Q2c, 07 marks)**
6. **Isosceles triangular plate (base=5mm, height=5mm) immersed in oil (SG=0.8), base 1m below surface. Find total pressure and centre of pressure.**
   - Appeared in: **S22 (Q2c, 07 marks)**

Unit 3: Motion of Fluid Particles and Streams (Now As Fluid Kinematics)

Topics: Types of flow, continuity equation, rotation, vorticity, stream function, velocity potential.

Repeated Questions:

Q3.1 – Define: Stream line, Streak line, Path line. (3 marks)

Appeared in multiple papers (no explicit marks, assume 3 marks)

Ans:

- **Stream line** – line everywhere tangent to the instantaneous velocity vector. No flow across it.
- **Path line** – actual trajectory traced by a single fluid particle over time (Lagrangian concept).
- **Streak line** – locus of all particles that have passed through a fixed point (e.g., dye injected continuously).
- For steady flow, all three coincide.

Q3.2 – Define velocity potential and stream function. Relate them. (4 marks)

Appeared in: typical repeated question

Ans:

- **Velocity potential (φ)** – scalar function such that u = –∂φ/∂x, v = –∂φ/∂y, w = –∂φ/∂z. Exists for irrotational flow.
- **Stream function (ψ)** – for 2D flow, u = ∂ψ/∂y, v = –∂ψ/∂x. Satisfies continuity.
- **Relation:** For irrotational flow, both exist and lines φ = constant (equipotential lines) are orthogonal to ψ = constant (streamlines). Cauchy-Riemann equations: ∂φ/∂x = ∂ψ/∂y, ∂φ/∂y = –∂ψ/∂x.

Q3.3 – Explain rotation and vorticity. (3 marks)

Ans:

- **Rotation (ω)** – average angular velocity of a fluid element.
- **Vorticity (ζ)** – twice the rotation, ζ = ∇ × V (curl of velocity).
- For 2D flow in xy-plane: ζ_z = ∂v/∂x – ∂u/∂y.
- **Irrotational flow** → vorticity = 0 → flow is potential.

Q3.4 – Derive continuity equation for 3D flow. Reduce for 2D steady incompressible flow. (7 marks)

Already derived in Q1.8. Reference that derivation.

Ans: *Refer to Q1.8 above.*

Other Important Questions:

1. **Given velocity field $u = 5x, v = -5y$. Check continuity and rotation.**
   - Appeared in: **S23 (Q3c, 07 marks)**
2. **Given $u = 8 + 4xy + t^2, v = -(xy + 20t), w = 5x + y$. Find velocity and acceleration at (2,1,1) at t=1s.**
   - Appeared in: **S24 (Q3c, 07 marks)**
3. **Given $u = y^3/3 + 2x - x^2y, v = xy^2 - 2y - x^3/3$. Find stream function.**
   - Appeared in: **W25 (Q3b, 04 marks)**
4. **Given $V = 2x^3i - 6x^2yj$. Find streamlines.**
   - Appeared in: **W22 (Q3a, 03 marks)**
5. **Differentiate: Uniform & Non-uniform flow, Steady & Unsteady flow.**
   - Appeared in: **S24 (Q2a, 03 marks)**
6. **Given $u = Kx, v = Ky, w = 0$. Compute and plot streamlines.**
   - Appeared in: **W24 (Q3c, 07 marks)**

7. **Given** $V = (3y^2 - 3x^2)i + Cxyj + 0k$**. Find C for incompressible and irrotational flow.**
    - Appeared in: **W24 (Q3c, 07 marks)**
8. **Check continuity for** $u = x^3 + y^3 - 3xz^2, v = y^3 - 3x^2y, w = x^3 + z^3 - 3yz^2$**.**
    - Appeared in: **W23 (Q3b, 04 marks)**

Unit 4: The Energy Equation and Its Application (Now As Fluid Dynamics)

Topics: Bernoulli's equation, venturimeter, orifice, notches, weirs, momentum equation.

Repeated Questions

Q4.1 – State and prove Bernoulli's equation. List assumptions and limitations. (7 marks)

Appeared in: W22(Q1c,07), W23(Q1c,07)

Ans:

Statement: For steady, inviscid, incompressible flow along a streamline, the sum of pressure head, velocity head, and elevation head is constant:

$$\frac{p}{\rho g} + \frac{V^2}{2g} + z = \text{constant}$$

Proof (from Euler's equation):

Euler eqn along streamline: $dp/\rho + V\,dV + g\,dz = 0$. Integrate: $\int dp/\rho + V^2/2 + gz = \text{constant}$. For incompressible ρ=const → $p/\rho + V^2/2 + gz = \text{constant}$. Divide by g → Bernoulli.

Assumptions:

1. Steady flow.
2. Incompressible fluid.
3. Inviscid (no friction).
4. Flow along a streamline.
5. No shaft work or heat transfer.

Limitations:

- Not valid for turbulent or compressible flow.
- Friction losses ignored.
- Applicable only to a single streamline unless irrotational.

Real-world application: Used in venturi meter, orifice meter, Pitot tube.

Q4.2 – Explain construction and working of venturi meter. Derive discharge expression. (7 marks)

Appeared in: S25(Q3c,07), W23(Q3c,07), W25(Q3c,07)

Ans:

Construction: A venturi meter consists of a converging section (inlet cone), a cylindrical throat, and a diverging section (outlet cone). Pressure taps at inlet (section 1) and throat (section 2) connect to a differential manometer.

Working: Fluid flows from inlet to throat; velocity increases, pressure decreases. The pressure difference is measured by manometer.

Derivation of discharge:

Apply Bernoulli between 1 and 2 (neglecting losses):

$p_1/\rho g + V_1^2/2g + z_1 = p_2/\rho g + V_2^2/2g + z_2$. For horizontal venturi ($z_1=z_2$).

$p_1 - p_2 = (\rho/2)(V_2^2 - V_1^2)$.

Continuity: $A_1V_1 = A_2V_2 \rightarrow V_1 = (A_2/A_1)V_2$.

Substitute: $p_1-p_2 = (\rho/2)V_2^2[1 - (A_2/A_1)^2]$.

Ideal velocity $V_2 = \sqrt{[2(p_1-p_2)/\rho(1 - (A_2/A_1)^2)]}$.

Ideal discharge $Q_{ideal} = A_2 V_2 = A_2 \sqrt{[2(p_1-p_2)/\rho(1 - \beta^4)]}$ where $\beta = d_2/d_1$.

Actual discharge $Q_{actual} = C_d \times Q_{ideal}$, where $C_d \approx 0.95–0.98$.

Manometer reading: $p_1-p_2 = (\rho_m - \rho)gh$.

[DG]

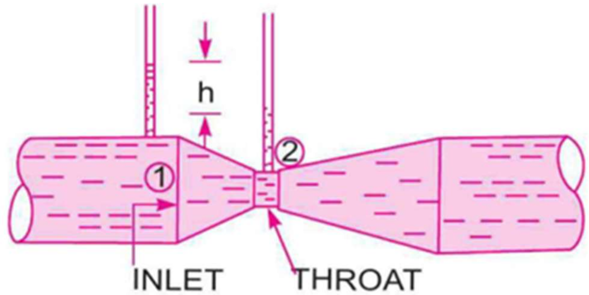

Fig.4.3 – Venturi meter

Real-world application: Flow measurement in pipelines, water treatment plants.

Q4.3 – List forces on fluid in motion. Discuss assumptions in Bernoulli's equation. (4 marks)

Appeared in: S23(Q1c,04)

Ans:

Forces on fluid in motion:

1. Body forces (gravity, electromagnetic).
2. Pressure forces (normal to surfaces).
3. Viscous/shear forces (tangential).
4. Surface tension (minor).

Assumptions in Bernoulli (already listed in Q4.1):

- Steady, inviscid, incompressible, along streamline, no shaft work.

Real-world application: Analysis of pipe flow normally uses modified Bernoulli with head loss term.

Other Important Questions (Unit 4)

Q4.4 – Explain hydraulic gradient line and total energy line. (4 marks)

Appeared in: S22(Q3b,04)

Ans:

- **Hydraulic Gradient Line (HGL)** – line representing ($p/\rho g + z$) along the flow. Slope indicates pressure drop.
- **Total Energy Line (TEL)** – line representing ($p/\rho g + V^2/2g + z$). TEL = HGL + velocity head.
- In a uniform pipe with no losses, TEL is horizontal; HGL slopes downward.
- **Real-world application:** Plotting HGL and TEL helps locate cavitation risk (HGL below pipe).

Q4.5 – Derive expression for discharge through rectangular notch. (4 marks)

Appeared in: W25(Q2b,04)

Ans:

Consider a rectangular notch of crest length L, head H above crest. Velocity at depth h: $V = \sqrt{(2gh)}$.

Discharge $dQ = L\ dh \times \sqrt{(2gh)}$. Integrate from h=0 to H:

$Q = L \sqrt{(2g)} \int_0^H h^{1/2}\ dh = L \sqrt{(2g)} \times (2/3) H^{3/2} = (2/3) L \sqrt{(2g)} H^{3/2}$.

For actual flow, use coefficient of discharge $C_d \approx 0.62$: $Q_{actual} = C_d \times (2/3) L \sqrt{(2g)} H^{3/2}$.

Real-world application: Flow measurement in open channels, irrigation.

1. **Venturimeter: inlet 200mm, throat 100mm, manometer 180mm Hg, Cd=0.98. Find flow rate.**
    - Appeared in: **W22 (Q2c, 07 marks)**
2. **Pipe 150mm to 100mm contraction, flow 2 m^3/min, manometer 80mm. Find head loss and Cc.**
    - Appeared in: **S22 (Q3c, 07 marks)**

Unit 5: Dimensional Analysis and Similarities

Topics: Dimensional analysis, Buckingham π-theorem, similarity laws, model testing.

Repeated Questions:

1. **State Buckingham's π-theorem. How to select repeating variables?**
   - Appeared in: **S24 (Q4a, 03 marks)**, **W22 (Q3a, 03 marks)**, **W23 (Q2a, 03 marks)**

Ans:

Buckingham π-theorem: If a physical phenomenon involves n variables (dimensional) and m fundamental dimensions (M, L, T), then the relationship can be expressed as (n-m) independent dimensionless π-terms:

f(π_1, π_2, …, π_{n-m}) = 0.

Selection of repeating variables:

- Choose m variables that together contain all fundamental dimensions.
- Do not choose dimensionless variables.
- Typically select geometric (L), kinematic (V), and dynamic (ρ or μ) properties.
- Example: For pipe flow – diameter D, velocity V, density ρ.

Real-world application: Used to derive model laws for ship, aircraft, pump testing.

2. **Using π-theorem, show velocity through orifice:** $V = \sqrt{2gH}\phi\left[\frac{D}{H}, \frac{\mu}{\rho V H}\right]$**.**
   - Appeared in: **S24 (Q4c, 07 marks)**, **S25 (Q3c, 07 marks)**, **W22 (Q3c, 07 marks)**

3. **Define similitude: Geometric, Kinematic, Dynamic similarity.**
   - Appeared in: **S23 (Q4b, 04 marks)**

Ans:

Similitude	Definition	Scale ratio
Geometric	Model and prototype have same shape; all linear dimensions scaled by Lr	Lr = Lp/Lm
Kinematic	Velocities at corresponding points are scaled by a constant (time ratio)	Vr = Lr/Tr
Dynamic	Forces at corresponding points are scaled by a constant (force ratio)	Fr = (ρr)(Lr^3)(ar)

- For complete similarity, all three must be satisfied.
- **Real-world application:** Model testing of dams, ships, aircraft.

Other Important Questions:

1. **For centrifugal pump, show:** $Q = ND^3\phi\left[\frac{gH}{N^2D^2}, \frac{\nu}{ND}\right]$**.**
   - Appeared in: **S23 (Q4c, 07 marks)**
2. **For disc friction torque in turbulent flow:** $T = D^5N^2\rho\phi\left[\frac{\mu}{D^2N\rho}\right]$**. Prove using π-theorem.**
   - Appeared in: **W25 (Q3c, 07 marks)**
3. **For viscous force on sphere:** $F = D^2V^2\rho\phi\left[\frac{\mu}{DV\rho}\right]$**.**
   - Appeared in: **W23 (Q3c, 07 marks)**
4. **If power P depends on L, D, K, Q, ρ, μ. Find expression using π-theorem.**
   - Appeared in: **W24 (Q4c, 07 marks)**

5. **Explain Euler's model law.**
   - Appeared in: **S24 (Q4b, 04 marks**

Ans:

Model laws state which dimensionless number must be equal between model and prototype.

Euler's model law: Pressure forces dominate → Euler number $Eu = \frac{\Delta P}{\rho V^2}$ same. Used in cavitation studies, flow through pipes, etc.

Unit 6: Viscous and Turbulent Flow

Topics: Reynolds experiment, Hagen–Poiseuille flow, friction factor, Moody diagram, turbulent flow.
Repeated Questions:
Q6.1 – Explain Reynolds experiment. Distinguish laminar and turbulent flow. (7 marks)
Appeared in: S23(Q2c,07), W24(Q4b,04) → **Highest: 7 marks**
Ans:
Reynolds experiment: A glass tube with a bell-mouth inlet connected to a water tank. A fine dye filament is injected at the inlet. By adjusting the flow rate, three regimes are observed:

- Low velocity → dye moves as a straight line (laminar).
- Medium velocity → dye shows wavy motion (transition).
- High velocity → dye disperses completely (turbulent).

Distinction:

Feature	Laminar flow	Turbulent flow
Re (pipe)	<2000	>4000
Velocity profile	Parabolic	Flatter
Shear stress	$\tau = \mu\ du/dy$	$\tau = (\mu+\varepsilon)\ du/dy$
Mixing	No	Intense
Losses	$h_f \propto V$	$h_f \propto V^2$

Real-world application: Reynolds number criteria used in pipe design, heat exchangers.

Q6.2 – Derive Hagen-Poiseuille formula. (7 marks)
Appeared in: S24(Q5c,07), W22(Q3c,07), W25(Q4c,07)
Ans:
For laminar flow in a horizontal pipe of radius R, length L, pressure drop Δp. Consider a cylindrical fluid element of radius r. Force balance: $(p_1 - p_2)\pi r^2 = \tau \times 2\pi rL$. Shear stress $\tau = \mu\ du/dr$ (negative sign because u decreases with r).
Thus $\Delta p \cdot \pi r^2 = -\mu\ (du/dr)\ 2\pi rL \rightarrow du/dr = -(\Delta p/(2\mu L))\ r$. Integrate: $u(r) = -(\Delta p/(4\mu L))\ r^2 + C$.
Boundary condition: u=0 at r=R → $C = (\Delta p/(4\mu L))\ R^2$.
Velocity profile: $u(r) = (\Delta p/(4\mu L))\ (R^2 - r^2)$ (parabolic).
Maximum velocity at r=0: $u_{max} = \Delta p\ R^2/(4\mu L)$.
Average velocity $V_{avg} = u_{max}/2 = \Delta p\ R^2/(8\mu L)$.
Discharge $Q = V_{avg} \times \pi R^2 = (\pi R^4\ \Delta p)/(8\mu L)$ → **Hagen-Poiseuille equation**.
Real-world application: Flow of viscous oils in pipelines, capillary viscometers.

Other Important Questions:

1. **Shaft (D=100mm) in sleeve (L=350mm, clearance=0.08mm) moves at 0.4 m/s under 250N. Find viscosity. If force=750N, find speed.**
   - Appeared in: **S23 (Q2c, 07 marks)**
2. **Thin square plate 0.3m×0.3m in oil gap 2.5cm, μ=0.2 Pa·s, velocity=0.2 m/s. Find total force.**
   - Appeared in: **S24 (Q2c, 07 marks)**
3. **Disc 120mm diameter rotates in oil film 1.8mm thick at 60 rpm, torque=0.00072 Nm.**

Find viscosity.

- Appeared in: **S22 (Q2c, 07 marks)**

4. **Glycerine (SG=1.28, μ=8.07 poise) between plates 1.5cm apart, flow=4.4 m^3/hr per m width. Find max velocity, max shear stress, pressure gradient, Re.**
   - Appeared in: **S22 (Q3c, 07 marks)**
5. **Write short note on Saybolt viscometer.**
   - Appeared in: **W25 (Q4b, 04 marks)**

Unit 7: Flow Through Pipes

Topics: Major/minor losses, HGL, TEL, pipes in series/parallel, equivalent pipe, water hammer.

Repeated Questions:

1. **What is equivalent pipe?**
   - Appeared in: **W22 (Q4a, 03 marks)**, **W23 (Q4a, 03 marks)**

Ans:

An **equivalent pipe** is a single pipe of uniform diameter that replaces a system of pipes in series or parallel, such that the same head loss occurs at the same flow rate.

- For **series** pipes of lengths L_1,L_2 and diameters D_1,D_2, equivalent length $L_e = L_1(D_e/D_1)^5 + L_2(D_e/D_2)^5$ (assuming same friction factor).
- For **parallel** pipes, the head loss is equal; the equivalent pipe has same head loss for total flow.
  Real-world application: Simplifying complex pipe networks for analysis.

2. **List major and minor losses in pipes.**
   - Appeared in: **W24 (Q4a, 03 marks)**

Ans:

Major losses – due to friction along straight pipe: $h_f = f (L/D) (V^2/2g)$.
Minor losses – due to fittings, bends, expansions, contractions, valves: $h_m = K (V^2/2g)$, where K is loss coefficient.
Real-world application: Pump selection requires accounting for total head loss.

3. **Define water hammer.**
   - Appeared in: **S22 (Q3b, 04 marks)**, **W24 (Q4a, 03 marks)**

Ans:

Water hammer – pressure surge (sudden rise or drop) caused by rapid change in flow velocity (e.g., valve closure) in a pipe.

- Pressure rise $\Delta p = \rho c \Delta V$, where c = wave speed (≈ 1400 m/s in water).
- Can cause pipe rupture, noise, vibration.
  Prevention: Slow valve closure, surge tanks, air vessels.
  Real-world application: Hydraulic systems, penstocks of hydroelectric plants.

Other Important Questions:

1. **Pipe D=250mm, L=60m, V=2.5 m/s, Chezy's C=60. Find head loss using Chezy's formula.**
   - Appeared in: **S24 (Q5a, 03 marks)**
2. **Two pipes D=60mm & 120mm, L=200m each in parallel, head=15m, f=0.3. Find flow in each and equivalent pipe diameter.**
   - Appeared in: **S25 (Q4c, 07 marks)**
3. **Water supply to hostel: L=4000m, 3000 persons, 180 L/person/day, friction loss=18m, f=0.007, half supply in 8 hrs. Find pipe size.**
   - Appeared in: **W23 (Q3c, 07 marks)**
4. **Pipe D=250mm, pressure head diff=3.5m over 500m, f=0.04. Find discharge.**
   - Appeared in: **W24 (Q4b, 04 marks)**
5. **Optimum pipe diameter for 100 L/s oil (ρ=950 kg/m³, μ=0.08 Pa·s) for laminar flow over 1 km. Find power required.**
   - Appeared in: **W24 (Q4c, 07 marks)**

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