Subject Name & Code:

FLUID MECHANICS - BE04000161

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Experiment No: 1 – Verification of Pascal's Law and Hydrostatic Pressure

1. Explain Pascal's Law.

Pascal's Law states that in an enclosed, stationary, incompressible fluid at rest, the pressure applied at any point is transmitted equally and undiminished in all directions throughout the fluid and acts perpendicular to the walls of the container.

Mathematically:

$$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Practical significance:
This principle is used in hydraulic lifts, hydraulic brakes, and hydraulic presses, where a small input force generates a large output force.

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2. Explain hydrostatic law.

Hydrostatic law states that the rate of increase of pressure in a fluid at rest in the vertical direction is equal to the weight density of the fluid at that point.

Mathematically:

$$\frac{dP}{dz} = -\rho g$$

For a constant density fluid, pressure at depth h is:

$$P = P_0 + \rho g h$$

where P_0 is atmospheric pressure.

Observation from experiment:
Water jet from the bottom hole travels farthest because pressure increases with depth.

Experiment No: 2 – Metacentric Height

1. Explain Archimedes' principle.

Archimedes' principle states that when a body is fully or partially submerged in a fluid, it experiences an upward buoyant force equal to the weight of the fluid displaced by the body.

$$F_b = \rho_{\text{fluid}} \cdot V_{\text{displaced}} \cdot g$$

This principle explains why ships float and is used to determine the density of objects.

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2. Enlist stability criteria of submerged and floating bodies.

Type of Body	Stable Equilibrium	Unstable Equilibrium	Neutral Equilibrium
Submerged	Center of gravity (G) below center of buoyancy (B)	G above B	G coincides with B
Floating	Metacenter (M) above G	M below G	M coincides with G

3. Define: Buoyancy, Center of Buoyancy, Metacenter, Metacentric height.

- **Buoyancy:** Upward force exerted by a fluid on a submerged or floating body, equal to the weight of displaced fluid.
- **Center of Buoyancy (B):** Geometric center of the displaced volume of fluid; point where buoyant force acts.
- **Metacenter (M):** Point of intersection of the line of action of buoyant force (through B) with the vertical axis of the body when tilted slightly.
- **Metacentric height (GM):** Distance between center of gravity (G) and metacenter (M). Determines stability of floating bodies.

4. Write the practical significance of Metacentric height.

- **Ship design:** Ensures stability against tilting due to waves, wind, or cargo shifts.
- **Submarine operation:** Helps maintain controlled underwater orientation.
- **Floating platforms:** Used in offshore drilling and pontoon bridges.
- **Safety regulation:** Minimum GM values are mandated for passenger and cargo ships.

Experiment No: 3 – Verification of Bernoulli's Theorem

1. State and derive Bernoulli's equation.

Statement:
For an ideal, incompressible fluid in steady, irrotational flow, the total mechanical energy per unit weight remains constant along a streamline.

$$\frac{P}{\rho g} + \frac{v^2}{2g} + z = \text{constant}$$

Derivation (from Euler's equation):
Consider a streamline element ds. Force balance along streamline:

$$P\,dA - (P + dP)\,dA - \rho g\,dA\,dz = \rho\,dA\,ds\,a_s$$

With $a_s = v\frac{dv}{ds}$:

$$-dP - \rho g\,dz = \rho v\,dv$$

Divide by ρ:

$$-\frac{dP}{\rho} - g\,dz = v\,dv$$

For incompressible flow (ρ constant), integrate:

$$\frac{P}{\rho} + gz + \frac{v^2}{2} = \text{constant}$$

Divide by g:

$$\frac{P}{\rho g} + z + \frac{v^2}{2g} = \text{constant}$$

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2. Assumptions while deriving Bernoulli's equation.

1. Fluid is **ideal** (inviscid – no viscosity).
2. Flow is **steady** (no change with time at a point).
3. Fluid is **incompressible** (constant density).
4. Flow is **irrotational** or along a streamline.
5. No energy added or removed (no pumps/turbines).

6. No heat transfer.

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3. Limitations of Bernoulli's equation.

- Not valid for **compressible flows** (gases at high speed).
- Fails in **viscous flows** where friction losses are significant.
- Cannot be applied across **shock waves**.
- Does not account for **rotational effects** (vortices, wakes).
- Inapplicable in unsteady or turbulent flow regions without correction.

Experiment No: 4 – Venturimeter

Explain venturimeter.

A **venturimeter** is a flow measurement device consisting of three sections:

1. **Converging cone** – velocity increases, pressure decreases.
2. **Throat** – minimum area, maximum velocity, minimum pressure.
3. **Diverging cone** – velocity decreases, pressure recovers.

Working principle: Based on Bernoulli's equation and continuity equation. Pressure difference between inlet and throat gives flow rate.

Advantages: Low head loss, high accuracy, less clogging.

Derive an expression for discharge through venturimeter.

Given:

- A_1, P_1, v_1 at inlet
- A_2, P_2, v_2 at throat
- Horizontal venturimeter ($z_1 = z_2$)

Step 1 – Continuity equation:

$$A_1 v_1 = A_2 v_2 \Rightarrow v_1 = \frac{A_2}{A_1} v_2$$

Step 2 – Bernoulli's equation (neglecting losses):

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g}$$

Step 3 – Simplify pressure terms:
Let $h = \frac{P_1 - P_2}{\rho g}$ (differential head).

$$h = \frac{v_2^2 - v_1^2}{2g}$$

Substitute v_1:

$$h = \frac{v_2^2 - \left(\frac{A_2}{A_1} v_2\right)^2}{2g} = \frac{v_2^2 \left[1 - \left(\frac{A_2}{A_1}\right)^2\right]}{2g}$$

Step 4 – Solve for v_2:

$$v_2 = \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Step 5 – Theoretical discharge:

$$Q_{\text{th}} = A_2 v_2 = A_2 \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Step 6 – Actual discharge (with coefficient of discharge C_d):

$$Q_{\text{act}} = C_d \cdot A_2 \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Where h is the pressure head difference measured by manometer.

Experiment No: 5 – Orifice Meter

1. Explain orifice meter.

An **orifice meter** is a flow measurement device consisting of a thin circular plate with a concentric hole (orifice) placed inside a pipe. When fluid flows through the orifice, the area suddenly decreases, causing an increase in velocity and a drop in pressure. This pressure difference is measured using a manometer and correlated to the flow rate.

Working principle: Same as venturimeter — Bernoulli's equation + continuity equation. However, due to sudden contraction and expansion, head loss is higher.

Applications: Used in pipelines where moderate accuracy is acceptable and cost is a constraint.

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2. Derive an expression for discharge through orifice meter.

Given:

- Pipe diameter = D_1, Area = A_1, Pressure = P_1, Velocity = v_1
- Orifice diameter = D_2, Area = A_2, Pressure = P_2, Velocity = v_2
- Horizontal pipe ($z_1 = z_2$)

Step 1 – Continuity equation:

$$A_1 v_1 = A_2 v_2 \Rightarrow v_1 = \frac{A_2}{A_1} v_2$$

Step 2 – Bernoulli's equation (neglecting losses):

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g}$$

Step 3 – Pressure head difference:
Let $h = \frac{P_1 - P_2}{\rho g}$ (differential head in meters of fluid). Then:

$$h = \frac{v_2^2 - v_1^2}{2g}$$

Substitute v_1:

$$h = \frac{v_2^2 - \left(\frac{A_2}{A_1} v_2\right)^2}{2g} = \frac{v_2^2 \left[1 - \left(\frac{A_2}{A_1}\right)^2\right]}{2g}$$

Step 4 – Solve for v_2:

$$v_2 = \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Step 5 – Theoretical discharge:

$$Q_{\text{th}} = A_2 v_2 = A_2 \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Step 6 – Actual discharge (with coefficient of discharge C_d):

$$Q_{\text{act}} = C_d \cdot A_2 \sqrt{\frac{2gh}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

Here, $h = 12.6 \times H$ (when mercury manometer is used, where H is manometer reading in meters of Hg).

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3. Compare venturi meter and orifice meter for measurement of flow through pipes.

Feature	Venturi Meter	Orifice Meter
Head loss	Low (due to gradual divergence)	High (due to sudden expansion)
Accuracy	High	Moderate
Cost	Expensive	Economical
Space required	Long (diverging cone)	Compact
Maintenance	Low	Moderate (edge wear affects accuracy)

Feature	Venturi Meter	Orifice Meter
Typical C_d	0.95 – 0.98	0.60 – 0.65
Application	Permanent installations requiring accuracy	Temporary or cost-sensitive applications

Experiment No: 6 – Flow Over Notches

1. Derive an expression for discharge over triangular notch (V-notch).

Given:

- Notch angle = θ
- Head over crest = H
- Width of elementary strip at depth h from free surface = $2(H-h)\tan(\theta/2)$
- Velocity through strip = $\sqrt{2gh}$

Step 1 – Discharge through elementary strip of thickness dh:

$$dQ = \text{Area} \times \text{Velocity} = [2(H-h)\tan(\theta/2)\cdot dh]\cdot\sqrt{2gh}$$

Step 2 – Integrate from $h=0$ to $h=H$:

$$Q_{\text{th}} = \int_0^H 2\tan\frac{\theta}{2}(H-h)\sqrt{2g}\cdot h^{1/2}\,dh$$
$$Q_{\text{th}} = 2\tan\frac{\theta}{2}\sqrt{2g}\int_0^H (H\,h^{1/2}-h^{3/2})\,dh$$

Step 3 – Integrate:

$$\int_0^H H\,h^{1/2}dh = H\cdot\frac{2}{3}H^{3/2} = \frac{2}{3}H^{5/2}$$
$$\int_0^H h^{3/2}\,dh = \frac{2}{5}H^{5/2}$$
$$\int_0^H (H\,h^{1/2}-h^{3/2})dh = \frac{2}{3}H^{5/2}-\frac{2}{5}H^{5/2} = \frac{4}{15}H^{5/2}$$

Step 4 – Final theoretical discharge:

$$Q_{\text{th}} = 2\tan\frac{\theta}{2}\sqrt{2g}\cdot\frac{4}{15}H^{5/2}$$
$$Q_{\text{th}} = \frac{8}{15}\sqrt{2g}\cdot\tan\frac{\theta}{2}\cdot H^{5/2}$$

Actual discharge: $Q_{\text{act}} = C_d \times Q_{\text{th}}$

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2. Derive an expression for discharge over rectangular notch.

Given:

- Crest length (width) = L

- Head over crest = H
- Velocity through elementary strip at depth $h = \sqrt{2gh}$
- Width of strip = L, thickness = dh

Step 1 – Discharge through strip:

$$dQ = L \cdot dh \cdot \sqrt{2gh}$$

Step 2 – Integrate from $h = 0$ to $h = H$:

$$Q_{\text{th}} = L\sqrt{2g}\int_0^H h^{1/2}\,dh = L\sqrt{2g}\cdot\frac{2}{3}H^{3/2}$$

Final theoretical discharge:

$$Q_{\text{th}} = \frac{2}{3}L\sqrt{2g}\cdot H^{3/2}$$

Actual discharge (with end contractions accounted for by effective length L_e):

$$Q_{\text{act}} = C_d\cdot\frac{2}{3}L_e\sqrt{2g}\cdot H^{3/2}$$

Experiment No: 7 – Orifice (Coefficients)

1. Define coefficient of contraction, coefficient of velocity, and coefficient of discharge.

- **Coefficient of contraction (C_c):**
  Ratio of area of jet at vena-contracta (a_c) to area of orifice (a).

$$C_c = \frac{a_c}{a}$$

Typical value: 0.62 – 0.64.

- **Coefficient of velocity (C_v):**
  Ratio of actual velocity of jet at vena-contracta (V_{act}) to theoretical velocity ($V_{\text{th}} = \sqrt{2gh}$).

$$C_v = \frac{V_{\text{act}}}{\sqrt{2gh}}$$

Typical value: 0.95 – 0.99.

- **Coefficient of discharge (C_d):**
  Ratio of actual discharge (Q_{act}) to theoretical discharge (Q_{th}).

$$C_d = \frac{Q_{\text{act}}}{Q_{\text{th}}} = C_c \times C_v$$

Typical value: 0.60 – 0.62.

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2. Derive an equation for discharge through an orifice.

Given:

- Head over orifice center = h
- Area of orifice = a
- Theoretical velocity $V_{\text{th}} = \sqrt{2gh}$

Step 1 – Theoretical discharge:

$$Q_{\text{th}} = a \cdot \sqrt{2gh}$$

Step 2 – Actual discharge considering contraction and velocity coefficients:
At vena-contracta:
Actual area $a_c = C_c \cdot a$
Actual velocity $V_{\text{act}} = C_v \cdot \sqrt{2gh}$

Thus:

$$Q_{\text{act}} = a_c \cdot V_{\text{act}} = (C_c a) \cdot (C_v \sqrt{2gh})$$
$$Q_{\text{act}} = (C_c \cdot C_v) \cdot a\sqrt{2gh}$$
$$Q_{\text{act}} = C_d \cdot a\sqrt{2gh}$$

This is the standard orifice discharge equation. C_d is determined experimentally.

Experiment No: 8 – Reynolds Experiment

Explain different types of flow.

Based on Reynolds experiment with dye filament in a glass tube, flow is classified into three regimes:

Type	Reynolds Number (Re)	Characteristics
Laminar flow	Re < 2000	Dye filament remains straight and steady. Fluid particles move in parallel layers with no mixing.
Transitional flow	2000 < Re < 4000	Dye filament begins to wave and shows slight irregularities. Flow is unstable.
Turbulent flow	Re > 4000	Dye filament breaks up and diffuses across the entire cross-section. Particles move in random, chaotic manner.

Reynolds number formula:

$$Re = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$$

where ν = kinematic viscosity, D = pipe diameter, V = average velocity.

Practical significance:

- Laminar flow: Oil flow in small tubes, capillary flow.
- Turbulent flow: Most water supply systems, river flows, air ducts.

Experiment No: 9 – Friction Factor for Pipes

1. State the various losses of energy when fluid flows through pipe.

Energy losses in pipe flow are classified as:

Major losses (friction losses):
Due to viscous shear along straight pipe length. Given by Darcy-Weisbach equation:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

Minor losses:
Due to fittings, bends, valves, expansions, contractions.

$$h_{\text{minor}} = K \cdot \frac{V^2}{2g}$$

Where K = loss coefficient.

Examples of minor losses:

- Sudden expansion
- Sudden contraction
- Pipe bend/elbow
- Valve partially open
- Entrance/exit losses

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2. Derive Darcy-Weisbach formula for head loss due to friction in pipe flow.

Given:
Pipe length L, diameter D, mean velocity V, wall shear stress τ_0.

Consider a horizontal pipe (no elevation change).
Forces acting on fluid element of length L:

- Pressure force = $(P_1 - P_2) \cdot \frac{\pi D^2}{4}$
- Shear force resisting motion = $\tau_0 \cdot (\pi D L)$

At steady flow, pressure force = shear force:

$$(P_1 - P_2) \cdot \frac{\pi D^2}{4} = \tau_0 \cdot \pi D L$$
$$P_1 - P_2 = \frac{4\tau_0 L}{D}$$

Head loss:

$$h_f = \frac{P_1 - P_2}{\rho g} = \frac{4\tau_0 L}{\rho g D}$$

Assume τ_0 proportional to dynamic pressure:

$$\tau_0 = \frac{f}{4} \cdot \frac{1}{2}\rho V^2$$

where f = Darcy friction factor (dimensionless).

Substitute:

$$h_f = \frac{4}{\rho g D} \cdot \frac{f}{4} \cdot \frac{1}{2}\rho V^2 \cdot L$$
$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$

This is the **Darcy-Weisbach equation**. f depends on Re and pipe roughness.

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3. Derive Chezy's formula for velocity of flow through pipe.

Chezy's formula is commonly used for open channel flow but adapted for pipes under certain conditions.

From Darcy-Weisbach:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$
$$V^2 = \frac{2gD}{f} \cdot \frac{h_f}{L}$$

Let $m = \frac{D}{4}$ = hydraulic mean depth (for full circular pipe, $m = \frac{\text{Area}}{\text{Wetted perimeter}} = \frac{\pi D^2/4}{\pi D} = \frac{D}{4}$).

Also, $S = \frac{h_f}{L}$ = hydraulic slope.

Then:

$$V^2 = \frac{2gD}{f} \cdot S = \frac{2g(4m)}{f} \cdot S = \left(\sqrt{\frac{8g}{f}}\right)^2 \cdot m \cdot S$$

Let $C = \sqrt{\frac{8g}{f}}$ = Chezy's coefficient.

Thus:

$$V = C\sqrt{mS}$$

This is **Chezy's formula**. C is not constant but depends on roughness and Re.

Experiment No: 10 – Loss Coefficients for Pipe Fittings

Derive equation of coefficient of discharge for different pipe fittings.

For pipe fittings, the head loss h_L is expressed as:

$$h_L = K \cdot \frac{V^2}{2g}$$

where:

- h_L = head loss across fitting (m of fluid)
- V = average velocity in the pipe (m/s)
- g = 9.81 m/s²
- K = **loss coefficient** (dimensionless) – depends on fitting type and geometry.

To derive K experimentally:

Step 1 – Measure pressure difference across fitting using manometer:

$$h_L = 12.6 \times H \text{(in meters of water, for Hg manometer)}$$

where H = manometer reading in meters of Hg.

Step 2 – Calculate velocity from discharge measurement:

$$Q = \frac{\text{Volume collected}}{\text{Time}} (\text{m}^3/\text{s})$$

$$V = \frac{Q}{A} \text{m/s}, A = \frac{\pi D^2}{4}$$

Step 3 – Rearrange the loss equation for K:

$$K = \frac{h_L}{\left(\frac{V^2}{2g}\right)} = \frac{2g \cdot h_L}{V^2}$$

Thus, the **coefficient (loss coefficient) for any fitting** is determined experimentally as:

$$\boxed{K = \frac{2g \cdot (12.6H)}{V^2}}$$

Typical values:

- **Elbow (small bend):** $K \approx 0.9$
- **Large bend:** $K \approx 0.6$

- **Sudden expansion (D_1 to D_2):** $K \approx \left(1 - \frac{D_1^2}{D_2^2}\right)^2$
- **Sudden contraction:** $K \approx 0.5\left(1 - \frac{D_2^2}{D_1^2}\right)$

Experiment No: 11 – Pitot Tube

(No separate quiz in manual for this experiment – only procedure and formula given)

Experiment No: 12 – Model Studies & Wind Tunnel

1. What is meant by model studies?

Model studies involve testing a scaled-down (or sometimes scaled-up) replica (model) of a full-scale engineering system (prototype) to predict its behavior under real operating conditions. The model is designed using **similitude laws** so that results can be scaled up to the prototype.

Purpose:

- Reduce cost and time
- Allow controlled experiments
- Predict performance before construction
- Study failure modes safely

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2. Explain similitude and its types.

Similitude is the principle of similarity between model and prototype. Three types:

Type	Definition	Example
Geometric similarity	All linear dimensions of model and prototype are in same ratio (scale ratio).	Length, width, diameter scaled equally.
Kinematic similarity	Velocities and accelerations at corresponding points are in same ratio.	Streamline patterns match.

Type	Definition	Example
Dynamic similarity	Forces at corresponding points are in same ratio (Reynolds, Froude, Mach numbers equal).	Pressure, drag, lift scaled correctly.

All three must be satisfied simultaneously for complete similarity, which is often difficult—so dominant forces are matched.

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3. Why is Reynolds number important in wind tunnel testing?

Reynolds number ($Re = \frac{\rho V L}{\mu}$**)** represents the ratio of inertial forces to viscous forces.

In wind tunnel testing:

- It ensures **dynamic similarity** for flows dominated by viscosity (e.g., boundary layers, drag, flow separation).
- If model scale is reduced, velocity or fluid density must be adjusted to keep Re same as prototype.
- Matching Re is critical for accurately predicting lift, drag, and stall behavior of airfoils, vehicles, and buildings.

Example: A 1:10 scale model requires 10 times the velocity (or denser fluid) to match prototype Re.

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4. Compare wind tunnel testing and CFD analysis.

Aspect	Wind Tunnel Testing	CFD Analysis
Cost	High (facility, instrumentation, model fabrication)	Lower once software and hardware are available
Time	Long (model fabrication, setup, testing)	Fast for simulation runs
Accuracy	Realistic for complex geometries	Depends on mesh, turbulence model, solver
Flow visualization	Physical (smoke, tufts) – intuitive	Digital (contours, streamlines) – detailed

Aspect	Wind Tunnel Testing	CFD Analysis
Limitations	Scaling effects, wall interference, model support interference	Numerical errors, turbulence model uncertainty
Parallel use	Used for validation of CFD	Used to reduce number of wind tunnel runs

Best practice: Use both – CFD for parametric studies, wind tunnel for final validation.

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5. List applications of CFD in engineering.

1. **Aerospace:** Airfoil and wing design, drag reduction, rocket nozzle flow.
2. **Automotive:** Vehicle aerodynamics, engine combustion, cooling system design.
3. **Civil engineering:** Wind load on buildings and bridges, HVAC system design.
4. **Energy:** Wind turbine blade optimization, pipeline flow, heat exchangers.
5. **Marine:** Hull resistance prediction, propeller design.
6. **Biomedical:** Blood flow in arteries, respiratory airflow.
7. **Turbomachinery:** Pump, compressor, turbine internal flow optimization.