

GUJARAT TECHNOLOGICAL UNIVERSITY

BE-3 SEMESTER – OLD PAPER – S22 TO W25 – QUESTION BANK ANSWER

Subject Name & Code:

FLUID FLOW OPERATIONS (3130502)

(Disclaimer: The purpose of these AI-generated responses is just education and reference. Utilise them to grasp topics and structure, but always rewrite in your own words and double-check)

Unit 1: Fluid Properties and Flow Characteristics

Q1 – Define/Explain: Ideal fluid, Potential flow, Fully developed flow. (3 marks)

Appeared in: S24 (Q1a, 03 marks), S23 (Q2a, 03 marks) → Highest: 3 marks

Ans:

Ideal fluid:

- A hypothetical fluid with **zero viscosity** ($\mu = 0$) and **incompressible** (ρ constant).
- No shear stress exists, regardless of motion.
- Used to simplify mathematical analysis (Euler's equation).

Potential flow:

- Flow of an **ideal fluid** that is **irrotational** (curl of velocity = 0).
- Velocity can be expressed as gradient of a **potential function** (ϕ).
- Governed by **Laplace's equation** ($\nabla^2\phi = 0$).
- Examples: Uniform flow, source/sink flow, vortex flow.

Fully developed flow:

- Occurs in a pipe/duct when the **velocity profile** no longer changes along the flow direction.
- Wall shear stress and pressure gradient become constant.
- For laminar flow: parabolic profile; for turbulent flow: flatter profile.

Q2 – Define viscosity and its units. (3 marks)

Appeared in: S23 (Q1a, 03 marks), S22 (Q4a, 03 marks) → Highest: 3 marks

Ans:

Viscosity is the property of a fluid that offers **resistance to relative motion** between its adjacent layers. It is a measure of internal friction.

Dynamic (absolute) viscosity (μ)

- Definition: Shear stress required to produce unit velocity gradient.
 $\tau = \mu (du/dy)$
- SI unit: **Pa·s** (Pascal-second) or **N·s/m²**
- CGS unit: **Poise** (1 P = 0.1 Pa·s)
- Common unit for water: 1 cP = 0.001 Pa·s

Kinematic viscosity (ν)

- Definition: Ratio of dynamic viscosity to density: $\nu = \mu/\rho$
- SI unit: **m²/s**
- CGS unit: **Stokes** (1 St = 10⁻⁴ m²/s)

Example: Water at 20°C → $\mu \approx 0.001$ Pa·s, $\nu \approx 1 \times 10^{-6}$ m²/s.

Q3 – Explain Newtonian and Non-Newtonian fluids with examples. (7 marks)

Appeared in: S24 (Q3c, 07 marks), S22 (Q5a, 03 marks), W25 (Q1c, 07 marks) → Highest: 7 marks

Ans:

Definition: Fluids are classified based on the relationship between **shear stress (τ)** and **rate of strain (du/dy)** (velocity gradient).

Newtonian Fluids

- Follow **Newton's law of viscosity:** $\tau = \mu (du/dy)$ where $\mu =$ constant viscosity.
- Viscosity depends only on temperature and pressure, **not** on shear rate.
- Shear stress vs. strain rate graph is a **straight line** through origin.
- **Examples:** Water, air, gasoline, glycerin, light oils.

Non-Newtonian Fluids

- Do **not** follow Newton's law; apparent viscosity (μ_{app}) changes with shear rate.
- Subtypes:
 - **Pseudoplastic (Shear-thinning):** Viscosity decreases with increasing shear rate.
 - **Dilatant (Shear-thickening):** Viscosity increases with increasing shear rate.
 - **Bingham plastic:** Requires yield stress before flow begins.
 - **Thixotropic:** Viscosity decreases with time under constant shear.

[DG PROMPT]

Title: Newtonian vs. Non-Newtonian Fluid Behavior

Description: Draw a Cartesian graph. X-axis = Shear rate (du/dy), Y-axis = Shear stress (τ).

Plot four curves:

1. Straight line from origin (slope μ) labelled "Newtonian".
2. Curve concave downward (slope decreasing) labelled "Pseudoplastic".
3. Curve concave upward (slope increasing) labelled "Dilatant".
4. Line with positive intercept on Y-axis (yield stress) then linear, labelled "Bingham plastic". Add arrows showing direction of increasing shear rate.

Real-world application:

- **Newtonian:** Water supply systems, hydraulic oils.
- **Pseudoplastic:** Blood, polymer melts, ketchup – pumping easier at high speeds.
- **Dilatant:** Cornstarch slurry – used in body armor.
- **Bingham plastic:** Drilling mud, toothpaste – stays in place until squeezed.

Numerical example (Newtonian):

Given: $\mu = 0.001 \text{ Pa}\cdot\text{s}$ (water at 20°C), $du/dy = 100 \text{ s}^{-1}$. Find τ .

$$\tau = \mu \times (du/dy) = 0.001 \times 100 = \mathbf{0.1 \text{ Pa}}$$

Advantages of classification: Helps select pumps, pipelines, and mixing equipment in chemical and food industries.

Q4 – Explain laminar and turbulent flow. (4 marks)

Appeared in: S22 (Q2b, 04 marks), W25 (Q1b, 04 marks), W23 (Q1b, 04 marks) →

Highest: 4 marks

Ans:

Parameter	Laminar Flow	Turbulent Flow
Definition	Fluid moves in smooth, parallel layers (streamlines) with no mixing between	Fluid moves in irregular, chaotic paths with eddies and cross-mixing.

Parameter	Laminar Flow	Turbulent Flow
	layers.	
Reynolds number (Re)	$Re < 2000$ (for pipe flow)	$Re > 4000$
Velocity profile	Parabolic (maximum at centre)	Flatter profile (more uniform)
Shear stress	Due to viscosity only	Due to viscosity + eddy fluctuations
Energy loss	Low, proportional to velocity	High, proportional to velocity ²
Example	Flow of honey, groundwater flow	Flow in rivers, water supply pipes

Real-world application:

- **Laminar** – Microfluidics, blood flow in capillaries.
- **Turbulent** – Industrial pipe transport (mixing ensures uniform temperature), aircraft wings (boundary layer transition).

Key formula: $Re = \rho V D / \mu$ (Reynolds number)

Q5 – Explain boundary layer formation in straight tubes/pipes. (4 marks)

Appeared in: S24 (Q5b, 04 marks), W25 (Q5b, 04 marks), W24 (Q1b, 04 marks) →

Highest: 4 marks

Ans:

Definition: Boundary layer is a thin region near the pipe wall where **viscous effects** are significant and velocity increases from **zero at the wall** (no-slip condition) to the free-stream velocity.

Formation stages in a pipe:

1. **Entrance region:** Boundary layer develops from the inlet. Thickness grows along the pipe.
2. **Core region:** Central flow remains irrotational (inviscid) and accelerates to maintain continuity.
3. **Fully developed flow:** Boundary layers from opposite walls meet at the centre. Velocity profile becomes **parabolic** (laminar) or **flatter** (turbulent) and no longer changes with distance.

Key points:

- **Hydrodynamic entrance length (L_{e})** = distance to fully developed flow.
 - Laminar: $L_{e} \approx 0.05 Re D$
 - Turbulent: $L_{e} \approx 10-20 D$ (shorter)
- **Boundary layer thickness (δ)** increases with distance until fully developed.

Real-world application:

- Heat exchanger design – thicker boundary layer reduces heat transfer.
- Pipe flow metering – fully developed flow required for accurate orifice plate readings.

Diagram description:

Pipe inlet → dashed line showing boundary layer growing from wall → central core shrinking → after L_{e} , dashed lines meet → fully developed parabolic profile.

Q6 – What is cavitation? / Define cavitation in pumps. (3 marks)

Appeared in: S24 (Q2a, 03 marks), S23 (Q5a, 03 marks), W25 (Q3a, 03 marks) → Highest: 3 marks

Ans:

Definition: Cavitation is the formation of **vapour bubbles** inside a liquid when local pressure falls below the **vapour pressure** of the liquid, followed by sudden **collapse (implosion)** of those bubbles when pressure recovers.

In pumps specifically:

- Occurs at the **impeller eye** (suction side) where pressure is lowest.
- Bubbles collapse near higher pressure regions (discharge side), causing:
 - **Pitting** (surface erosion)
 - **Noise** (like gravel inside pump)
 - **Vibration** and efficiency drop
 - **Reduced flow** and head

Real-world application:

- Centrifugal pumps: Avoid by maintaining **Net Positive Suction Head (NPSH_{available}) > NPSH_{required}**.
- Ship propellers, control valves, turbine runners – common cavitation sites.

Prevention methods:

1. Increase suction pressure (raise tank level).
2. Reduce pump speed.
3. Use cavitation-resistant materials (stainless steel, bronze).

Q7 – Define: Dynamic and kinematic viscosity. (3 marks)

Appeared in: W25 (Q1a, 03 marks) → Highest: 3 marks

Ans:

Dynamic viscosity (μ):

- Measure of internal resistance to shear flow.
- SI unit: **Pa·s** ($\text{N}\cdot\text{s}/\text{m}^2$).
- 1 centipoise (cP) = 0.001 Pa·s.

Kinematic viscosity (ν):

- Ratio of dynamic viscosity to density: $\nu = \mu/\rho$.
- SI unit: **m^2/s** .
- 1 centistoke (cSt) = $10^{-6} \text{ m}^2/\text{s}$.

Relationship: $\nu = \mu/\rho$.

Example (water at 20°C): $\mu = 1.002 \text{ cP}$, $\rho = 998 \text{ kg}/\text{m}^3$ → $\nu = 1.004 \times 10^{-6} \text{ m}^2/\text{s}$.

Q8 – Define: Mass velocity, ideal fluid, real fluid. (3 marks)

Appeared in: S22 (Q1a, 03 marks) → Highest: 3 marks

Ans:

Mass velocity (G):

- Mass flow rate per unit cross-sectional area: $G = \dot{m} / A$.
- Units: $\text{kg}/(\text{s}\cdot\text{m}^2)$.
- Related to velocity: $G = \rho V$.

Ideal fluid:

- Inviscid ($\mu = 0$) and incompressible.
- No shear stress – simplifies Euler's equation.

Real fluid:

- Possesses viscosity ($\mu > 0$).

- Exhibits shear stress and boundary layer.
- All practical fluids are real (water, air, oil).

Q9 – Define: Mach number, Drag coefficient, Reynolds number. (3 marks)

Appeared in: S24 (Q4a, 03 marks) → Highest: 3 marks

Ans:

Mach number (Ma):

- Ratio of flow velocity (V) to speed of sound (c): $Ma = V / c$.
- **Subsonic** ($Ma < 1$), **Sonic** ($Ma = 1$), **Supersonic** ($Ma > 1$).

Drag coefficient (C_{D}):

- Dimensionless parameter for drag force: $C_{D} = F_{D} / (\frac{1}{2} \rho V^2 A)$.
- Depends on shape and Reynolds number.

Reynolds number (Re):

- Ratio of inertial to viscous forces: $Re = \rho V D / \mu = V D / \nu$.
- Indicates laminar ($Re < 2000$) or turbulent ($Re > 4000$) flow.

Q10 – Explain continuous gravity decanter. (4 marks)

Appeared in: S24 (Q1b, 04 marks), S22 (Q3b, 04 marks) → Highest: 4 marks

Ans:

Definition: A **continuous gravity decanter** is a vessel that separates two immiscible liquids of different densities by gravity in a continuous flow process.

Working principle:

- Lighter liquid rises to top; heavier liquid settles to bottom.
- Interface (boundary) maintained at a specific height by adjusting outlet positions.
- Based on **Stokes' law**: separation rate $\propto (\Delta\rho) d^2 / \mu$

Construction:

- Horizontal cylindrical or rectangular tank.
- Inlet at one end; two outlets at the other end – **top overflow** for light phase, **bottom underflow** for heavy phase.
- **Interface controller** (e.g., weir or adjustable leg) to maintain stable zone.

Applications:

- Oil-water separation in refineries.
- Solvent extraction (e.g., water + organic solvent).
- Food industry (cream separation from milk).

Advantages: No moving parts, low energy, simple operation.

Limitations: Large footprint; only effective for large density difference ($>50 \text{ kg/m}^3$); emulsion formation reduces efficiency.

Q11 – Explain centrifugal decanter. (4 marks)

Appeared in: S22 (Q3b, 04 marks) → Highest: 4 marks

Ans:

Definition: A **centrifugal decanter** (or solid-bowl centrifuge) uses high rotational speed to separate solids from liquids or two immiscible liquids based on density difference under **centrifugal force** (up to $3000 \times g$).

Working principle:

- Slurry fed into a rotating bowl (horizontal or vertical).
- **Centrifugal acceleration** ($r\omega^2$) separates denser phase toward bowl wall, lighter phase toward centre.

- Solids (if present) accumulate on wall and are conveyed by screw conveyor.

Construction (Horizontal decanter):

- Cylindrical-conical rotating bowl.
- Internal **scroll conveyor** (rotates at slightly different speed).
- Feed pipe, liquid weir plates, solids discharge ports.

Applications:

- Dewatering sewage sludge.
- Edible oil clarification.
- Chemical industry – separating crystals from mother liquor.

Advantages: Continuous operation, handles high solids concentration, compact compared to gravity settlers.

Limitations: High energy consumption, noise, maintenance of bearings.

Q12 – Explain boundary layer separation and wake formation. (4 marks)

Appeared in: S22 (Q1b, 04 marks), W25 (Q5a, 03 marks) → Highest: 4 marks

Ans:

Boundary layer separation:

- Occurs when the boundary layer detaches from the solid surface due to **adverse pressure gradient** (pressure increases in flow direction).
- Near surface, low-momentum fluid cannot overcome the rising pressure and **flows backwards** (reverse flow).
- Separation point is where **wall shear stress becomes zero** ($\partial u/\partial y = 0$ at wall).

Wake formation:

- After separation, a **low-pressure region** (wake) forms behind the body.
- Wake contains **eddies and recirculating flow**.
- Causes **pressure drag** (form drag) and energy loss.

Real-world application:

- **Airfoils:** Separation at high angle of attack → **stall** (loss of lift).
- **Bluff bodies (cars, buildings):** Wake leads to drag – streamlined shapes delay separation.
- **Pipe diffusers:** Sudden expansion causes separation and pressure loss.

Diagram description (DG PROMPT):

Flow from left to right over a curved surface. Draw boundary layer (thin dashed line). At separation point, show reverse flow near wall and eddy region downstream. Label “Separation point”, “Wake”, “Reverse flow”.

Q13 – Explain significance of Reynolds number. (3 marks)

Appeared in: W25 (Q3a, 03 marks) → Highest: 3 marks

Ans:

Reynolds number ($Re = \rho VD/\mu$) determines flow regime and dynamic similarity.

Significance:

1. **Predicts laminar vs. turbulent flow:**
 - $Re < 2000$ → laminar (viscous forces dominate).
 - $Re > 4000$ → turbulent (inertial forces dominate).
2. **Scale-up of fluid systems:** Two geometrically similar flows are dynamically similar if Re is equal.
3. **Heat/mass transfer correlations:** Nusselt number (Nu) = $f(Re, Pr)$.
4. **Pressure drop calculation:** Darcy friction factor depends on Re .

Example: Water pipe ($D=0.1$ m, $V=0.5$ m/s, $\nu=1e-6$) → $Re = 50,000$ → turbulent flow.

Q14 – Explain significance of Mach number. (3 marks)

Appeared in: S23 (Q4a, 03 marks) → Highest: 3 marks

Ans:

Mach number ($Ma = V / c$) indicates the importance of compressibility.

Significance:

- **$Ma < 0.3$:** Incompressible flow (density change $< 5\%$) – use Bernoulli's equation.
- **$0.3 < Ma < 0.8$:** Subsonic compressible flow – small density variations.
- **$Ma \approx 1$ (transonic):** Shock waves appear, drag increases sharply.
- **$Ma > 1$ (supersonic):** Oblique shocks, expansion fans – requires gas dynamics equations.

Real-world application:

- Aircraft design – avoid transonic drag rise.
- Rocket nozzles – Ma at throat = 1 for maximum thrust.
- Gas pipelines – high Ma causes choking.

Q15 – Classify fluids based on externally applied temperature and pressure with examples. (3 marks)

Appeared in: W23 (Q1a, 03 marks) → Highest: 3 marks

Ans:

Based on response to temperature and pressure, fluids are classified as:

1. Perfect gas:

- Follows $PV = RT$ (ideal gas law).
- Example: Air at low pressure and high temperature.

2. Real gas:

- Deviates from ideal behavior near saturation or high pressure.
- Example: Steam at high pressure; CO_2 in refrigeration.

3. Incompressible fluid:

- Density nearly constant with pressure and temperature.
- Example: Water (for most engineering flows).

4. Compressible fluid:

- Density changes significantly with pressure ($\Delta\rho/\rho > 5\%$).
- Example: Gases at high velocity ($Ma > 0.3$).

5. Thermally expandable fluid:

- Density changes due to temperature (used in natural convection).
- Example: Oil in thermometers, air in hot-air balloons.

Q16 – Define/Explain: Compressible and incompressible fluids. (3 marks)

Appeared in: S22 (Q5a, 03 marks) → Highest: 3 marks

Ans:

Compressible fluid:

- Density (ρ) changes significantly with pressure (or temperature).
- Bulk modulus (K) is finite; Mach number > 0.3 for gases.
- Examples: Gases (air, hydrogen), steam at high velocity.

Incompressible fluid:

- Density remains constant (or nearly constant) regardless of pressure.
- Bulk modulus $K \rightarrow \infty$ (theoretical).
- Assumption valid for liquids and gases at $Ma < 0.3$.
- Examples: Water, oil, liquid metals.

Key difference:

- Compressible flow requires energy equation (first law of thermodynamics).

- Incompressible flow uses simplified continuity ($\nabla \cdot \mathbf{V} = 0$).

Real-world: Water hammer in pipes (compressibility of water matters for transient pressure surges).

Q17 – Define/Explain: Stagnation point. (3 marks)

Appeared in: W24 (Q1a, 03 marks), W22 (Q1a, 03 marks) → Highest: 3 marks

Ans:

Definition: A **stagnation point** is a point in a flow field where the **fluid velocity becomes zero** relative to the solid body.

Key features:

- Occurs on the surface of an object placed in a flowing fluid, at the **leading edge** where flow divides.
- Pressure at stagnation point is **maximum** – called **stagnation pressure** ($P_{>0} = P_{\text{static}} + \frac{1}{2}\rho V^2$).
- Total head (Bernoulli) is constant, so stagnation pressure equals total pressure.

Real-world application:

- **Pitot tube:** Measures stagnation pressure to calculate flow velocity.
- **Aircraft nose:** Stagnation point used for air data probes.
- **Intake ducts:** Design avoids separation at stagnation region.

Example: A sphere in uniform flow – front-most point ($\theta = 0^\circ$) is stagnation point.

Q18 – Define/Explain: Pseudoplastic fluids (with example). (3 marks)

Appeared in: W24 (Q1a, 03 marks), W22 (Q1a, 03 marks) → Highest: 3 marks

Ans:

Definition: Pseudoplastic fluids are **non-Newtonian** fluids whose **apparent viscosity decreases** as shear rate (du/dy) increases – also called **shear-thinning** fluids.

Behavior:

- At rest or low shear, high viscosity (e.g., paste).
- Under high shear, viscosity drops (flows easily).
- No yield stress – flow starts immediately.

Mathematical model (Power law): $\tau = K (du/dy)^n$ where $n < 1$.

Examples:

- **Blood** (at high shear rates, red blood cells align).
- **Ketchup, paint, polymer solutions, shampoo.**

Real-world application:

- **Paint:** Low viscosity when brushed (high shear) for smooth application; high viscosity after brushing to prevent drips.
- **Drilling mud:** Pseudoplasticity reduces pumping power.

Contrast with dilatant ($n > 1$) – viscosity increases with shear.
