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 7: Flow Meters – Venturimeter, Orifice Meter, Pitot Tube

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Q1 – Derive flow equation for Venturimeter starting from Bernoulli's theorem. (7 marks)

Ans:

Assumptions:

- Steady, incompressible flow.
- Frictionless flow (ideal) – later corrected by discharge coefficient.
- Horizontal venturimeter ($z_1 = z_2$).
- Uniform velocity at inlet (1) and throat (2).

Derivation:

Step 1 – Apply Bernoulli's equation between inlet (section 1) and throat (section 2):

$P_1/\rho g + V_1^2/2g + z_1 = P_2/\rho g + V_2^2/2g + z_2$

For horizontal venturimeter: $z_1 = z_2$, so:

$P_1/\rho g + V_1^2/2g = P_2/\rho g + V_2^2/2g$

Rearrange:

$(P_1 - P_2)/\rho g = (V_2^2 - V_1^2)/2g$ …(1)

Step 2 – Use continuity equation:

$Q = A_1 V_1 = A_2 V_2 \Rightarrow V_1 = (A_2/A_1) V_2$ …(2)

Step 3 – Substitute (2) into (1):

$(P_1 - P_2)/\rho = (V_2^2 - (A_2^2/A_1^2) V_2^2)/2 = V_2^2/2 \, [1 - (A_2/A_1)^2]$

Thus:

$V_2^2 = [2(P_1 - P_2)/\rho] / [1 - (A_2/A_1)^2]$

Step 4 – Volumetric flow rate (ideal):

$Q_{ideal} = A_2 V_2 = A_2 * \text{sqrt}([2(P_1 - P_2)/\rho] / [1 - (A_2/A_1)^2])$

$Q_{ideal} = A_2 / \text{sqrt}(1 - (A_2/A_1)^2) * \text{sqrt}(2\Delta P/\rho)$

Step 5 – Introduce coefficient of discharge (Cd):

Due to friction and vena contracta (though venturi has minimal contraction), actual flow:

$Q_{actual} = C_d * Q_{ideal}$

Where C_d for venturimeter ≈ 0.96–0.99.

Final venturimeter equation:

$Q = C_d * A_2 / \text{sqrt}(1 - (A_2/A_1)^2) * \text{sqrt}(2\Delta P/\rho)$

Alternative form using manometer reading (Δh):

$\Delta P = (\rho_m - \rho) g \Delta h$ (if manometer fluid denser than flowing fluid)

Then $Q = C_d * A_2 / \text{sqrt}(1 - (A_2/A_1)^2) * \text{sqrt}(2g\Delta h (\rho_m/\rho - 1))$

[DG PROMPT]

Title: Venturimeter flow derivation – sections

Description: Draw horizontal venturimeter. Label left larger section as (1) with diameter D_1, area A_1, pressure P_1, velocity V_1. Label throat as (2) with D_2, A_2, P_2, V_2. Add pressure taps at both sections connected to a U-tube manometer showing Δh. Arrows indicate flow direction left to right.

Real-world application:

- Water flow measurement in treatment plants.
- Oil and gas industry (custody transfer).

Numerical example:

Water: $D_1 = 0.2$ m, $D_2 = 0.1$ m, $\Delta P = 10$ kPa, $\rho = 1000$ kg/m³, C_d = 0.98.
$A_1 = 0.0314$ m², $A_2 = 0.00785$ m², $\beta = A_2/A_1 = 0.25$.
Q = 0.98 * 0.00785 / sqrt(1-0.0625) * sqrt(2*10000/1000)
= 0.98*0.00785/0.967 * sqrt(20) = 0.00796 * 4.472 = 0.0356 m³/s = 35.6 L/s.

Q2 – Why coefficient of discharge of Venturimeter > Orifice meter? (4 marks)
Ans:

Parameter	Venturimeter	Orifice meter
C_d typical range	0.96 – 0.99	0.60 – 0.65
Flow pattern	Smooth, streamlined contraction and gradual expansion	Sudden contraction, sharp edge, vena contracta
Energy loss	Very low (pressure recovery due to divergent cone)	High (no pressure recovery, permanent loss)
Vena contracta	Absent (gradual area change)	Present (flow contracts to minimum area downstream of orifice)
Turbulence & eddies	Minimal	Significant, especially downstream

Reasons for higher C_d in venturimeter:

1. **No sudden expansion:** The diverging section gradually recovers pressure, reducing energy loss.
2. **No vena contracta:** The throat is the minimum area, and flow remains attached to walls.
3. **Smoother velocity profile:** Less turbulence means the theoretical flow rate is approached more closely.

Real-world application:

- Venturimeters used where energy conservation is important (e.g., pumping systems).
- Orifice meters used where low cost and simplicity outweigh higher energy loss.

Q3 – Explain Pitot tube / insertion meters. (4 marks)
Ans:
Pitot Tube
Definition: A Pitot tube measures **local velocity** at a point in a flow by converting kinetic energy into pressure (stagnation pressure).
Construction:

- A small tube with its open end facing directly upstream (impact tube).
- A second tube with openings perpendicular to flow (static pressure tap) – often integrated in a single probe (Pitot-static tube).

Working principle (Bernoulli):

- Stagnation pressure $P_0 = P + \frac{1}{2} \rho V^2$.
- Static pressure P measured at the wall or by static ports.
- Velocity $V = \text{sqrt}(2(P_0 - P)/\rho)$.

Insertion meter concept (general):

- A sensing element (Pitot tube, thermal probe, turbine rotor) inserted through a small opening into a pipe.
- Measures point velocity; average velocity inferred from velocity profile (e.g., log law for turbulent flow).
- Can be installed without cutting the pipe (hot tapping).

Advantages:

- Low pressure drop.
- Easy installation in large pipes.
- Low cost compared to full-bore meters.

Limitations:

- Less accurate (needs profile correction).
- Sensitive to upstream disturbances (requires straight run).
- Not suitable for dirty fluids (clogging).

[DG PROMPT]
Title: Pitot-static tube and insertion meter
Description: Draw a horizontal pipe cross-section. Insert a thin tube from top. Tube bent 90° so open end faces upstream – label "Impact tube (P_0)". On the same probe, side holes perpendicular to flow – label "Static ports (P)". Arrows show flow left to right. Below, sketch a pipe with an insertion turbine meter: small rotor inserted radially, wired to an external transmitter.
Real-world application:

- Aircraft airspeed indicator.
- HVAC duct velocity measurement.
- Large water mains (insertion electromagnetic meter).

Q4 – Discuss different types of flow measuring devices with utility and application. (7 marks)
Appeared in: S24 (Q4c, 07 marks)
Ans:
Flow measuring devices are classified into several categories based on operating principle. Below is a comprehensive discussion.
1. Differential Pressure (Head) Meters

Device	Working Principle	Utility	Applications
Venturimeter	Pressure drop between inlet and throat (Bernoulli)	High accuracy, low permanent loss	Water treatment, oil pipelines
Orifice meter	Pressure drop across a sharp-edged plate	Simple, cheap, easy to install	Natural gas, steam, water

Device	Working Principle	Utility	Applications
Flow nozzle	Similar to venturi but shorter	Higher flow than orifice, moderate loss	High-velocity steam, gas

2. Variable Area Meters (Rotameter)

- **Principle:** Float rises in tapered tube until drag + buoyancy = weight.
- **Utility:** Direct reading, no external power, wide range (10:1).
- **Applications:** Laboratory, chemical dosing, purge gas measurement.

3. Positive Displacement Meters

Type	Working	Application
Nutating disc	Disc wobbles as fluid passes	Water meters (domestic)
Oval gear	Interlocking gears rotate	Fuel dispensing, oils
Rotary piston	Piston rotates in chamber	High viscosity liquids

4. Velocity Meters

Device	Principle	Utility	Application
Turbine meter	Rotor speed ∝ flow rate	High accuracy, good repeatability	Petrochemical, cryogenic
Ultrasonic (Doppler/Transit time)	Sound wave time difference	Non-invasive, no pressure drop	Dirty liquids, wastewater
Electromagnetic	Faraday's law (voltage ∝ velocity)	Conductive fluids only	Slurries, corrosive acids
Vortex shedding	Frequency of vortices behind bluff body	No moving parts	Steam, gas, liquids

5. Mass Flow Meters

- **Coriolis meter:** Direct mass flow measurement via tube vibration.
- **Thermal mass flow:** Heat transfer from heated element ∝ mass flow.
- **Utility:** High accuracy, no density compensation needed.
- **Applications:** Natural gas custody transfer, chemical reactors.

6. Insertion Meters

- **Principle:** Sensor inserted through pipe wall measures point velocity; average inferred.
- **Utility:** Low cost, minimal pressure drop, hot-tap installation.
- **Applications:** Large water mains, HVAC ducts, stack gas.

7. Open Channel Flow Meters

- **Devices:** Weirs (V-notch, rectangular), flumes (Parshall, Palmer-Bowlus).

- **Principle:** Head–flow relationship.
- **Applications:** Sewage treatment plants, irrigation canals.

Summary of selection criteria:

- Accuracy required → Coriolis, ultrasonic, turbine.
- Cost constraints → Orifice, rotameter.
- Fluid type (clean/dirty, conductive/non-conductive) → EM for conductive, ultrasonic for dirty.
- Pressure drop allowed → Venturi, insertion, ultrasonic (low loss).
- Pipe size → Insertion meters for large diameters.

Q5 – Discuss various types of flow observed in two-phase flow. (7 marks)
Appeared in: W24 (Q5c, 07 marks), W22 (Q5c, 07 marks)
Ans:
Two-phase flow refers to simultaneous flow of two immiscible fluids or the same fluid in two phases (e.g., liquid + gas). The **flow pattern (flow regime)** depends on: pipe orientation (horizontal/vertical), flow rates, fluid properties, and pressure.

Horizontal Two-Phase Flow Regimes (Gas–Liquid)

Regime	Description	Sketch characteristics
Bubbly flow	Discrete gas bubbles dispersed in continuous liquid. Low gas flow.	Small circles randomly distributed.
Plug flow	Large gas bubbles (bullet-shaped) separated by liquid slugs.	Elongated ellipses with liquid gaps.
Stratified flow	Gas flows above liquid, separated by a smooth interface.	Two horizontal layers, gas on top.
Wavy stratified	Stratified with waves at interface.	Wavy line between gas and liquid.
Slug flow	Large, aerated liquid slugs separated by gas pockets.	Chaotic, large waves hitting top of pipe.
Annular flow	Liquid film on pipe wall, gas core with entrained droplets.	Thin ring of liquid, central gas.
Dispersed bubble (froth)	High liquid fraction, gas bubbles finely dispersed.	Many small bubbles.

[DG PROMPT]
Title: Horizontal two-phase flow regimes
Description: Draw seven horizontal pipe segments side-by-side. 1) Bubbly: random small circles. 2) Plug: large elongated bubbles. 3) Stratified: straight horizontal line separating gas (top) and liquid (bottom). 4) Wavy stratified: wavy line. 5) Slug: large irregular liquid regions with bubbles inside. 6) Annular: ring of liquid at wall, empty centre. 7) Dispersed bubble: many small dots throughout. Label each.

Vertical Two-Phase Flow Regimes (Upward)

Regime	Description
Bubbly	Small bubbles dispersed uniformly.
Slug (plug)	Large Taylor bubbles (diameter ≈ pipe) with liquid slugs.
Churn flow	Chaotic, oscillating, breakdown of large slugs.
Annular flow	Liquid film on wall, gas core with droplets.

Flow Pattern Maps

- **Baker map** – for horizontal flow (uses corrected flow rates).
- **Mandelbaum map** – for vertical flow.
- **Taitel & Dukler** – mechanistic model based on dimensionless parameters.

Utility of identifying flow regimes:

- Heat transfer coefficient varies widely (e.g., annular flow gives high heat transfer).
- Pressure drop correlations depend on regime.
- Design of pipelines, boilers, condensers, nuclear reactors.

Real-world applications:

- **Boiling in nuclear reactor core** – bubbly → slug → annular flow.
- **Oil & gas pipelines** – stratified or slug flow; slugging can damage equipment.
- **Condensers** – annular flow in horizontal tubes.

Q6 – Distinguish between area meters and insertion meters. (3 marks)
Appeared in: W23 (Q5a OR, 03 marks)
Ans:

Parameter	Area Meters	Insertion Meters
Definition	Flow passes through a constriction or variable area (e.g., rotameter, orifice, venturi).	Sensor is inserted into the pipe through a small opening; measures point velocity.
Flow area	Flow area is restricted (orifice, venturi throat) or varies with float position.	Pipe cross-section remains unchanged; sensor occupies a small fraction.
Pressure drop	Significant (especially orifice) – except rotameter has low drop.	Very low (minimal obstruction).
Installation	Requires cutting pipe and flanges (full-bore installation).	Can be installed via hot-tap without stopping flow.
Accuracy	High for calibrated venturi/rotameter (typically ±1-2%).	Lower (±2-5%) because point velocity must be converted to average (profile dependent).
Typical	Venturimeter, orifice meter, rotameter.	Insertion turbine, insertion

Parameter	Area Meters	Insertion Meters
examples		electromagnetic, pitot tube.
Pipe size range	Any size, but cost increases with diameter.	Most economical for large pipes (≥150 mm).
Maintenance	Requires removal from line.	Sensor can be withdrawn without line shutdown.

Real-world application:

- **Area meter** – chemical plant with small pipes, precise dosing.
- **Insertion meter** – large water main (1 m diameter) where full-bore meter is expensive.

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